PUBLIC NOTICE

Date posted: 5/13/2024

DEQ Requests Comments on Proposed Biosolids Management Plan and Site Authorization for City of North Powder

HOW TO PROVIDE PUBLIC COMMENT

Facility name: City of North Powder
Permit type: WPCF and NPDES
Comments due by: Monday, June 17, 2024 at 5 p.m.

Send written comments to:

By mail: Permit Coordinator, Oregon DEQ
800 SE Emigrant Ave., Ste 330 Pendleton OR 97801

By email: Water.PermitER@deq.oregon.gov

The Oregon Department of Environmental Quality invites the public to provide written comments on the City of North Powder's proposed Biosolids Management Plan and Site Authorization.

Summary

This plan allows the City of North Powder to remove biosolids from the City's wastewater treatment lagoon and land apply on private agricultural land in Union County. DEQ requires the permittee to maintain a biosolids management plan as a condition of the City's permit. The biosolids program including the beneficial use sites are described in the biosolids management plan. As a permit requirement, these plans have been updated and are on public notice. Part of the review process is an opportunity for public comment on the plan and other DEQ information. Subject to public review and comment, DEQ plans to approve the plan.

About the facility

North Powder Wastewater Treatment facility is a domestic wastewater treatment facility consisting of two treatment lagoons with an effluent disinfection system and an evaporative wetland. The facility plans to apply biosolids for beneficial reuse on private lands located east of Highway 237 in North Powder.

The facility holds a WPCF Permit # 103297 and NPDES Permit #102209 from DEQ.

What happens next?

DEQ will hold a public hearing if it receives written requests for a hearing during the public comment period from at least 10 people or from an organization representing at least 10 people.

DEQ will consider and respond to all comments received and may modify the proposed permit based on comments.

For more information

Translation or other formats

Español | 한국어 | 繁體中文 | Русский | Tiếng Việt | العربية
800-452-4011 | TTY: 711 | deqinfo@deq.oregon.gov

State of Oregon
DEQ Department of Environmental Quality

View information about this proposed Biosolids Management Plan and Site Authorization documents online, or contact Patty Isaak at 541-613-1125 or Water.PermitER@deq.oregon.gov with questions or to view documents in person at a DEQ office. Visit the Your DEQ Online Help page for more information on how to access public notice documents and submit comments through this platform. **Non-discrimination statement**

DEQ does not discriminate on the basis of race, color, national origin, disability, age or sex in administration of its programs or activities. Visit DEQ's Civil Rights and Environmental Justice page.

BIOSOLIDS MANAGEMENT PLAN

WATER POLLUTION CONTROL FACILITIES PERMIT NO. 103297
FILE NO. 61600

MAY 2024

Prepared for the
City of North Powder, Oregon

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BIOSOLIDS MANAGEMENT PLAN

FOR

CITY OF NORTH POWDER, OREGON

WATER POLLUTION CONTROL FACILITIES PERMIT NO. 103297
FILE NO. 61600

MAY 2024

ANDERSON PERRY & ASSOCIATES, INC.

La Grande, Redmond, Hermiston, and Enterprise, Oregon
Walla Walla, Washington

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Introduction

This Biosolids Management Plan outlines the beneficial use of sewage sludge removed from the City of North Powder, Oregon's wastewater treatment facility (WWTF) to aid in crop production. This Plan has been developed in accordance with the Oregon Department of Environmental Quality (DEQ) Biosolids Management Plan Outline. This Plan has also been developed in accordance with Oregon Administrative Rules (OAR), Chapter 340, Division 050, and supersedes all previous plans. The City intends to remove and land-apply stored biosolids from the existing lagoons, and the intent of this Plan is to provide beneficial use of lagoon biosolids for crop production.

The City owns and operates a municipal wastewater collection and treatment system. Wastewater processed by the treatment works is primarily of domestic origin, and no formal pretreatment program is required under Water Pollution Control Facilities (WPCF) Permit No. 103297. WPCF Permit No. 103297 was issued in October 2023 and expires in 2033. The City also has a National Pollutant Discharge Elimination System (NPDES) Permit that allows discharge of treated wastewater to the Powder River. The NPDES Permit is anticipated to be terminated, and the City will operate only under the WPCF Permit. The City recently completed construction of a new evaporative wetland. The biosolids to be land-applied were produced in the existing treatment lagoons. For the purposes of this Plan, only the treatment lagoons will be described.

Wastewater Treatment Facility

Liquids Processing

The City's WWTF is a two-cell facultative lagoon secondary wastewater treatment system (see Figure 1, Location and Vicinity Maps, and Figure 2, Treatment Facility Site Plan). The WWTF consists of a 2-acre primary lagoon, Cell A, and a single 0.8-acre secondary lagoon, Cell B; direct discharge to surface water is currently permitted under the NPDES Permit. The influent enters the primary lagoon at the northwest corner through a 3-inch fiberglass Parshall flume. Effluent from the WWTF is either discharged to the evaporative wetland or to the Powder River. The City's WWTF receives an average annual flow of 44,000 gallons per day (gpd), a maximum daily flow of 123,000 gpd, and a daily minimum flow of 13,000 gpd. The flow of influent is only from commercial and residential buildings.

Solids Processing

Sewage sludge is a natural by-product of the wastewater treatment process. The solids accumulate as sludge on the bottom of the lagoons until the sludge buildup is deep enough that it becomes necessary to remove and dispose of it. Biosolids at the WWTF were last removed in the late-1990s. Cell A was surveyed in 2020 and contained an average of 2 feet of biosolids across the bottom of the 2-acre lagoon with an estimated volume of 6,450 cubic yards (CY). Cell B is assumed to also contain 2 feet of biosolids across the bottom of the 0.8 acre and have an estimated biosolids volume of approximately 2,580 CY. Based on the survey of Cell A, assumed volume in Cell B, and solids content of 6 percent, the lagoons are estimated to contain 460 dry tons of biosolids. The solids were tested in preparation of this Plan and found to be 2.13 percent solids. Six percent solids is used for determining the total dry weight to provide a conservative estimate.

Septage Receiving Facilities

The City does not receive septage.

Pretreatment Program

The City is not required to implement an industrial wastewater pretreatment program, as no industrial dischargers are utilizing the system. Pollutant monitoring requirements, as stated in the WPCF Permit, will ensure biosolids land application occurs within federal and state limitations.

Biosolids Treatment Processes

Under 40 Code of Federal Regulations (CFR) Part 503 and OAR 340-050, pathogen reduction and vector attraction reduction for biosolids must be met prior to land application. Vector attraction reduction requirements can also be met at the time of land application if biosolids are injected below the surface of the land or incorporated into the soil within six hours after land application. Biosolids are categorized as Class A or B, depending on the mode used to determine pathogen reduction. Biosolids may also be classified as exceptional quality if they meet pollutant concentration limits in 40 CFR Part 503, one of the Class A pathogen reduction alternatives in 40 CFR 503.32(a), and one of the vector attraction reduction options in 40 CFR 503.33(b)(1) through (8). To meet regulatory requirements, pathogen reduction must be met before or at the time vector attraction reduction is achieved.

The City will certify, in writing, that Class B pathogen requirements and vector attraction reduction requirements are met. The City will also notify the DEQ in writing and obtain written approval prior to any process change that would use a pathogen reduction or vector attraction reduction method other than what is specified in this Plan.

Pathogen Reduction

Pathogen reduction requirements of 40 CFR 503 and OAR 340-050 for biosolids will be met by utilizing Alternative 1, Fecal Coliform Testing. The geometric mean of the density of fecal coliform of seven representative samples shall be less than either 2 million most probable number or 2 million colony forming units (CFUs) per gram of total solids (dry weight basis). Before the sludge is removed, seven samples will be collected and tested to find the seven-sample geometric mean of the fecal coliform density to within a reasonable error. Each sample will consist of seven aliquots to create a composite. Provided the results have a low standard deviation, and the seven-sample mean is less than the 2 million CFUs per gram of total solids as outlined in 40 CFR 503, the biosolids meet compliance requirements. When the appropriate Class B biosolids pathogen and vector attraction reduction parameters are met, the biosolids are considered available for spreading at the DEQ-approved biosolids land application sites.

Vector Attraction Reduction

Vector attraction reduction requirements of 40 CFR 503 are met by Option 2, 40 CFR 503.33(b)(2), additional digestion of anaerobically digested biosolids. For Option 2, the biosolids will be tested utilizing a 40-day bench test to demonstrate the volatile solids in the biosolids are reduced by less than 17 percent from the beginning to the end of the test. If the biosolids are unable to meet the requirements of Option 2, the biosolids will then follow Option 9 for vector attraction reduction and the solids will be injected into the soil.

Biosolids Storage

Treatment Facility

Sewage sludge will be stored in the lagoons until it is dredged for disposal. Biosolids may be stored in a tank at the WWTF on a limited time basis.

Staging

Staging of biosolids may occur on a limited time basis in a holding tank at the approved application sites.

Field Storage

The City will not store biosolids at the land application sites.

Transportation and Land Application

A contractor will be hired by the City to complete all biosolids removal and application. The contractor will utilize a dredge for removal of the biosolids and tanker trucks for transporting the liquid biosolids to the sites. The contractor will be able to handle the volume of biosolids produced.

The liquid biosolids will be land-applied by the contractor using tender trucks, or other applicable equipment, to evenly apply the biosolids at the approved application sites, at the recommended rate. The application rate will be determined based on nitrogen levels in the biosolids and the agronomic rate for crops being grown. The dredging process will remove inorganic debris (garbage) larger than 1 inch.

If biosolids are spilled during transport to the land application sites, immediate action will be taken to cease further spillage and remediate the spill. A vacuum truck, front-end loader, or other appropriate equipment will be used to remove the spilled biosolids and reload the biosolids into the truck.

Remedial Procedures

All spills into Waters of the State or ground surface spills likely to enter Waters of the State will be reported immediately to the Oregon Emergency Response System at 1-800-452-0311 and to the DEQ's regional biosolids specialist as soon as possible after a spill incident.

Spill During Transportation of Biosolids

The City is responsible for cleanup of any biosolid spills that occur during transport to the land application sites. If a spill occurs while transporting biosolids between the WWTF and the land application sites, the City will:

- Contain the spill
- If there is potential for public exposure, post the area and set up temporary fencing
- Remove spilled biosolids with a vacuum truck, front-end loader, shovel, or other appropriate equipment

- Cover the area with dry lime for sterilization, if appropriate (not appropriate adjacent to Waters of the State)
- Apply absorbent material (i.e., sand) if the biosolids were in a liquid state during transportation
- Transport spilled product to a DEQ-authorized biosolids land application site or permitted landfill

Solids Treatment Process Failure or Modification

If a mechanical problem occurs during any portion of the biosolids removal and land application, biosolids will remain in the lagoons until needed repairs are made.

Monitoring and Reporting

Biosolids Monitoring and Sampling Plan

The City has developed and will implement a Biosolids Monitoring and Sampling Plan prior to the removal and disposal of the biosolids. Samples collected and analyzed will be representative of the biosolids to be land-applied. Quality control measures and procedures will be implemented for tests to verify precision and accuracy. Only biosolids from the primary and secondary lagoons will be removed and applied at the approved biosolids land application sites; therefore, the samples will provide an appropriate representation of the biosolids. Sampling was performed to help prepare this Plan, and an analysis of pollutants and nutrients will occur again before application. Four sampling events will occur, and each is described below:

- The sampling locations (for each sampling event)
    - One composite sample will be taken for nutrient and pollutant analysis, and one will be taken for the 40-day bench test. Each composite will consist of seven aliquots taken randomly across the lagoons. Four aliquots will be taken from Cell A and three will be taken from Cell B.
    - Seven composites will be taken for the fecal coliform testing, each consisting of seven aliquots taken along a transect. Five transects will be across Cell A and two transects will be across Cell B. The transects are shown on Figure 2.
- How samples will be collected, preserved, and transported
    - Collection of samples (to occur during each sampling event)
        - A sludge judge will be used to collect each aliquot containing material from the top layer of the sludge to the bottom of the lagoon. Samples will provide an accurate representation of the sludge to be removed from the lagoons.
        - The seven aliquots will be placed in a mixing container and stirred to create a composite sample.
        - Liquid sludge will be carefully poured into a sampling container to avoid entrapping air within the sample.
        - The container will be filled until overflowing, then the lid will be screwed on.

        - To check if air bubbles are present in the sample, the container will be turned upside down and the lid tapped.
        - In the event air bubbles are present in the sample, additional sludge will be poured into the container until overflowing and the lid refastened.
        - Collection and mixing equipment will be cleaned between each sample/aliquot.
    - Preservation of samples
        - To prevent solids separation in the sample, glass or Teflon-coated stirring rods or stainless steel spoons will be utilized to mix the sample before splitting or transferring any portion of the sample to another container.
        - The sample container materials, container preparation, preservation, and holding time prior to analysis will adhere to the 2003 Environmental Protection Agency Control of Pathogens and Vector Attraction in Sewage Sludge guidance.
    - Transportation of samples
        - Samples will be packaged to protect the container and reduce the risk of leakage. Containers will be held upright and cushioned from shock, with sufficient insulation and/or artificial refrigerant to maintain a sample temperature of 39.2° Fahrenheit (4°C) throughout transportation.
        - The transportation/shipment time of samples will not exceed 24 hours.
- The analytical method for each analysis
    - The analytical method utilized for each analysis will follow the analytical techniques outlined in 40 CFR 136.

All monitoring and reporting will be conducted in accordance with the City's WPCF Permit and this Plan. The monitoring frequency is based on the amount of biosolids generated that are land-applied. The biosolids monitoring frequencies are included in Appendix A.

Recordkeeping and Reporting Procedures

The City, as the preparer and land applier of biosolids, is required to maintain records to demonstrate that federal and state biosolids requirements are met. Records will be kept on file by the City and will be available upon request by the DEQ. Monitoring and sampling records will be retained for a period of no less than five years, unless otherwise required by the WPCF Permit or a site authorization letter. The minimum required records include the following information:

- Pollutant concentrations of each parameter stated in the WPCF Permit
- Pathogen requirements as stated in the WPCF Permit for Class B biosolids
- Description of how one of the vector attraction reduction requirements in 40 CFR 503.33 and site restrictions in 40 CFR 503.32(b)(5) are met for each land application site (note: this is for Class B bulk biosolids)

- Certification that the information submitted is accurate to determine compliance with pathogen and vector attraction reduction requirements and site restriction/management requirements
- Lab reports, sampling logs, and calibration logs for equipment

Annual Reporting

A biosolids annual report is required to be submitted to the DEQ by February 19 of each year, or as required by the WPCF Permit if bulk biosolids were land-applied the previous year. Information required with the annual report includes:

- Daily site logs or records, including date, time, and quantity (gallons, pounds) of nitrogen per acre that was land-applied
- Map, including scale, showing the site and the land application location that coincides with the daily site application method (i.e., truck spreader bar)
- Signed copy of the certification statement shown under the Certification Statement section of this Plan

The current Annual Report form from the DEQ will be submitted annually.

Certification Statement

The City is capable of meeting Class B pathogen reduction and vector attraction reduction requirements. As required under 40 CFR 503.17, the City must retain a certification statement indicating whether compliance with pathogen reduction, vector attraction reduction, and certain site restrictions has been met. The certification statement must be retained for a period of five years and must be submitted with the annual report due February 19 or as required. The City will retain the following certification statement, and it will be signed by a principal executive officer or ranking elected official or their duly authorized representative (e.g., individual or position having responsibility for the overall operation of the system, such as the position of plant manager, supervisor, superintendent, or equivalent responsibility).

> "I certify, under penalty of law, that the information that will be used to determine compliance with the management practices in Section 503.14, the Class B, Alternative 1, Monitoring of Fecal Coliform, pathogen requirements in 40 CFR 503.32(b)(2), the site restrictions in Section 503.32(b)(5), and the vector attraction reduction requirement in Section 503.33(b)(2) or 503.33(b)(9) was prepared for the site on which bulk sewage sludge was applied under my direction and supervision in accordance with the system designed to ensure that qualified personnel properly gather and evaluate this information. I am aware that there are significant penalties for false certification including the possibility of fine and imprisonment."

Signature_____Date_____

The City is also required, as the land applier, to certify that the management practices in 40 CFR 503.14 are being met. This certification includes that biosolids are being land-applied at approved agronomic loading rates as specified in the DEQ-issued site authorization letters.

"I certify, under penalty of law, that the management practices in 40 CFR 503.14 have been met for the site on which bulk biosolids are applied. This determination has been made under my direction and supervision in accordance with the system designed to ensure that qualified personnel properly gather and evaluate the information used to determine that the management practices have been met. I am aware that there are significant penalties for false certification, including the possibility of fine and imprisonment."

Signature_____Date_____

Biosolids Characteristics

In preparation of this Plan, preliminary testing was performed. Prior to land application, testing will occur in accordance with the Biosolids Monitoring and Sampling Plan section above.

Pollutant Characteristics

Table 1 is a representative analysis for pollutant characteristics. Samples of the sewage sludge were collected on December 19, 2023. Samples were taken on three separate transects in Cell A, each consisting of seven aliquots. The aliquots were obtained using a sludge judge to collect a sample of the entire thickness of the solids layer. The aliquots were then mixed to produce a composite. The composites were sent to the lab on ice for analysis. No sampling was performed in Cell B due to ice accumulation in the cell. Sampling was performed to help prepare this Plan, and an analysis of pollutants in accordance with the above-mentioned sampling plan will occur again before application.

TABLE 1
ALLOWED BIOSOLIDS POLLUTION LIMITS AND CONCENTRATIONS

Pollutant	Lagoon Biosolids Analytical Result mg/kg (lbs/ton)	40 CFR 503.13(b)(1) Pollutant Concentration Limits mg/kg (lbs/ton)
Arsenic (As)	<9.21 (0.018)	75 (0.15)
Cadmium (Cd)	<1.84 (0.004)	85 (0.17)
Chromium (Cr)	<18.4 (0.037)	-
Copper (Cu)	118.10 (0.237)	4,300 (8.6)
Lead (Pb)	23.80 (0.048)	840 (1.68)
Mercury (Hg)	<3.68 (0.007)	57 (0.114)
Molybdenum (Mo)	<18.4 (0.037)	75 (0.15)
Nickel (Ni)	<18.4 (0.037)	420 (0.84)
Potassium, percent	0.20 (0.000)	-
Selenium (Se)	<18.4 (0.037)	100 (0.2)
Zinc (Zn)	481 (0.962)	7,500 (15.0)

lbs/ton = pounds per ton

mg/kg = milligrams per kilogram

< = less than

Nutrient Characteristics and Other Parameters

Table 2 is a representative analysis for nutrient characteristics and other parameters. Samples of the sewage sludge were collected on December 19, 2023. Samples were taken on three separate transects in Cell A, each consisting of seven aliquots. The aliquots were obtained using a sludge judge to collect a sample of the entire thickness of the solids layer. The aliquots were then mixed to produce a composite. The composites were sent to the lab on ice for analysis. No sampling was performed in Cell B due to ice accumulation in the cell. Sampling was performed to help prepare this Plan, and an analysis of pollutants in accordance with the above-mentioned sampling plan will occur again before application.

TABLE 2
BIOSOLIDS NUTRIENT CHARACTERISTICS

Source	Lagoon Biosolids Analytical Result		
Parameter/ Measurement Unit	**Wet Weight**	**Dry Weight**	**Pounds per Dry Ton**
Total Solids, percent	2.13	N/A	N/A
Volatile Solids, percent	57.43	N/A	N/A
TKN, mg/kg	807	37,967	1.61
NO_3-N, mg/kg	<0.72	<33.9	<0.001
NH_4-N, mg/kg	134	6,317	0.27
Phosphate (P), percent	0.70	N/A	N/A
pH, standard units	6.9	N/A	N/A

N/A = not applicable
NH_4-N = ammonium nitrogen
NO_3-N = nitrate nitrogen
TKN = total Kjeldahl nitrogen

Biosolids Utilization Program

Biosolids will be dredged and land-applied to the land application sites by the contractor. Biosolids will be loaded, hauled, spread, and otherwise handled using conventional construction and farming equipment.

Agronomic Application Rate and Site Crops

Class B biosolids are required to be land-applied to a site at a rate that is equal to or less than the agronomic rate for the site. An agronomic rate is the whole biosolids application rate (dry weight basis) designed to provide the annual total amount of nitrogen needed by a crop and to minimize the amount of nitrogen passing below the root zone of the crop or vegetation to groundwater. In the case of winter wheat, the application rate is calculated from the amount of nitrogen the plant can remove from the soil.

Biosolids application rates for the City are developed based on test results of the biosolids and guidance provided by Washington State University Puyallup and Oregon State University (OSU). The calculations and assumptions made can be found in Appendix B, Nutrient Uptake Calculations. These

calculations are an example of the calculations that will be performed once additional testing is performed. Only alfalfa is anticipated to be grown on the privately owned land application sites.

The alfalfa is anticipated to uptake 175 pounds of nitrogen per acre (lbs N/acre). Since alfalfa is a nitrogen fixer and does not require nitrogen fertilizer to grow, it was assumed that the crop would uptake 50 pounds of nitrogen per ton of alfalfa. This is a conservative value stated in the *Nutrient Management Guide for Dryland and Irrigated Alfalfa in the Inland Northwest, Northwest Extension Publication, PNW0611.* Approximately 3.5 tons per acre of alfalfa is estimated to be harvested based on average production rates for Baker County provided by the Baker County OSU Extension Office. This results in a total of 175 lbs N/acre that could be applied. Soil testing was performed to determine the plant-available nitrogen (PAN) already at the site. The testing resulted in 88 pounds per acre of PAN in the soil. The completed PNW 511 worksheets can be found in Appendix B, Nutrient Uptake Calculations.

The following are example calculations for biosolids application rates; the calculations need to be performed prior to each application. PAN is calculated by adding inorganic nitrogen retained and organic nitrogen mineralized. Inorganic nitrogen retained is calculated by multiplying the weight of ammonium nitrogen per dry ton of biosolids by the percent retained after application and adding the weight of nitrate-nitrogen per dry ton. The percent retained is based on the drying method used and days to incorporation by tillage after application. The biosolids will be applied as a liquid with no incorporation and will retain approximately 55 percent of the ammonium nitrogen. The inorganic nitrogen retained is calculated to be 6.95 pounds of nitrogen per dry ton (lbs N/dry ton). The organic nitrogen mineralized is calculated by subtracting the ammonium nitrogen from the TKN and multiplying by the percent of organic nitrogen that is plant-available in year one. The percent of organic nitrogen available in year one is approximately 10 percent based on the biosolids processing and moisture content. The amount of organic nitrogen mineralized is calculated as 6.33 lbs N/dry ton. The PAN in the biosolids is calculated as 13.28 lbs N/dry ton.

The alfalfa application sites are anticipated to uptake 175 lbs N/acre; subtracting the PAN in the soil gives an application rate of 87 lbs N/acre, which divided by the estimated PAN in the biosolids, results in an application rate of 6.55 dry tons per acre.

With the combination of application Sites 1 and 2, it is anticipated that approximately 615 dry tons of biosolids can be applied. With an estimated 460 dry tons of biosolids in the lagoons, the City has sufficient land to apply biosolids.

Future versions of fertilizer guides, for appropriate crops and regions, may be used to calculate biosolids application rates. The above application rates are example calculations and will not be used for final application rates. These example calculations do not include prior biosolids applications or fertilizer applications. Prior biosolid applications and fertilizer applications will need to be included for final application rates. Biosolids will only be applied once; therefore, soil nitrogen will not be accounted for in the application rate.

Site Inventory of Existing and Potential Sites

The City previously land-applied biosolids to application Sites 1 and 2 in the 1990's. The existing site approval was deemed inadequate for current regulations. Per the DEQ's request, the City is requesting reapproval of Sites 1 and 2.

Site Selection Criteria for Application Sites

The City requests that Sites 1 through 4 be approved for land application. Prior to using any site for land application, the City is required to receive a written site authorization letter from the DEQ. The City will look for application sites within Union and Baker Counties should the need for additional land arise. The following site conditions will be considered when determining the suitability of a site for land application:

- All sites will be located on agricultural land in Union or Baker County relatively close to the City's existing WWTF.
- All sites should be on a stable geological formation not subject to flooding or excessive runoff from adjacent land.
- Minimum depth to permanent groundwater should be 4 feet, and the minimum depth to temporary groundwater should be 1 foot when application of biosolids occurs.
- Topography should be suitable for normal agricultural operations. Liquid biosolids should not be land-applied on bare soils when the slope exceeds 12 percent. Dewatered or dried biosolids may be land-applied on well vegetated slopes, up to 30 percent.
- Soil should have a minimum rooting depth of 24 inches.
- Sites with saline and/or sodic soils should be avoided.

Application Site Owner/Leaseholder

The City proposes the following new parcel be approved as an application site (see Figure 3, Biosolids Land Application Sites). This site exceeds the acreage needed for biosolids disposal but provides flexibility in ensuring all site criteria are met.

The following land application sites are owned by Myron Miles:

Application Sites 1 and 2:	Parcel Map No.: 06S39E Lot: 800 Land Application Area: 94 acres

Site Management Agreement

A site management agreement between the City and the landowner will be completed.

Soils

Soils at the land application sites are mapped as Powval silt loam and Baker silt loam (see Figure 4, Soils Map - Sites 1 and 2).

In general, Powval silt loam are well-drained soils with moderately high to high permeability and a depth to water table of 48 to 72 inches. Roots are present to 60 inches.

In general, Baker silt loam are well-drained soils with low to moderately low permeability and a depth to water table of greater than 80 inches. Roots are present to 31 inches.

Public Notice

The City is required to notify the public of the proposed land application activity. A public notice campaign addressing property owners adjacent or near the application sites will be completed. Letters and maps will be provided to notify them of the application of biosolids and provide pertinent information. The information will explain what biosolids are along with the benefits and protective measures to be practiced during the application process. It will also include notification of the availability of this Plan for review by the public. Letters will be hand-delivered to local or resident owners and mailed to owners located out of the area.

Site Management Practices

Site access restrictions and setbacks will be followed as outlined in the DEQ's site authorization letters. The City will ensure that access is restricted by the appropriate means necessary, such as fencing or posting signs at the land application sites. Biosolids land application will not occur in those areas designated as buffer strips. Maintaining the buffer areas will be achieved through accurate measurement of the buffer areas prior to commencing land application.

Crop Management Practices

Biosolids will only be applied to fields being utilized for agricultural purposes. Soil conditions must be favorable, so runoff, leaching, or soil compaction does not occur. The timing of land application will take into consideration tilling and irrigation practices that may occur on an authorized site.

The agreement with the proposed application site landowner stipulates that additional restrictions apply if food crops are grown. These restrictions are from 14 months for crops whose harvested parts may touch the biosolids/soil mixture (such as edible peas) to 38 months for root crops (such as carrots). The agreement also stipulates that public contact will be restricted for 30 days following biosolids land application.

The overall management of nutrients at the land application sites considers the amount of land-applied biosolids, the amount of commercial fertilizer used, and the amount of residual nutrients in the soil. When additional sources of nitrogen (e.g., commercial fertilizer) are applied to a site, the application of biosolids should be reduced to compensate for the additional nitrogen loading.

FIGURES

To La Grande

To Cove

T. 6 S., R. 39 E., W.M.

1,500 0 1,500

SCALE IN FEET

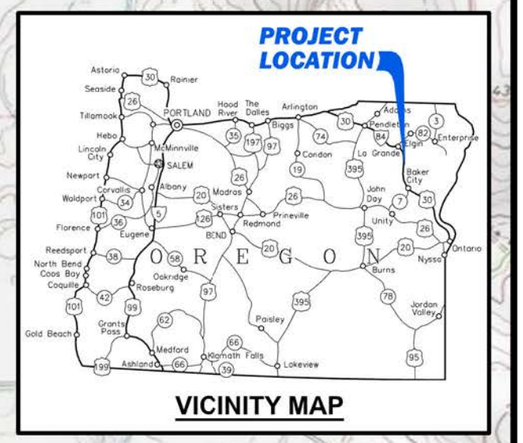
WASTEWATER TREATMENT FACILITY

CITY LIMITS

URBAN GROWTH BOUNDARY

To Haines

To Baker City



VICINITY MAP

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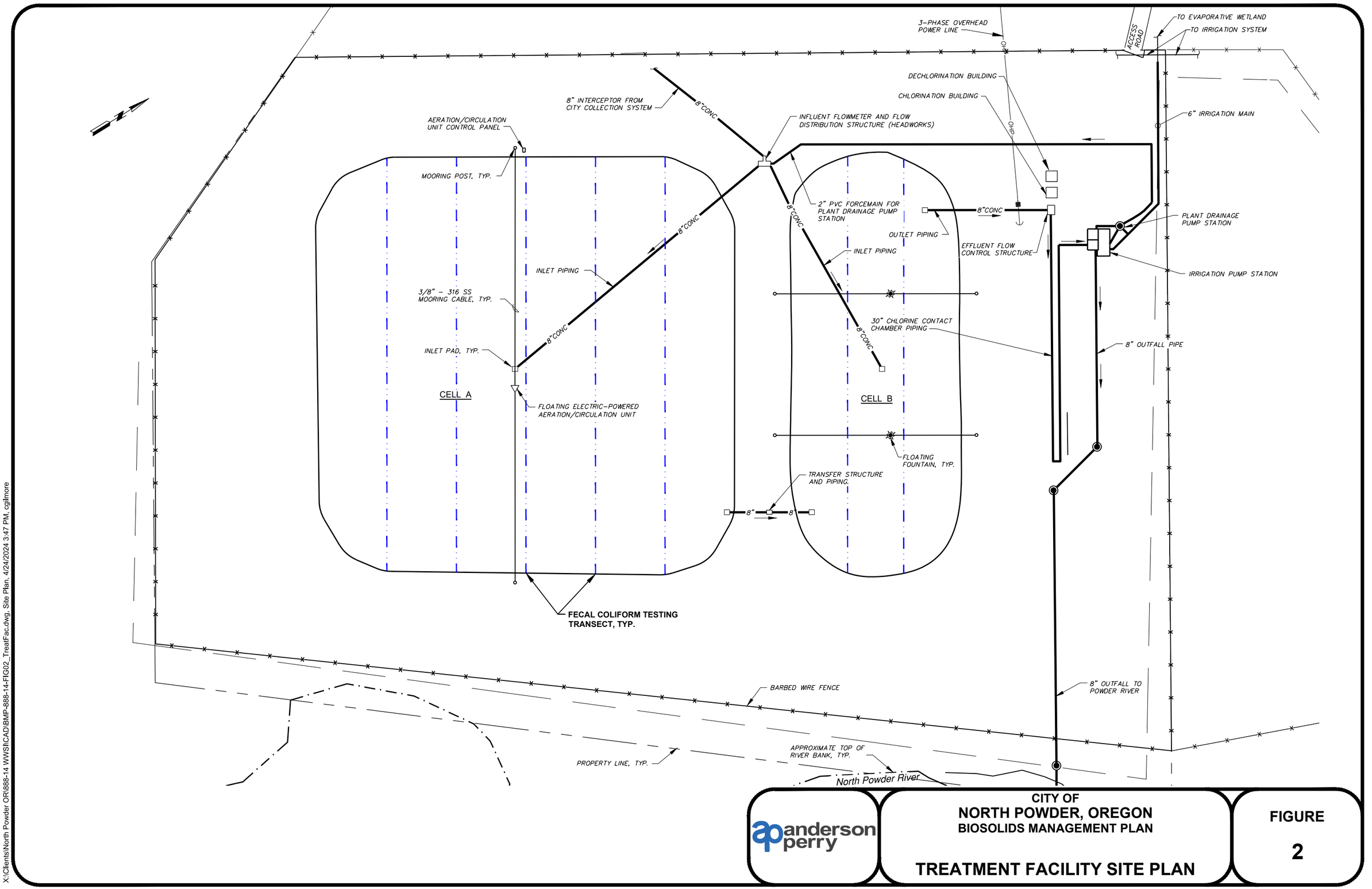
anderson perry

CITY OF
NORTH POWDER, OREGON
BIOSOLIDS MANAGEMENT PLAN

LOCATION AND VICINITY MAPS

FIGURE
1



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anderson perry

CITY OF
NORTH POWDER, OREGON
BIOSOLIDS MANAGEMENT PLAN

TREATMENT FACILITY SITE PLAN

FIGURE
2

500 0 500

SCALE IN FEET

LEGEND

- PARCEL BOUNDARY
- BIOSOLIDS LAND APPLICATION SITE

Site 1

Site 2

200 FT. BUFFER, TYP.

BIDWELL RD.

Powder River

North Powder River

CLOSEST WELL AND DWELLING

WASTEWATER TREATMENT FACILITY

237

Source: Esri, Maxar, Earthstar Geographics, IGN, and the GIS User Community

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CITY OF
NORTH POWDER, OREGON
BIOSOLIDS MANAGEMENT PLAN

BIOSOLIDS LAND APPLICATION SITES

FIGURE
3

SOILS LEGEND

11A BAKER SILT LOAM, 0 TO 2 PERCENT SLOPES
13A BALDOCK SILT LOAM, 0 TO 2 PERCENT SLOPES
62A HAINES SILT LOAM, 0 TO 2 PERCENT SLOPES
126A POWVAL SILT LOAM, 0 TO 3 PERCENT SLOPES
170A UMAPINE SILT LOAM, 0 TO 2 PERCENT SLOPES

SITE 2
APPROX. 22 AC.

SITE 1
APPROX. 72 AC.

170A
176A
159A
62A
13A
126A
11A

River
Powder

BIDWELL RD.

LEGEND

SOILS BOUNDARY
PARCEL BOUNDARY
BIOSOLIDS LAND APPLICATION SITE

500 0 500
SCALE IN FEET

Source: Esri, Maxar, Earthstar Geographics, IGN, and the GIS User Community

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CITY OF
NORTH POWDER, OREGON
BIOSOLIDS MANAGEMENT PLAN

SOILS MAP - SITES 1 AND 2

FIGURE
4

Appendices Table of Contents

Appendix A - Biosolids Monitoring and Sampling Requirements

Appendix B - Nutrient Uptake Calculations

APPENDIX A
Biosolids Monitoring and Sampling Requirements

CITY OF NORTH POWDER, OREGON
BIOSOLIDS MANAGEMENT PLAN
MONITORING AND SAMPLING REQUIREMENTS FOR BIOSOLIDS LAND APPLICATION

ITEM	MONITORING FREQUENCY	MONITORING POINT	TYPE OF MONITORING	PARAMETER[1]
Biosolids Quality (General)	Initial Report	Lagoons	Composite	Total metals (As, Cd, Cu, Pb, Hg, Mo, Ni, Se, Ag, Zn), TKN, NO_3-N, NH_4-N, Total P, K, pH, Totals Solids, Volatile Solids
	Before Application	Lagoons	Composite[2]	Total metals (As, Cd, Cu, Pb, Hg, Mo, Ni, Se, Ag, Zn), TKN, NO_3-N, NH_4-N, Total P, K, pH, Totals Solids, Volatile Solids, *E. coli* , Fecal Coliform
Biosolids Quantity	Daily	Loads Taken to Fields	Calculated	Biosolids Delivered to Application Site
	Daily	Land Application Site	Calculated	Pounds PAN per Acre per Field
Reporting	Daily Field Log	Application Documentation	Calculated	Quantity (Tons) Quality (Nutrients Applied) Location (Field Applied To)
	Final Report	Application Documentation	Observed/Calculated	Crops, Acres Applied, Nitrogen Applied (lbs/acre), Application Rate (dry tons/acre), Biosolids Quality Test Data, and Vector Attraction Reduction Monitoring/Management Records

Notes:

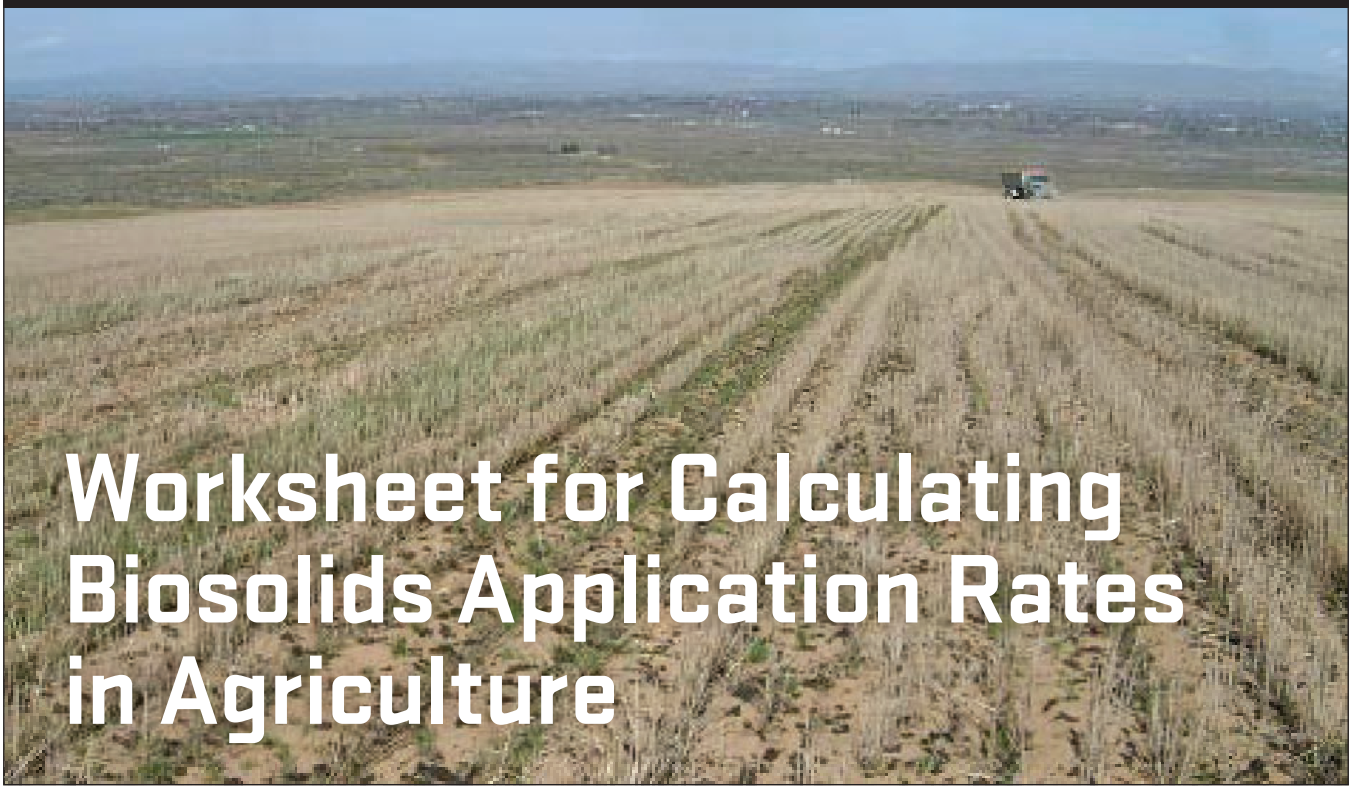
[1] Abbreviations are defined as follows: As = arsenic, Cd = cadmium, Cu = copper, Pb = lead, Hg = Mercury, Mo = molybdenum, Ni = nickel, Se = selenium, Ag = silver, Zn = zinc, TKN = total Kjeldahl nitrogen, NO_3-N = nitrate-nitrogen, NH_4-N = ammonium-nitrogen, P = phosphorus, K = potassium

[2] Composite samples will be taken according to the Biosolids Monitoring and Sampling Plan.

dry tons/acre = dry tons per acre
lbs/acre = pounds per acre
PAN = plant available nitrogen

APPENDIX B
Nutrient Uptake Calculations

A PACIFIC NORTHWEST EXTENSION PUBLICATION



Worksheet for Calculating Biosolids Application Rates in Agriculture

Photo: Brian Campbell, Natural Selection Farms

Dan M. Sullivan, Deirdre Griffin LaHue, Biswanath Dari, Andy I. Bary and Craig G. Cogger

Biosolids are a product of municipal wastewater treatment. Raw sewage solids must be processed to meet U.S. Environmental Protection Agency standards before they can be called biosolids. Biosolids contain organic matter and nutrients that are beneficial for soil and crop productivity.

This publication focuses on matching the nitrogen (N) supplied by biosolids to the nitrogen needs of the crop. Regulatory agencies require agronomic rate calculations for most biosolids applications to cropland.

Overview: agronomic rate calculation

There are six steps to calculate the agronomic rate of a biosolids application:

1. Collect information on the site and crop, including crop N requirement.
2. Estimate the plant-available N needed from the biosolids application.
3. Collect biosolids N data.
4. Estimate plant-available N per dry ton of biosolids.
5. Calculate the agronomic biosolids application rate on a dry ton basis.
6. Convert the application rate to an "as is" basis.

In determining biosolids application rates, it's important to evaluate trace element concentrations in biosolids and the regulatory limits for trace element application (see Appendix A). However, in almost all cases, nitrogen controls the biosolids application rate.

A companion publication, *Fertilizing with Biosolids* (PNW 508), provides additional information about the value of biosolids as a fertilizer. The "For more information" section of this publication gives a summary of Pacific Northwest research and Extension publications on land application of municipal biosolids.

Dan M. Sullivan, Extension soil scientist and professor of nutrient management, and Biswanath Dari, agronomist and assistant professor, both of the Department of Crop and Soil Science, Oregon State University; Deirdre Griffin LaHue, sustainable soil management specialist and assistant professor, Andy I. Bary, senior scientific assistant, and Craig C. Cogger, Extension soil scientist (emeritus), all of the Department of Crop and Soil Sciences, Washington State University

Oregon State University • University of Idaho • Washington State University

PNW 511 • February 2021

WORKSHEET

For guidance on completing this worksheet, see "How to Use the Worksheet," starting on page 5.

Step 1. Collect site information

Soil and crop information:

Line number		Your information	Example
1.1	Soil series and texture (NRCS soil survey)	Baker, Baldlock, Haines, Powval, Umapine Silt Loam	Puyallup sandy loam
1.2	Yield goal (units/acre/year*) estimated from grower records or by agronomist**	3.5 tons/acre	5 tons/acre
1.3	Crop rotation (grower; e.g., wheat, fallow, wheat)	Alfalfa	perennial grass
1.4	Plant-available N needed to produce yield goal (university fertilizer/nutrient management guide; agronomist) (lb N/acre/year)	175	200 lb N/acre

Plant-available N provided by other sources:

Line number		Your calculation	Example	Unit
Pre-application testing				
1.5	Nitrate-N applied in irrigation water	0	10	lb N/acre
1.6	Preplant nitrate-N in root zone (east of Cascades)***	88	—	lb N/acre
Adjustments to typical soil N mineralization				
1.7	Plowdown of cover or green manure crop***	0	—	lb N/acre
1.8	Previous biosolids applications (see Table 1, page 7)	0	30	lb N/acre
1.9	Previous manure applications	0	—	lb N/acre
Grower information				
1.10	N applied at seeding (starter fertilizer)	0	—	lb N/acre
Total				
1.11	Total plant-available N from other sources = sum of lines 1.5 through 1.10	0	40	lb N/acre

* Yield goals may be expressed in weight (tons, pounds, etc.) or in volume (bushels).
** The American Society of Agronomy certifies professional agronomists as Certified Crop Advisors (CCAs). See https://www.certifiedcropadviser.org for more information.
*** Do not list here if these N sources were accounted for in the nitrogen fertilizer recommendation from a university fertilizer/nutrient management guide.

Step 2. Estimate the amount of plant-available N needed from biosolids

Line number		Your calculation	Example	Unit
2.1	Plant-available N needed to produce yield goal (from line 1.4)	175	200	lb N/acre
2.2	Plant-available N from other sources (from line 1.11)	88	40	lb N/acre
2.3	Amount of plant-available N needed from biosolids = line 2.1 – line 2.2	87	160	lb N/acre

Step 3. Collect biosolids data

Application information:

Line number		Your information	Example
3.1	Moisture content of biosolids	Liquid	liquid
3.2	Biosolids processing method (see Table 3, page 10)	Lagoon > 10 years	anaerobic
3.3	Method of application (surface or injected)	Surface	surface
3.4	Number of days to incorporation of biosolids	No incorporation	no incorporation
3.5	Expected application season	Summer 2024	March to September

Laboratory biosolids analysis (dry weight basis):

If your biosolids analysis is on an "as is" or wet weight basis, you will need to divide your analysis by the percent total solids (line 3.10) and multiply the result by 100 to convert to a dry weight basis.

Line number		Your calculation	Example	Unit
3.6	Total Kjeldahl N (TKN)*	37,966.67	50,000	mg/kg
3.7	Ammonium N*	6,316.67	10,000	mg/kg
3.8	Nitrate N *,**	--	not analyzed	mg/kg
3.9	Organic N*,*** = line 3.6 – line 3.7	31,650.00	40,000	mg/kg
3.10	Total solids	2.13	2.5	percent

* If your analysis is in percent, multiply by 10,000 to convert to mg/kg.
** Nitrate-N analysis required for composted or aerobically digested biosolids, but not for anaerobically digested biosolids.
*** Organic N = total Kjeldahl N – ammonium N.

Step 4. Estimate plant-available N per dry ton of biosolids

Convert biosolids N analysis to lb per dry ton:

Line number		Your calculation	Example	Unit
4.1	Total Kjeldahl N (TKN)*	75.93	100	lb N/dry ton
4.2	Ammonium N*	12.63	20	lb N/dry ton
4.3	Nitrate N*	--	not analyzed	lb N/dry ton
4.4	Organic N = line 4.1 – line 4.2	63.30	80	lb N/dry ton

*Multiply mg/kg (from lines 3.6 through 3.9) × 0.002. If your analyses are expressed in percent, multiply by 20 instead of 0.002.

Estimate inorganic N retained:

Line number		Your calculation	Example	Unit
4.5	Percent of ammonium-N retained after application (see Table 2, page 9)	55	55	percent
4.6	Ammonium-N retained after application = line 4.2 × (line 4.5 ÷ 100)	6.95	11	lb N/dry ton
4.7	Biosolids inorganic N retained = line 4.3 + line 4.6	6.95	11	lb N/dry ton

Estimate organic N mineralized:

Line number		Your calculation	Example	Unit
4.8	Percent of organic N that is plant-available in Year 1 (see Table 3, page 10)	10	35	percent
4.9	First year plant-available organic N = line 4.4 × (line 4.8 ÷ 100)	6.33	28	lb N/dry ton

Plant-available N:

Line number		Your calculation	Example	Unit
4.10	Estimated plant-available N = available inorganic N (line 4.7) + available organic N (line 4.9)	13.28	39	lb N/dry ton

Step 5. Calculate the agronomic biosolids application rate

Line number		Your calculation	Example	Unit
5.1	Amount of plant-available N needed from biosolids (from line 2.3)	87	160	lb N/acre
5.2	Estimated plant-available N in biosolids (from line 4.10)	13.28	39	lb N/dry ton
5.3	Agronomic biosolids application rate = line 5.1 ÷ line 5.2	6.55	4.1	dry ton/acre

Step 6. Convert to "as is" biosolids basis

Desired units		Your calculation	Example
Gallons per acre =	(line 5.3 ÷ line 3.10) × 24,000	73,941.4	39,400
Inches per acre =	(line 5.3 ÷ line 3.10) × 0.88	2.71	1.44
Wet tons per acre =	(line 5.3 ÷ line 3.10) × 100	308.1	164

HOW TO USE THE WORKSHEET

Step 1. Collect site information

Soil series and surface soil texture (line 1.1)

Find the location on the Natural Resources Conservation Service (NRCS) soil survey. Record the series name and surface texture of the predominant soil. NRCS soil survey data is available online at https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm.

Crop yield goal (line 1.2)

Field records are the best source for crop yield estimates. You can find proven yields for most grain farms from the local Farm Service Agency office. For most other cropping systems, grower records are the only source available. Be sure to note whether the yield records are on an "as is" or dry matter basis.

A site used repeatedly for biosolids application should have yield data collected each year. Use this accumulated data for determining crop nitrogen requirement.

Yield data is typically not available for grazed pastures because grazing animals consume the crop in the field. In these cases, omit the yield goal and go directly to line 1.4. Estimate plant nitrogen needs from the appropriate university fertilizer/nutrient management guide, based on the level of pasture management.

Crop rotation (line 1.3)

Consult with the grower and discuss possible crop rotations. Rotations that include root crops or other crops with long post-application waiting periods are not suitable for Class B biosolids application. A companion publication (*Fertilizing with Biosolids*, PNW 508) provides more information about USEPA standards for Class A and Class B biosolids.

Plant-available N needed to produce yield goal (line 1.4)

You can estimate plant-available N needs by referring to university fertilizer/nutrient management guides.

University fertilizer and nutrient management guides

Land grant universities (for example, Washington State University, Oregon State University, and the University of Idaho) publish fertilizer and nutrient management guides that estimate plant-available N needs. Use the guide most appropriate for the site and crop. For major crops, guides may cover irrigated or rainfed (dryland) cropping and different geographic areas. Don't use guides produced for irrigated sites when evaluating dryland sites. When appropriate guides do not exist, consult university Extension agronomists/

soil scientists or professional agronomists (Certified Crop Advisors) who have expertise working within the cropping system.

Nitrogen fertilizer application rates listed in the fertilizer/nutrient management guides are based on field trials conducted under the specified climate and cultural conditions. Growth trial results are averaged over a variety of soil types and years. Note that guide recommendations are not the same as crop uptake. This is because the guides account for N available from mineralization of soil organic matter and the efficiency of N removal by the crop.

The N rate recommended in fertilizer/nutrient management guides assumes average yields, good management practices, and removal of N from the field through crop harvest or grazing. In terms of satisfying crop N needs, plant-available N from biosolids application is considered equal to fertilizer N.

Agronomist calculations

Because of the general nature of university fertilizer and nutrient management guides, it may be worthwhile to have a professional agronomist calculate how much plant-available N is needed for a specific field. The American Society of Agronomy certifies professional agronomists as Certified Crop Advisors (CCAs). See https://www.certifiedcropadviser.org for more information.

Always use the same method to calculate the N requirements. You will need to document your reasons for using agronomist calculations instead of the university guide.

Photo: Andy Bary, ©Washington State University

Dewatered biosolids stockpile at field application site

Plant-available N provided by other sources (lines 1.5 to 1.11)

To make sure there isn't too much nitrogen applied to a crop, you must determine how much nitrogen comes from sources other than biosolids and soil organic matter. These sources of N are grouped into three categories in the worksheet:

- Plant-available N estimated by pre-application testing
- Adjustments to typical soil organic N mineralization (usually obtained from an agronomist)
- Information supplied by the grower

N estimated by pre-application testing (lines 1.5 to 1.6)

Irrigation water

Since the amount of nitrate-N in irrigation water varies, it should be determined by water testing. Irrigation water containing 5 mg nitrate-N per liter will contribute 1.1 pounds of nitrogen per acre-inch applied; irrigation water containing 10 mg nitrate-N per liter will contribute 2.3 pounds of N per acre-inch.

Preplant nitrate-N in the root zone (east of Cascades)

You can estimate the preplant nitrate-N in the root zone by testing the soil in early spring. Sample in 1-foot increments to a depth of at least 2 feet.

Some university fertilizer/nutrient management guides use preplant soil nitrate-N when calculating N fertilizer application rates. If you use these guides, don't count soil test nitrate-N in our worksheet—it has already been accounted for in the recommended fertilizer N rate prescribed in the university fertilizer/nutrient management guide.

In dryland cropping systems, soil testing below 3 feet is used to assess long-term N management. Accumulation of nitrate below 3 feet indicates that past N applications were not efficiently utilized by the crop. However, soil nitrate-N below 3 feet is typically not included as a credit when making a N fertilizer recommendation.

Adjustments to typical soil N mineralization (lines 1.7 to 1.9)

Nitrogen mineralization is the release of nitrogen from organic forms to plant-available inorganic forms (ammonium and nitrate). Soil organic matter supplies plant-available N through mineralization, but this is accounted for in the university fertilizer/nutrient

management guides. Sites with a history of cover crops, biosolids applications, or manure applications supply more plant-available N than do sites without a history of these inputs, and biosolids recommendations must be adjusted based on this additional supply of N.

Plowdown of cover crops

Cover crops are not removed from the field, but are recycled back into the soil. You can get an estimate of the total N contributed by estimating the biomass dry matter (lb per acre) and the nitrogen concentration (percent total) in the cover crop. Plant-available N provided by a cover crop typically ranges from 10 to 40 percent of the total N contained in aboveground cover crop biomass. Consult *Estimating Plant-Available Nitrogen Release from Cover Crops* (PNW 636) for more information.

Previous biosolids applications

Previous biosolids applications contribute to plant-available nitrogen in the years after the initial application. In the worksheet, they are considered as "N from other sources." We estimate that 8, 3, 1, and 1 percent of the organic N *originally applied* mineralizes in Years 2, 3, 4, and 5, respectively, after application (Table 1). After Year 5, biosolids N is considered part of "stable" soil organic matter and is not included in calculations.

In using Table 1, consider the following example. Suppose:

- You applied biosolids with an average organic N content of 30,000 mg/kg
- Applications were made the previous 2 years
- The application rate was 4 dry tons per acre

Table 1 gives estimates of nitrogen credits *in terms of the organic N originally applied*. Look up 30,000 mg/kg under Year 2 and Year 3 columns in the table. The table estimates 4.8 lb plant-available N per dry ton for year 2, and 1.8 lb plant-available N for year 3 (two-year credit of 6.6 lb N per dry ton). To calculate the N credit in units of lb per acre, multiply your application rate (4 dry ton per acre) by the N credit per ton (6.6 lb N per dry ton). The N credit is 26.4 lb plant-available N per acre.

Previous manure applications

Previous manure applications contribute to plant-available nitrogen in a similar manner to previous biosolids applications. To estimate this contribution, consider field history (manure type, application rate, and date of application). The Extension publication *Fertilizing with Manure and Other Organic Amendments* (PNW 533) provides plant-available N estimates.

Information supplied by the grower (line 1.10)

N applied at seeding

Some crops need a starter fertilizer (N applied at seeding) for best growth. These fertilizers usually supply N, P, and S. Examples are 16-20-0, 10-34-0. Starters are usually applied at rates that supply 10 to 30 lb N per acre. Enter all N supplied by starter fertilizer on line 1.10 in the worksheet.

Table 1. Estimated nitrogen credits for previous biosolids applications at a site

	Years after biosolids application			
	Year 2	Year 3	Year 4 and 5	Cumulative (Years 2, 3, 4, and 5)
	Percent of organic N applied first year			
	8	3	1	13
Biosolids organic N as applied (mg/kg dry weight basis)	**Plant-available N released (lb N per dry ton)**			
10,000	1.6	0.6	0.2	2.6
20,000	3.2	1.2	0.4	5.2
30,000	4.8	1.8	0.6	7.8
40,000	6.4	2.4	0.8	10.4
50,000	8.0	3.0	1.0	13.0
60,000	9.6	3.6	1.2	15.6

Photo: Brian Campbell, Natural Selection Farms

Dewatered biosolids application to dryland wheat during fallow

Step 2. Estimate plant-available N needed from biosolids

Next you will estimate the amount of plant-available N the biosolids must provide. This is the difference between the total plant-available N needed to produce the yield goal and the plant-available N from other sources.

Step. 3. Collect biosolids data

To make the calculation, managers will need the following analyses:

- Total Kjeldahl N (TKN)
- Ammonium-N (NH_4-N)
- Nitrate-N (NO_3-N; composted or aerobically digested biosolids only)
- Percent total solids

If your laboratory results are on an "as is" or wet weight basis, you must convert them to a dry weight basis. To convert from an "as is" to a dry weight basis, divide your analysis by the percent solids in the biosolids and multiply the result by 100. Total Kjeldahl N includes over 95 percent of the total N in biosolids. In using the worksheet, we will assume that total Kjeldahl N equals total N.

Ammonium-N usually makes up most of the inorganic N present in biosolids. Depending on your laboratory, results for ammonium-N may be expressed as either ammonia-N (NH_3-N) or ammonium-N (NH_4-N). Make sure that the laboratory determines ammonium-N on a fresh (not dried) biosolids sample. The ammonium-N present in fresh biosolids is lost as gaseous ammonia when biosolids are dried.

There may be significant amounts of nitrate in aerobically digested biosolids or in composts. There is little nitrate in anaerobically digested biosolids; therefore, nitrate analysis is not needed for these materials.

Determine biosolids organic N by subtracting ammonium-N from total Kjeldahl N (line 3.6 minus line 3.7). Percent total solids analyses are used to calculate application rates. Biosolids applications are calculated as the dry weight of solids applied per acre (e.g., dry tons per acre).

Step 4. Estimate plant-available N per dry ton of biosolids

The estimate of plant-available N per dry ton of biosolids includes:

- Some of the ammonium-N
- All of the nitrate-N
- Some of the organic N

Inorganic N retained (lines 4.5 to 4.7)

Ammonium-N (lines 4.5 to 4.6)

Under some conditions, ammonium is readily transformed to ammonia and lost as a gas. This gaseous ammonia loss reduces the amount of plant-available N supplied by biosolids. The following section explains the factors used to estimate ammonia-N retained in plant-available form after application.

Biosolids processing

The following types of biosolids processing cause most of the ammonia-N to be lost as ammonia gas or converted to organic forms before application:

- Drying beds
- Alkaline stabilization at pH 12
- Composting

Application method

Ammonia loss occurs only with surface application. Injecting liquid biosolids eliminates most ammonia loss, since the injected liquid is not exposed to the air. Surface applications of liquid biosolids lose less ammonia than do dewatered biosolids. For liquid biosolids, the ammonia is less concentrated and is held as NH_4^+ on negatively-charged soil surfaces after the liquid contacts the soil.

Ammonia loss is fastest just after application to the field. As ammonia is lost, the remaining biosolids are acidified—that is, each molecule of NH_3 lost generates H^+ (acidity). Acidification gradually slows ammonia loss.

Biosolids that remain on the soil surface will eventually reach a pH near 7, and further ammonia losses will be small. Ammonia loss takes place very rapidly after application, with most of the loss occurring during the first two days after application.

Time to soil incorporation

Tillage to cover biosolids can reduce ammonia loss by adsorption of ammonium-N onto soil particles.

Table 2 estimates the amount of ammonium-N retained after field application. To use this table, you will need information on biosolids stabilization processes, method of application (surface or injected), and the number of days to soil incorporation.

Nitrate-N (line 4.3)

We assume 100 percent availability of biosolids nitrate-N.

Organic N mineralized (lines 4.8 to 4.9)

Biosolids organic N, which includes proteins, amino acids, and other organic N compounds, is not available to plants at the time of application. Plant-available N is released from organic N through microbial activity in soil. This process is called mineralization. It is more rapid in soils that are warm and moist, and is slower in soils that are cold or dry. Biosolids organic N mineralization rates in soil also depend on the treatment plant processes that produced the biosolids.

Use Table 3 (page 10) to estimate biosolids mineralization rates based on processing. Use the middle of the range presented, unless you have information specific to the site or biosolids that justify using higher or lower values within the range.

Photo: City of Portland, Bureau of Environmental Services

Spring grass growth on dryland pasture following dewatered biosolids application (top) vs. no biosolids (bottom)

Step 5. Calculate the agronomic biosolids application rate

Perform this calculation using the results of the previous sections, as shown in lines 5.1 through 5.3.

Step 6. Convert agronomic biosolids application rate to "as is" basis

Use the appropriate conversion factors (given in Table 4, page 10) to convert to gallons, acre-inches, or wet tons per acre.

Table 2. Estimates of ammonium-N retained after biosolids application

	Surface-applied			Injected
	Liquid biosolids	Dewatered biosolids	Composted, air-dried, or heat-dried biosolids	All biosolids
Time to incorporation by tillage	**Ammonium-N retained (percent of applied)**			
Incorporated immediately	95	95	100	100
After 1 day	70	50	100	100
After 2 days	60	30	100	100
No incorporation	55	20	100	100

Table 3. First year mineralization estimates for organic N in biosolids

Processing	First-year organic N mineralization rate (percent of organic N)
Fresh*	
Anaerobic digestion, liquid or dewatered	30–40
Aerobic digestion, liquid or dewatered	30–40
Drying bed	30–40
Heat-dried	30–40
Lagoon	
Less than 6 months	30–40
6 months to 2 years	20–25
2 to 10 years	10–20
More than 10 years	5–10
Composting	0–10
Blends and soil products	†

*"Fresh" includes all biosolids that have not been stabilized by long-term storage in lagoons or composting.

†Because blends (with woody materials) and soil products that contain biosolids vary widely in composition and age depending on intended use, available N may vary widely among products. For blends, available N can be estimated through laboratory incubation studies.

Table 4. Conversion factors

1%	=	10,000 mg/kg or ppm 20 lb/ton
1 mg/kg	=	1 ppm 0.0001 % 0.002 lb/ton
1 wet ton	=	1 dry ton ÷ (percent solids × 0.01)
1 dry ton	=	1 wet ton × (percent solids × 0.01)
1 acre-inch	=	27,000 gallons

Other considerations for calculations

Small acreage sites without a reliable yield history

Some communities apply biosolids to small acreages managed by part-time farmers. In many of these cases, there is no reliable yield history for the site, and the goal of management is not to make the highest economic returns. You can be sure of maintaining agronomic use of biosolids nitrogen on these sites by applying at a rate substantially below that estimated for maximum yield.

Equipment limitations at low application rates

At some low-rainfall dryland cropping locations east of the Cascades, the agronomic rate calculated with the worksheet will be lower than can be spread with manure spreaders (usually 2 to 3 dry tons per acre). At these locations, you may be able to apply the dewatered biosolids at the equipment limit, but check with your permitting agency for local requirements.

Appendix A: Cumulative loading of trace elements

Under EPA regulations (40 CFR Part 503.13), managers must maintain records on cumulative loading of trace elements only when bulk biosolids do not meet EPA Exceptional Quality Standards for trace elements (Table 5). Contact your regulatory agency for details on record keeping if your biosolids do not meet the standards in Table 5.

Table 5. Trace elements concentration limits for land application

Element	Symbol	Concentration limit	
		Exceptional quality standard (EPA Table 3)* (mg/kg)	Ceiling limit (EPA Table 1)* (mg/kg)
Arsenic	As	41	75
Cadmium	Cd	39	85
Copper	Cu	1,500	4,300
Lead	Pb	300	840
Mercury	Hg	17	57
Molybdenum	Mo	**	75
Nickel	Ni	420	420
Selenium	Se	100	100
Zinc	Zn	2,800	7,500

Source: EPA 40 CFR Part 503

*EPA Table 3 and Table 1 refer to tables in EPA biosolids rule (40 CFR Part 503).

**Molybdenum concentration standard level is under review by the EPA.

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SITE AUTHORIZATION DOCUMENTATION

MAY 2024

Prepared for the
City of North Powder, Oregon

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CITY OF

NORTH POWDER, OREGON

SITE AUTHORIZATION DOCUMENTATION

MAY 2024

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Appendix B Custom Soil Resource Report
Appendix C Fertilizer Guide
Appendix D Biosolids Test Results
Appendix E Nutrient Uptake Calculations
Appendix F Example Notification Letter

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Introduction

This document presents the site authorization documentation required for the land application of biosolids from the City of North Powder's wastewater treatment facility (WWTF). This document has been developed in accordance with the Oregon Department of Environmental Quality Biosolids Land Application Site Authorization Request Checklist.

Site Information

Geographic Area

The City of North Powder is located approximately 22 miles south of the City of La Grande, Oregon, in Union County. The WWTF, located in Township 6 South, Range 39 East, Sections 23 and 26, Willamette Meridian, serves a population of approximately 445 people. The proposed biosolids application site is located south of the City in Baker County and is zoned for Exclusive Farm Use.

Landscape Position

The application sites proposed to receive biosolids are located east of Interstate 84 and between the North Powder River and Bidwell Road (Township 6 South, Range 39 East, Sections 23 and 26, Willamette Meridian). Figure 1 shows the location and vicinity maps and the proposed biosolids application sites. Figure 2 shows the WWTF. The privately owned land application sites are utilized for alfalfa hay and pasture.

Application Site Owner

Table 1 shows the location of the sites to be utilized in the land application of biosolids and the owner. It also indicates the nearest residence to the biosolids application sites. Figure 3 shows the biosolids application site with nearby wells and dwellings.

TABLE 1
APPLICATION SITE

Alfalfa	Owner:	Myron Miles 70440 Miles Ranch Road North Powder, Oregon 97867
	Nearest Residence:	Myron Miles 70440 Miles Ranch Road North Powder, Oregon 97867

Site Management Agreements

A site management agreement between the City of North Powder and the owner of the application sites is in progress and will be included in Appendix A once finalized.

Adjacent Land Uses

Adjacent land is used for agricultural and rural residential purposes.

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Soil Information

The Natural Resources Conservation Service (NRCS) Soil Survey of Baker County lists Powval silt loam and Baker silt loam as the main soil series at the application sites. Figure 4 shows the soil survey map of the proposed biosolids application sites. A Custom Soil Resource Report from the National Cooperative Soil Survey completed by the NRCS is provided in Appendix B. The following describes the major soil series indicated on the soil survey map.

Powval Silt Loam

Powval silt loam consists of well-drained soils. The parent material consists of mixed alluvium. The depth to hardpan, a root-restrictive layer, is more than 80 inches. Water movement in the most restrictive layer is moderately high to high, and slopes range from 0 to 3 percent. This soil is not flooded or ponded. The depth to water table is 48 to 72 inches.

Baker Silt Loam

Baker silt loam consists of well-drained soils. The parent material consists of alluvial sediments mixed with volcanic ash and loess. The depth to duripan, a root-restrictive layer, is 20 to 40 inches. Water movement in the most restrictive layer is low to moderately low, and slopes range from 0 to 2 percent. The soil is not flooded or ponded. There is no zone of water saturation within a depth of 80 inches.

Agriculture and Crop Management Information

As mentioned above, the biosolids application site will be utilized for alfalfa and pasture cultivation.

Crop Assimilative Capacity

Class B biosolids are required to be land-applied to a site at a rate that is equal to or less than the agronomic rate for the site. An agronomic rate is the whole biosolids application rate (dry weight basis) designed to provide the annual total amount of nitrogen needed by a crop and to minimize the amount of nitrogen passing below the root zone of the crop or vegetation to groundwater.

The alfalfa is anticipated to uptake 175 pounds of nitrogen per acre (lbs N/acre). Since alfalfa is a nitrogen fixer and does not require nitrogen fertilizer to grow, it was assumed that the crop would uptake 50 pounds of nitrogen per ton of alfalfa. This is a conservative value as stated in the *Nutrient Management Guide for Dryland and Irrigated Alfalfa in the Inland Northwest, Northwest Extension Publication, PNW0611*, which is provided in Appendix C. Approximately 3.5 tons per acre of alfalfa is estimated to be harvested based on average production rate for Baker County provided by the Baker County Oregon State University Extension Office. This results in an uptake of approximately 175 lbs N/acre.

Time of Application

Biosolids from the WWTF are anticipated to start being applied in summer 2024.

Harvesting Methods

The alfalfa application sites will be harvested in accordance with standard haying practices.

Irrigation and Fertilizing Practices

Table 2 shows the irrigation and fertilizing practices for the biosolids application sites.

TABLE 2
IRRIGATION AND FERTILIZING PRACTICES

	Alfalfa Application Sites
Irrigation Type	Center Pivot Irrigation
Fertilizer	Biosolids/Supplemental

Biosolids and Land Application Information

Pollutant Characteristics

Table 3 is a representative biosolids analysis for pollutant characteristics. Samples for the lagoon biosolids were collected on December 19, 2023. These data and previous data indicate that pollutant concentrations for all regulated pollutants below have been met. The pollutant concentrations will be analyzed again prior to application. Test results are included in Appendix D.

TABLE 3
ALLOWED BIOSOLIDS POLLUTION LIMITS AND CONCENTRATIONS

Pollutant	**Lagoon Biosolids Analytical Result mg/kg (lbs/ton)**	**40 CFR 503.13(b)(1) Pollutant Concentration Limits mg/kg (lbs/ton)**
Arsenic (As)	< 9.21 (0.018)	75 (0.15)
Cadmium (Cd)	< 1.84 (0.004)	85 (0.17)
Chromium (Cr)	< 18.4 (0.037)	-
Copper (Cu)	118.10 (0.237)	4,300 (8.6)
Lead (Pb)	23.80 (0.048)	840 (1.68)
Mercury (Hg)	< 3.68 (0.007)	57 (0.114)
Molybdenum (Mo)	< 18.4 (0.037)	75 (0.15)
Nickel (Ni)	< 18.4 (0.037)	420 (0.84)
Selenium (Se)	< 18.4 (0.037)	100 (0.2)
Zinc (Zn)	481 (0.962)	7,500 (15.0)

CFR = Code of Federal Regulations
lbs/ton = pounds per ton
mg/kg = milligrams per kilogram
< = less than

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Nutrient Characteristics and Other Parameters

Table 4 is a representative biosolids analysis for nutrient characteristics and other parameters. Samples for the lagoon were collected on December 19, 2023. The nutrient characteristics shown on Table 4 below were utilized for calculating the preliminary application rates below. The nutrient characteristics will be resampled prior to application.

TABLE 4
BIOSOLIDS NUTRIENT CHARACTERISTICS

Source	Lagoon Biosolids Analytical Result		
Parameter/ Measurement Unit	**Wet Weight**	**Dry Weight**	**Pounds per Dry Ton**
Total Solids, percent	2.13	N/A	N/A
Volatile Solids, percent	57.43	N/A	N/A
TKN, mg/kg	807.42	37,966.67	1.61
NO_3-N, mg/kg	<0.72	<33.9	<0.001
NH_4-N, mg/kg	134.33	6,316.67	0.27
Phosphate (P), percent	0.7	N/A	N/A
pH. percent	6.9	N/A	N/A

N/A = Not Applicable *TKN = total Kjeldahl nitrogen*

NO_3-N = nitrate nitrogen

NH_4-N = ammonium nitrogen

Biosolids Application Rates

The following are example calculations for biosolids application rates; the calculations need to be performed prior to each application. Plant-available nitrogen (PAN) is calculated by adding inorganic nitrogen retained and organic nitrogen mineralized. Inorganic nitrogen retained is calculated by multiplying the weight of ammonium nitrogen per dry ton of biosolids by the percent retained after application and adding the weight of nitrate-nitrogen per dry ton. The percent retained is based on the drying method used and days to incorporation by tillage after application. The biosolids will be applied as a liquid with no incorporation and will retain approximately 55 percent of the ammonium nitrogen. The inorganic nitrogen retained is calculated to be 6.95 pounds of nitrogen per dry ton (lbs N/dry ton). The organic nitrogen mineralized is calculated by subtracting the ammonium nitrogen from the TKN and multiplying by the percent of organic nitrogen that is plant-available in year one. The percent of organic nitrogen available in year one is approximately 10 percent based on the biosolids processing and moisture content. The amount of organic nitrogen mineralized is calculated as 6.33 lbs N/dry ton. The PAN in the biosolids is calculated as 13.28 lbs N/dry ton. The nutrient uptake calculations can be found in Appendix E.

The alfalfa anticipated uptake, 175 lbs N/acre, subtracting the PAN in the soil gives an application rate of 87 lbs N/acre, divided by the estimated PAN in the biosolids, resulting in an application rate of 6.55 dry tons/acre. With approximately 94 acres of alfalfa, 615 dry tons of biosolids can be applied.

Table 5 provides a breakdown of where the biosolids will be applied, the crop, and the number of available acres.

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TABLE 5
ACREAGE OF APPLICATION SITE

Biosolids Application Site	Crop	Acres Available
Application Site 1	Alfalfa	72
Application Site 2	Alfalfa	22

Sampling and Monitoring Program

In 2023, in preparation for lagoon improvements and biosolids removal, biosolids were sampled in the lagoon. Sludge sampling and testing were also completed to determine the preliminary applicable land application rates. The nutrient and pollutant characteristics will be resampled prior to application.

Neighbor Notifications

Notifications will be sent to all neighboring property owners. An example notification letter and attachments are included in Appendix F.

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FIGURES

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T. 6 S., R. 39 E., W.M.

1,500 0 1,500

SCALE IN FEET

To La Grande

To Cove

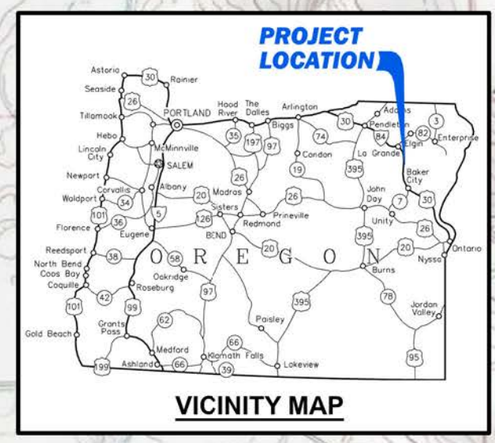
WASTEWATER TREATMENT FACILITY

CITY LIMITS

URBAN GROWTH BOUNDARY

To Haines

To Baker City



VICINITY MAP

Copyright:© 2013 National Geographic Society, i-cubed

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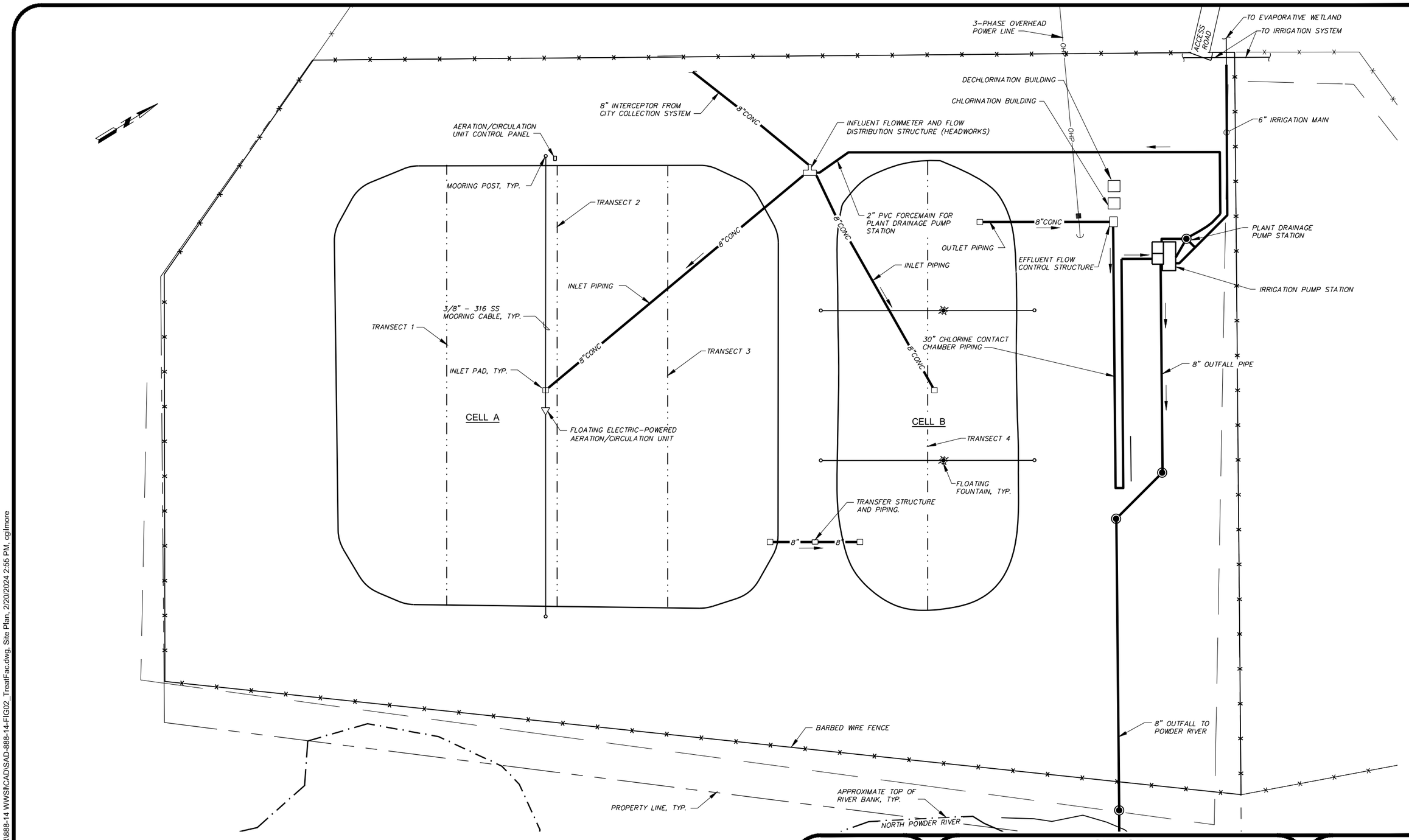
anderson perry

CITY OF
NORTH POWDER, OREGON
SITE AUTHORIZATION DOCUMENTATION

LOCATION AND VICINITY MAPS

FIGURE
1



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anderson perry

CITY OF
NORTH POWDER, OREGON
SITE AUTHORIZATION DOCUMENTATION

TREATMENT FACILITY SITE PLAN

FIGURE
2

500 0 500

SCALE IN FEET

LEGEND

- PARCEL BOUNDARY
- BIOSOLIDS LAND APPLICATION SITE

Site 1

Site 2

Site 3

Site 4

200 FT. BUFFER, TYP.

200 FT. BUFFER, TYP.

BIDWELL RD.

Powder River

North Powder River

CLOSEST WELL AND DWELLING

WASTEWATER TREATMENT FACILITY

237

Source: Esri, Maxar, Earthstar Geographics, IGN, and the GIS User Community

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CITY OF
NORTH POWDER, OREGON
SITE AUTHORIZATION DOCUMENTATION

BIOSOLIDS LAND APPLICATION SITES

FIGURE
3

SOILS LEGEND

11A BAKER SILT LOAM, 0 TO 2 PERCENT SLOPES
13A BALDOCK SILT LOAM, 0 TO 2 PERCENT SLOPES
62A HAINES SILT LOAM, 0 TO 2 PERCENT SLOPES
126A POWVAL SILT LOAM, 0 TO 3 PERCENT SLOPES
170A UMAPINE SILT LOAM, 0 TO 2 PERCENT SLOPES

SITE 2
APPROX. 22 AC.

SITE 1
APPROX. 90 AC.

170A
176A
159A
62A
13A
126A
11A

River
Powder

BIDWELL RD.

LEGEND

SOILS BOUNDARY
PARCEL BOUNDARY
BIOSOLIDS LAND APPLICATION SITE

500 0 500
SCALE IN FEET

Source: Esri, Maxar, Earthstar Geographics, IGN, and the GIS User Community

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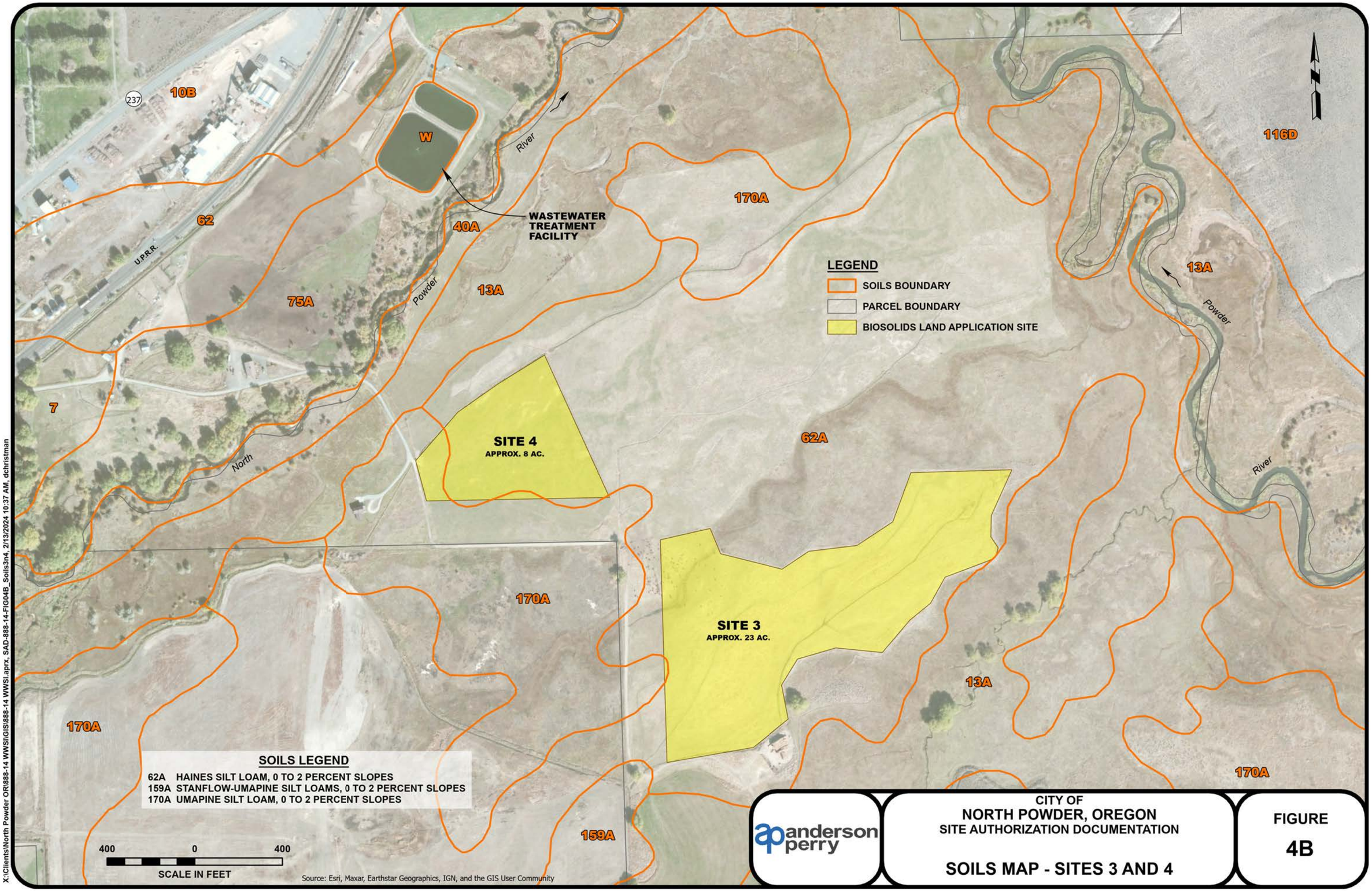
CITY OF
NORTH POWDER, OREGON
SITE AUTHORIZATION DOCUMENTATION

SOILS MAP - SITES 1 AND 2

FIGURE
4A



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CITY OF
NORTH POWDER, OREGON
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SOILS MAP - SITES 3 AND 4

FIGURE
4B

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Appendix A Site Management Agreement (*Forthcoming)*

Appendix B Custom Soil Resource Report

Appendix C Fertilizer Guide

Appendix D Biosolids Test Results

Appendix E Nutrient Uptake Calculations

Appendix F Example Notification Letter

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APPENDIX A
Site Management Agreement
(Forthcoming)

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APPENDIX B
Custom Soil Resource Report

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United States Department of Agriculture

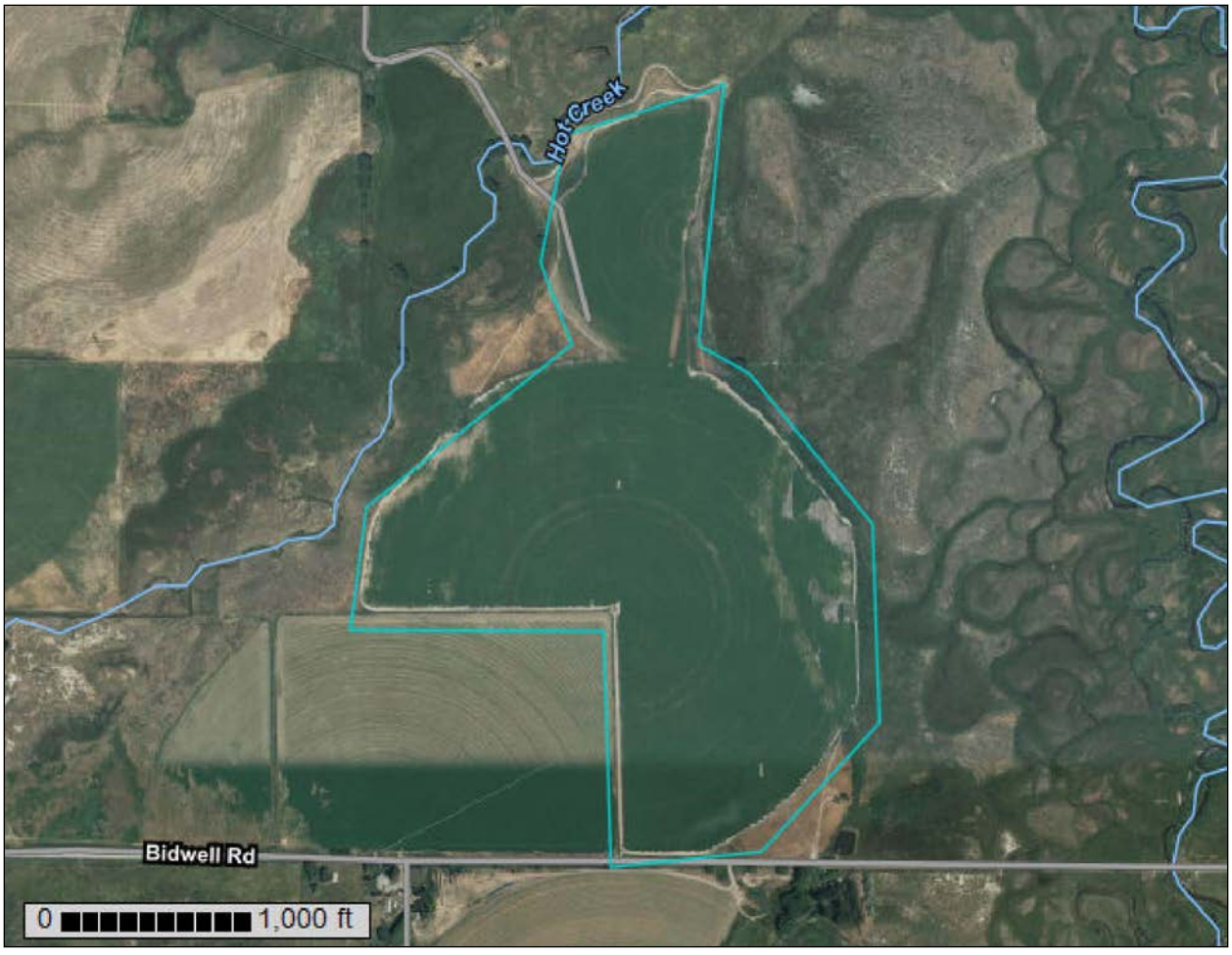
NRCS

Natural Resources Conservation Service

A product of the National Cooperative Soil Survey, a joint effort of the United States Department of Agriculture and other Federal agencies, State agencies including the Agricultural Experiment Stations, and local participants

Custom Soil Resource Report for Baker County Area, Oregon

Application Sites 1 and 2



February 8, 2024

Preface

Soil surveys contain information that affects land use planning in survey areas. They highlight soil limitations that affect various land uses and provide information about the properties of the soils in the survey areas. Soil surveys are designed for many different users, including farmers, ranchers, foresters, agronomists, urban planners, community officials, engineers, developers, builders, and home buyers. Also, conservationists, teachers, students, and specialists in recreation, waste disposal, and pollution control can use the surveys to help them understand, protect, or enhance the environment.

Various land use regulations of Federal, State, and local governments may impose special restrictions on land use or land treatment. Soil surveys identify soil properties that are used in making various land use or land treatment decisions. The information is intended to help the land users identify and reduce the effects of soil limitations on various land uses. The landowner or user is responsible for identifying and complying with existing laws and regulations.

Although soil survey information can be used for general farm, local, and wider area planning, onsite investigation is needed to supplement this information in some cases. Examples include soil quality assessments (http://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/health/) and certain conservation and engineering applications. For more detailed information, contact your local USDA Service Center (https://offices.sc.egov.usda.gov/locator/app?agency=nrcs) or your NRCS State Soil Scientist (http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/contactus/?cid=nrcs142p2_053951).

Great differences in soil properties can occur within short distances. Some soils are seasonally wet or subject to flooding. Some are too unstable to be used as a foundation for buildings or roads. Clayey or wet soils are poorly suited to use as septic tank absorption fields. A high water table makes a soil poorly suited to basements or underground installations.

The National Cooperative Soil Survey is a joint effort of the United States Department of Agriculture and other Federal agencies, State agencies including the Agricultural Experiment Stations, and local agencies. The Natural Resources Conservation Service (NRCS) has leadership for the Federal part of the National Cooperative Soil Survey.

Information about soils is updated periodically. Updated information is available through the NRCS Web Soil Survey, the site for official soil survey information.

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How Soil Surveys Are Made

Soil surveys are made to provide information about the soils and miscellaneous areas in a specific area. They include a description of the soils and miscellaneous areas and their location on the landscape and tables that show soil properties and limitations affecting various uses. Soil scientists observed the steepness, length, and shape of the slopes; the general pattern of drainage; the kinds of crops and native plants; and the kinds of bedrock. They observed and described many soil profiles. A soil profile is the sequence of natural layers, or horizons, in a soil. The profile extends from the surface down into the unconsolidated material in which the soil formed or from the surface down to bedrock. The unconsolidated material is devoid of roots and other living organisms and has not been changed by other biological activity.

Currently, soils are mapped according to the boundaries of major land resource areas (MLRAs). MLRAs are geographically associated land resource units that share common characteristics related to physiography, geology, climate, water resources, soils, biological resources, and land uses (USDA, 2006). Soil survey areas typically consist of parts of one or more MLRA.

The soils and miscellaneous areas in a survey area occur in an orderly pattern that is related to the geology, landforms, relief, climate, and natural vegetation of the area. Each kind of soil and miscellaneous area is associated with a particular kind of landform or with a segment of the landform. By observing the soils and miscellaneous areas in the survey area and relating their position to specific segments of the landform, a soil scientist develops a concept, or model, of how they were formed. Thus, during mapping, this model enables the soil scientist to predict with a considerable degree of accuracy the kind of soil or miscellaneous area at a specific location on the landscape.

Commonly, individual soils on the landscape merge into one another as their characteristics gradually change. To construct an accurate soil map, however, soil scientists must determine the boundaries between the soils. They can observe only a limited number of soil profiles. Nevertheless, these observations, supplemented by an understanding of the soil-vegetation-landscape relationship, are sufficient to verify predictions of the kinds of soil in an area and to determine the boundaries.

Soil scientists recorded the characteristics of the soil profiles that they studied. They noted soil color, texture, size and shape of soil aggregates, kind and amount of rock fragments, distribution of plant roots, reaction, and other features that enable them to identify soils. After describing the soils in the survey area and determining their properties, the soil scientists assigned the soils to taxonomic classes (units). Taxonomic classes are concepts. Each taxonomic class has a set of soil characteristics with precisely defined limits. The classes are used as a basis for comparison to classify soils systematically. Soil taxonomy, the system of taxonomic classification used in the United States, is based mainly on the kind and character of soil properties and the arrangement of horizons within the profile. After the soil

scientists classified and named the soils in the survey area, they compared the individual soils with similar soils in the same taxonomic class in other areas so that they could confirm data and assemble additional data based on experience and research.

The objective of soil mapping is not to delineate pure map unit components; the objective is to separate the landscape into landforms or landform segments that have similar use and management requirements. Each map unit is defined by a unique combination of soil components and/or miscellaneous areas in predictable proportions. Some components may be highly contrasting to the other components of the map unit. The presence of minor components in a map unit in no way diminishes the usefulness or accuracy of the data. The delineation of such landforms and landform segments on the map provides sufficient information for the development of resource plans. If intensive use of small areas is planned, onsite investigation is needed to define and locate the soils and miscellaneous areas.

Soil scientists make many field observations in the process of producing a soil map. The frequency of observation is dependent upon several factors, including scale of mapping, intensity of mapping, design of map units, complexity of the landscape, and experience of the soil scientist. Observations are made to test and refine the soil-landscape model and predictions and to verify the classification of the soils at specific locations. Once the soil-landscape model is refined, a significantly smaller number of measurements of individual soil properties are made and recorded. These measurements may include field measurements, such as those for color, depth to bedrock, and texture, and laboratory measurements, such as those for content of sand, silt, clay, salt, and other components. Properties of each soil typically vary from one point to another across the landscape.

Observations for map unit components are aggregated to develop ranges of characteristics for the components. The aggregated values are presented. Direct measurements do not exist for every property presented for every map unit component. Values for some properties are estimated from combinations of other properties.

While a soil survey is in progress, samples of some of the soils in the area generally are collected for laboratory analyses and for engineering tests. Soil scientists interpret the data from these analyses and tests as well as the field-observed characteristics and the soil properties to determine the expected behavior of the soils under different uses. Interpretations for all of the soils are field tested through observation of the soils in different uses and under different levels of management. Some interpretations are modified to fit local conditions, and some new interpretations are developed to meet local needs. Data are assembled from other sources, such as research information, production records, and field experience of specialists. For example, data on crop yields under defined levels of management are assembled from farm records and from field or plot experiments on the same kinds of soil.

Predictions about soil behavior are based not only on soil properties but also on such variables as climate and biological activity. Soil conditions are predictable over long periods of time, but they are not predictable from year to year. For example, soil scientists can predict with a fairly high degree of accuracy that a given soil will have a high water table within certain depths in most years, but they cannot predict that a high water table will always be at a specific level in the soil on a specific date.

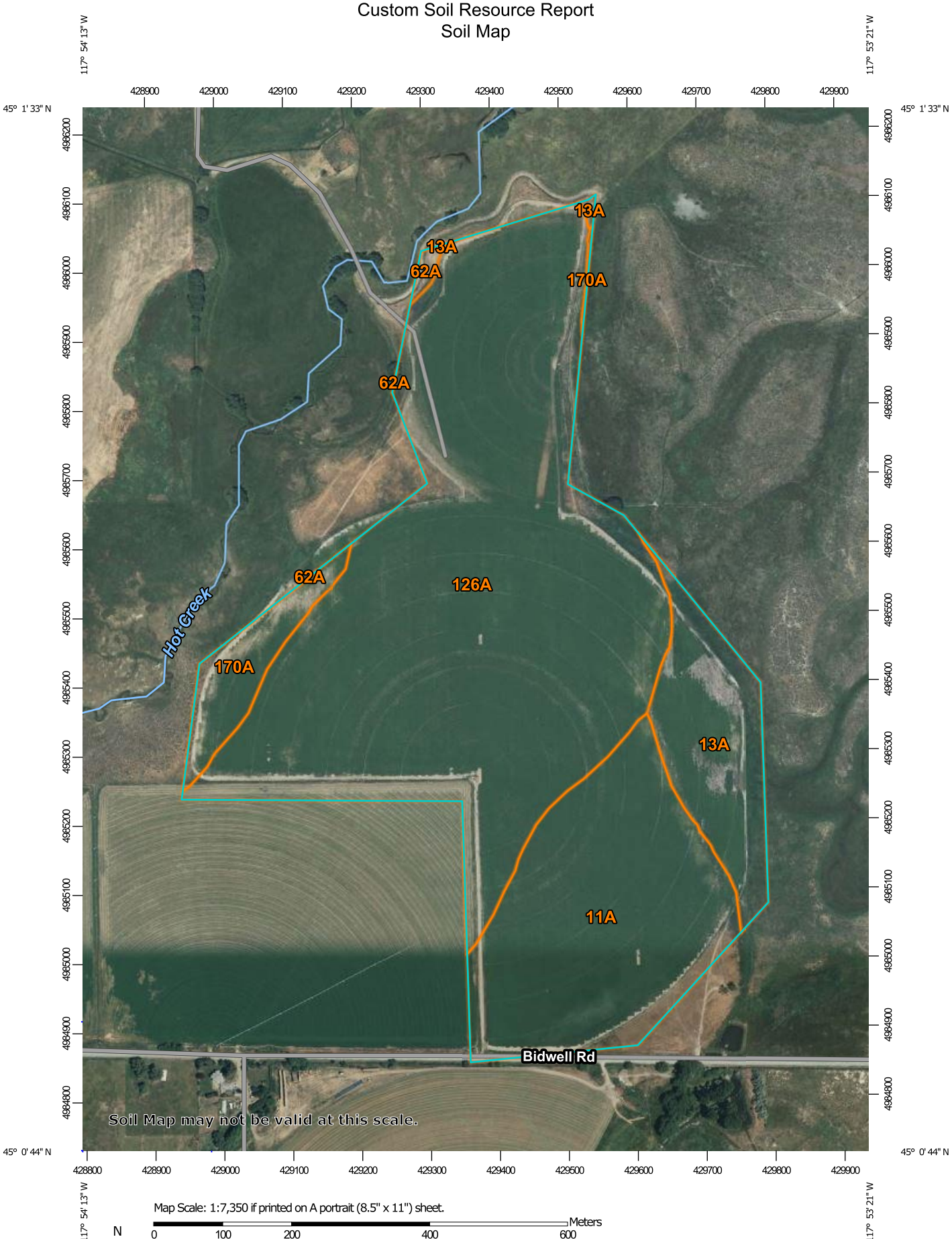
After soil scientists located and identified the significant natural bodies of soil in the survey area, they drew the boundaries of these bodies on aerial photographs and

identified each as a specific map unit. Aerial photographs show trees, buildings, fields, roads, and rivers, all of which help in locating boundaries accurately.

Soil Map

The soil map section includes the soil map for the defined area of interest, a list of soil map units on the map and extent of each map unit, and cartographic symbols displayed on the map. Also presented are various metadata about data used to produce the map, and a description of each soil map unit.

Custom Soil Resource Report
Soil Map



Map Scale: 1:7,350 if printed on A portrait (8.5" x 11") sheet.

N

Meters: 0 100 200 400 600

Feet: 0 350 700 1400 2100

Map projection: Web Mercator Corner coordinates: WGS84 Edge tics: UTM Zone 11N WGS84

MAP LEGEND

Area of Interest (AOI)
- Area of Interest (AOI)

Soils
- Soil Map Unit Polygons
- Soil Map Unit Lines
- Soil Map Unit Points

Special Point Features
- Blowout
- Borrow Pit
- Clay Spot
- Closed Depression
- Gravel Pit
- Gravelly Spot
- Landfill
- Lava Flow
- Marsh or swamp
- Mine or Quarry
- Miscellaneous Water
- Perennial Water
- Rock Outcrop
- Saline Spot
- Sandy Spot
- Severely Eroded Spot
- Sinkhole
- Slide or Slip
- Sodic Spot
- Spoil Area
- Stony Spot
- Very Stony Spot
- Wet Spot
- Other
- Special Line Features

Water Features
- Streams and Canals

Transportation
- Rails
- Interstate Highways
- US Routes
- Major Roads
- Local Roads

Background
- Aerial Photography

MAP INFORMATION

The soil surveys that comprise your AOI were mapped at 1:24,000.

Warning: Soil Map may not be valid at this scale.

Enlargement of maps beyond the scale of mapping can cause misunderstanding of the detail of mapping and accuracy of soil line placement. The maps do not show the small areas of contrasting soils that could have been shown at a more detailed scale.

Please rely on the bar scale on each map sheet for map measurements.

Source of Map: Natural Resources Conservation Service
Web Soil Survey URL:
Coordinate System: Web Mercator (EPSG:3857)

Maps from the Web Soil Survey are based on the Web Mercator projection, which preserves direction and shape but distorts distance and area. A projection that preserves area, such as the Albers equal-area conic projection, should be used if more accurate calculations of distance or area are required.

This product is generated from the USDA-NRCS certified data as of the version date(s) listed below.

Soil Survey Area: Baker County Area, Oregon
Survey Area Data: Version 20, Sep 8, 2023

Soil map units are labeled (as space allows) for map scales 1:50,000 or larger.

Date(s) aerial images were photographed: Jul 20, 2020—Aug 14, 2020

The orthophoto or other base map on which the soil lines were compiled and digitized probably differs from the background imagery displayed on these maps. As a result, some minor shifting of map unit boundaries may be evident.

Map Unit Legend

Map Unit Symbol	Map Unit Name	Acres in AOI	Percent of AOI
11A	Baker silt loam, 0 to 2 percent slopes	30.1	22.9%
13A	Baldock silt loam, 0 to 2 percent slopes	12.5	9.5%
62A	Haines silt loam, 0 to 2 percent slopes	0.4	0.3%
126A	Powval silt loam, 0 to 3 percent slopes	82.9	63.1%
170A	Umapine silt loam, 0 to 2 percent slopes	5.4	4.1%
Totals for Area of Interest		**131.4**	**100.0%**

Map Unit Descriptions

The map units delineated on the detailed soil maps in a soil survey represent the soils or miscellaneous areas in the survey area. The map unit descriptions, along with the maps, can be used to determine the composition and properties of a unit.

A map unit delineation on a soil map represents an area dominated by one or more major kinds of soil or miscellaneous areas. A map unit is identified and named according to the taxonomic classification of the dominant soils. Within a taxonomic class there are precisely defined limits for the properties of the soils. On the landscape, however, the soils are natural phenomena, and they have the characteristic variability of all natural phenomena. Thus, the range of some observed properties may extend beyond the limits defined for a taxonomic class. Areas of soils of a single taxonomic class rarely, if ever, can be mapped without including areas of other taxonomic classes. Consequently, every map unit is made up of the soils or miscellaneous areas for which it is named and some minor components that belong to taxonomic classes other than those of the major soils.

Most minor soils have properties similar to those of the dominant soil or soils in the map unit, and thus they do not affect use and management. These are called noncontrasting, or similar, components. They may or may not be mentioned in a particular map unit description. Other minor components, however, have properties and behavioral characteristics divergent enough to affect use or to require different management. These are called contrasting, or dissimilar, components. They generally are in small areas and could not be mapped separately because of the scale used. Some small areas of strongly contrasting soils or miscellaneous areas are identified by a special symbol on the maps. If included in the database for a given area, the contrasting minor components are identified in the map unit descriptions along with some characteristics of each. A few areas of minor components may not have been observed, and consequently they are not mentioned in the descriptions, especially where the pattern was so complex that it was impractical to make enough observations to identify all the soils and miscellaneous areas on the landscape.

The presence of minor components in a map unit in no way diminishes the usefulness or accuracy of the data. The objective of mapping is not to delineate pure taxonomic classes but rather to separate the landscape into landforms or landform segments that have similar use and management requirements. The delineation of such segments on the map provides sufficient information for the development of resource plans. If intensive use of small areas is planned, however, onsite investigation is needed to define and locate the soils and miscellaneous areas.

An identifying symbol precedes the map unit name in the map unit descriptions. Each description includes general facts about the unit and gives important soil properties and qualities.

Soils that have profiles that are almost alike make up a *soil series*. Except for differences in texture of the surface layer, all the soils of a series have major horizons that are similar in composition, thickness, and arrangement.

Soils of one series can differ in texture of the surface layer, slope, stoniness, salinity, degree of erosion, and other characteristics that affect their use. On the basis of such differences, a soil series is divided into *soil phases*. Most of the areas shown on the detailed soil maps are phases of soil series. The name of a soil phase commonly indicates a feature that affects use or management. For example, Alpha silt loam, 0 to 2 percent slopes, is a phase of the Alpha series.

Some map units are made up of two or more major soils or miscellaneous areas. These map units are complexes, associations, or undifferentiated groups.

A *complex* consists of two or more soils or miscellaneous areas in such an intricate pattern or in such small areas that they cannot be shown separately on the maps. The pattern and proportion of the soils or miscellaneous areas are somewhat similar in all areas. Alpha-Beta complex, 0 to 6 percent slopes, is an example.

An *association* is made up of two or more geographically associated soils or miscellaneous areas that are shown as one unit on the maps. Because of present or anticipated uses of the map units in the survey area, it was not considered practical or necessary to map the soils or miscellaneous areas separately. The pattern and relative proportion of the soils or miscellaneous areas are somewhat similar. Alpha-Beta association, 0 to 2 percent slopes, is an example.

An *undifferentiated group* is made up of two or more soils or miscellaneous areas that could be mapped individually but are mapped as one unit because similar interpretations can be made for use and management. The pattern and proportion of the soils or miscellaneous areas in a mapped area are not uniform. An area can be made up of only one of the major soils or miscellaneous areas, or it can be made up of all of them. Alpha and Beta soils, 0 to 2 percent slopes, is an example.

Some surveys include *miscellaneous areas*. Such areas have little or no soil material and support little or no vegetation. Rock outcrop is an example.

Baker County Area, Oregon

11A—Baker silt loam, 0 to 2 percent slopes

Map Unit Setting

National map unit symbol: 22lp
Elevation: 2,000 to 3,500 feet
Mean annual precipitation: 9 to 12 inches
Mean annual air temperature: 45 to 48 degrees F
Frost-free period: 110 to 125 days
Farmland classification: Prime farmland if irrigated

Map Unit Composition

Baker and similar soils: 85 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Baker

Setting

Landform: Terraces
Landform position (three-dimensional): Tread
Down-slope shape: Linear
Across-slope shape: Linear
Parent material: Old alluvium mixed with volcanic ash and loess

Typical profile

H1 - 0 to 8 inches: silt loam
H2 - 8 to 16 inches: silt loam
H3 - 16 to 31 inches: loam
H4 - 31 to 39 inches: cemented material
H5 - 39 to 60 inches: stratified extremely gravelly sand to gravelly loam

Properties and qualities

Slope: 0 to 2 percent
Depth to restrictive feature: 20 to 40 inches to duripan
Drainage class: Well drained
Capacity of the most limiting layer to transmit water (Ksat): Very low to moderately low (0.00 to 0.06 in/hr)
Depth to water table: More than 80 inches
Frequency of flooding: None
Frequency of ponding: None
Calcium carbonate, maximum content: 10 percent
Maximum salinity: Nonsaline to very slightly saline (0.0 to 2.0 mmhos/cm)
Available water supply, 0 to 60 inches: Low (about 5.5 inches)

Interpretive groups

Land capability classification (irrigated): 3s
Land capability classification (nonirrigated): 4s
Hydrologic Soil Group: C
Ecological site: R010XC030OR - SR Cool 9-12 PZ
Hydric soil rating: No

13A—Baldock silt loam, 0 to 2 percent slopes

Map Unit Setting

National map unit symbol: 22mj
Elevation: 2,000 to 3,600 feet
Mean annual precipitation: 9 to 12 inches
Mean annual air temperature: 45 to 50 degrees F
Frost-free period: 110 to 140 days
Farmland classification: Prime farmland if irrigated and drained

Map Unit Composition

Baldock and similar soils: 85 percent
Minor components: 9 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Baldock

Setting

Landform: Flood plains
Landform position (three-dimensional): Tread
Down-slope shape: Linear
Across-slope shape: Linear
Parent material: Mixed alluvium

Typical profile

H1 - 0 to 6 inches: silt loam
H2 - 6 to 36 inches: silt loam
H3 - 36 to 60 inches: silt loam

Properties and qualities

Slope: 0 to 2 percent
Depth to restrictive feature: More than 80 inches
Drainage class: Poorly drained
Capacity of the most limiting layer to transmit water (Ksat): Moderately high to high (0.57 to 1.98 in/hr)
Depth to water table: About 0 to 18 inches
Frequency of flooding: Occasional
Frequency of ponding: None
Calcium carbonate, maximum content: 15 percent
Maximum salinity: Nonsaline to very slightly saline (0.0 to 2.0 mmhos/cm)
Sodium adsorption ratio, maximum: 5.0
Available water supply, 0 to 60 inches: High (about 10.9 inches)

Interpretive groups

Land capability classification (irrigated): 3w
Land capability classification (nonirrigated): 4w
Hydrologic Soil Group: B/D
Ecological site: R010XY003OR - WET MEADOW
Hydric soil rating: Yes

Minor Components

Haines

Percent of map unit: 3 percent
Landform: Flood plains
Landform position (three-dimensional): Tread
Down-slope shape: Linear
Across-slope shape: Linear
Ecological site: R010XY008OR - SODIC MEADOW
Hydric soil rating: Yes

Boyce

Percent of map unit: 3 percent
Landform: Flood plains
Landform position (three-dimensional): Tread
Down-slope shape: Linear
Across-slope shape: Linear
Ecological site: R010XY003OR - WET MEADOW
Hydric soil rating: Yes

Wingdale

Percent of map unit: 3 percent
Landform: Flood plains
Landform position (three-dimensional): Tread
Down-slope shape: Linear
Across-slope shape: Linear
Ecological site: R010XY003OR - WET MEADOW
Hydric soil rating: Yes

62A—Haines silt loam, 0 to 2 percent slopes

Map Unit Setting

National map unit symbol: 22rv
Elevation: 2,000 to 3,600 feet
Mean annual precipitation: 9 to 12 inches
Mean annual air temperature: 45 to 50 degrees F
Frost-free period: 110 to 140 days
Farmland classification: Farmland of statewide importance

Map Unit Composition

Haines and similar soils: 85 percent
Minor components: 10 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Haines

Setting

Landform: Flood plains
Landform position (three-dimensional): Tread
Down-slope shape: Linear

Across-slope shape: Linear
Parent material: Mixed alluvium with loess and volcanic ash in the surface layer

Typical profile

H1 - 0 to 3 inches: silt loam
H2 - 3 to 43 inches: silt loam
H3 - 43 to 60 inches: sandy clay loam

Properties and qualities

Slope: 0 to 2 percent
Depth to restrictive feature: More than 80 inches
Drainage class: Poorly drained
Capacity of the most limiting layer to transmit water (Ksat): Moderately high (0.20 to 0.57 in/hr)
Depth to water table: About 12 to 24 inches
Frequency of flooding: Rare
Frequency of ponding: None
Calcium carbonate, maximum content: 30 percent
Maximum salinity: Slightly saline to moderately saline (4.0 to 8.0 mmhos/cm)
Sodium adsorption ratio, maximum: 2.0
Available water supply, 0 to 60 inches: High (about 10.0 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 4w
Hydrologic Soil Group: B/D
Ecological site: R010XY008OR - SODIC MEADOW
Hydric soil rating: Yes

Minor Components

Baldock

Percent of map unit: 5 percent
Landform: Flood plains
Landform position (three-dimensional): Tread
Down-slope shape: Linear
Across-slope shape: Linear
Ecological site: R010XY003OR - WET MEADOW
Hydric soil rating: Yes

Burkemont

Percent of map unit: 5 percent
Landform: Terraces
Landform position (three-dimensional): Tread
Down-slope shape: Linear
Across-slope shape: Linear
Ecological site: R010XY008OR - SODIC MEADOW
Hydric soil rating: Yes

126A—Powval silt loam, 0 to 3 percent slopes

Map Unit Setting

National map unit symbol: 22lz
Elevation: 2,600 to 3,500 feet
Mean annual precipitation: 9 to 12 inches
Mean annual air temperature: 45 to 46 degrees F
Frost-free period: 110 to 125 days
Farmland classification: Prime farmland if irrigated

Map Unit Composition

Powval and similar soils: 85 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Powval

Setting

Landform: Terraces
Landform position (three-dimensional): Tread
Down-slope shape: Linear
Across-slope shape: Linear
Parent material: Mixed alluvium

Typical profile

H1 - 0 to 13 inches: silt loam
H2 - 13 to 41 inches: silt loam
H3 - 41 to 100 inches: silt loam

Properties and qualities

Slope: 0 to 3 percent
Depth to restrictive feature: More than 80 inches
Drainage class: Well drained
Capacity of the most limiting layer to transmit water (Ksat): Moderately high to high (0.57 to 1.98 in/hr)
Depth to water table: About 48 to 72 inches
Frequency of flooding: None
Frequency of ponding: None
Calcium carbonate, maximum content: 8 percent
Maximum salinity: Nonsaline to very slightly saline (0.0 to 2.0 mmhos/cm)
Sodium adsorption ratio, maximum: 4.0
Available water supply, 0 to 60 inches: Very high (about 12.8 inches)

Interpretive groups

Land capability classification (irrigated): 2c
Land capability classification (nonirrigated): 4c
Hydrologic Soil Group: B
Ecological site: R010XY005OR - LOAMY BOTTOM
Hydric soil rating: No

170A—Umapine silt loam, 0 to 2 percent slopes

Map Unit Setting

National map unit symbol: 22pb
Elevation: 2,000 to 3,500 feet
Mean annual precipitation: 9 to 12 inches
Mean annual air temperature: 45 to 50 degrees F
Frost-free period: 110 to 140 days
Farmland classification: Farmland of statewide importance

Map Unit Composition

Umapine and similar soils: 85 percent
Minor components: 8 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Umapine

Setting

Landform: Terraces
Landform position (three-dimensional): Tread
Down-slope shape: Linear
Across-slope shape: Linear
Parent material: Mixed alluvium and loess

Typical profile

H1 - 0 to 12 inches: silt loam
H2 - 12 to 40 inches: silt loam
H3 - 40 to 60 inches: silt loam

Properties and qualities

Slope: 0 to 2 percent
Depth to restrictive feature: More than 80 inches
Drainage class: Somewhat poorly drained
Capacity of the most limiting layer to transmit water (Ksat): Moderately high to high (0.57 to 1.98 in/hr)
Depth to water table: About 12 to 24 inches
Frequency of flooding: Rare
Frequency of ponding: None
Calcium carbonate, maximum content: 30 percent
Maximum salinity: Strongly saline (16.0 to 32.0 mmhos/cm)
Sodium adsorption ratio, maximum: 5.0
Available water supply, 0 to 60 inches: High (about 11.9 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 4w
Hydrologic Soil Group: B/D
Ecological site: R010XY007OR - SODIC BOTTOM
Hydric soil rating: No

Minor Components

Haines

Percent of map unit: 8 percent
Landform: Flood plains
Landform position (three-dimensional): Tread
Down-slope shape: Linear
Across-slope shape: Linear
Ecological site: R010XY008OR - SODIC MEADOW
Hydric soil rating: Yes

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United States Department of Agriculture

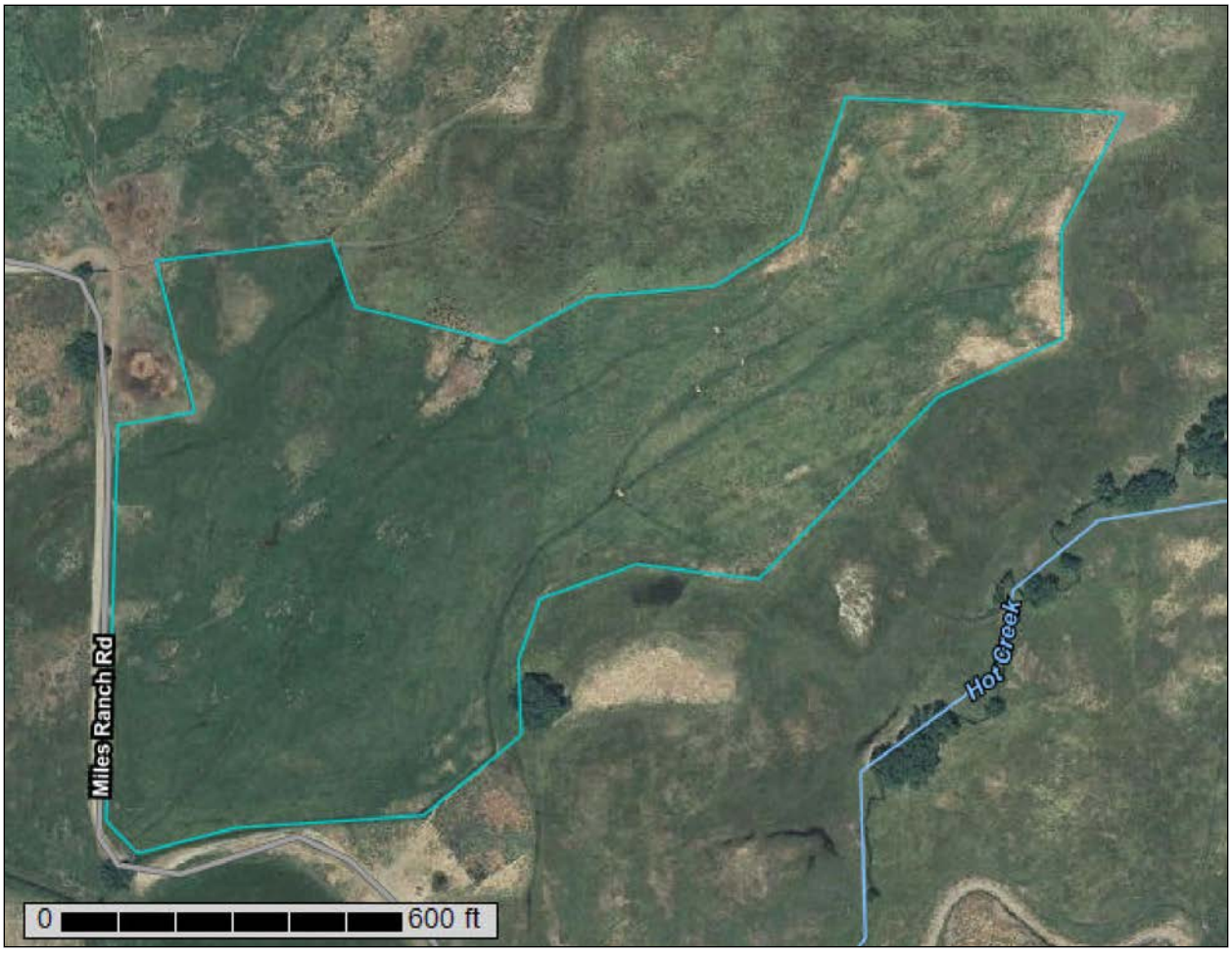
NRCS

Natural Resources Conservation Service

A product of the National Cooperative Soil Survey, a joint effort of the United States Department of Agriculture and other Federal agencies, State agencies including the Agricultural Experiment Stations, and local participants

Custom Soil Resource Report for Baker County Area, Oregon

Application Site 3



February 8, 2024

Preface

Soil surveys contain information that affects land use planning in survey areas. They highlight soil limitations that affect various land uses and provide information about the properties of the soils in the survey areas. Soil surveys are designed for many different users, including farmers, ranchers, foresters, agronomists, urban planners, community officials, engineers, developers, builders, and home buyers. Also, conservationists, teachers, students, and specialists in recreation, waste disposal, and pollution control can use the surveys to help them understand, protect, or enhance the environment.

Various land use regulations of Federal, State, and local governments may impose special restrictions on land use or land treatment. Soil surveys identify soil properties that are used in making various land use or land treatment decisions. The information is intended to help the land users identify and reduce the effects of soil limitations on various land uses. The landowner or user is responsible for identifying and complying with existing laws and regulations.

Although soil survey information can be used for general farm, local, and wider area planning, onsite investigation is needed to supplement this information in some cases. Examples include soil quality assessments (http://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/health/) and certain conservation and engineering applications. For more detailed information, contact your local USDA Service Center (https://offices.sc.egov.usda.gov/locator/app?agency=nrcs) or your NRCS State Soil Scientist (http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/contactus/?cid=nrcs142p2_053951).

Great differences in soil properties can occur within short distances. Some soils are seasonally wet or subject to flooding. Some are too unstable to be used as a foundation for buildings or roads. Clayey or wet soils are poorly suited to use as septic tank absorption fields. A high water table makes a soil poorly suited to basements or underground installations.

The National Cooperative Soil Survey is a joint effort of the United States Department of Agriculture and other Federal agencies, State agencies including the Agricultural Experiment Stations, and local agencies. The Natural Resources Conservation Service (NRCS) has leadership for the Federal part of the National Cooperative Soil Survey.

Information about soils is updated periodically. Updated information is available through the NRCS Web Soil Survey, the site for official soil survey information.

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How Soil Surveys Are Made

Soil surveys are made to provide information about the soils and miscellaneous areas in a specific area. They include a description of the soils and miscellaneous areas and their location on the landscape and tables that show soil properties and limitations affecting various uses. Soil scientists observed the steepness, length, and shape of the slopes; the general pattern of drainage; the kinds of crops and native plants; and the kinds of bedrock. They observed and described many soil profiles. A soil profile is the sequence of natural layers, or horizons, in a soil. The profile extends from the surface down into the unconsolidated material in which the soil formed or from the surface down to bedrock. The unconsolidated material is devoid of roots and other living organisms and has not been changed by other biological activity.

Currently, soils are mapped according to the boundaries of major land resource areas (MLRAs). MLRAs are geographically associated land resource units that share common characteristics related to physiography, geology, climate, water resources, soils, biological resources, and land uses (USDA, 2006). Soil survey areas typically consist of parts of one or more MLRA.

The soils and miscellaneous areas in a survey area occur in an orderly pattern that is related to the geology, landforms, relief, climate, and natural vegetation of the area. Each kind of soil and miscellaneous area is associated with a particular kind of landform or with a segment of the landform. By observing the soils and miscellaneous areas in the survey area and relating their position to specific segments of the landform, a soil scientist develops a concept, or model, of how they were formed. Thus, during mapping, this model enables the soil scientist to predict with a considerable degree of accuracy the kind of soil or miscellaneous area at a specific location on the landscape.

Commonly, individual soils on the landscape merge into one another as their characteristics gradually change. To construct an accurate soil map, however, soil scientists must determine the boundaries between the soils. They can observe only a limited number of soil profiles. Nevertheless, these observations, supplemented by an understanding of the soil-vegetation-landscape relationship, are sufficient to verify predictions of the kinds of soil in an area and to determine the boundaries.

Soil scientists recorded the characteristics of the soil profiles that they studied. They noted soil color, texture, size and shape of soil aggregates, kind and amount of rock fragments, distribution of plant roots, reaction, and other features that enable them to identify soils. After describing the soils in the survey area and determining their properties, the soil scientists assigned the soils to taxonomic classes (units). Taxonomic classes are concepts. Each taxonomic class has a set of soil characteristics with precisely defined limits. The classes are used as a basis for comparison to classify soils systematically. Soil taxonomy, the system of taxonomic classification used in the United States, is based mainly on the kind and character of soil properties and the arrangement of horizons within the profile. After the soil

scientists classified and named the soils in the survey area, they compared the individual soils with similar soils in the same taxonomic class in other areas so that they could confirm data and assemble additional data based on experience and research.

The objective of soil mapping is not to delineate pure map unit components; the objective is to separate the landscape into landforms or landform segments that have similar use and management requirements. Each map unit is defined by a unique combination of soil components and/or miscellaneous areas in predictable proportions. Some components may be highly contrasting to the other components of the map unit. The presence of minor components in a map unit in no way diminishes the usefulness or accuracy of the data. The delineation of such landforms and landform segments on the map provides sufficient information for the development of resource plans. If intensive use of small areas is planned, onsite investigation is needed to define and locate the soils and miscellaneous areas.

Soil scientists make many field observations in the process of producing a soil map. The frequency of observation is dependent upon several factors, including scale of mapping, intensity of mapping, design of map units, complexity of the landscape, and experience of the soil scientist. Observations are made to test and refine the soil-landscape model and predictions and to verify the classification of the soils at specific locations. Once the soil-landscape model is refined, a significantly smaller number of measurements of individual soil properties are made and recorded. These measurements may include field measurements, such as those for color, depth to bedrock, and texture, and laboratory measurements, such as those for content of sand, silt, clay, salt, and other components. Properties of each soil typically vary from one point to another across the landscape.

Observations for map unit components are aggregated to develop ranges of characteristics for the components. The aggregated values are presented. Direct measurements do not exist for every property presented for every map unit component. Values for some properties are estimated from combinations of other properties.

While a soil survey is in progress, samples of some of the soils in the area generally are collected for laboratory analyses and for engineering tests. Soil scientists interpret the data from these analyses and tests as well as the field-observed characteristics and the soil properties to determine the expected behavior of the soils under different uses. Interpretations for all of the soils are field tested through observation of the soils in different uses and under different levels of management. Some interpretations are modified to fit local conditions, and some new interpretations are developed to meet local needs. Data are assembled from other sources, such as research information, production records, and field experience of specialists. For example, data on crop yields under defined levels of management are assembled from farm records and from field or plot experiments on the same kinds of soil.

Predictions about soil behavior are based not only on soil properties but also on such variables as climate and biological activity. Soil conditions are predictable over long periods of time, but they are not predictable from year to year. For example, soil scientists can predict with a fairly high degree of accuracy that a given soil will have a high water table within certain depths in most years, but they cannot predict that a high water table will always be at a specific level in the soil on a specific date.

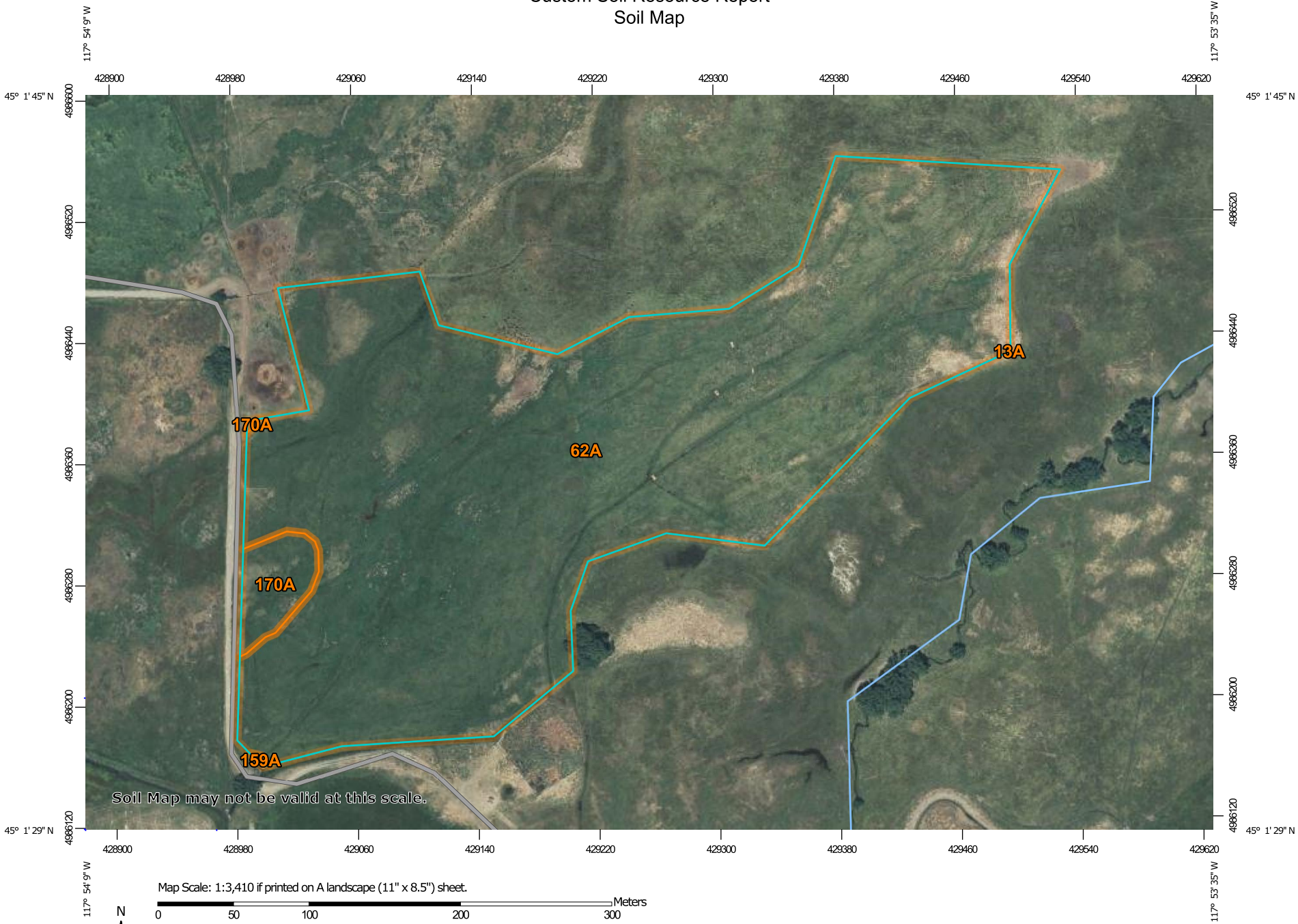
After soil scientists located and identified the significant natural bodies of soil in the survey area, they drew the boundaries of these bodies on aerial photographs and

identified each as a specific map unit. Aerial photographs show trees, buildings, fields, roads, and rivers, all of which help in locating boundaries accurately.

Soil Map

The soil map section includes the soil map for the defined area of interest, a list of soil map units on the map and extent of each map unit, and cartographic symbols displayed on the map. Also presented are various metadata about data used to produce the map, and a description of each soil map unit.

Custom Soil Resource Report
Soil Map



Map Scale: 1:3,410 if printed on A landscape (11" x 8.5") sheet.

N

Meters: 0 50 100 200 300

Feet: 0 150 300 600 900

Map projection: Web Mercator Corner coordinates: WGS84 Edge tics: UTM Zone 11N WGS84

MAP LEGEND

Area of Interest (AOI)
- Area of Interest (AOI)

Soils
- Soil Map Unit Polygons
- Soil Map Unit Lines
- Soil Map Unit Points

Special Point Features
- Blowout
- Borrow Pit
- Clay Spot
- Closed Depression
- Gravel Pit
- Gravelly Spot
- Landfill
- Lava Flow
- Marsh or swamp
- Mine or Quarry
- Miscellaneous Water
- Perennial Water
- Rock Outcrop
- Saline Spot
- Sandy Spot
- Severely Eroded Spot
- Sinkhole
- Slide or Slip
- Sodic Spot
- Spoil Area
- Stony Spot
- Very Stony Spot
- Wet Spot
- Other
- Special Line Features

Water Features
- Streams and Canals

Transportation
- Rails
- Interstate Highways
- US Routes
- Major Roads
- Local Roads

Background
- Aerial Photography

MAP INFORMATION

The soil surveys that comprise your AOI were mapped at 1:24,000.

Warning: Soil Map may not be valid at this scale.

Enlargement of maps beyond the scale of mapping can cause misunderstanding of the detail of mapping and accuracy of soil line placement. The maps do not show the small areas of contrasting soils that could have been shown at a more detailed scale.

Please rely on the bar scale on each map sheet for map measurements.

Source of Map: Natural Resources Conservation Service
Web Soil Survey URL:
Coordinate System: Web Mercator (EPSG:3857)

Maps from the Web Soil Survey are based on the Web Mercator projection, which preserves direction and shape but distorts distance and area. A projection that preserves area, such as the Albers equal-area conic projection, should be used if more accurate calculations of distance or area are required.

This product is generated from the USDA-NRCS certified data as of the version date(s) listed below.

Soil Survey Area: Baker County Area, Oregon
Survey Area Data: Version 20, Sep 8, 2023

Soil map units are labeled (as space allows) for map scales 1:50,000 or larger.

Date(s) aerial images were photographed: Aug 4, 2020—Aug 14, 2020

The orthophoto or other base map on which the soil lines were compiled and digitized probably differs from the background imagery displayed on these maps. As a result, some minor shifting of map unit boundaries may be evident.

Map Unit Legend

Map Unit Symbol	Map Unit Name	Acres in AOI	Percent of AOI
13A	Baldock silt loam, 0 to 2 percent slopes	0.0	0.0%
62A	Haines silt loam, 0 to 2 percent slopes	25.6	97.2%
159A	Stanflow-Umapine silt loams, 0 to 2 percent slopes	0.0	0.0%
170A	Umapine silt loam, 0 to 2 percent slopes	0.7	2.7%
Totals for Area of Interest		**26.4**	**100.0%**

Map Unit Descriptions

The map units delineated on the detailed soil maps in a soil survey represent the soils or miscellaneous areas in the survey area. The map unit descriptions, along with the maps, can be used to determine the composition and properties of a unit.

A map unit delineation on a soil map represents an area dominated by one or more major kinds of soil or miscellaneous areas. A map unit is identified and named according to the taxonomic classification of the dominant soils. Within a taxonomic class there are precisely defined limits for the properties of the soils. On the landscape, however, the soils are natural phenomena, and they have the characteristic variability of all natural phenomena. Thus, the range of some observed properties may extend beyond the limits defined for a taxonomic class. Areas of soils of a single taxonomic class rarely, if ever, can be mapped without including areas of other taxonomic classes. Consequently, every map unit is made up of the soils or miscellaneous areas for which it is named and some minor components that belong to taxonomic classes other than those of the major soils.

Most minor soils have properties similar to those of the dominant soil or soils in the map unit, and thus they do not affect use and management. These are called noncontrasting, or similar, components. They may or may not be mentioned in a particular map unit description. Other minor components, however, have properties and behavioral characteristics divergent enough to affect use or to require different management. These are called contrasting, or dissimilar, components. They generally are in small areas and could not be mapped separately because of the scale used. Some small areas of strongly contrasting soils or miscellaneous areas are identified by a special symbol on the maps. If included in the database for a given area, the contrasting minor components are identified in the map unit descriptions along with some characteristics of each. A few areas of minor components may not have been observed, and consequently they are not mentioned in the descriptions, especially where the pattern was so complex that it was impractical to make enough observations to identify all the soils and miscellaneous areas on the landscape.

The presence of minor components in a map unit in no way diminishes the usefulness or accuracy of the data. The objective of mapping is not to delineate pure taxonomic classes but rather to separate the landscape into landforms or landform segments that have similar use and management requirements. The delineation of such segments on the map provides sufficient information for the development of resource plans. If intensive use of small areas is planned, however, onsite investigation is needed to define and locate the soils and miscellaneous areas.

An identifying symbol precedes the map unit name in the map unit descriptions. Each description includes general facts about the unit and gives important soil properties and qualities.

Soils that have profiles that are almost alike make up a *soil series*. Except for differences in texture of the surface layer, all the soils of a series have major horizons that are similar in composition, thickness, and arrangement.

Soils of one series can differ in texture of the surface layer, slope, stoniness, salinity, degree of erosion, and other characteristics that affect their use. On the basis of such differences, a soil series is divided into *soil phases*. Most of the areas shown on the detailed soil maps are phases of soil series. The name of a soil phase commonly indicates a feature that affects use or management. For example, Alpha silt loam, 0 to 2 percent slopes, is a phase of the Alpha series.

Some map units are made up of two or more major soils or miscellaneous areas. These map units are complexes, associations, or undifferentiated groups.

A *complex* consists of two or more soils or miscellaneous areas in such an intricate pattern or in such small areas that they cannot be shown separately on the maps. The pattern and proportion of the soils or miscellaneous areas are somewhat similar in all areas. Alpha-Beta complex, 0 to 6 percent slopes, is an example.

An *association* is made up of two or more geographically associated soils or miscellaneous areas that are shown as one unit on the maps. Because of present or anticipated uses of the map units in the survey area, it was not considered practical or necessary to map the soils or miscellaneous areas separately. The pattern and relative proportion of the soils or miscellaneous areas are somewhat similar. Alpha-Beta association, 0 to 2 percent slopes, is an example.

An *undifferentiated group* is made up of two or more soils or miscellaneous areas that could be mapped individually but are mapped as one unit because similar interpretations can be made for use and management. The pattern and proportion of the soils or miscellaneous areas in a mapped area are not uniform. An area can be made up of only one of the major soils or miscellaneous areas, or it can be made up of all of them. Alpha and Beta soils, 0 to 2 percent slopes, is an example.

Some surveys include *miscellaneous areas*. Such areas have little or no soil material and support little or no vegetation. Rock outcrop is an example.

Baker County Area, Oregon

13A—Baldock silt loam, 0 to 2 percent slopes

Map Unit Setting

National map unit symbol: 22mj
Elevation: 2,000 to 3,600 feet
Mean annual precipitation: 9 to 12 inches
Mean annual air temperature: 45 to 50 degrees F
Frost-free period: 110 to 140 days
Farmland classification: Prime farmland if irrigated and drained

Map Unit Composition

Baldock and similar soils: 85 percent
Minor components: 9 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Baldock

Setting

Landform: Flood plains
Landform position (three-dimensional): Tread
Down-slope shape: Linear
Across-slope shape: Linear
Parent material: Mixed alluvium

Typical profile

H1 - 0 to 6 inches: silt loam
H2 - 6 to 36 inches: silt loam
H3 - 36 to 60 inches: silt loam

Properties and qualities

Slope: 0 to 2 percent
Depth to restrictive feature: More than 80 inches
Drainage class: Poorly drained
Capacity of the most limiting layer to transmit water (Ksat): Moderately high to high (0.57 to 1.98 in/hr)
Depth to water table: About 0 to 18 inches
Frequency of flooding: Occasional
Frequency of ponding: None
Calcium carbonate, maximum content: 15 percent
Maximum salinity: Nonsaline to very slightly saline (0.0 to 2.0 mmhos/cm)
Sodium adsorption ratio, maximum: 5.0
Available water supply, 0 to 60 inches: High (about 10.9 inches)

Interpretive groups

Land capability classification (irrigated): 3w
Land capability classification (nonirrigated): 4w
Hydrologic Soil Group: B/D
Ecological site: R010XY003OR - WET MEADOW
Hydric soil rating: Yes

Minor Components

Haines

Percent of map unit: 3 percent

Landform: Flood plains
Landform position (three-dimensional): Tread
Down-slope shape: Linear
Across-slope shape: Linear
Ecological site: R010XY008OR - SODIC MEADOW
Hydric soil rating: Yes

Boyce

Percent of map unit: 3 percent
Landform: Flood plains
Landform position (three-dimensional): Tread
Down-slope shape: Linear
Across-slope shape: Linear
Ecological site: R010XY003OR - WET MEADOW
Hydric soil rating: Yes

Wingdale

Percent of map unit: 3 percent
Landform: Flood plains
Landform position (three-dimensional): Tread
Down-slope shape: Linear
Across-slope shape: Linear
Ecological site: R010XY003OR - WET MEADOW
Hydric soil rating: Yes

62A—Haines silt loam, 0 to 2 percent slopes

Map Unit Setting

National map unit symbol: 22rv
Elevation: 2,000 to 3,600 feet
Mean annual precipitation: 9 to 12 inches
Mean annual air temperature: 45 to 50 degrees F
Frost-free period: 110 to 140 days
Farmland classification: Farmland of statewide importance

Map Unit Composition

Haines and similar soils: 85 percent
Minor components: 10 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Haines

Setting

Landform: Flood plains
Landform position (three-dimensional): Tread
Down-slope shape: Linear
Across-slope shape: Linear
Parent material: Mixed alluvium with loess and volcanic ash in the surface layer

Typical profile

H1 - 0 to 3 inches: silt loam

H2 - 3 to 43 inches: silt loam
H3 - 43 to 60 inches: sandy clay loam

Properties and qualities

Slope: 0 to 2 percent
Depth to restrictive feature: More than 80 inches
Drainage class: Poorly drained
Capacity of the most limiting layer to transmit water (Ksat): Moderately high (0.20 to 0.57 in/hr)
Depth to water table: About 12 to 24 inches
Frequency of flooding: Rare
Frequency of ponding: None
Calcium carbonate, maximum content: 30 percent
Maximum salinity: Slightly saline to moderately saline (4.0 to 8.0 mmhos/cm)
Sodium adsorption ratio, maximum: 2.0
Available water supply, 0 to 60 inches: High (about 10.0 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 4w
Hydrologic Soil Group: B/D
Ecological site: R010XY008OR - SODIC MEADOW
Hydric soil rating: Yes

Minor Components

Baldock

Percent of map unit: 5 percent
Landform: Flood plains
Landform position (three-dimensional): Tread
Down-slope shape: Linear
Across-slope shape: Linear
Ecological site: R010XY003OR - WET MEADOW
Hydric soil rating: Yes

Burkemont

Percent of map unit: 5 percent
Landform: Terraces
Landform position (three-dimensional): Tread
Down-slope shape: Linear
Across-slope shape: Linear
Ecological site: R010XY008OR - SODIC MEADOW
Hydric soil rating: Yes

159A—Stanflow-Umapine silt loams, 0 to 2 percent slopes

Map Unit Setting

National map unit symbol: 22np
Elevation: 2,000 to 3,600 feet
Mean annual precipitation: 9 to 12 inches
Mean annual air temperature: 45 to 50 degrees F

Frost-free period: 110 to 140 days
Farmland classification: Farmland of statewide importance

Map Unit Composition

Stanflow and similar soils: 50 percent
Umapine and similar soils: 35 percent
Minor components: 15 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Stanflow

Setting

Landform: Terraces
Landform position (three-dimensional): Tread
Down-slope shape: Linear
Across-slope shape: Linear
Parent material: Mixed alluvium with volcanic ash in the surface layer

Typical profile

H1 - 0 to 8 inches: silt loam
H2 - 8 to 21 inches: silt loam
H3 - 21 to 28 inches: silt loam
H4 - 28 to 60 inches: loam

Properties and qualities

Slope: 0 to 2 percent
Depth to restrictive feature: More than 80 inches
Drainage class: Moderately well drained
Capacity of the most limiting layer to transmit water (Ksat): Moderately low to moderately high (0.06 to 0.20 in/hr)
Depth to water table: About 24 to 48 inches
Frequency of flooding: None
Frequency of ponding: None
Calcium carbonate, maximum content: 30 percent
Maximum salinity: Strongly saline (16.0 to 32.0 mmhos/cm)
Sodium adsorption ratio, maximum: 5.0
Available water supply, 0 to 60 inches: Moderate (about 8.6 inches)

Interpretive groups

Land capability classification (irrigated): 4s
Land capability classification (nonirrigated): 4s
Hydrologic Soil Group: C
Ecological site: R010XY007OR - SODIC BOTTOM
Hydric soil rating: No

Description of Umapine

Setting

Landform: Terraces
Landform position (three-dimensional): Tread
Down-slope shape: Linear
Across-slope shape: Linear
Parent material: Mixed alluvium and loess

Typical profile

H1 - 0 to 12 inches: silt loam
H2 - 12 to 40 inches: silt loam

H3 - 40 to 60 inches: silt loam

Properties and qualities

Slope: 0 to 2 percent
Depth to restrictive feature: More than 80 inches
Drainage class: Somewhat poorly drained
Capacity of the most limiting layer to transmit water (Ksat): Moderately high to high (0.57 to 1.98 in/hr)
Depth to water table: About 12 to 24 inches
Frequency of flooding: Rare
Frequency of ponding: None
Calcium carbonate, maximum content: 30 percent
Maximum salinity: Strongly saline (16.0 to 32.0 mmhos/cm)
Sodium adsorption ratio, maximum: 5.0
Available water supply, 0 to 60 inches: High (about 11.9 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 4w
Hydrologic Soil Group: B/D
Ecological site: R010XY007OR - SODIC BOTTOM
Hydric soil rating: No

Minor Components

Burkemont

Percent of map unit: 5 percent
Landform: Terraces
Landform position (three-dimensional): Tread
Down-slope shape: Linear
Across-slope shape: Linear
Ecological site: R010XY008OR - SODIC MEADOW
Hydric soil rating: Yes

Haines

Percent of map unit: 5 percent
Landform: Flood plains
Landform position (three-dimensional): Tread
Down-slope shape: Linear
Across-slope shape: Linear
Ecological site: R010XY008OR - SODIC MEADOW
Hydric soil rating: Yes

Baldock

Percent of map unit: 5 percent
Landform: Flood plains
Landform position (three-dimensional): Tread
Down-slope shape: Linear
Across-slope shape: Linear
Ecological site: R010XY003OR - WET MEADOW
Hydric soil rating: Yes

170A—Umapine silt loam, 0 to 2 percent slopes

Map Unit Setting

National map unit symbol: 22pb
Elevation: 2,000 to 3,500 feet
Mean annual precipitation: 9 to 12 inches
Mean annual air temperature: 45 to 50 degrees F
Frost-free period: 110 to 140 days
Farmland classification: Farmland of statewide importance

Map Unit Composition

Umapine and similar soils: 85 percent
Minor components: 8 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Umapine

Setting

Landform: Terraces
Landform position (three-dimensional): Tread
Down-slope shape: Linear
Across-slope shape: Linear
Parent material: Mixed alluvium and loess

Typical profile

H1 - 0 to 12 inches: silt loam
H2 - 12 to 40 inches: silt loam
H3 - 40 to 60 inches: silt loam

Properties and qualities

Slope: 0 to 2 percent
Depth to restrictive feature: More than 80 inches
Drainage class: Somewhat poorly drained
Capacity of the most limiting layer to transmit water (Ksat): Moderately high to high (0.57 to 1.98 in/hr)
Depth to water table: About 12 to 24 inches
Frequency of flooding: Rare
Frequency of ponding: None
Calcium carbonate, maximum content: 30 percent
Maximum salinity: Strongly saline (16.0 to 32.0 mmhos/cm)
Sodium adsorption ratio, maximum: 5.0
Available water supply, 0 to 60 inches: High (about 11.9 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 4w
Hydrologic Soil Group: B/D
Ecological site: R010XY007OR - SODIC BOTTOM
Hydric soil rating: No

Minor Components

Haines

Percent of map unit: 8 percent
Landform: Flood plains
Landform position (three-dimensional): Tread
Down-slope shape: Linear
Across-slope shape: Linear
Ecological site: R010XY008OR - SODIC MEADOW
Hydric soil rating: Yes

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United States Department of Agriculture

NRCS

Natural Resources Conservation Service

A product of the National Cooperative Soil Survey, a joint effort of the United States Department of Agriculture and other Federal agencies, State agencies including the Agricultural Experiment Stations, and local participants

Custom Soil Resource Report for Baker County Area, Oregon

Application Site 4

February 8, 2024

Preface

Soil surveys contain information that affects land use planning in survey areas. They highlight soil limitations that affect various land uses and provide information about the properties of the soils in the survey areas. Soil surveys are designed for many different users, including farmers, ranchers, foresters, agronomists, urban planners, community officials, engineers, developers, builders, and home buyers. Also, conservationists, teachers, students, and specialists in recreation, waste disposal, and pollution control can use the surveys to help them understand, protect, or enhance the environment.

Various land use regulations of Federal, State, and local governments may impose special restrictions on land use or land treatment. Soil surveys identify soil properties that are used in making various land use or land treatment decisions. The information is intended to help the land users identify and reduce the effects of soil limitations on various land uses. The landowner or user is responsible for identifying and complying with existing laws and regulations.

Although soil survey information can be used for general farm, local, and wider area planning, onsite investigation is needed to supplement this information in some cases. Examples include soil quality assessments (http://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/health/) and certain conservation and engineering applications. For more detailed information, contact your local USDA Service Center (https://offices.sc.egov.usda.gov/locator/app?agency=nrcs) or your NRCS State Soil Scientist (http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/contactus/?cid=nrcs142p2_053951).

Great differences in soil properties can occur within short distances. Some soils are seasonally wet or subject to flooding. Some are too unstable to be used as a foundation for buildings or roads. Clayey or wet soils are poorly suited to use as septic tank absorption fields. A high water table makes a soil poorly suited to basements or underground installations.

The National Cooperative Soil Survey is a joint effort of the United States Department of Agriculture and other Federal agencies, State agencies including the Agricultural Experiment Stations, and local agencies. The Natural Resources Conservation Service (NRCS) has leadership for the Federal part of the National Cooperative Soil Survey.

Information about soils is updated periodically. Updated information is available through the NRCS Web Soil Survey, the site for official soil survey information.

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How Soil Surveys Are Made

Soil surveys are made to provide information about the soils and miscellaneous areas in a specific area. They include a description of the soils and miscellaneous areas and their location on the landscape and tables that show soil properties and limitations affecting various uses. Soil scientists observed the steepness, length, and shape of the slopes; the general pattern of drainage; the kinds of crops and native plants; and the kinds of bedrock. They observed and described many soil profiles. A soil profile is the sequence of natural layers, or horizons, in a soil. The profile extends from the surface down into the unconsolidated material in which the soil formed or from the surface down to bedrock. The unconsolidated material is devoid of roots and other living organisms and has not been changed by other biological activity.

Currently, soils are mapped according to the boundaries of major land resource areas (MLRAs). MLRAs are geographically associated land resource units that share common characteristics related to physiography, geology, climate, water resources, soils, biological resources, and land uses (USDA, 2006). Soil survey areas typically consist of parts of one or more MLRA.

The soils and miscellaneous areas in a survey area occur in an orderly pattern that is related to the geology, landforms, relief, climate, and natural vegetation of the area. Each kind of soil and miscellaneous area is associated with a particular kind of landform or with a segment of the landform. By observing the soils and miscellaneous areas in the survey area and relating their position to specific segments of the landform, a soil scientist develops a concept, or model, of how they were formed. Thus, during mapping, this model enables the soil scientist to predict with a considerable degree of accuracy the kind of soil or miscellaneous area at a specific location on the landscape.

Commonly, individual soils on the landscape merge into one another as their characteristics gradually change. To construct an accurate soil map, however, soil scientists must determine the boundaries between the soils. They can observe only a limited number of soil profiles. Nevertheless, these observations, supplemented by an understanding of the soil-vegetation-landscape relationship, are sufficient to verify predictions of the kinds of soil in an area and to determine the boundaries.

Soil scientists recorded the characteristics of the soil profiles that they studied. They noted soil color, texture, size and shape of soil aggregates, kind and amount of rock fragments, distribution of plant roots, reaction, and other features that enable them to identify soils. After describing the soils in the survey area and determining their properties, the soil scientists assigned the soils to taxonomic classes (units). Taxonomic classes are concepts. Each taxonomic class has a set of soil characteristics with precisely defined limits. The classes are used as a basis for comparison to classify soils systematically. Soil taxonomy, the system of taxonomic classification used in the United States, is based mainly on the kind and character of soil properties and the arrangement of horizons within the profile. After the soil

scientists classified and named the soils in the survey area, they compared the individual soils with similar soils in the same taxonomic class in other areas so that they could confirm data and assemble additional data based on experience and research.

The objective of soil mapping is not to delineate pure map unit components; the objective is to separate the landscape into landforms or landform segments that have similar use and management requirements. Each map unit is defined by a unique combination of soil components and/or miscellaneous areas in predictable proportions. Some components may be highly contrasting to the other components of the map unit. The presence of minor components in a map unit in no way diminishes the usefulness or accuracy of the data. The delineation of such landforms and landform segments on the map provides sufficient information for the development of resource plans. If intensive use of small areas is planned, onsite investigation is needed to define and locate the soils and miscellaneous areas.

Soil scientists make many field observations in the process of producing a soil map. The frequency of observation is dependent upon several factors, including scale of mapping, intensity of mapping, design of map units, complexity of the landscape, and experience of the soil scientist. Observations are made to test and refine the soil-landscape model and predictions and to verify the classification of the soils at specific locations. Once the soil-landscape model is refined, a significantly smaller number of measurements of individual soil properties are made and recorded. These measurements may include field measurements, such as those for color, depth to bedrock, and texture, and laboratory measurements, such as those for content of sand, silt, clay, salt, and other components. Properties of each soil typically vary from one point to another across the landscape.

Observations for map unit components are aggregated to develop ranges of characteristics for the components. The aggregated values are presented. Direct measurements do not exist for every property presented for every map unit component. Values for some properties are estimated from combinations of other properties.

While a soil survey is in progress, samples of some of the soils in the area generally are collected for laboratory analyses and for engineering tests. Soil scientists interpret the data from these analyses and tests as well as the field-observed characteristics and the soil properties to determine the expected behavior of the soils under different uses. Interpretations for all of the soils are field tested through observation of the soils in different uses and under different levels of management. Some interpretations are modified to fit local conditions, and some new interpretations are developed to meet local needs. Data are assembled from other sources, such as research information, production records, and field experience of specialists. For example, data on crop yields under defined levels of management are assembled from farm records and from field or plot experiments on the same kinds of soil.

Predictions about soil behavior are based not only on soil properties but also on such variables as climate and biological activity. Soil conditions are predictable over long periods of time, but they are not predictable from year to year. For example, soil scientists can predict with a fairly high degree of accuracy that a given soil will have a high water table within certain depths in most years, but they cannot predict that a high water table will always be at a specific level in the soil on a specific date.

After soil scientists located and identified the significant natural bodies of soil in the survey area, they drew the boundaries of these bodies on aerial photographs and

identified each as a specific map unit. Aerial photographs show trees, buildings, fields, roads, and rivers, all of which help in locating boundaries accurately.

Soil Map

The soil map section includes the soil map for the defined area of interest, a list of soil map units on the map and extent of each map unit, and cartographic symbols displayed on the map. Also presented are various metadata about data used to produce the map, and a description of each soil map unit.

Custom Soil Resource Report
Soil Map

Map Scale: 1:2,200 if printed on A landscape (11" x 8.5") sheet.

N

Meters
0 30 60 120 180

Feet
0 100 200 400 600

Map projection: Web Mercator Corner coordinates: WGS84 Edge tics: UTM Zone 11N WGS84

MAP LEGEND

Area of Interest (AOI)
- Area of Interest (AOI)

Soils
- Soil Map Unit Polygons
- Soil Map Unit Lines
- Soil Map Unit Points

Special Point Features
- Blowout
- Borrow Pit
- Clay Spot
- Closed Depression
- Gravel Pit
- Gravelly Spot
- Landfill
- Lava Flow
- Marsh or swamp
- Mine or Quarry
- Miscellaneous Water
- Perennial Water
- Rock Outcrop
- Saline Spot
- Sandy Spot
- Severely Eroded Spot
- Sinkhole
- Slide or Slip
- Sodic Spot
- Spoil Area
- Stony Spot
- Very Stony Spot
- Wet Spot
- Other
- Special Line Features

Water Features
- Streams and Canals

Transportation
- Rails
- Interstate Highways
- US Routes
- Major Roads
- Local Roads

Background
- Aerial Photography

MAP INFORMATION

The soil surveys that comprise your AOI were mapped at 1:24,000.

Warning: Soil Map may not be valid at this scale.

Enlargement of maps beyond the scale of mapping can cause misunderstanding of the detail of mapping and accuracy of soil line placement. The maps do not show the small areas of contrasting soils that could have been shown at a more detailed scale.

Please rely on the bar scale on each map sheet for map measurements.

Source of Map: Natural Resources Conservation Service
Web Soil Survey URL:
Coordinate System: Web Mercator (EPSG:3857)

Maps from the Web Soil Survey are based on the Web Mercator projection, which preserves direction and shape but distorts distance and area. A projection that preserves area, such as the Albers equal-area conic projection, should be used if more accurate calculations of distance or area are required.

This product is generated from the USDA-NRCS certified data as of the version date(s) listed below.

Soil Survey Area: Baker County Area, Oregon
Survey Area Data: Version 20, Sep 8, 2023

Soil map units are labeled (as space allows) for map scales 1:50,000 or larger.

Date(s) aerial images were photographed: Aug 4, 2020—Aug 14, 2020

The orthophoto or other base map on which the soil lines were compiled and digitized probably differs from the background imagery displayed on these maps. As a result, some minor shifting of map unit boundaries may be evident.

Map Unit Legend

Map Unit Symbol	Map Unit Name	Acres in AOI	Percent of AOI
62A	Haines silt loam, 0 to 2 percent slopes	7.8	64.8%
170A	Umapine silt loam, 0 to 2 percent slopes	4.2	35.2%
Totals for Area of Interest		**12.0**	**100.0%**

Map Unit Descriptions

The map units delineated on the detailed soil maps in a soil survey represent the soils or miscellaneous areas in the survey area. The map unit descriptions, along with the maps, can be used to determine the composition and properties of a unit.

A map unit delineation on a soil map represents an area dominated by one or more major kinds of soil or miscellaneous areas. A map unit is identified and named according to the taxonomic classification of the dominant soils. Within a taxonomic class there are precisely defined limits for the properties of the soils. On the landscape, however, the soils are natural phenomena, and they have the characteristic variability of all natural phenomena. Thus, the range of some observed properties may extend beyond the limits defined for a taxonomic class. Areas of soils of a single taxonomic class rarely, if ever, can be mapped without including areas of other taxonomic classes. Consequently, every map unit is made up of the soils or miscellaneous areas for which it is named and some minor components that belong to taxonomic classes other than those of the major soils.

Most minor soils have properties similar to those of the dominant soil or soils in the map unit, and thus they do not affect use and management. These are called noncontrasting, or similar, components. They may or may not be mentioned in a particular map unit description. Other minor components, however, have properties and behavioral characteristics divergent enough to affect use or to require different management. These are called contrasting, or dissimilar, components. They generally are in small areas and could not be mapped separately because of the scale used. Some small areas of strongly contrasting soils or miscellaneous areas are identified by a special symbol on the maps. If included in the database for a given area, the contrasting minor components are identified in the map unit descriptions along with some characteristics of each. A few areas of minor components may not have been observed, and consequently they are not mentioned in the descriptions, especially where the pattern was so complex that it was impractical to make enough observations to identify all the soils and miscellaneous areas on the landscape.

The presence of minor components in a map unit in no way diminishes the usefulness or accuracy of the data. The objective of mapping is not to delineate pure taxonomic classes but rather to separate the landscape into landforms or landform segments that have similar use and management requirements. The delineation of such segments on the map provides sufficient information for the development of resource plans. If intensive use of small areas is planned, however,

onsite investigation is needed to define and locate the soils and miscellaneous areas.

An identifying symbol precedes the map unit name in the map unit descriptions. Each description includes general facts about the unit and gives important soil properties and qualities.

Soils that have profiles that are almost alike make up a *soil series*. Except for differences in texture of the surface layer, all the soils of a series have major horizons that are similar in composition, thickness, and arrangement.

Soils of one series can differ in texture of the surface layer, slope, stoniness, salinity, degree of erosion, and other characteristics that affect their use. On the basis of such differences, a soil series is divided into *soil phases*. Most of the areas shown on the detailed soil maps are phases of soil series. The name of a soil phase commonly indicates a feature that affects use or management. For example, Alpha silt loam, 0 to 2 percent slopes, is a phase of the Alpha series.

Some map units are made up of two or more major soils or miscellaneous areas. These map units are complexes, associations, or undifferentiated groups.

A *complex* consists of two or more soils or miscellaneous areas in such an intricate pattern or in such small areas that they cannot be shown separately on the maps. The pattern and proportion of the soils or miscellaneous areas are somewhat similar in all areas. Alpha-Beta complex, 0 to 6 percent slopes, is an example.

An *association* is made up of two or more geographically associated soils or miscellaneous areas that are shown as one unit on the maps. Because of present or anticipated uses of the map units in the survey area, it was not considered practical or necessary to map the soils or miscellaneous areas separately. The pattern and relative proportion of the soils or miscellaneous areas are somewhat similar. Alpha-Beta association, 0 to 2 percent slopes, is an example.

An *undifferentiated group* is made up of two or more soils or miscellaneous areas that could be mapped individually but are mapped as one unit because similar interpretations can be made for use and management. The pattern and proportion of the soils or miscellaneous areas in a mapped area are not uniform. An area can be made up of only one of the major soils or miscellaneous areas, or it can be made up of all of them. Alpha and Beta soils, 0 to 2 percent slopes, is an example.

Some surveys include *miscellaneous areas*. Such areas have little or no soil material and support little or no vegetation. Rock outcrop is an example.

Baker County Area, Oregon

62A—Haines silt loam, 0 to 2 percent slopes

Map Unit Setting

National map unit symbol: 22rv
Elevation: 2,000 to 3,600 feet
Mean annual precipitation: 9 to 12 inches
Mean annual air temperature: 45 to 50 degrees F
Frost-free period: 110 to 140 days
Farmland classification: Farmland of statewide importance

Map Unit Composition

Haines and similar soils: 85 percent
Minor components: 10 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Haines

Setting

Landform: Flood plains
Landform position (three-dimensional): Tread
Down-slope shape: Linear
Across-slope shape: Linear
Parent material: Mixed alluvium with loess and volcanic ash in the surface layer

Typical profile

H1 - 0 to 3 inches: silt loam
H2 - 3 to 43 inches: silt loam
H3 - 43 to 60 inches: sandy clay loam

Properties and qualities

Slope: 0 to 2 percent
Depth to restrictive feature: More than 80 inches
Drainage class: Poorly drained
Capacity of the most limiting layer to transmit water (Ksat): Moderately high (0.20 to 0.57 in/hr)
Depth to water table: About 12 to 24 inches
Frequency of flooding: Rare
Frequency of ponding: None
Calcium carbonate, maximum content: 30 percent
Maximum salinity: Slightly saline to moderately saline (4.0 to 8.0 mmhos/cm)
Sodium adsorption ratio, maximum: 2.0
Available water supply, 0 to 60 inches: High (about 10.0 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 4w
Hydrologic Soil Group: B/D
Ecological site: R010XY008OR - SODIC MEADOW
Hydric soil rating: Yes

Minor Components

Baldock

Percent of map unit: 5 percent

Landform: Flood plains
Landform position (three-dimensional): Tread
Down-slope shape: Linear
Across-slope shape: Linear
Ecological site: R010XY003OR - WET MEADOW
Hydric soil rating: Yes

Burkemont

Percent of map unit: 5 percent
Landform: Terraces
Landform position (three-dimensional): Tread
Down-slope shape: Linear
Across-slope shape: Linear
Ecological site: R010XY008OR - SODIC MEADOW
Hydric soil rating: Yes

170A—Umapine silt loam, 0 to 2 percent slopes

Map Unit Setting

National map unit symbol: 22pb
Elevation: 2,000 to 3,500 feet
Mean annual precipitation: 9 to 12 inches
Mean annual air temperature: 45 to 50 degrees F
Frost-free period: 110 to 140 days
Farmland classification: Farmland of statewide importance

Map Unit Composition

Umapine and similar soils: 85 percent
Minor components: 8 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Umapine

Setting

Landform: Terraces
Landform position (three-dimensional): Tread
Down-slope shape: Linear
Across-slope shape: Linear
Parent material: Mixed alluvium and loess

Typical profile

H1 - 0 to 12 inches: silt loam
H2 - 12 to 40 inches: silt loam
H3 - 40 to 60 inches: silt loam

Properties and qualities

Slope: 0 to 2 percent
Depth to restrictive feature: More than 80 inches
Drainage class: Somewhat poorly drained
Capacity of the most limiting layer to transmit water (Ksat): Moderately high to high (0.57 to 1.98 in/hr)

Depth to water table: About 12 to 24 inches
Frequency of flooding: Rare
Frequency of ponding: None
Calcium carbonate, maximum content: 30 percent
Maximum salinity: Strongly saline (16.0 to 32.0 mmhos/cm)
Sodium adsorption ratio, maximum: 5.0
Available water supply, 0 to 60 inches: High (about 11.9 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 4w
Hydrologic Soil Group: B/D
Ecological site: R010XY007OR - SODIC BOTTOM
Hydric soil rating: No

Minor Components

Haines

Percent of map unit: 8 percent
Landform: Flood plains
Landform position (three-dimensional): Tread
Down-slope shape: Linear
Across-slope shape: Linear
Ecological site: R010XY008OR - SODIC MEADOW
Hydric soil rating: Yes

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APPENDIX C
Fertilizer Guide

DRAFT

Nutrient Management Guide for Dryland and Irrigated Alfalfa in the Inland Northwest

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Washington State University • Oregon State University • University of Idaho

Nutrient Management Guide for Dryland and Irrigated Alfalfa in the Inland Northwest

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Nutrient management is necessary to produce high-yielding, high-quality alfalfa economically, while at the same time preserving soil, air, and water quality. As the term implies, nutrient management includes activities such as sampling to monitor soil and plant tissue nutrient levels, adjusting nutrient application rates based on soil and tissue test results, and varying the placement, timing, and source of nutrients to optimize plant availability and uptake.

The information presented here is applicable to alfalfa grown throughout Idaho and east of the Cascade mountain range in Oregon and Washington. Different climates, soils, and topography result in considerable variation in alfalfa yields across a region, an individual farm, and even within a field on the same farm. Due to this inherent variability, a one-size-fits-all recommendation for the management of any one nutrient is of little value. Nutrient management choices should be based on individual grower practices, realistic yield expectations, and current soil and tissue test information.

This document summarizes locally-based guidelines for managing major nutrients in alfalfa, emphasizes how producers can tailor recommendations to their production system, and identifies opportunities where information such as soil and tissue test results can help refine and improve nutrient management practices to optimize alfalfa yield, quality, and economic returns. The recommendations are based on existing Extension bulletins, recent research data, field experiences, and estimates of nutrient removal and efficiency.

Nutrient removal by alfalfa

Growing alfalfa removes large quantities of nutrients from soil (Table 1). In fact, high-yielding stands of alfalfa hay remove as much or more nutrients than any other intensive forage managed for hay or silage. Growers have historically relied on phosphorus and potassium as the main nutrients added for optimal alfalfa production. Areas with a long history of alfalfa and other intensive crops have commonly mined soil nutrient reserves. This, coupled with modern, higher-yielding varieties and production systems, means that many alfalfa fields now require supplementation with multiple nutrients.

Soil pH and alfalfa

Optimum alfalfa yields occur when soil pH is near 7.0; however, alfalfa can tolerate soil in the pH range 6.0–8.2 and still produce high yields. Northern Idaho and western Oregon and Washington, where rainfall is high, have lower soil pH than more arid regions of the inland

Table 1. Average tissue nutrient contents and their removal in alfalfa hay production.

Nutrient	Nutrient concentration in early bloom hay (dry matter basis)[1]	Nutrients removed per ton of early bloom alfalfa hay (analysis from previous column, 88% dry matter)	Range of nutrients removed per ton of hay at 88% dry matter[2]
Nitrogen (N)	19.9% crude protein (3% N)	56 lb N	50–70 lb N
Phosphorus (P)	0.2% P	8 lb P_2O_5[3]	8–16 lb P_2O_5
Potassium (K)	2.6% K	54 lb K_2O[4]	48–72 lb K_2O
Sulfur (S)	0.3% S	5 lb S	4–6 lb S
Calcium (Ca)	1.6% Ca	30 lb Ca	28–35 lb Ca
Magnesium (Mg)	0.3% Mg	6 lb Mg	5–8 lb Mg
Boron (B)	—	—	0.05 lb B
Zinc (Zn)	30 ppm[5] Zn	0.05 lb Zn	0.05 lb Zn
Copper (Cu)	12.7 ppm[5] Cu	0.02 lb Cu	0.02 lb Cu
Molybdenum (Mo)	0.29 ppm[5] Mo	0.0005 lb Mo	0.0005 lb Mo

[1]Adapted from National Research Council 2000, pp. 134–135.
[2]Variations in nutrient removal that may occur with different soil residual nutrient values.
[3]To convert P (phosphorus) to P_2O_5 (oxide form), divide by 0.44.
[4]To convert K (potassium) to K2O (oxide form), divide by 0.83.
[5]parts per million

Figure 1. Symptoms of phosphorus deficiency in alfalfa include short plants, thin and weedy stands, and small, dark, or blue-green leaves. The overview photo is of a severely phosphorus-deficient stand of alfalfa. The left insert photo is of a phosphorus-deficient stand, while the right insert photo is of a phosphorus-fertilized stand.

Pacific Northwest. Soil pH below 6.0 limits nitrogen fixation and alfalfa yield. In these low pH areas, lime may be needed to increase soil pH. A soil test to determine alfalfa lime requirements (SMP buffer test) will indicate the lime application rates needed for low pH soils. For more information on this test, contact a soil testing lab (Daniels 2005) and see Oregon State University (Hart 1990) and University of Idaho (Mahler 1994) Extension bulletins on lime materials.

Many inland Pacific Northwest soils have become acidic (pH less than 7.0) due to long-term use of ammonium-based nitrogen fertilizer. Often these acidified soils have higher pH subsoil. When this situation exists, deep tillage can mix the topsoil and subsoil and delay the need for lime application.

Nitrogen (N)

Fortunately, alfalfa obtains most of the nitrogen it needs from the atmosphere through a symbiotic association with rhizobia (*Sinorhizobium meliloti*) bacteria that inhabit nodules in the alfalfa root system. Successful conversion of atmospheric nitrogen to a form usable by alfalfa ("fixation") depends on the presence of rhizobia in soil or inoculated seed, suitable soil pH (discussed above), and nutrient availability—particularly molybdenum, copper, and cobalt (discussed later).

Rhizobia require a source of energy (carbohydrate) from alfalfa. This comes at some cost to the plant, so alfalfa preferentially uses ammonium- and nitrate-nitrogen in the soil, if available, rather than fixing its own nitrogen. Nitrogen fixation is, however, a very cost-effective way to obtain nitrogen. Given the high nitrogen content of alfalfa (Table 1), fertilizing stands with nitrogen is seldom economical. For long-term production, correcting the underlying problem that is limiting fixation or shifting to non-legume (grass) production is normally more economical than fertilizing alfalfa with nitrogen.

Alfalfa is deep-rooted and drought-tolerant, making it well-suited for nitrogen uptake. The crop is commonly used to dispose of waste nitrogen from a variety of industries. At 50–70 lb per ton of hay, alfalfa removes more nitrogen than almost any other crop. When nitrogen is supplied via wastewater or manure, alfalfa preferentially absorbs nitrogen from the soil rather than fixing it from the atmosphere. A reasonable nitrogen application rate for disposal situations is 80% of the nitrogen removed by the hay crop. Fertilizing alfalfa with nitrogen may increase nitrate in the hay, so monitoring is helpful to curtail this problem if necessary.

Phosphorus (P)

Phosphorus is an important nutrient in alfalfa production with mild to moderate deficiencies commonly delaying maturity and limiting hay yield. Visual symptoms (Figure 1) can be difficult to recognize since they also resemble drought stress and certain diseases. Also, visual symptoms may not be apparent until deficiencies become severe enough to significantly reduce yield and allow grassy weeds to encroach on the stand.

Soil testing is a reliable way to diagnose phosphorus deficiency before it causes major yield reductions. Samples should be collected in late fall or early spring when alfalfa is dormant. Soil samples collected in-season will have lower test levels as a result of active absorption by growing plants and the relatively slow release of plant-available phosphorus from soil minerals. Tissue testing can also be used to diagnose phosphorus deficiencies during the growing season. Guidelines for phosphorus and other important alfalfa nutrient concentrations are summarized in Table 2. Soil or tissue testing for phosphorus should be done annually in irrigated systems and every 2–3 years in dryland systems to monitor nutrient levels.

Phosphorus recommendations based on soil test results are summarized in Table 3. For new stands, apply the amount of P_2O_5 specified in Table 2 plus enough additional P_2O_5 for 2 years of production based on expected yields and estimated crop removal (Table 1). Phosphorus movement in soil is very limited, so extra phosphorus applied during or prior to stand establishment will be available in future years.

Soil Testing for Alfalfa

It is difficult to generalize about the location and occurrence of specific nutrient deficiencies. Soils are inherently variable due to geologic processes and historic crop yields and nutrient applications. Some irrigation water sources also add nutrients to soil. For these reasons, soil testing is necessary to determine which nutrients are needed and in what amounts. Soil testing also provides important information on soil pH, salinity, and other conditions that may influence alfalfa growth. Common sampling depths for alfalfa are the surface 0–6 inches for lime requirements and 0–12 inches for most nutrients and soil pH. See the reference section at the end of this guide for information on where to send soil samples for analysis (Daniels 2005).

If a field will be fertilized as one unit, collect a minimum of 20 soil cores from representative locations throughout the field and combine these for the sample. This composite sampling technique provides a field average measure of soil properties. (If you are concerned about unusual or unrepresentative areas, collect cores from these separately and clearly distinguish via labeling.)

An alternative sampling approach is to divide a field into management units based on knowledge of variability in soil properties and yield potential. However, this approach is only warranted if you have the ability to manage units within a field separately. For example, you could separate a field into 2–3 management units based on slope, drainage, and/or soil type. Sample each management unit separately by collecting cores from several locations within the unit. Fertilize each unit according to the soil test results.

Additional information on soil sampling strategies can be found in publications listed at the end of this guide (Staben et al. 2003, Summers and Putnam 2008).

When possible, incorporate fertilizer into the surface 3–5 inches of soil with light tillage prior to establishing a new stand so that phosphorus will still be available to the plant when the soil surface dries.

Table 2. Interpretations of tissue tests for nutrient concentrations in alfalfa sampled at first bloom[1,2].

Nutrient	Critical concentration for sufficiency	Concentration including excess
Nitrogen (N)	3–4% 4–5%	
Phosphorus (P)	0.20–0.25% 0.25–0.35%	
Potassium (K)	2.0–2.5% 2.5–3.5%	above 3%[3] above 4%
Sulfur (S)	0.20–0.25% 0.25–0.30%	
Boron (B)	20 ppm 20–40 ppm	above 200[4] above 200
Manganese (Mn)	15 ppm 30–50 ppm	125–250
Iron (Fe)	40 ppm 40–100 ppm	
Zinc (Zn)	12 ppm 20–70 ppm	
Copper (Cu)	5 ppm 5–25 ppm	
Molybdenum (Mo)	0.8 ppm[5] 1–5 ppm[5]	above 10[6] above 10

[1]Correct insufficiencies in a manner similar to correcting low soil test results for these nutrients.
[2]The first concentration listed per nutrient corresponds to the whole plant top, while the second corresponds to the top 1/3 of the plant.
[3]Excess potassium may aggravate milk fever in "close-up" cows, hyperkalemic periodic paralysis in genetically susceptible horses, and winter tetany in beef cows.
[4]Tissue concentrations of boron above this level indicate plant toxicity, which may reduce yield.
[5]When a molybdenum tissue test indicates deficiency, this nutrient can be applied as a seed treatment at a maximum rate of 1 oz/acre or broadcast at 1–2 oz/acre.
[6]High molybdenum may cause secondary copper deficiency in ruminants. The ratio of copper to molybdenum should be above 2.

Supplemental applications of phosphorus made to established stands should be based on soil and/or tissue tests. Broadcast applications of dry phosphorus fertilizers are most effective when made in the fall or early spring to allow time for the phosphorus to dissolve before active growth begins. In furrow-irrigated systems, fall application of phosphorus is more important if dry forms are used since winter moisture is necessary to dissolve fertilizer pellets stranded on the beds. Fluid phosphorus forms are preferred for in-season applications to actively growing stands.

Tissue Testing for Alfalfa

Tissue testing is an effective way to directly monitor the nutrient status of alfalfa and diagnose nutrient-related problems. For certain elements like molybdenum where no soil test is available, tissue testing is the only way to accurately determine whether the nutrient is present in sufficient quantities that yield quality alfalfa.

Diagnosis of a nutrient deficiency with tissue testing may necessitate subsequent soil testing since insufficient databases exist from which to develop fertilizer recommendations based on tissue tests alone. One good source to check for tissue test-based fertilizer recommendation information is Summers and Putnam 2008.

Both growth stage and plant parts are important when sampling alfalfa tissue (Table 2). Gather sample tissues by removing the appropriate plant part at first bloom in 10 locations throughout a field, and then combine. Keep tissue samples cool and transport them to a testing lab as soon as possible (Daniels 2005). When you get the results, compare the tissue nutrient levels to the critical values given in Table 2 to determine if your alfalfa's nutrient concentrations are sufficient.

Another way to diagnose nutrient deficiencies in your alfalfa is to collect paired tissue samples where one composite sample is from a good section of a field and another, separate composite is from a problem area. Clearly label each composite and send to a lab. Compare the findings for the problem area with the critical levels in Table 2 as well as what the lab found for both the good and problem areas to identify major differences.

Fluids can be applied through an irrigation system (fertigation), in surface bands spaced 12 inches or less apart with stream nozzles, or sprayed uniformly on fields using a fan nozzle.

Several high analysis (high P_2O_5 concentration) sources of phosphorus fertilizer are available, including dry triple superphosphate (0-45-0; 45% P_2O_5 by weight), monoammonium phosphate (11-52-0; 52% P_2O_5 by weight), diammonium phosphate (18-46-0; 46% P_2O_5 by weight), fluid ammonium polyphosphate (10-34-0 or 11-37-0, 34 or 37% P_2O_5 concentrations on a weight basis), and phosphoric acids (various P_2O_5 concentrations). High analysis forms are typically the least expensive fertilizers per unit of phosphorus. Other, lower analysis phosphorus fertilizers are available such as 16-20-0-13S (20% P_2O_5), but the extra cost for nitrogen in the material is often not warranted and the sulfur concentration is too high to make this a practical phosphorus fertilizer source. Numerous comparisons indicate that when topdressed at the same rate of P_2O_5, the fertilizer sources mentioned above are equally effective. Therefore, it is most economical to select a phosphorus source based on local availability, ease of application, and cost per unit of P_2O_5. Rock phosphate is insoluble and is not recommended as a source of phosphorus for alfalfa.

Potassium (K)

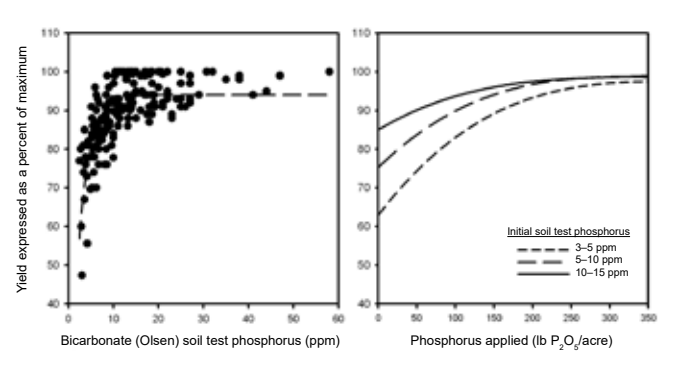
After phosphorus, potassium is often the second most limiting nutrient in alfalfa production. Moderate potassium deficiencies can limit yields and reduce stand life. Visual symptoms (Figure 2) are easy to recognize but may not become apparent until deficiencies are severe enough to significantly reduce yield and shorten stand life.

Figure 2. Potassium deficiency in alfalfa is represented by necrotic spots on the outer margins of young leaves and thin, declining stands.

Predicting Alfalfa Responses to Phosphorus Fertilizer

Soil test interpretations and fertilizer recommendations are based in part on the probability of obtaining a yield response to fertilizer application as well as the magnitude of that yield response. The probability and magnitude of a response are generally higher when initial soil test values are lower; however, both depend on many other factors that influence yield, including water availability, stand quality, and pest pressures.

The graph below and to the left illustrates an example of relative alfalfa yields at soil test phosphorus levels using the Olsen (sodium bicarbonate) extraction procedure. Relative yield is used here in order to combine data from a large number of studies and identify trends. According to the lefthand graph, yield approaches 95% of the maximum for most locations when the Olsen soil test for phosphorus results in 15 ppm. The graph below and to the right shows an example of relative alfalfa yield responses to phosphorus fertilizer application when the initial soil test is very low (3–5 ppm), low (5–10 ppm), or moderate (10–15 ppm). As expected, the yield response is greatest and the most fertilizer phosphorus is required to reach maximum yield when the initial soil test indicates phosphorus is very low.



Data from Koenig et al. 1999

The phosphorus fertilizer recommendations summarized in Table 3 are based on initial soil test values and yield potentials for irrigated and dryland production situations. There is some uncertainty in developing these recommendations since individual soil types vary in their ability to supply phosphorus and yield is influenced annually by more factors than just the soil test level. However, attempts to further refine fertilizer recommendations are not justified given the uncertainty and variability in yield responses to soil test phosphorus levels and fertilizer rates. Growers are encouraged to use the recommendations in this document as a guide as well as monitor their alfalfa yields and soil and plant tissue concentrations to evaluate the success of their fertilizer programs.

Alfalfa removes large quantities of potassium from soil (Table 1). In areas with a long history of alfalfa production, soil potassium reserves are commonly depleted. Soil testing is a reliable way to diagnose potassium deficiency before it causes significant yield reductions. The standard sampling depth for potassium is 0–12 inches. Samples should be collected in late fall or early spring when alfalfa is dormant. Soil samples collected in-season will have lower test levels as a result of active absorption by growing plants and the relatively slow release of plant-available potassium from soil minerals. Tissue sampling can be used to diagnose potassium deficiencies in-season. In areas with a history of potassium deficiency, soil or tissue sampling for potassium should be done annually to monitor nutrient levels.

Potassium recommendations based on soil test results are summarized in Table 4. Alfalfa will absorb more potassium than it needs for optimum yields. This tendency for "luxury consumption" may result in the harvest of

Table 3. Soil test-based phosphorus fertilizer recommendations for irrigated and dryland alfalfa.

Table 3a. Per acre recommendations based on P soil testing.

Soil test for phosphorus[1]		P_2O_5[2] recommendation	
Olsen (bicarbonate) method	Morgan (accetate) method	Irrigated	Dryland
—mg/kg of soil or ppm—		—lb P_2O_5/acre[3]—	
0–5[4]	0–3[4]	150–200	50–75
5–10	3–4	100–150	25–50
10–15	4–5	50–100	0–25
15–20	5–6	0–50	0
above 20	above 6	0	0

Table 3b. Per ton recommendations based on yield expectations and P soil testing.

Soil test for phosphorus[1]		P_2O_5[2] recommendation	
Olsen (bicarbonate) method	Morgan (accetate) method	Irrigated	Dryland
—mg/kg of soil or ppm—		—lb P_2O_5/acre[3]—	
0–5[4]	0–3[4]	20–30	15–20
5–10	3–4	15–20	10–15
10–15	4–5	8–15	0–10
15–20	5–6	0–8	0
above 20	above 6	0	0

[1]Soil testing for phosphorus is based on a 0–12-inch sample depth. Olsen is the preferred extract method. While some labs use Morgan, it is the least reliable extract method and should be avoided. Interpretations are given here only because some testing labs still use the Morgan procedure. In southern Idaho, soil lime content is also included in the interpretation of an Olsen soil test for phosphorus (Stark et al. 2002).
[2]Fertilizer labels are expressed in % P_2O_5. To convert P_2O_5 to P, multiply by 0.44.
[3]Recommendations in Table 3a assume a 6–8 ton/acre yield for irrigated and a 2–3 ton/acre yield for dryland alfalfa.
[4]Low soil test levels severely limit yield. Test soil and apply phosphate annually until levels are adequate.

Table 4. Soil test-based potassium fertilizer recommendations for irrigated and dryland alfalfa.

Table 4a. Per acre recommendations based on K soil testing[3].

Soil test for potassium	K_2O recommendation[2]	
Olsen (sodium bicarbonate), Morgan (acetate), or equivalent exchangeable method[1]	Irrigated	Dryland
—mg/kg of soil or ppm—	—lb K_2O/acre[3]—	
0–50[4]	200–300[5]	50–100
50–100	100–200	0–50
100–150	50–100	0
150–200	0–50	0
above 200	0	0

Table 4b. Per ton recommendations based on yield expectations and K soil testing.

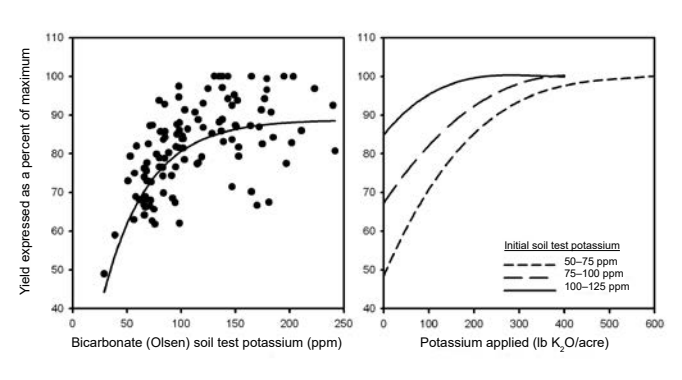
Soil test for potassium	K_2O recommendation[2]	
Olsen (sodium bicarbonate), Morgan (acetate), or equivalent exchangeable method[1]	Irrigated	Dryland
—mg/kg of soil or ppm—	—lb K_2O/acre[3]—	
0–50[4]	30–40[5]	20–30
50–100	15–25	0–20
100–150	10–15	0
150–200	0–5	0
above 200	0	0

[1]Soil testing for potassium is based on a 0–12-inch sample depth. These 2 extract methods are commonly used for potassium. Both are accurate across a range of soil conditions and the results and interpretations are identical.
[2]Fertilizer labels are expressed in % K_2O. To convert K_2O to K, multiply K_2O by 0.83.
[3]Recommendations in Table 4a assume a 6–8 ton/acre yield for irrigated and a 2–3 ton/acre yield for dryland alfalfa.
[4]Low soil test levels severely limit yield. Test soil and apply potash annually until levels are adequate.
[5]Split K_2O applications by applying 50% in early spring and 50% after the second cutting.

Predicting Alfalfa Responses to Potassium Fertilizer

Similar to phosphorus, potassium fertilizer recommendations at a given soil test level are based in part on the probability of obtaining a yield response and the magnitude of that response. The graph below and to the left illustrates an example of relative alfalfa yield at a soil test potassium level using Olsen (sodium bicarbonate) or acetate extract procedures. Again, relative yield is used in order to combine data from a large number of studies and identify trends. The relationship is not as clear as for phosphorus. Yield approaches 90% of the maximum for most locations when soil test potassium is 150 ppm.

The graph below and to the right shows an example of relative alfalfa yield responses to potassium fertilizer application when an initial soil test result is very low (50–75 ppm), low (75–100 ppm), or moderate (100–125 ppm). As with phosphorus, the lower the level of potassium an initial soil test indicates, the greater the yield response will be but more fertilizer potassium required to reach maximum yield.



Data from Koenig et al. 2001

high potassium hay and accelerated removal of potassium from soil. For this reason, large applications to meet multiple years of potassium needs are not recommended; annual applications above 200 lb K_2O/acre should be split between early spring and mid-season dates.

Several high analysis sources of potassium fertilizer are available, including dry potassium chloride (0-0-60; 60% K_2O by weight), potassium sulfate (0-0-50-18S; 50% K_2O by weight), and potassium-magnesium sulfate (0-0-22-18S, 22% K_2O by weight). Fluid forms of potassium fertilizer also exist, but these contain less potassium per pound and are commonly more expensive than dry sources. High analysis (high K_2O concentration) forms are typically the least expensive fertilizers per unit of potassium. As with phosphorus, multiple comparisons indicate that when applied at the same rate of K_2O, the materials mentioned above are equally effective. Therefore, it is most economical to select a potassium source based on local availability, ease of application, and cost per unit of K_2O. Irrigation water may also contain potassium; to estimate, analyze a sample of irrigation water and multiply the parts per million of potassium by 3.28 to convert to pounds of K_2O per acre-foot of water.

Sulfur (S)

Sulfur deficiency in alfalfa is common in areas with high rainfall, as well as sandy soils and when irrigation water with low sulfur concentrations is used. The effects of sulfur deficiency (Figure 3) resemble those of nitrogen deficiency, except that sulfur deficiency symptoms appear on the newest foliage first. A

Figure 3. Symptoms of sulfur deficiency in alfalfa include short plants, thin stands, and light green color. The main photo shows a sulfur Z-strip applied to a sulfur-deficient field of alfalfa. The inset photo illustrates alfalfa that is sulfur-deficient (right) and sulfur-fertilized (left).

deficiency in sulfur for alfalfa results in reduced yield, crude protein content, and feed value.

The soil test for sulfur is somewhat unreliable due to the mobility of the plant-available form of sulfur (sulfate) and inability of the soil test to estimate sulfur release from soil organic matter. Most soil tests report sulfur in the sulfate (SO_4-S) form. Interpretations of sulfate-sulfur soil test values are summarized in Table 5. Tissue testing can also be used to monitor the sulfur status of alfalfa. Irrigation water from return flows and certain groundwater wells may contain substantial sulfur, so analysis of these sources may be warranted. To estimate this contribution, multiply parts per million sulfate-sulfur (SO_4-S) in irrigation water by 2.72 to convert to pounds of sulfur per acre-foot of water applied.

Common sources of dry sulfur fertilizer include ammonium sulfate (21-0-0-24S; 24% sulfur), potassium sulfate (0-0-50-18S; 18% sulfur), potassium-magnesium sulfate (0-0-22-18S, 18% S), gypsum (0-0-0-17S, 17% sulfur), and elemental sulfur (0-0-0-90S; 90% sulfur). Fluids such as potassium thiosulfate (0-0-25-17S, 17% S), potassium polysulfide (0-0-22-23S, 23% S), ammonium thiosulfate (12-0-0-26S, 26% S), and ammonium polysulfide (20-0-0-40S, 40% S) are also available. Many of these fluids can be mixed with irrigation water and applied in-season. Undiluted fluid forms of sulfur will burn tissue if applied to actively growing alfalfa, but are generally safe when applied to dormant alfalfa.

Micronutrients

Zinc, molybdenum, and boron deficiencies occur relatively frequently in alfalfa. Zinc deficiency is more common in high pH soils. Molybdenum and boron deficiencies are more common in high rainfall areas with low pH soils. Soil or tissue testing can be used as a guide to zinc and boron deficiencies, although the boron test has not proven reliable. Copper and manganese deficiencies are very rare in alfalfa. Micronutrient soil (Table 6) or tissue testing can be used to determine if copper fertilization is necessary. Manganese deficiency should be diagnosed with a tissue test. There is no soil test for molybdenum, so it is best to rely on tissue testing to diagnose a deficiency. A very small amount of cobalt is needed for nitrogen fixation; however, there is no evidence that cobalt deficiency is a problem and no soil tests or critical tissue values for alfalfa are available.

Sources of zinc, iron, copper, and manganese include metal salts and oxides (e.g., zinc sulfate or zinc oxide) and chelated forms. Chelated forms are more available to alfalfa than salts or oxides and can generally be applied at lower rates to correct deficiencies. However, chelated forms cost more than salts or oxides. Sodium

Table 5. Soil test-based sulfur fertilizer recommendations for irrigated and dryland alfalfa.

Table 5a. Per acre recommendations based on S soil testing.

Soil test for sulfur in the sulfate form (SO_4–S)[1]		Sulfur recommendation	
		Irrigated	Dryland
mg/kg of soil or ppm	—lb/acre—	—lb sulfate or sulfide-sulfur/acre[2,3]—	
0–5	0–20	25–35	10–20
5–10	20–40	15–25	0–10
10–15	40–60	10–15	0
above 15	above 60	0	0

Table 5b. Per ton recommendations based on yield expectations and S soil testing.

Soil test for sulfur in the sulfate form (SO_4–S)[1]		Sulfur recommendation	
		Irrigated	Dryland
mg/kg of soil or ppm	—lb/acre—	lb sulfate or sulfide-sulfur/ton of expected yield[2]	
0–5	0–20	3–5	2–4
5–10	20–40	2–3	0–2
10–15	40–60	0–2	0
above 15	above 60	0	0

[1]Soil testing for sulfur is based on a 0–12-inch sample depth. Various extract methods are used for sulfur, but the results and interpretations are identical. All soil test sulfur methods are subject to limitations described in the sulfur section of the text.
[2]Sulfate- and sulfide-sulfur forms are rapidly available to the plant and should be used to correct a deficiency. Combining these recommendations with 50–100 lb of elemental sulfur (0-0-0-90 S, a slow release form) will provide sufficient sulfur for the current year of production plus an additional 10–20 tons of hay production over the next 2–3 years.
[3]These recommendations assume 6–8 ton/acre yield for irrigated and a 2–3 ton/acre yield for dryland alfalfa.

Table 6. Micronutrient soil test concentrations, interpretations, and recommendations for alfalfa[1].

Micronutrient	Low	Marginal	Adequate
	soil test concentration in mg/kg or ppm[2]		
Zinc	below 0.8	0.8–1.0	above 1.0
Copper	below 0.2	—	above 0.2
Manganese	Rely on tissue testing to diagnose a deficiency.		
Molybdenum	Rely on tissue testing to diagnose a deficiency.		
Boron (coarse-textured soils)[3]	below 0.2	0.3–0.4	0.5–1.0
Boron (fine-textured soils)[4]	below 0.3	0.4–0.8	0.9–1.5
Recommendation	Apply 10 lb of zinc and 2 lb of copper or boron.	Apply 5 lb of zinc and 1 lb of copper or boron.	NA

[1]Soil test levels are based on a 0–12-inch sample depth.
[2]The soil test extraction method for zinc and copper is abbreviated DTPA (Diethylene triamine pentaacetic acid). Boron is extracted with hot water.
[3]sand, loamy sand, sandy loam
[4]loam, silt loam, clay loam, clay

or calcium salts of boron and molybdenum are highly soluble and available to plants.

Additional considerations

Fertigation

Application of liquid fertilizers via irrigation is an efficient and convenient way to supply nutrients to alfalfa, including during the growing season. Liquid sources of phosphorus, potassium, sulfur, and micronutrients are available. It is important to carefully compare the cost and convenience of using liquid sources vs. dry fertilizer materials. Also understand that some fluid fertilizer sources can precipitate in irrigation lines and plug orifices, while others are corrosive. Seek advice from your fertilizer and irrigation system dealers on injecting specific chemicals into your system.

Manure and alfalfa

Livestock manures contain large quantities of phosphorus and potassium, and smaller amounts of all other nutrients alfalfa requires. When applied to grain or other crops in a rotation, manure is an efficient way to build soil nutrient levels before reestablishing alfalfa. Manure can also be applied to dormant alfalfa, but may increase weed problems in established alfalfa stands by supplying weed seeds and high rates of nitrogen that stimulate grassy weed growth.

Potassium and animal health

The high potassium content of alfalfa hay is related to milk fever in dairy cows and hyperkalemic periodic paralysis in genetically susceptible horses. Potassium levels in hay can be moderated by limiting potassium fertilizer to anticipated crop use and available soil potassium as determined by soil testing. Not surprisingly, alfalfa harvested from fields known to have low soil test potassium will be lower in potassium content than hay harvested from fields with adequate soil potassium. Delaying alfalfa harvest until early to mid-bloom also reduces hay potassium content. Rain that occurs while the crop is still in the windrow causes potassium to leach from hay.

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Introduction

C. Cheyney and G. Shewmaker

PASTURES ARE REMARKABLE PLACES. They beautify the landscape, protect soil from erosion, capture carbon to reduce greenhouse gases, release oxygen for us to breathe, produce feed for livestock, and provide habitat for wildlife. Ecologically diverse, well-managed pastures are relatively resistant to the scourges of diseases and insects, and they seldom need chemical inputs to control weeds. What more could we want?

All of Earth's inhabitants benefit from the ecosystem services provided by pastures. For example:

- Both rural and urban residents value pastoral landscapes. Most people enjoy scenes of animals grazing well-managed pastures.
- Pastures protect and enrich the soil with their extensive root system.
- Grasses, legumes, and other forbs serve as millions of little solar panels to capture huge amounts of solar energy. Through photosynthesis, they convert this energy into chemical energy and store it in carbohydrates, a process that takes carbon dioxide (CO_2) from the atmosphere and releases oxygen. Irrigated perennial pastures in the Northwest can sequester 88,000 pounds per acre of carbon over 30 years. This is 160% of the carbon stored in irrigated annual cropland. Most of the gain in carbon sequestration in pastures is in perennial plant growth. In addition, production and harvesting of irrigated pastures emit only 26% of the carbon emitted to produce and harvest annual crops.
- Pastures filter sediment and excess nutrients from overland water flows. They protect the soil from the impact of raindrops, increase water infiltration and soil moisture storage, and decrease overland flows.
- Well-managed pastures reduce the loss of nitrogen to the atmosphere.

Humans are seldom content with a system that functions well, unless it produces food or fiber they can use. Thus, pastures pose a problem. They store solar energy primarily in structural carbohydrates (cellulose and hemicelluloses), which humans cannot digest. Only certain protozoa and bacteria can utilize the energy in structural carbohydrates, and they need to live in a warm, moist, protected environment.

Nature provided a solution to this problem through the specially adapted digestive tracts of ruminants, camelids, rodents, and horses. Of these, ruminants have the most sophisticated digestive system.

The ruminant's digestive tract has four compartments, including the true stomach. The largest compartment is the rumen. The rumen serves as a fermentation vat, where protozoa and bacteria live in a mutually beneficial relationship (symbiosis) with the animal. The microbes enzymatically break down otherwise indigestible structural carbohydrates and use the nutrients to grow and multiply. The remaining forage mass, as well as some of the microorganisms, are further digested in the ruminant's true stomach.

The resulting liberated nutrients are absorbed into the ruminant's bloodstream through the small intestine, allowing the animal to grow and reproduce. The ruminant then provides humans with fiber and food that is high in energy, essential amino and fatty acids, and other nutrients that we would otherwise need to acquire from a variety of plants. Energy and nutrients not used by the animal are returned to the pasture. There they are reused in growth processes involving soil,

plants, animals, microorganisms, and the atmosphere. Thanks to this system, millions of acres of land that are unsuitable for intensive cultivation due to soil quality, erosion, or climate can produce high-quality pasture and, consequently, high-quality human food.

To obtain these benefits, pastures must be well managed. According to the 2007 Census of Agriculture, there are 16.2 million acres of domestic pasture in Idaho, Utah, Oregon, and Washington. Unfortunately, most of this land is simultaneously overgrazed and underutilized. It produces as little as half of its potential forage, and grazing animals often utilize as little as half of the forage produced. Many of these pastures are characterized by poor energy capture, low yield, poor water infiltration, high runoff from precipitation, and the presence of weedy species.

These poorly managed pastures require more fertilizer, herbicides, water, and fuel than do well-managed pastures. Managers see them as unprofitable because of high input costs. The combination of high input costs and low productivity leads to indifferent management, which in turn fuels a downward spiral of ecological and economic condition. Ultimately, the pasture "needs" to be "renovated" at great expense. Without a change in management, however, history repeats itself in only a few years!

This cycle can be broken, however. We often hear a lot about "intensive grazing." All grazing animals graze "intensively"! What needs to be intensified is management. In 1999, Martz, Gerrish, Belyea, and Tate defined Management-intensive Grazing (MiG) as "a flexible approach to rotational grazing management whereby animal nutrient demand through the grazing season is balanced with forage supply and available forage is allocated based on animal requirements."

It would be nice if we could give you a recipe for good pasture management, but none is available. The number of variables is too great, and they change too often, to be reduced to a recipe. What we can give you is knowledge about the ecological processes involved in pasture growth and utilization, and an understanding of how your management influences those processes for "good" or "bad." You will still need to practice, however, for good pasture management is both an art and a science.

Nobel laureate Max Plank said, "The nature of any system cannot be discovered by dividing it into its component parts and studying each part by itself. . . . We must keep our attention fixed on the whole and on the interconnection between the parts. . . . The whole is never equal simply to the sum of its various parts." So it is with pastures. Thus, although we will consider the pasture system in parts, we must always keep in mind the interconnection between the parts. No matter where you exert influence in the pasture-animal system, you will affect the entire ecological and economic production system for days, seasons, and sometimes years into the future.

CHAPTER 1

Pasture Resources, Goals, and Planning

S. Williams and S. Baker

PLANNING IS AN IMPORTANT PART of pasture and grazing management. Planning begins with inventorying and analyzing resources. The end product is a set of goals and a plan for reaching them. Resources and goals are interconnected. To know whether you are using your resources efficiently, you need goals. To determine whether you can reach your goals, you need to identify and inventory your resources.

A plan can be for a week, month, growing season, or year. A plan can be developed specifically for grazing management, animal management, or other aspects of the ranch operation.

In this chapter, we will discuss the planning process, including the steps involved, the type of information to include in a resource inventory, and how to write effective goals.

Key Points

- Resource inventory and goal setting are interconnected. You can't do one without the other.
- The planning process is cyclical and has four key components: inventory, analysis, planning, and implementation.
- Goals need to be specific, measurable, achievable, and reasonable.

The planning process

The planning process is cyclical in nature and has four key components: inventory, analysis, planning, and implementation (figure 1.1). Each of these is discussed below.

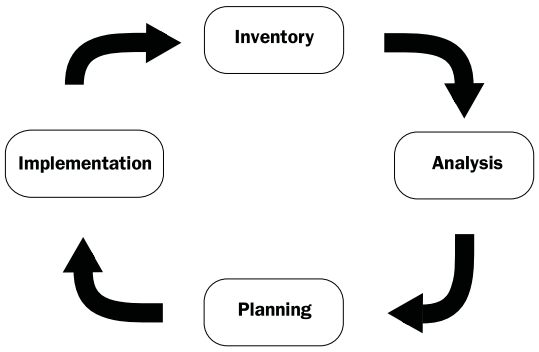

Figure 1.1. Four steps in the planning process.

INVENTORY

An inventory is a snapshot—it looks at the resources available at a certain moment in time. It is accurate only on the day and time it is taken. For example, you might inventory grazing days available on June 1. By June 2, after 24 additional hours of grazing or regrowth, that number will be different. Some resources change frequently (e.g., number of calves during calving season). Others remain fairly constant (e.g., corrals and buildings).

Resources can include available aid, support, means, funds, supplies, or assets.

There are four major categories of resources: natural, human, economic, and physical (figure 1.2).

Natural resources

Natural resources include land, water, soil, and livestock. A complete land inventory should include the total acres of pasture, hay, grains, other crops, and waste lands, including weedy areas. Include land ownership (rented or leased) and public grazing permits.

If possible, include the number of grazing days for each pasture. List the forage plants available in each pasture so that you can monitor plant succession. The

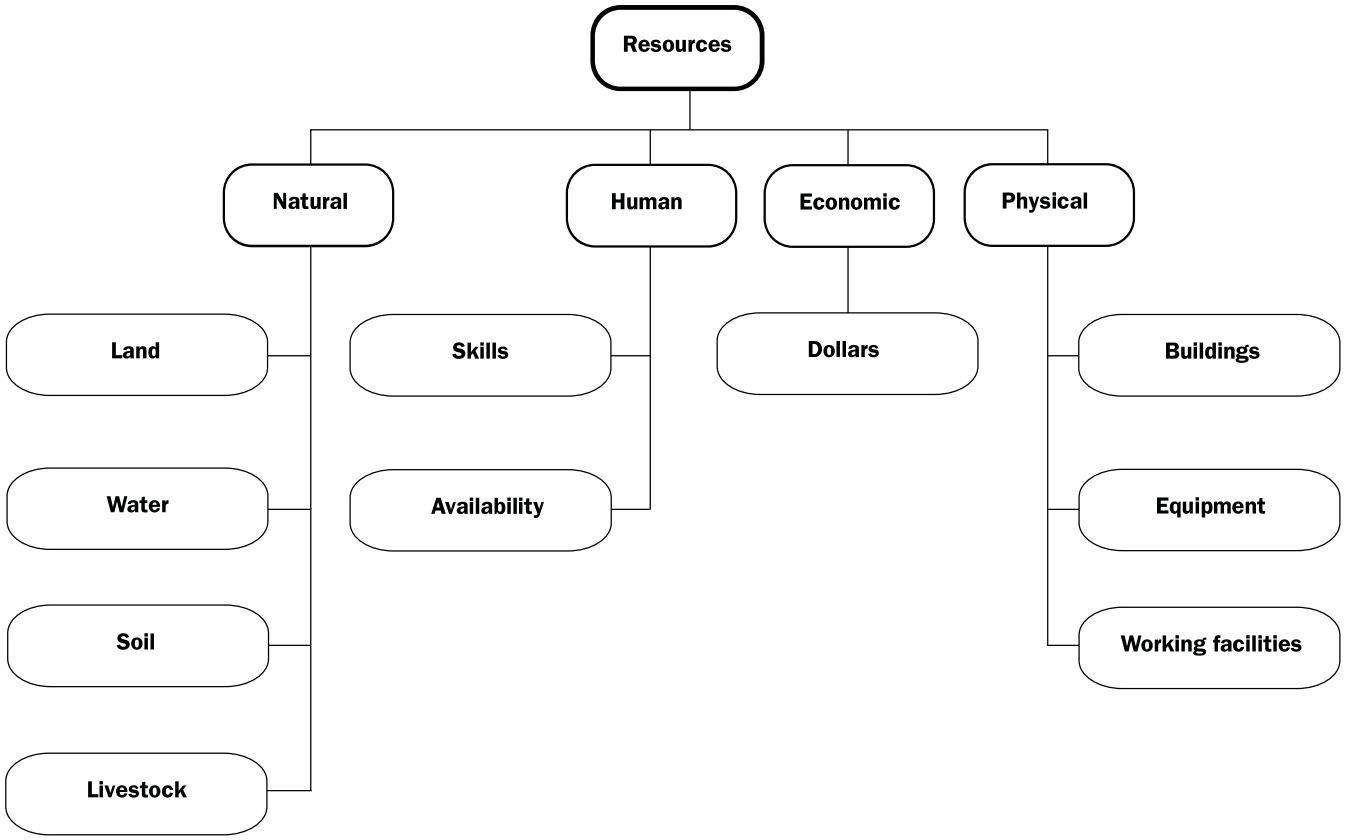

Figure 1.2. Components of a resource inventory.

amount of hay produced or purchased is also important. If forage analysis has been completed (see chapter 16), include that information as well.

Water is a necessary resource. It is important to know how many shares of water are available and when they are available. Turn-on and turn-off dates can affect your plan. Record the irrigation method for each piece of land. Note the efficiency of each method. Include information on dry and naturally wet areas.

Soil is the base of a pasture (see chapter 3). You can obtain a soil survey map of your property at http://soils.usda.gov/survey/ or from your local USDA-NRCS office. The map will include a written description of the soil type and its limiting factors.

If you have soil test results, include them in your inventory. If you have not obtained a soil analysis for several years, plan to test a few pastures each year until all of them have been tested.

Fertilizer records should also be part of the inventory. Record the amount and type of fertilizer applied to each field. See chapter 3 for more information on pasture fertility and nutrient management.

The species, production level, and age of livestock will have a major effect on the number of potential grazing days. The species will determine the amount of forage, type of forage, and type of fencing and water system needed. Pregnant and nursing females have higher nutritional requirements than castrated males. Young weaned animals need a higher level of nutrition than mature dry females. See chapter 10 for more information.

Human resources

People are your most important resource. They can be either an asset or a liability in your quest to achieve your goals.

As a manager, you need to identify the skills and knowledge needed for your operation. Then determine when specific skills and knowledge are needed. For example, you may need someone who knows how to change hand lines from May 1 to September 30. You may need someone to pay bills and balance the books 2 days each month.

The next step is to determine whether anyone involved in the operation has the knowledge, skills, and desire to do the needed tasks. If not, you'll need to decide whether to train someone, hire someone new, or utilize a consultant or contract service.

Economic resources

An economic inventory is an inventory of the dollars available to the operation. It should include a cash flow statement and lists of assets, potential income, and expenses. See chapter 17 for more information.

Physical resources

An inventory of physical resources includes a list of buildings, working facilities, and equipment. This inventory usually remains fairly constant.

List all of the buildings, including their primary use, square footage, repairs needed, potential improvements, and location. Many insurance policies contain this information. Working facility inventories should include feed yards (including bunk space), stock yards (type and location of each), chutes, and information on needed maintenance.

The equipment inventory should include the type of equipment and year of purchase. Include operating cost, as well as a planned maintenance schedule, for each piece of equipment.

ANALYSIS

With your resource inventory in hand, now look at how you are currently using your resources.

The following are some possible questions:

- How many grazing days am I currently getting?
- Are any areas overutilized or underutilized?
- Are my livestock reaching their genetic potential for weight gain?

Answering these questions with data from your ranch will allow you to establish a baseline for your operation.

PLANNING

After establishing a baseline of your current situation, you can begin planning to improve your resource use and increase your operation's success. In the planning stage, you will first set priorities and goals. An example of a goal might be to "provide enough forage of adequate quality for 300 cow-calf pairs from April 20 to December 30." Then you can develop a detailed plan with specific steps to ensure that your goals are met.

Goals need to be SMART. SMART goals are "Specific, Measurable, Achievable, Realistic, and Timely."

Goals also need to be flexible. It has been said that "failure to make adjustments is to go the way of the

buggy-whip manufacturers who failed to notice Henry Ford." Few things are constant, so we must be willing to change our goals to adapt to new situations.

Goals should not conflict with one other. Saying yes to one item means saying no to something else. For example, setting a goal to increase grazing days by grazing fields you hayed in the past would conflict with a goal of increased hay production.

Goals must be realistic and manageable. If they are not, we tend to become frustrated and stop working toward them.

As you determine your goals, write them down. Determine where you are right now in relation to each goal. List all potential obstacles to reaching the goal as well as possible solutions to these obstacles.

Next, write down the steps necessary to reach each goal. Set a timetable for taking these steps. Finally, determine the cost of achieving each goal. Assigning a cost to each goal gives you direction, focus, and a standard of measurement.

After you have completed this process, you will be able to write out your goals in a structured way. This helps make your goals official and will help you stay on track as you implement your plan. There are four parts to a written goal: action, result, timetable, and cost (table 1.1).

- Action is the change you would like to see.
- Results are what you are going to achieve.
- A timetable tells how long it will take to accomplish the goal.
- Costs tell how much it will cost to accomplish the goal.

In summary, remember the following when setting goals:

- Choose the right goals. Make sure they are SMART goals.
- Make your goals official by writing them down and sharing them with family and employees.
- Create a plan to achieve your goals.
- Stick to the plan.
- Stay flexible.

Table 1.1. Example goals with action, result, timetable, and cost.

Action	Result	Timetable	Cost
Want to increase	Carrying capacity by 30 head	2010	$10,000
Want to gain	25 grazing days	By 2011	$2,000

IMPLEMENTATION

In the implementation phase, you will apply these processes or steps. Plans often change during implementation. What looks good on paper does not always implement well. It is important to continually inventory and analyze your resources to see whether the plan is working.

For more information

USDA Natural Resources Conservation Service soil surveys. http://soils.usda.gov/survey/

CHAPTER 2

Species Selection and Grazing Management Guidelines

D. Ogle, L. St. John, and K. Jensen

PASTURES COMMONLY ARE CULTIVATED FIELDS planted to introduced grasses and legumes. The objectives or goals of pasture plantings may include:

- Livestock grazing or hay
- Forage to improve animal nutrition
- Forage to improve animal health
- A more balanced forage supply
- Forage for low-production periods
- Forage for winter use
- Forage for earlier or later season of use
- Food/habitat for wildlife
- Reduced soil erosion and sedimentation
- Improved soil quality
- Improved water quality

All of these goals are achievable when the pasture plant community is healthy. Healthy pasture plants capture energy from the sun and facilitate water and nutrient cycling.

This chapter discusses factors that will help you choose appropriate grass and legume species for your pasture. It includes descriptions of common pasture species, including areas of adaptation, growth characteristics, use, and grazing management recommendations.

Key Points

- Select pasture forage species that are adapted to your site conditions, livestock needs, and management style.
- Manage grazing to maintain pasture and livestock health based on the optimum season of use and appropriate grazing/stubble heights for your forage species.

Species selection

Select plant species on the basis of site conditions and what the species can contribute to your objectives. Keep in mind the following:

- Recognize that each site is unique and that conditions change with the seasons and over time.
- Select species that will accommodate your grazing goals and type(s) of grazing animals.
- Plant forages that will best match your management style.
- Choose species with regrowth characteristics that will meet your objectives.
- After selecting species, choose varieties that will provide good yield, quality, and disease resistance.
- Be sure that the planned seeding is within your economic capabilities and that you can complete the planting with available manpower and equipment.

Remember, species that are not adapted to the site or to its intended use will fail even if all other requirements are met.

We recommend that you review your local soil survey, which describes your farm's soils and their characteristics. Soil surveys are prepared by the USDA Natural Resources Conservation Service. Most are available online (http://soils.usda.gov/survey/), although some are available only in hard copy from local USDA-NRCS offices.

Soil surveys include maps, photos, descriptions, and tables. The tables contain detailed information about soil uses such as crops, pasture, rangeland, recreation, and engineering. They also include information about depth to rock or restrictive layers, soil texture, permeability, water-holding capacity, soil chemical characteristics, soil salinity, soil reaction (pH), and erosion. Climate information includes the average frost-free period and annual precipitation.

Use these site characteristics to help select adapted grasses and legumes. Before choosing a species or mixture of species, consult the species descriptions in this or other pasture guides. See table 2.1 for more information.

DRYLAND PASTURE

Generally, only perennial species should be planted on non-irrigated sites. Perennial plants provide a dependable source of nutritious forage and do not require annual seedbed preparation and seeding.

The risk of seedling failure increases as annual precipitation declines. For example, an area that receives 16 inches of annual rainfall has a greater chance of seedling establishment than an area that receives less than 12 inches of annual precipitation.

Consider adding adapted forbs and legumes to the planting. They add diversity, increase forage yield, and contribute to improved soil and forage quality. Legumes also fix nitrogen (N).

Some legumes, such as alfalfa and clovers, may cause grazing animals to bloat (see chapter 12). Others, such as sainfoin, birdsfoot trefoil, and cicer milkvetch, do not cause bloat. Small burnet is a non-bloat, non-leguminous forb.

Siberian wheatgrass, crested wheatgrass, Russian wildrye, forage kochia, and sweetclover are best adapted to areas receiving less than 12 inches of annual precipitation. These species are more widely used for grazing rather than haying. Altai wildrye, intermediate and pubescent wheatgrass, and alfalfa perform best in areas receiving 12 inches or more annual precipitation, where they produce more than crested wheatgrass.

In regions exceeding 15 to 18 inches of annual precipitation, meadow brome, smooth brome, tall fescue, orchardgrass, small burnet, alfalfa, sainfoin, cicer milkvetch, and birdsfoot trefoil provide increased forage production and quality. On wet soils, consider creeping foxtail, timothy, tall fescue, cicer milkvetch, birdsfoot trefoil, and clover species.

On wet, saline sites where the water table is within 3 feet of the soil surface, consider tall wheatgrass, 'NewHy' hybrid wheatgrass, Altai wildrye, tall fescue, western wheatgrass, or strawberry clover. On dry, saline sites with less than 16 inches of annual precipitation, consider Russian wildrye, tall wheatgrass, or western wheatgrass. On both wet saline and dry saline sites, consider including slender wheatgrass in the seed mixture as a cover crop species at no more than 1 pound per acre. Slender wheatgrass is saline-tolerant and easy to establish, but will not persist in the stand for more than 2 or 3 years.

Table 2.1. Growth stage for grazing or harvesting forage, stubble height, optimum season of use, and regrowth ability.

	Minimum plant height before and after haying or grazing (inch)			
	Before	**Stubble**	**Optimum season of use[a]**	**Regrowth ability**
GRASSES				
Brome				
Meadow	8	4	Sp/Su/F	Good
Smooth	8	4	Sp/Su/W	Poor
Cereals, grains	8	4	F/W/Sp	Good
Creeping foxtail	6	4	Sp/Su/F	Excellent
Festulolium	8 to 10	3	Sp/F	Good
Kentucky bluegrass	5	2	Sp/F	Excellent
Orchardgrass	8	4	Sp/Su/F	Good
Perennial ryegrass	8 to 10	3	Sp/Su	Good
Reed canarygrass	8	4	Sp/Su	Excellent
Tall fescue	6	4	Sp/F/W	Good
Timothy	6	4	Sp/Su	Fair
Wheatgrass				
Crested	6	3	Sp/F	Poor
Intermediate	8	4	Sp/Su/F	Good
Pubescent	8	4	Sp/Su/F	Good
Siberian	6	3	Sp/F	Poor
Tall	10	6	Su	Fair
Western	4	3	Sp/F/W	Fair
Wildrye				
Altai	8	6	Sp/Su/F/W	Good
Basin	10 to 12	10	F/W	Poor
Russian	8	3	Su/F/W	Good
LEGUMES AND OTHER FORBS				
Alfalfa	6	3	Su/F	Excellent
Birdsfoot trefoil	6	3	Su	Excellent
Cicer milkvetch	4	3	Su/F	Excellent
Clover				
Alsike	6	3	Sp	Excellent
Red	6	3	Sp	Excellent
White (Ladino)	6	3	Sp	Excellent
Sainfoin	12	6	Sp/Su	Good
Small burnet	12	6	Su/F/W	Good
Sweetclover	8	6	Su	Excellent

[a] Sp = spring; Su = summer; F = fall; W = winter

PRECIPITATION OVER 18 INCHES AND IRRIGATED PASTURE

The easiest type of pasture to manage consists of a single grass with or without a legume. A single species is easier to seed and establish and more uniformly palatable than multiple-species seedings. It also requires a lower level of management. This type of planting is often suitable for a specific class of animal on a site with uniform soil, landscape, and moisture conditions. It has the advantage of allowing you to match your soil, climate, and grazing resources to your management, resources, and goals.

In this scenario, you likely know the type of grazing animal. Understanding soil and climatic limitations can be more difficult, but is essential to long-term success. After identifying all of your resources and environmental conditions, you can choose a forage species and seed at the appropriate depth, time, and rate. Daily and seasonal management decisions (such as Management-intensive Grazing) then become keys to long-term success.

For irrigated seedings, simple mixes including a grass (such as orchardgrass or meadow brome) and a legume (such as alfalfa, sainfoin, or cicer milkvetch) are recommended. Simple grass-legume mixes require less total seed than a complex mixture. They produce as much forage as complex mixtures and are easier to manage and graze uniformly.

A simple grass-legume mix is also easier to establish in alternate rows, which is recommended when possible (figure 2.1). Seeding the grass and legume in alternating rows allows both species to establish in their own rows with minimal competition between the grass and legume. Partitioning a drill box into alternating rows of grass and legume seed is one way to accomplish alternate-row seeding. Another method is to use a grass or grain box for the grass and an alfalfa or fluffy box for the legume. Route the seed flow accordingly in an alternate-row fashion.

On irrigated sites, annual species, such as cereal grains and ryegrass, may be a viable alternative, depending on your objectives and forage needs. They require preparing a new seedbed and planting each year, however.

In mountainous or rolling areas, or in fields with multiple soil types or moisture conditions, mixes of multiple grasses or grass-legume-forb mixes may be desirable. On these sites, pastures with multiple plant species often perform better than a monoculture. Under these conditions, plant diversity confers several advantages:

Figure 2.1. Alternate-row planting of Russian wildrye and alfalfa. (Photo by Larry Holzworth, USDA Natural Resources Conservation Service, Montana)

- Legumes increase forage quality and add valuable N to the soil. (They may, however, limit weed-control options.)
- Diversity increases resistance to pests.
- A mixed seeding can ensure that one or more of the species will establish and survive under various environmental conditions.

Complex mixtures may include grasses such as intermediate wheatgrass, meadow brome, and orchardgrass. In many situations, the addition of a forb such as small burnet will add diversity to the planting. Legumes that fix N, both bloat-type species (for example, alfalfa and clovers) and non-bloat species (for example, sainfoin, birdsfoot trefoil, and cicer milkvetch) increase soil N and forage quality.

As the number of species in a mixture increases, pasture management must become more complex in order to maintain the composition and health of the stand. With mixtures of two or more species, relative palatability is of major importance. If species differ in palatability, the more palatable species will decline due to excessive grazing. The result may be a single-species stand invaded by aggressive annual and perennial weeds. For example, tall fescue is high-yielding and very competitive, but it is less palatable than many other irrigated forage species. In a mixed seeding, it will dominate the stand after several years.

Management-intensive Grazing can overcome the tendency of animals to overgraze the more palatable species. Ultimately, a pasture diverse in species composition is desirable, but in the long term species composition depends more on grazing management than on what is seeded.

See chapter 4 for more information on seeding methods, rates, and mixtures.

See chapters 13–15 for grazing management recommendations.

If you plan to cut forage for hay or use a less intensive grazing system, it is better to plant a simple mixture of one grass species and a single legume. If you do plant more than one grass species, select species similar in palatability.

Pasture species—grasses

BLUEGRASS, KENTUCKY (*POA PRATENSIS*)

Kentucky bluegrass is a long-lived, introduced, shallow-rooted, sod-forming perennial grass.

Adaptation and use—Even with 18 inches of annual precipitation, Kentucky bluegrass does not provide much forage. Irrigation or additional rainfall is required for good forage production. In the Intermountain West, Kentucky bluegrass is not recommended for pasture planting, except for use as high-quality horse pasture. However, under irrigated conditions it commonly comes in on its own if the pasture is overgrazed.

Existing Kentucky bluegrass pastures can provide highly palatable forage and fair to good yield if managed through irrigation, a good fertility program, and periodic ripping or chiseling of the root zone. Kentucky bluegrass generally is not harvested for hay because of its short stature and very fine stems and leaves, which can be difficult to cure properly for hay.

Grazing management—Grazing can begin in spring when grass is 5 inches tall. Remove livestock when stubble height is approximately 2 inches. Regrowth ability is excellent. Livestock can be rotated back onto Kentucky bluegrass pastures when regrowth is approximately 6 inches tall.

BROME, MEADOW (*BROMUS BIEBERSTEINI* [SYN. *B. RIPARIUS*])

Meadow brome is a long-lived, introduced, deep-rooted perennial grass with short (4- to 6-inch) rhizomes.

Adaptation and use—Meadow brome is an excellent choice in areas that are prone to frost in early to late spring. It is one of the earliest sources of spring forage available. This species is palatable to all classes of livestock and wildlife. It is productive and compatible in mixtures with legumes such as alfalfa, sainfoin, cicer milkvetch, and birdsfoot trefoil.

Growth begins in early spring, and productivity is very high during the cool season. This species is also capable of strong summer growth when fully irrigated. Meadow brome initiates regrowth more quickly than smooth brome, even during high summer temperatures.

Grazing management—Meadow brome reaches full productivity in 2 to 3 years. Because it establishes roots slowly, livestock can easily uproot young plants. New plantings should not be grazed until late summer or early fall under irrigated conditions. Under dryland conditions, do not graze until the second year. Harvesting for hay during the establishment period is recommended.

On established stands, begin spring grazing when the forage is 8 inches tall. Remove livestock when stubble is 4 inches tall. Meadow brome recovers quickly from grazing if soil moisture is available, as it initiates regrowth from existing tillers and not from the crown. A 21- to 28-day recovery period is recommended.

Four to 6 inches of fall regrowth will build food reserves to provide for early growth the following spring.

BROME, SMOOTH (*BROMUS INERMIS*)

Smooth brome is a long-lived, introduced, aggressive, sod-forming grass.

Adaptation and use—Smooth brome is best adapted to moist, well-drained soils where annual precipitation is at least 14 inches or the pasture is irrigated. It is very shade-tolerant.

Seedlings are often weak, but established plants spread via rhizomes to provide full stands. Smooth brome is a very aggressive grass that generally does not allow invasion by other species. It often invades adjacent pastures and areas along ditches, canals, drains, and streams. It can be a serious weed in these areas.

Smooth brome is high in crude protein, low in crude fiber, and highly palatable. It is compatible in mixtures with legume species such as alfalfa, sainfoin, cicer milkvetch, and birdsfoot trefoil.

Vegetative growth begins in early spring, and most growth occurs during the cool spring period. Smooth brome is slow to regrow, even under fully irrigated conditions, because new tillers must develop before initiating above-ground growth.

Grazing management—New stands do not tolerate heavy grazing and may die out if utilized heavily when young.

Stockpiling for fall, winter, and early spring grazing should begin between the first of June and the beginning of July. Grazing should not occur until smooth brome has reached 8 inches tall. Remove livestock when stubble is 4 inches tall. Regrowth is initiated from the crown and rhizomes, and recovery is slow. A rest period of 35 to 42 days is recommended between grazing periods.

CANARYGRASS, REED (*PHALARIS ARUNDINECEA*)

Reed canarygrass is a long-lived, introduced, widely adapted, coarse, vigorous, productive, sod-forming grass.

Adaptation and use—Reed canarygrass is frost-tolerant and suited to wet soils with a pH of 4.9 to 8.2. Initial stands are often poor because of poor germination and weak seedlings. Once established, reed canarygrass can withstand continuous water inundation for 70 days in cool weather. Reed canarygrass invades wet areas along ditches, canals, drains, and streams and is a serious weed in these areas.

This species produces high forage yields on moist, fertile soils that are high in N and organic matter. When fertility is limiting, it becomes sod-bound. Mature stands are unpalatable, requiring careful grazing and haying management for quality forage production. Reed canarygrass contains alkaloids that repel herbivores. The lack of palatability and poor animal performance often seen with this species may result from the presence of these alkaloids. Newer varieties contain lower levels of alkaloids.

Grazing management—In spring, early and frequent grazing (with rotations as often as 2 weeks) helps prevent or reduce stem and panicle production. Grazing should occur when reed canarygrass has reached 8 inches tall. Remove livestock when stubble is 4 inches tall. The recommended rest period is approximately 14 to 21 days. Forage quality can be maintained by not allowing growth over 12 inches tall.

FESCUE, TALL (*SCHEDONORUS PHOENIX* [SYN. *FESTUCA ARUNDINACEA*])

Tall fescue is a long-lived, introduced, deep-rooted, high-yielding, cool-season bunchgrass.

Adaptation and use—Tall fescue is suited to irrigation, sub-irrigation, moderately wet conditions, and dryland areas where effective annual precipitation exceeds 18 inches. It performs very well in acidic soils, as well as in soils that are moist, saline, and alkaline (pH 4.7 to 9.5). It is not well adapted to sandy soils with prolonged droughty periods.

The leaves' thick cuticle helps tall fescue stay green into early winter. Thus, it can be stockpiled for winter use.

Tall fescue is recommended as a monoculture seeding or as part of an alternate-row planting. It is very competitive and tends to out-compete other species in a mixture. It has lower palatability than most pasture grasses, so other species often are overgrazed and eventually eliminated from the pasture.

Avoid turf-type tall fescues for grazing use. Fungal endophyte problems can develop in livestock grazing on tall fescue when the endophyte is in the seed, the only time the plant can become infected. Infected tall fescue plants produce alkaloids that cause fescue foot, bovine fat disorder, and fescue toxicosis disorders (see chapter 12). Toxin concentration is greatest in the inflorescence, moderate in stems and leaf sheaths, and lowest in leaf blades. You can reduce or eliminate this problem by using endophyte-free seed or new varieties with endophytes that don't produce toxins.

Grazing management—Growth begins in early spring, and grazing should begin after plants are at least 6 inches tall. Maintain stubble height at 4 inches. Regrowth is good in cool spring and fall weather, but only fair during summer heat. The recommended rest period between grazing cycles is approximately 21 to 28 days. Frequent spring grazing cycles when plants are in the vegetative stage will help reduce alkaloid concentrations in animal diets if the endophyte is present.

FESTULOLIUM (*FESTULOLIUM BRAUNII*)

Festuloliums are derived from a cross between either an Italian or perennial ryegrass and meadow fescue. Meadow fescue traits provide persistence, ease of establishment and management, and good disease resistance. The high palatability and forage qualities of ryegrass are combined with seasonal productivity of meadow fescue. Although first developed in the 1950s, most festuloliums are relatively new varieties, and little forage research data or experience is available.

Adaptation and use—Festuloliums are suited to fertile soils with irrigation, including sub-irrigation, and to humid areas where effective annual precipitation exceeds 18 inches. Persistence may be short term.

Grazing management—Growth begins in early spring, and grazing should begin after plants are 8 to 10 inches tall. Maintain stubble height at 3 to 4 inches.

Regrowth is good in cool spring and fall weather and better than that of perennial ryegrass during summer heat. The recommended rest period between grazing cycles is approximately 21 to 28 days.

FOXTAIL, CREEPING (*ALOPECURUS ARUNDINACEUS*)

Creeping foxtail is a long-lived, introduced, cool-season, deep-rooted, dense, sod-forming grass. Creeping foxtail is similar in appearance to timothy, but seed heads generally are black and hairy.

Adaptation and use—Creeping foxtail is very well adapted to wet, acidic, poorly drained sites. It has slight to moderate saline/alkaline tolerance, but produces abundant excellent-quality forage on wet, fertile sites. It is suited to irrigation, sub-irrigation, moderately wet to very wet conditions, and to dryland areas where effective annual precipitation exceeds 18 inches. On wet sites, it is usually superior to other adapted grasses such as reed canarygrass and timothy. It is very cold-tolerant and can persist in areas where the frost-free period averages less than 30 days.

Creeping foxtail invades wet areas along ditches, canals, drains, and streams and can be a serious weed in these areas.

Creeping foxtail is productive and compatible in mixtures with legume species such as cicer milkvetch and birdsfoot trefoil.

Seed is very light and difficult to drill without the use of cracked corn, rice hulls, or other carriers. Creeping foxtail has low seedling vigor, but once established it spreads readily by rhizomes.

Productivity is very high during the cool season. This species is also capable of strong summer growth when fully irrigated, and leaves remain green until after hard frosts in the fall.

Grazing management—Growth begins early in the spring. Spring grazing should begin after the forage is 6 inches tall. Remove livestock when stubble is 4 inches tall. Creeping foxtail recovers quickly from grazing if soil moisture is available, and regrowth ability is excellent. A 21- to 28-day recovery period is recommended.

ORCHARDGRASS (*DACTYLIS GLOMERATA*)

Orchardgrass is a long-lived, deep-rooted, high-yielding, introduced bunchgrass.

Adaptation and use—Orchardgrass does best on soils with few limitations and good drainage. Avoid shallow and sandy soils. At 18 inches of annual precipitation, orchardgrass does not provide much forage. Irrigation or additional rainfall is required for good forage production. Orchardgrass is shade-tolerant. It is more vulnerable to diseases than many pasture grasses.

Orchardgrass is less winter-hardy than meadow brome, smooth brome, timothy, or creeping foxtail. It is not well adapted to areas with cold, dry winters. Production is also lower in areas that commonly experience mid- to late-spring frost. Other species may be a better selection under these conditions.

Orchardgrass is highly palatable to livestock and wildlife, especially in the early part of the growing season. It is widely preferred by all classes of livestock and wildlife. It is used for hay, pasture, or silage. It is compatible in alfalfa, sainfoin, and clover mixes. It is also used in erosion-control mixes, primarily for its forage value.

Varieties are early-, mid-, and late-season in maturity. Late-season varieties are preferred in mixtures with alfalfa.

Grazing management—Do not graze new plantings until late summer or fall of the first growing season. Harvesting for hay during the establishment period is recommended.

On established pastures, orchardgrass initiates growth early in the spring, with long, folded leaves arising mostly from the plant base. For optimum forage quality and regrowth, harvest orchardgrass while still in the boot stage. Grazing should begin when growth reaches approximately 8 inches. Remove livestock when plants have at least 4 inches of stubble height remaining. Regrowth is good when plants are properly grazed. A 28- to 35-day recovery period is recommended. Orchardgrass does not tolerate close or continuous grazing, because energy is stored mainly in the lower stems and leaf parts. Close grazing in the fall is associated with winter kill. Winter grazing should be limited to 60 percent of annual growth.

RYEGRASS, PERENNIAL (*LOLIUM PERENNE*)

Perennial ryegrass is an introduced, short-lived, rapidly establishing, vigorous bunchgrass.

Adaptation and use—Perennial ryegrass is adapted to a wide variety of soil conditions. For high yields, it requires as much as 30 to 50 inches of precipitation or irrigation and large nutrient inputs. This species does best where winters are mild. Perennial ryegrass prefers acidic to mildly basic soils (pH of 5.0 to 8.0).

Perennial ryegrass is moderately productive and produces high-quality forage. Because it is strongly preferred by grazing animals, it is not recommended in mixtures with other grasses. It also may retard the establishment of other perennials if seeded too heavily in a mixture.

In cooler regions of the Intermountain West, treat this species as an annual. It will provide good forage for grazing within 60 to 90 days following planting, but probably will not maintain a full stand the following year.

Perennial ryegrass often contains a fungal endophyte that is linked to the occurrence of ryegrass staggers (see chapter 12). There have been reports of ryegrass staggers in Oregon and California. You can reduce or eliminate this problem by using endophyte-free seed, although production may be lower.

Because of the need for high fertilizer application rates, split applications are recommended.

Grazing management—Grazing can begin when vegetation is 8 to 10 inches tall. Leave a 3-inch stubble height. Perennial ryegrass has good recovery after grazing. A 21- to 28-day recovery period between grazing cycles is recommended. Perennial ryegrass tends to go dormant when summer temperatures exceed 80°F.

TIMOTHY (*PHLEUM PRATENSIS*)

Timothy is a short-lived, shallow-rooted, introduced, perennial bunchgrass.

Adaptation and use—Timothy is adapted to cool, humid areas and to high elevations. It is adapted to irrigated areas and areas with effective annual precipitation of at least 18 inches. It produces moderate to high yields on wet, fertile soils. It is compatible in mixes with legumes.

Timothy establishes quickly and volunteers readily on preferred sites. It invades wet areas along ditches, canals, drains, and streams and can be a serious weed in these areas.

Timothy is preferred by cattle and horses, and timothy hay is a premium feed for horses. This species is very palatable in late spring and early summer, but only moderately palatable in late summer and fall (after seedhead development). It is late-maturing.

Timothy can also be used for ground cover and erosion control on cut or burned-over forest land.

Grazing management—In spring, the crowns form swollen, bulb-like internodes that store energy. Close grazing and trampling during moist conditions can damage these internodes and severely reduce stands.

Begin grazing during the vegetative stage, after grass has reached at least 6 inches in height. A 4-inch stubble height should remain following grazing. Timothy should be hayed before seedheads have emerged from the boot. It regrows slowly following grazing or haying. A 28- to 35-day recovery period between grazing cycles is recommended.

WHEATGRASS, CRESTED

Crested wheatgrass growth begins early in the spring. Following heading, protein levels drop rapidly, and forage becomes coarse and less desirable. Growth may begin again in fall if moisture is available.

Standard-type crested wheatgrass (*Agropyron desertorum*) is adapted to a wide range of sites and to precipitation zones as low as 9 to 10 inches. This species is more drought-tolerant than Fairway-type crested wheatgrass. Above 6,500 feet elevation, expect lower plant vigor and reduced stands.

Fairway-type crested wheatgrass (*Agropyron cristatum*) is similar to standard crested wheatgrass but shorter statured and earlier maturing. It also has finer stems and leaves. It establishes on similar sites (10 to 18 inches annual precipitation), but is better adapted to higher elevations. It does not survive as well as standard crested wheatgrass under prolonged drought conditions.

Hybrid crested wheatgrass (*Agropyron cristatum* x *A. desertorum*) is a hybrid cross between standard-type and induced tetraploid Fairway-type crested wheatgrass. Seedlings are very vigorous during germination and early establishment. It is adapted to a wide range of sites and to annual precipitation zones as low as 9 to 10 inches. This species is more drought-tolerant than Fairway-type crested wheatgrasses.

Grazing management—Begin grazing after plants have reached the 6-inch growth stage. To maintain long-term plant health, leave 3 inches of stubble at the end of the grazing period or going into winter. In spring, a 28- to 35-day recovery period between grazing periods is recommended. Crested wheatgrass has poor regrowth ability in early to late summer, primarily because it goes dormant following heading and in hot weather.

Fall grazing is possible in some years following fall rains. Late-fall and winter grazing requires protein supplements. To avoid grass tetany, ensure that adequate stubble remains following fall grazing or supplement livestock with magnesium and calcium during spring grazing. Grazing stubble with spring green-up reduces the risk of tetany.

WHEATGRASS, INTERMEDIATE AND PUBESCENT (*THINOPYRUM INTERMEDIUM*)

Intermediate wheatgrass is a mildly rhizomatous, sod-forming, late-maturing, long-lived, introduced grass. Pubescent and intermediate wheatgrass are very similar, but pubescent wheatgrass has pubescence (fine hairs) on the leaves and seedheads.

Adaptation and use—Intermediate and pubescent wheatgrass are recommended for upland, medium- to fine-textured soils. Intermediate wheatgrass is best adapted to areas with 13 to 18 inches of annual rainfall, while pubescent wheatgrass is suitable for areas with 11 to 18 inches of annual rainfall. Both are somewhat saline-tolerant (electrical conductivity of 6 to 12 mmhos/cm). Neither is shade-tolerant.

This species is excellent for situations where only one to three irrigation applications are possible. It readily responds to irrigation and fertilization with increased forage production, but can withstand extended drought periods without irrigation.

Intermediate and pubescent wheatgrass are suited for use as hay and pasture, alone or with alfalfa or other legumes. Both are useful for soil stabilization and erosion control on disturbed sites.

This species begins growth early in the spring and remains green and palatable into the summer, producing large amounts of nutritious forage. Forage quality and growth are reduced during mid- to late summer.

Grazing management—On established stands, begin spring grazing after grass has reached a height of 8 inches. Regrowth following grazing is good if soil moisture is available. Nitrogen application significantly increases forage production and regrowth following clipping or grazing under irrigated conditions. On irrigated pasture with high moisture conditions, allow a 21- to 28-day recovery period in the spring. A longer recovery period may be needed in late spring, early summer, and fall. Leave a 4-inch stubble height after each grazing period and going into winter. Heavier grazing will result in reduction and eventual loss of the stand.

WHEATGRASS, SIBERIAN (*AGROPYRON FRAGILE*)

Siberian wheatgrass is a long-lived, drought-tolerant, vigorous, winter-hardy, introduced bunchgrass.

Adaptation and use—Siberian wheatgrass is well adapted to medium loam to light, sandy, droughty soils.

Siberian wheatgrass has finer leaves than crested wheatgrass and retains its greenness and palatability later into the summer. It yields less than crested wheatgrass during normal rainfall years, but generally produces higher yields than crested wheatgrass during periods of extended drought. It is adapted to sites with as little as 7 to 16 inches of annual precipitation.

Siberian wheatgrass is palatable to all classes of livestock. It is a preferred feed in spring and again in fall if soil moisture is available and regrowth occurs. Following heading, protein levels drop rapidly. Forage becomes coarse and less desirable in early to mid-summer. Late-fall and winter grazing requires protein supplements.

Grazing management—Growth begins early in the spring. Begin grazing after plants have reached the 6-inch growth stage. To maintain long-term plant health, leave 3 inches of stubble at the end of the grazing period. In spring, a 28- to 35-day recovery period between grazing cycles is recommended. Siberian wheatgrass has poor regrowth ability in summer, primarily because it goes dormant following heading during the heat of the summer.

Growth resumes with fall moisture, and fall grazing is possible in years when sufficient regrowth occurs.

To avoid grass tetany, ensure that adequate stubble remains following fall grazing or supplement livestock with magnesium and calcium during spring grazing. Grazing stubble with spring green-up reduces the risk of tetany.

WHEATGRASS, TALL (*THINOPYRUM PONTICUM*)

Tall wheatgrass is a long-lived, tall, coarse, vigorous, late-maturing, winter-hardy, introduced bunchgrass.

Adaptation and use—Tall wheatgrass is adapted to a wide range of soils and climates. It is recommended for 14-inch or higher annual rainfall zones or sites with high water tables. Once established, tall wheatgrass tolerates saline, alkali, and high water table conditions better than most grasses. It is adapted to saline areas such as

greasewood and saltgrass sites where the water table is from a few inches to several feet below the surface.

Tall wheatgrass is useful for erosion control and as a wind barrier to control soil erosion and drifting snow. It provides nesting cover and food for upland game birds.

This species is the latest maturing of the wheatgrasses. Palatability is acceptable early in the growing season, but mature plants become very unpalatable. Late-standing material becomes good winter forage for livestock when used with supplemental protein sources.

Grazing management—Grazing should not begin until grass is at least 10 inches tall. Stubble height should never be less than 6 inches between grazing periods and at the end of the grazing season. Regrowth is slow, and rest periods should be at least 35 days.

Tall wheatgrass does not stand continuous close grazing. Mowing at an 8- to 10-inch stubble height can set grazing height; the stubble will prevent closer grazing.

WHEATGRASS, WESTERN (*PASCOPYRUM SMITHII*)

Western wheatgrass is a long-lived, late-maturing, widely distributed, winter-hardy, strongly rhizomatous, native grass with coarse, blue-green leaves.

Adaptation and use—Western wheatgrass is adapted to lowlands prone to early-season flooding. It is particularly productive in clayey to silty swales and waterways and has moderate to high salt tolerance. It is best adapted to 12- to 14-inch and higher rainfall zones in the Intermountain West. It is a productive native hay producer during above-normal precipitation years and under irrigation.

When used as pasture, this species is an excellent source of spring and early-summer forage, with crude protein content of 16 to 18 percent. However, forage quality declines rapidly as plants mature. Western wheatgrass provides good winter grazing if protein supplements are provided. Protein content of cured western wheatgrass is usually a little higher (4 to 5 percent) than that of other wheatgrasses.

Western wheatgrass is typified by poor germination and low seedling vigor. Plantings usually result in scattered stands that spread in 3 to 5 years to dominate the site.

Once established, western wheatgrass becomes very persistent and provides excellent soil-binding and erosion-control characteristics.

Grazing management—Western wheatgrass begins growth later than most wheatgrasses. Grazing should not begin until grass is at least 4 inches tall. Stubble height should not be less than 3 inches between grazing periods and at the end of the grazing season. Regrowth is slow, and rest periods should be at least 35 days.

WILDRYE, ALTAI (*LEYMUS ANGUSTUS*)

Altai wildrye is a long-lived, deep-rooted, winter-hardy, drought-resistant, cool-season, introduced grass with short rhizomes.

Adaptation and use—Altai wildrye is adapted to moderately deep to deep loam to clay loam soils with 14 inches or more of annual rainfall. Roots can grow and use moisture to a depth of 15 feet. This species can withstand saline conditions almost as well as tall wheatgrass and is almost as productive on saline sites.

Seedlings develop slowly, and good seedbed preparation and weed control are essential.

Altai wildrye begins growth in midspring and grows into late fall. Basal leaves are somewhat coarse, but are very palatable during late summer and early fall. Altai wildrye provides excellent winter forage. Coarse, erect, stiff stems reach 2 to 4 feet in height and tolerate snow loads. Protein levels of 8 percent are common in standing winter feed. This species can also be swathed into windrows, cured and utilized as winter feed (see chapter 14).

Grazing management—Grazing can begin when grass is 8 inches tall. Remove livestock when stubble is 6 inches. This species has fair to good regrowth characteristics if soil moisture is available. Grazing cycles with approximately 35 days or more rest are recommended.

WILDRYE, BASIN (*LEYMUS CINEREUS*)

Basin wildrye is a slightly spreading, robust, tall, coarse, long-lived, native bunchgrass.

Adaptation and use—Basin wildrye is especially suited to deep, fine-textured clayey to loamy soils that receive 10 to 16 inches of annual precipitation. It is well adapted to moderately saline or alkaline lowlands, floodplains, and areas with high water-holding capacity.

Basin wildrye is useful for calving pasture and for wildlife forage and cover. Once established, this is a very high-yielding species. Basin wildrye is highly

palatable in the spring, but palatability declines rapidly with maturity. The old, coarse growth is readily utilized by late-fall or winter grazing, as long as protein supplements are provided.

Grazing management—Poor seedling vigor usually results in sparse stands. Do not graze new seedings until seedheads are evident or until at least the end of the second growing season.

On established stands, allow basin wildrye to reach at least 10 to 12 inches of growth before grazing. Take great care to avoid close grazing or clipping, which may result in high levels of plant loss in a single season. During active growth, do not graze below a 10-inch stubble height to avoid removing the growing point. Regrowth ability following grazing is poor, and multiple grazing cycles are not recommended. Maintain at least a 6-inch stubble height going into the winter.

WILDRYE, RUSSIAN (*PSATHYROSTACHYS JUNCEA*)

Russian wildrye is a long-lived, saline-, drought-, and cold-tolerant introduced bunchgrass.

Adaptation and use—Plant in areas that receive at least 8 inches of annual precipitation.

Russian wildrye can withstand saline conditions almost as well as tall wheatgrass. It is useful on soils too alkaline for crested wheatgrass and too dry for tall wheatgrass. Once established, Russian wildrye competes very effectively against undesirable plants.

This species produces abundant basal leaves that remain green and palatable through summer and fall as long as soil moisture is available. Russian wildrye is palatable to all classes of livestock. It cures better on the stump than most cool-season grasses and makes excellent fall and winter feed. In late-summer, fall, and winter, it is more palatable than crested wheatgrass. Russian wildrye is not suited for hay production due to the predominance of basal leaves, which make it difficult to harvest.

Russian wildrye is very sensitive to deep seed placement. Plant at 0.25 to 0.5 inch depth. Wide row spacing (at least 18 inches) results in the highest potential production.

Grazing management—Russian wildrye grows rapidly in the spring. It can be grazed when plant growth reaches 8 inches. At least 3 inches of stubble should remain following grazing. Manage stands carefully to avoid overutilization, as stands can be damaged by heavy spring use. In spring, a 28- to 35-day recovery period between grazing cycles is recommended. Recovery periods during summer should be more than 35 days. Russian wildrye regrows quickly if soil moisture becomes available, and it responds very well to supplemental irrigation.

Pasture species—legumes and other forbs

ALFALFA (*MEDICAGO SATIVA*)

Alfalfa is a very productive, palatable, perennial, introduced legume (plants that fix N). Many varieties are available, each with specific characteristics and purposes.

Adaptation and use—Alfalfa is adapted to well-drained sites. It does poorly at higher elevations and on sites with a high water table. It is suitable for irrigated sites or on dryland sites with effective annual precipitation of at least 12 inches. Varieties differ in their fall dormancy rating. Fall dormancy is correlated with winter hardiness in older varieties. Newer varieties that have a winter survival rating of less than 3 are suitable for areas with hard winters.

Alfalfa is suited for use as hay, pasture, or haylage. It is compatible with most dryland and irrigated forage grasses. Bloat can be a problem when grazing alfalfa. To reduce bloat problems, limit alfalfa to 25 percent of a mixed stand and seed at 1 pound per acre.

The taproot of alfalfa is vulnerable to pocket gopher damage. Creeping varieties are less susceptible to damage. Creeping types are also more tolerant of grazing than are crown-type varieties.

Plant alfalfa in midspring after the risk of a killing frost has passed or in summer at least 6 weeks before a killing frost. Seed requires inoculation with N-fixing bacteria before planting. See chapter 4 for the proper inoculum.

Grazing management—Grazing can begin after alfalfa reaches a height of 6 inches. Following grazing or haying, alfalfa starts to regrow quickly but replenishes its food reserves slowly. Frequent defoliation at short intervals depletes reserves and reduces survival. A rest period of 28 to 35 days is recommended. Terminate grazing 3 to 4 weeks before the first killing frost to allow buildup of food reserves for winter survival.

BURNET, SMALL (*SANGUISORBA MINOR*)

Small burnet is a perennial, semi-evergreen, introduced forb that grows up to 2.5 feet tall. It is non-leguminous (does not fix N) and deep rooted.

Adaptation and use—Small burnet is best adapted to well-drained soils. It can be grown on low-fertility, droughty soils, as well as on moderately wet, acid soils. It establishes easily on good soils, but will not persist with less than 14 inches of annual precipitation or in areas that are shaded, poorly drained, or have a high water table.

Small burnet provides moderate amounts of forage. It is very palatable to livestock and wildlife. Upland game and songbirds utilize its seed.

Grazing management—Defer grazing until the second growing season to allow plants to become established. In established stands, growth is most vigorous in spring and fall. Allow plants to reach a height of 12 inches before grazing. Recovery following grazing is good. Rest periods should be about 35 days. Stubble height at the end of the grazing period or season should be 6 inches.

CLOVER, ALSIKE (*TRIFOLIUM HYBRIDUM*)

Alsike clover is a short-lived (3 to 5 years), perennial legume.

Adaptation and use—Alsike clover is adapted to flooded or poorly drained, acid soils. It makes good hay from wet bottomlands and tolerates moderately saline to alkaline conditions with high water tables. It produces best under irrigation or on dryland where the effective annual precipitation is at least 18 inches. This species is especially useful in cool areas, as it is very tolerant of cold temperatures and frost heaving. It does not tolerate droughty conditions or hot temperatures and is not well adapted to sandy soils or shade.

Alsike clover produces abundant palatable foliage on fertile soils. It is most productive in mixtures with grasses. Bloat is a potential problem. To reduce bloat problems in grazing situations, limit alsike clover to 25 percent of a mixed stand and seed at 1 pound per acre. Seed requires inoculation with N-fixing bacteria before planting. See chapter 4 for proper inoculum.

Grazing management—Alsike clover is best if grazed in spring. Begin grazing after 6 inches of growth. In spring and early summer, a rest period of 21 to 35 days is recommended. Regrowth is excellent in spring when temperatures are low and soil moisture is available, but poor later in the summer. A stubble height of 3 inches should remain at the end of the grazing period or season.

CLOVER, RED (*TRIFOLIUM PRATENSE*)

Red clover is a short-lived (2 to 3 years), perennial legume.

Adaptation and use—Red clover is adapted to irrigated conditions or to dryland where effective annual precipitation is at least 25 inches. It requires well-drained soils and produces best under medium acid to neutral soil conditions (pH 6.0 to 7.5). It is tolerant of shade, but does not tolerate flooding, saline conditions, or waterlogged soils. It does not tolerate drought or hot temperatures.

Red clover is suited primarily for hay and silage. It is compatible with white clover and grasses in pasture mixtures. Because red clover is short lived, production is usually greater in the second year than in the first or third. This species will reseed and spread under favorable conditions.

Bloat is a potential problem. To reduce bloat problems in grazing situations, limit red clover to 25 percent of a mixed stand and seed at 1.5 pounds per acre. Seed requires inoculation with N-fixing bacteria before planting. See chapter 4 for proper inoculum.

Grazing management—Red clover is best if grazed in spring. Begin grazing after about 6 inches of growth or at the quarter- to half-bloom stage. In spring and early summer, a rest period of 21 to 35 days is recommended. Regrowth is excellent in spring when temperatures are low and soil moisture is available, but poor later in the summer. A stubble height of 3 inches should remain at the end of the grazing period or season.

CLOVER, WHITE (LADINO) (*TRIFOLIUM REPENS*)

White clover is a long-lived, shallow-rooted, stoloniferous, low-growing, perennial legume.

Adaptation and use—White clover thrives in cool, moist mountain and intermountain areas with winter snow cover. It can be grown under irrigation or on dryland where effective annual precipitation is at least 18 inches. In general, it is best adapted to clay and loam soils in humid and irrigated areas. It grows successfully on sandy soils with a high water table or on irrigated, droughty soils when adequately fertilized.

White clover seldom roots deeper than 2 feet, making it adapted to shallow soils as long as adequate soil moisture is available. It is not tolerant of strongly acid or strongly alkaline conditions or of poor drainage. It does not tolerate drought or high temperatures.

White clover is suited primarily for pasture and is best grazed in spring. It is compatible with red clover and grasses in pasture mixtures and will reseed and spread under favorable conditions. Bloat is a potential problem. To reduce bloat problems in grazing situations, limit white clover to 25 percent of a mixed stand and seed at 1 pound per acre. Seed requires inoculation with N-fixing bacteria before planting. See chapter 4 for proper inoculum.

This species is also a good erosion-control plant, although usually lacking in persistence.

Grazing management—Begin grazing after about 6 inches of growth. In spring and early summer, a rest period of 21 to 35 days is recommended. Regrowth is excellent in spring when temperatures are low and soil moisture is available, but poor later in the summer. A stubble height of 3 inches should remain at the end of the grazing period or season.

MILKVETCH, CICER (*ASTRAGALUS CICER*)

Cicer milkvetch is a long-lived, slow-establishing, late-maturing, grazing-tolerant, winter-hardy, introduced, rhizomatous, non-bloat legume.

Adaptation and use—Cicer milkvetch is adapted to cold lowland areas and to soils with high water-holding capacity that receive at least 14 inches of annual precipitation. It is moderately tolerant of flooding.

Cicer milkvetch is a heavy seed and forage producer with nutritious forage. The best time to utilize cicer milkvetch forage is summer and fall. This species is very tolerant of livestock trampling. It is a good species for fall and early-winter stockpiled forage, as nutrients are retained in later growth. Hay yield is nearly equal to that of alfalfa.

Cicer milkvetch is very compatible with irrigated pasture grasses. It can substitute for alfalfa at higher elevations where alfalfa winter kills, or where a high water table limits alfalfa production.

In a 50 percent mixed stand, a seeding rate of 4 pounds per acre is recommended. This species establishes slowly due to very hard seed. Scarification of seed is recommended. Seed requires inoculation with N-fixing bacteria. See chapter 4 for proper inoculum.

Grazing management—Begin grazing after cicer milkvetch has reached a 4-inch height. After grazing, new shoots grow from buds on the rhizomes, crowns, and nodes of the lower leaves, allowing for relatively rapid recovery and growth. Rest periods of 35 to 42 days are recommended. Stubble should be 3 inches at the end of the grazing period or season.

SAINFOIN (*ONOBRYCHIS VICIIFOLIA*)

Sainfoin is a deep-rooted, medium-lived, drought-resistant, introduced, cool-season, non-bloating legume.

Adaptation and use—Sainfoin is adapted to deep, well-drained, medium-textured soils, to high lime content, and to slightly alkaline soils. It is adapted to irrigated conditions and to dryland with at least 14 inches of annual precipitation. It is not tolerant of wet soils or high water tables.

Sainfoin can be grazed or used for hay. It blooms early, but is not as productive as alfalfa. It is highly palatable.

The recommended seeding rate for a 50 percent mixed-stand pasture is 17 pounds per acre. Sainfoin has good seedling vigor, but seedlings are not competitive against weeds or other plants. Seed requires inoculation with N-fixing bacteria before planting. See chapter 4 for proper inoculum.

Stands seldom live more than 10 years due to problems with stem and root rot. To maintain a stand long-term, allow established plants to reseed every 3 or 4 years.

Grazing management—Begin grazing in the early-bloom stage or at about 12 inches of height. Rest periods of 35 to 42 days are recommended. A stubble height of 6 inches should remain at the end of the grazing period or season.

SWEETCLOVER, YELLOW AND WHITE (*MELILOTUS OFFICINALIS* AND *M. ALBA*)

Sweetclover is an introduced, tall, stemmy, deep-rooted, biennial legume.

Adaptation and use—Sweetclover is adapted to many sites, but does not tolerate acid soils. It is the most drought-tolerant legume commercially available.

Sweetclover produces abundant forage the first 2 years and is commonly utilized as a cover crop for perennial seedings. It is also suited for green manure or green-chop haylage under irrigation or on dryland where effective annual precipitation is at least 9 inches.

Sweetclover reseeds and maintains good stands in years of above-normal spring precipitation, as long as perennials do not crowd it out. Forage quality is poor in mid- to late summer. Bloat is a potential problem. To reduce bloat problems in grazing situations, limit sweetclover to 25 percent of a mixed stand and seed at 1 pound per acre. Seed requires inoculation with N-fixing bacteria before planting. See chapter 4 for proper inoculum.

Grazing management—Begin grazing after sweetclover has reached 8 inches in height. In spring and early summer, a rest period of 28 to 35 days is recommended. This species has excellent recovery and growth in spring and early summer if soil moisture is available. Stubble height should be at least 6 inches at the end of the grazing period or season.

Sweetclover contains coumarin, a derivative of dicoumarol, a blood anticoagulant. Death may occur in animals foraging on pure stands or consuming spoiled hay or silage.

TREFOIL, BIRDSFOOT (*LOTUS CORNICULATUS*)

Birdsfoot trefoil is a short-lived, deep tap-rooted, nonbloat, introduced legume.

Adaptation and use—Birdsfoot trefoil can be grown under irrigation or on dryland where effective annual precipitation is at least 18 inches. It is very winter-hardy where protected by snow cover and is useful in high-elevation settings. It tolerates poor drainage and waterlogged soils. Under ideal growing conditions, it may invade adjacent areas.

Birdsfoot trefoil is suited for use as pasture or hay. Compared to alfalfa, it retains higher quality forage on mature growth. The decumbent and intermediate types tolerate close grazing better than erect types. This legume is quite vigorous and is an excellent plant for erosion control.

For grazing situations in a 50 percent mixed stand, a seeding rate of 1.5 pounds per acre is recommended. If the mixture includes grasses, alternate-row planting is recommended to allow birdsfoot trefoil to establish. Seed requires inoculation with N-fixing bacteria before planting. See chapter 4 for proper inoculum.

Birdsfoot trefoil is short lived (2 to 4 years), making reseeding necessary. However, if plants are allowed to go to seed, stands will persist for many years.

Grazing management—New stands establish slowly and should be hayed the first growing season. On established stands, grazing can begin after 6 inches of new growth. Regrowth initiates from buds formed in the leaf axils. Allow 28 to 35 days between grazing periods. Terminate grazing 3 to 4 weeks before the first killing frost to allow buildup of food reserves for winter survival. Stubble height should be at least 3 inches at the end of the grazing period or season.

For more information

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CHAPTER 3

Soils, Fertility, and Nutrient Management for Pastures

G. Shewmaker, R. Koenig, D. Horneck, M. Bohle, G. Cardon, and S. Jensen

STEWARDSHIP OF SOIL RESOURCES, combined with good grazing management, produces sustainable pastures, reduces input costs, provides aesthetically pleasing landscapes, and optimizes livestock production. Forage from properly fertilized pastures may have higher crude protein content than forage from unfertilized pastures. Thus, it may provide higher quality livestock feed.

With good management, perennial mixed grass-legume pastures need only limited fertilizer, since nutrients are exported only in the body composition of grazing animals gaining weight or in animal products (such as milk). Where pastures are composed mostly of grasses, some nutrients, especially nitrogen, need to be replenished.

This chapter reviews basic soils information and discusses nutrient management strategies that can help ensure a long-lived, productive pasture. Fertilizer rates are recommendations based on university research and on estimates of nutrient removal and uptake efficiency. When combined with careful soil sampling, these guidelines can ensure a high-quality pasture.

Key Points

- Soils are a basic resource that must be considered in management decisions. Degradation of the soil resource can take a lifetime to recover.
- Nutrients in a soil-plant-animal system are dynamic and cyclic.
- Pasture systems can be sustainable with a minimum of external inputs.
- Intensive management and high stock density are required to minimize the tendency for nutrients to be concentrated near water, shade, and other attractions.
- Soil testing (and in some cases plant tissue testing) is essential to prescribing nutrient additions to pasture.

Soils as a resource

Soil is an essential and dynamic resource that supports plant growth and, therefore, livestock production. Soils have unique biological, chemical, and physical properties that change in response to management. Your job as a pasture manager is to keep these properties in balance in order to optimize forage productivity and quality.

We recommend that you review your local soil survey, which describes your farm's soils and their characteristics. Soil surveys are prepared by the USDA-Natural Resources Conservation Service. Most are available online (http://soils.usda.gov/survey/), although some are available only in hard copy from local USDA-NRCS offices.

Soil surveys include maps, photos, descriptions, and tables. The tables contain detailed information about soil properties and suitability for uses such as crops, pasture, recreation, and engineering. They also include information about depth to rock or restrictive layers, soil texture, permeability, water-holding capacity, native soil reaction (pH), and erosion. Climate information includes the average frost-free period and annual precipitation.

To use a soil survey, locate your area on the soil maps and note the map unit symbols. They are the key to unlocking the information in the tables. To use the tables, look for the map unit symbol in the tables, which are organized alphabetically.

SOIL REACTION (pH)

The soil reaction or soil solution pH is a measure of soil acidity or alkalinity. Soil pH is measured between 0 and 14, with acidic soils having a pH less than 7 and alkaline soils having a pH above 7.

Soil pH is a product of parent material and the environment. Rainfall and temperature largely control processes that determine soil pH. Fertilizer sources can also affect soil pH.

The presence of minerals containing exchangeable bases (calcium, magnesium, potassium, and sodium) causes soil to be alkaline. Rainfall slowly dissolves these minerals and leaches them from the soil, leaving behind aluminum, iron, and hydrogen. These elements make soil more acidic. Thus, acidic soils occur naturally in high-rainfall areas, while low-rainfall zones tend to have alkaline soils. The mountainous and coastal regions of the western U.S. have high rainfall and therefore acidic soils.

Table 3.1. Recommended lime application rates for grass-legume pastures on acidic soils (tons/acre).

SMP buffer test for lime	Recommended lime application
below 5.5	4 to 5
5.5 to 5.8	3 to 4
5.8 to 6.1	2 to 3
6.1 to 6.5	1 to 2
above 6.5	0 to 1

Source: Adapted from Hart, J., G. Pirelli, L. Cannon, and S. Fransen. 2000. *Fertilizer Guide: Pasture, Western Oregon and Washington*. FG 63. Oregon State University Extension Service.

Soil pH affects nutrient availability and the biology of soil organisms. In low-pH soils, availability of some metallic elements can reach levels that are toxic to plants. A soil test is essential to determine pH and to know whether soil amendments are necessary to meet pasture performance goals.

Grass pastures are moderately tolerant to soil acidity. We recommend applying lime if the soil pH is below 5.4 or the calcium soil test is below 5 meq Ca/100 g soil. Use the SMP buffer test to estimate the amount of agricultural lime to apply (table 3.1). If the soil is also low in magnesium (less than 0.8 meq Mg/100 g soil), substitute 1 ton dolomitic lime per acre for 1 ton of agricultural lime.

Legumes are more sensitive to low soil pH than grasses. Beneficial bacteria present on legume roots convert atmospheric nitrogen to a form plants can use. Strongly acidic conditions limit this biological nitrogen fixation. Thus, legumes generally are more responsive to liming than grasses. For legumes, surface application of 1 to 2 tons lime per acre is recommended when soil pH is below 5.8.

Broadcasting lime on established pastures is not as effective as mixing it with the top 6 inches of soil at planting. Lime rates can exceed 2 tons per acre when re-establishing a pasture. Additional information is available in FG 52-E, *Fertilizer and Lime Materials*, published by Oregon State University (OSU).

In low-rainfall climates, lime often accumulates in the soil, forming calcium-rich (calcic) horizons called caliche. These lime accumulations develop when rainfall is not sufficient to leach calcium and magnesium carbonates from the profile. The depth to the calcic horizon depends on the depth of leaching, which is reg-

ulated by annual rainfall, season of rainfall, and soil texture. Land leveling or erosion can expose these horizons.

Calcic horizons have pH greater than 8.2. Compared to adjacent soils, they are lighter in color, lower in organic matter, and more difficult to manage. They commonly cause problems such as iron deficiency in plants and/or poor water penetration.

Soil amendments such as elemental sulfur and gypsum can improve highly alkaline and sodic soils. These amendments are effective only if the cause of the condition is remedied, however. This situation often requires professional advice and assistance. See OSU publication PNW 601-E, *Managing Salt-affected Soils for Crop Production*, for more information.

Diagnosing soil compaction

SOIL AND PLANT INDICATORS

- Irregular plant height
- Nutrient deficiencies in the presence of adequate soil test levels
- Roots change direction 90 degrees at a compaction zone
- Coarse, blocky soil structure in the topsoil
- Plate-like structure below the surface
- Ponded water

DIAGNOSTIC TECHNIQUES

- Use a soil probe or compaction probe to sample the depth and amount of compaction.
- Dig a hole 2 feet in diameter and 2 feet deep in a compacted area. Probe the exposed soil profile with a knife and observe soil structure and firmness at 2-inch intervals.
- Observe root growth.
- Use a soil probe to map penetration depth in moist soil.
- Associate results with your management practices and observed grazing behavior.

SOIL STRUCTURE

Soil structure is defined as the arrangement of the solid parts of the soil and the pore space between them. It is the result of the geologic parent material, soil processes, environmental conditions under which the soil formed, clay and organic materials present, and soil management (e.g., tillage).

From an agricultural perspective, soil has good structure when it is aggregated and has low density and high porosity. A well-structured soil encourages biological activity and allows roots to penetrate.

Soil aggregates are "clumps" of soil particles that are held together by clay, organic matter (such as roots), organic compounds (from bacteria and fungi), and fungal hyphae. The spaces, or pores, within and between soil aggregates are essential for air and water storage and flow, root passage, and microbial life. Because aggregates vary in size, they create spaces of many different sizes in the soil.

Grazing affects soil structure, as livestock hooves can reduce aggregates and severely compact wet soils. Soil compaction reduces water infiltration and the amount of air (oxygen) available to plant roots and soil organisms. As available water and air decrease, plant production declines. Some plant species cannot survive in compacted soil, and the loss of desirable grass and legume species allows weeds and less desirable species to increase. Heavy, prolonged livestock traffic can result in bare soil areas. The damage caused by grazing animals can take years to correct.

Organic matter promotes soil structure, thus improving water infiltration and availability. Thus, pastures perform best when rapidly growing perennial plants supply organic matter to the soil. A vigorous, healthy plant community also reduces the potential for weed invasion and soil erosion.

Nutrient distribution and cycling in grazed pastures

Pastures require less fertilization than field crops or lawns. Grazing livestock return as much as 85 to 95 percent of the nitrogen (N), phosphorus (P), potassium (K), and other nutrients consumed to the pasture through urine and dung.

Nutrients are not distributed uniformly, however. They are concentrated next to water sources, shade,

bedding areas, and trails (figure 3.1). After four or five grazing seasons, concentrations of P and K within 30 feet of water sources can be five times greater than in other areas of the pasture. When grazing patterns remain unchanged for more than 20 years, increased P and K concentrations can be found up to 100 feet from the water source. You can improve nutrient distribution with Management-intensive Grazing, i.e., a high stock density (many animals on a small area of pasture) and the use of portable fencing, water, and shade.

Nutrients cycle within pasture systems, and nutrient levels do not remain constant throughout the year. Nutrients continually move among the atmosphere, soil, plants, and animals (figure 3.2). Plants shed leaves and slough roots, and animals produce dung and urine. These organic materials are broken down by physical, chemical, and biological processes to mineral forms of calcium, nitrate, sulfate, and other nutrients. This process is called mineralization.

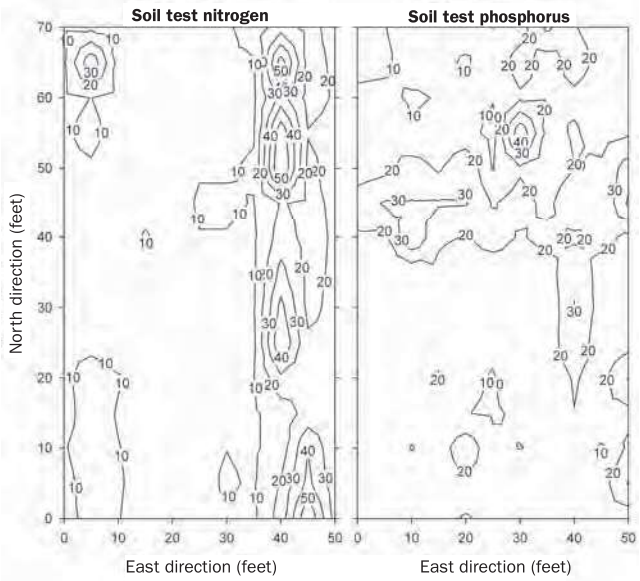

Figure 3.1. Distribution of soil test nitrogen (lb/acre) and phosphorus (ppm or mg/kg soil) in a small, intensively grazed paddock. The paddock was grazed six times during the season before these samples were collected. The water trough is located in the northeast corner of the paddock. (Source: R. Koenig, unpublished data)

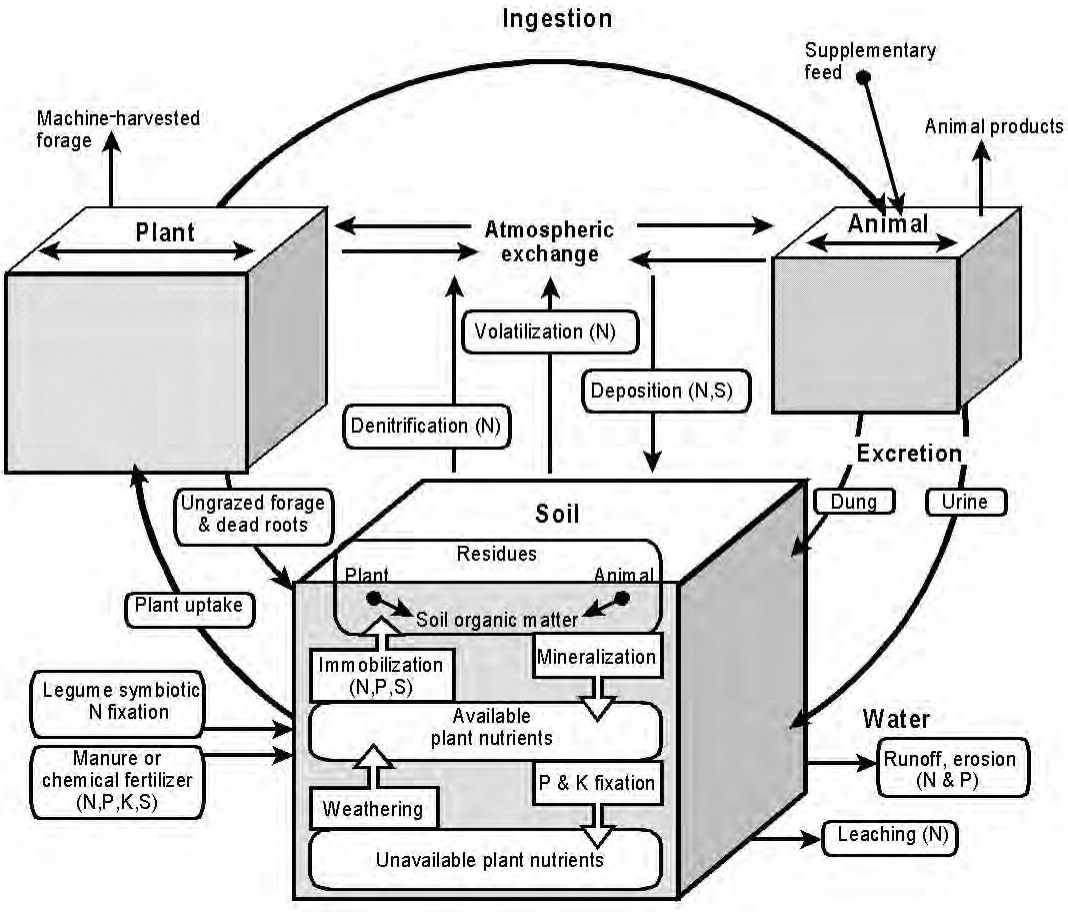

Figure 3.2. Nutrient (primarily nitrogen) cycle showing inputs, losses, and complex pathways of internal cycling in pastures.

Plant roots take up mineralized nutrients and use them for growth. Soil microbes also incorporate them into organic matter through a process called immobilization. Some nutrients, such as nitrate and sulfate, are highly water soluble and can be leached from the soil. Some N, particularly from urine, is also lost to the atmosphere as ammonia through volatilization or nitrous oxide through denitrification (the reduction of nitrates to nitrites, ammonia, and free nitrogen in soil by microorganisms).

Soil testing in pastures

Take soil samples annually if your pasture has nutrient deficiencies or every 3 or 4 years if soil fertility is within recommended levels. Sample soil on about the same date each year, since nutrient levels fluctuate seasonally. Fall and early spring are good times for soil testing. Spring sampling will allow you to apply nutrients at the beginning of the growing season. However, fall sampling allows time to apply P and get some movement into the root zone. See University of Idaho Extension bulletin 704, *Soil Sampling*, for more information.

For soil sampling purposes, divide each pasture into "zones" to account for differences in manure deposition and nutrient concentrations. Areas around watering and shade areas should be separate zones. Sample low-lying areas, north- and south-sloping hillsides, and areas with different cropping histories separately. Test each zone separately so that you can apply nutrients at appropriate rates where needed. Sample to a depth of 1 foot. If there is less than 1 foot of soil, sample to a uniform depth.

A plant-available N (ammonium and nitrate) soil test generally is not as useful for perennial forage crops and pasture as it is for annual crops. Most of the N released from organic matter during the growing season is rapidly used by grasses, so little available N accumulates in the soil. Also, available N is mobile in soils and can be leached below the root zone with spring precipitation or overirrigation.

Soil test results may include fertilizer recommendations based on assumptions made by the laboratory. The recommendations may be higher than necessary for grazed pastures because they may not take into account the recycling of nutrients by grazing animals.

When using soil test results to evaluate fertilization needs, also take into account your observations of forage productivity and nutrient cycling. For example, the presence of persistent cow pies (old dung) means that some of the nutrients in manure are not cycling rapidly into the soil. In this case, more N may be needed.

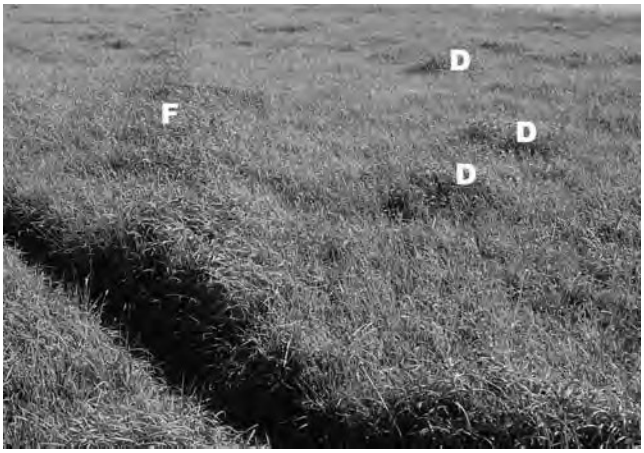

Figure 3.3. Evidence of nutrient deficiency(ies) or fertility problem: more vigorous growth is seen around dung piles or urine spots (D) and in the center of the fertilizer spreader pattern (F). (Photo by Glenn Shewmaker)

Figure 3.3 shows two indicators of nutrient deficiencies. Several strips of vigorous forage growth are seen in the center of a fan-type spreader application pattern (labeled F). This uneven growth pattern indicates that fertilizer was applied nonuniformly and that a nutrient deficiency still exists. More vigorous regrowth and darker color is also seen around dung piles or urine spots (labeled D), indicating a probable nutrient deficiency.

Fertilization planning is most effective when fertilization rates and soil test results are tracked in a spreadsheet for several years. Good records can help you see how fertilization has changed soil test levels and pasture productivity. You then can adjust rates as needed. Multiple years of soil and tissue testing (see "Plant tissue testing," below), combined with periodic observations, can help you fine-tune the recommendations in this guide for optimal pasture production.

Nitrogen

Grass pastures respond well to N fertilizer applications. For example, research has shown that forage grass production increases by 35 to 80 pounds of dry matter per acre for every 1 pound of N applied. The rate of yield increase in forage production for every pound of N applied decreases as more N is applied.

N APPLICATION

Nitrogen recommendations are based on the production potential of the stand. Production potential depends on the length of the growing season, the availability of irrigation water or precipitation, the amount of legumes in the stand, and the number of cuttings or grazing periods.

The recommendations in table 3.2 assume normal growing conditions. Climatic variability can affect production potential and N needs. For example, production potential increases as the growing period is extended. If the frost-free growing season is longer than normal one year, or if you have more cutting or grazing periods than normal, you may need more N. On the other hand, if precipitation or irrigation is reduced one year, you may need less N.

As the amount of legume increases in a grass-legume mixture, the need for N fertilizer decreases (table 3.2). When legumes make up more than 60 percent of the mixture, yield responses to N fertilizer are limited. Optimal legume performance is achieved by inoculating the legume seed before planting to ensure biological N fixation (see chapter 4).

N applications usually reduce the proportion of legume in a grass-legume mixed stand. Excessive N will encourage grasses as the dominant species.

Be cautious when applying more than 160 pounds N per acre in a single application. High N rates may be economically unwise and can cause nitrate to leach to groundwater or accumulate in forage. High nitrate concentrations in forage can cause animal health problems (see chapter 12). The potential for nitrate accumulation is highest when excess N is applied to a drought-stressed pasture.

Soil testing is essential!

It is difficult to generalize about the location and occurrence of specific nutrient deficiencies in the Northwest. Soils vary greatly due to differences in geologic processes, manure application, and inorganic fertilizer use. In addition, some irrigation water adds nutrients to soil. For these reasons, soil testing is essential to determine which nutrients are needed and how much fertilizer to apply. Fertilizer recommendations in this guide are based on the latest research results from university trials.

Table 3.2. Nitrogen (N) recommendations for irrigated and high-rainfall grass and grass-legume pastures.

Plant composition	Yield potential of the site			
	1 to 2 tons/acre	2 to 4 tons/acre	4 to 6 tons/acre	6 to 8 tons/acre
	N (lb/acre)			
100% grass	50	75[a]	100 to 150[a]	150 to 200[a]
75% grass, 25% legume	25	50	75 to 100[a]	100 to 150[a]
50% grass, 50% legume	0	25	50	75
25% grass, 75% legume	0	0	25	50

[a] For pasture, split the total N rate into two or three applications. Apply one-third to one-half of the N in early spring, one-third to one-half in June, and the remainder in late August. If early pasture is needed, use the T-sum method to determine the timing of earlier fertilization. For hay-pasture systems, apply two-thirds of the N in early spring and one-third after the hay crop is removed.

Source: Koenig, R., M. Nelson, J. Barnhill, and D. Miner. 2002. *Fertilizer Management for Grass and Grass-legume Mixtures*. AF-FG-03. Utah State University Cooperative Extension.

Split applications of N fertilizer maintain more uniform forage production through summer and fall than does a single application. They also increase N use efficiency. If needed (based on rates in table 3.2), broadcast 30 to 50 pounds N per acre after each cutting or grazing cycle. Check with your local extension office for specific recommendations.

Irrigate to move N into the plant root zone and minimize volatilization losses. Irrigation or rainfall of 0.5 inch within 48 hours of application is sufficient.

SOURCES OF N

Common dry forms of N for topdressing (surface broadcast applications) are urea (46-0-0) and ammonium sulfate (21-0-0-24). Urea is the most common. Solutions containing both urea and ammonium nitrate (UAN or Solution 32 or 28) are also available.

Urea seems to produce a smaller response (per unit of N) than ammonium nitrate. As urea absorbs moisture, it is converted to the ammonium form, and some ammonia may be lost via volatilization. Nitrogen losses of 5 to 20 percent have been reported when urea is applied to grass under certain conditions (on calcareous soils or during warm weather) and several days elapse before rain or irrigation incorporates the fertilizer into the soil.

Conventional N fertilizers provide pulses of N that temporarily exceed demand. Controlled-release urea fertilizers may better match N supply with demand. However, research is needed on the efficacy of controlled-release products in pastures.

If P is also needed, consider using diammonium phosphate (18-46-0) or monoammonium phosphate (10-48-0 to 11-55-0). Calcium nitrate (16-0-0) supplies both N and Ca. Ammonium sulfate is recommended when both nitrogen and sulfur are deficient.

Fertigation

The application of liquid fertilizers through the sprinkler irrigation system (fertigation) is an efficient way to supply nutrients. Fertigation works best with properly designed and maintained systems with uniform water application. A backflow prevention valve and chemigation license are required. With fertigation, you can make in-season or split applications if desired. Liquid sources of most nutrients are available. Carefully compare liquid sources, dry fertilizers, and organic materials in terms of cost and convenience.

TIMING N APPLICATION FOR EARLY SPRING FORAGE PRODUCTION

Grasses green up in the spring based on "thermal" time, not calendar time. Thus, the optimum time for early-spring fertilization can vary by 1 to 5 weeks from year to year. Temperature-summing (T-sum) is a method for determining the optimum time to fertilize grass pastures for early-spring forage production.

T-sum is based on the current year's weather. It uses a base temperature of 32°F to accumulate growing degrees, beginning on January 1. When 360 growing degree days (GDD) have accumulated, the optimum time to fertilize the pasture with N has been reached.

Calculate growing degree days as follows:

$$GDD = \left(\frac{Tmax + Tmin}{2}\right) - Tbase$$

1. Beginning January 1, add together each day's maximum and minimum air temperature and divide this total by 2. The result is the average temperature for the day.

Table 3.3. Sample growing degree calculation for base 32°F.[a]

Day	Maximum air temperature (°F)	Minimum air temperature (°F)	Average air temperature (°F)	Growing degree days (base 32°F)
Jan 1	35	10	22.5	0.0
Jan 2	40	25	32.5	0.5
Jan 3 to Feb 28	—	—	—	347.0
Mar 1	45	26	35.5	3.5
Mar 2	50	32	41.0	9.0
Sum				**360.0**

[a] To calculate growing degree days: GDD = [(Tmax + Tmin) ÷ 2] – Tbase.

2. Subtract the base temperature (32°F) from the average air temperature to calculate the GDD for that day. If the value is a negative number, use 0 for that day.
3. Add together the number of GDD since January 1 to get the accumulated GDD.

Table 3.3 shows an example of a growing degree calculation.

While the T-sum timing of N fertilizer application does increase early forage production, it does not increase total forage production over a couple of grazing rotations. For more information on using the T-sum method, see OSU Extension publication EM 8852-E, *Early Spring Forage Production for Western Oregon Pastures*.

Phosphorus

Intensively managed, high-producing pastures may respond to P fertilization. Grasses generally have a low P requirement, and legumes generally have a high P requirement. Thus, P fertilization tends to maintain or increase the legume portion of mixed pastures.

Soil testing for pH and available P indicates whether P fertilization is needed. More soil and fertilizer P is available to plants when pH is between 6 and 7.5 than at lower or higher pH. Thus, knowing both pH and P concentration helps to recommend a P application rate.

To obtain valid results, the laboratory must use the proper soil analysis method. For alkaline, calcareous soils, available P is best determined with the Olsen extraction method, which uses sodium bicarbonate as the extracting agent. For acidic soils, the Bray

extraction method should be used. The appropriate method is largely determined geographically. In the arid inland west, use the Olsen method. In higher rainfall areas, use the Bray method.

Phosphorus movement in soils is limited. Apply P during seedbed preparation if possible and incorporate it into the rooting zone. Fall is the best time to topdress established pastures with P fertilizer.

Rates of P needed for optimum forage production are shown in table 3.4 (interior Columbia Basin) and table 3.5 (west side of the Cascade Mountains). Consult your county extension office for local recommendations.

Table 3.4. Phosphorus (P) recommendations for grass and grass-legume pastures in the interior Columbia Basin.

Soil test P[a] (ppm)	P recommendation[b,c] (lb P_2O_5/acre)	
	Irrigated	Rainfed
0 to 3	100 to 125	60 to 100
4 to 7	75 to 100	40 to 60
8 to 10	50 to 75	20 to 40
11 to 15	0 to 50	10 to 20
15 and above	0	0

[a] Soil test P is based on a 12-inch sample depth and sodium bicarbonate soil extract (Olsen method).

[b] Fertilizer labels are expressed in percent P_2O_5. To convert P_2O_5 to P, multiply by 0.44.

[c] Refer to local fertilizer guides for more specific recommendations.

Table 3.5. Phosphorus (P) recommendations for grass and grass-legume pastures on the west side of the Cascades.

Soil test P[a] (ppm)	P recommendation[b,c] (lb P_2O_5/acre)
0 to 20	60 to 100
20 to 40	0 to 60
Over 40	0

[a] Soil test P is based on a 12-inch sample depth and Bray soil extract.

[b] Fertilizer labels are expressed in percent P_2O_5. To convert P_2O_5 to P, multiply by 0.44.

[c] Refer to local fertilizer guides for more specific recommendations.

Source: Adapted from Hart, J., G. Pirelli, L. Cannon, and S. Fransen. 2000. *Fertilizer Guide: Pasture, Western Oregon and Washington*. FG 63. Oregon State University Extension Service.

Potassium

Grasses have moderate K requirements, and legumes have high K requirements. Both grasses and legumes can take up larger quantities of K than are needed by the plant, potentially causing animal health problems (see chapter 12).

Northwest soils vary in K content, so a soil test is highly recommended. Various extracts are used for K, but all should give nearly the same result.

Irrigation well water may contain some K. Most surface water does not contain a significant amount of K. Information on irrigation water quality can be found in OSU Extension publication PNW 597-E, *Managing Irrigation Water Quality for Crop Production in the Pacific Northwest.*

Potassium movement in soils is limited, although not to the same extent as P. Incorporate K during seedbed preparation or broadcast in the fall on established stands.

Potassium chloride (0-0-60) and potassium sulfate (0-0-50) are the most common sources of fertilizer K. Both are equally effective. Potassium-magnesium sulfate, known as K-Mag (0-0-22-22S), is also available in some areas. This material supplies sulfur (S) as well as K.

Rates of K needed for optimum forage production are shown in table 3.6.

Table 3.6. Potassium (K) recommendations for grass and grass-legume pastures.

Soil test K[a] (mg/kg soil or ppm)	K recommendation[b] (lb K_2O/acre)
0 to 40[c]	180 to 220
40 to 70	140 to 180
70 to 100	80 to 120
100 to 150	40 to 60
Above 150	0

[a] Soil test K is based on a 12-inch sample depth and sodium bicarbonate soil extract. Sodium acetate or ammonium acetate extraction should give similar results.

[b] K is expressed as both the oxide and elemental forms: K_2O x 0.83 = K or K x 1.20 = K_2O.

[c] Low soil test levels are severely limiting.

Source: Koenig, R., M. Nelson, J. Barnhill, and D. Miner. 2002. *Fertilizer Management for Grass and Grass-legume Mixtures.* AG-FG-03. Utah State University Extension.

Sulfur

Legumes use more sulfur (S) than grasses. Sulfur fertilization requirements depend on soil texture, leaching losses, S soil test level, and S in irrigation water.

Areas irrigated with water from the Snake River or other streams fed by return flow should have adequate S. High-rainfall areas, mountain valleys, and foothill areas have the potential for S deficiencies.

Sample soil to a depth of 1 foot for S analysis. Apply 30 pounds S per acre if soil test results show less than 10 ppm sulfate-sulfur (SO_4-S). (This recommendation is based on extractable S with turbidimetric analysis and may not apply if a different method is used.) In high-rainfall environments, apply S annually.

Select S sources carefully, as availability to plants depends on the form of S. Sulfate-sulfur sources, such as ammonium sulfate, gypsum, potassium sulfate, and potassium-magnesium sulfate, can alleviate deficiencies in the year of application. However, these readily available S fertilizers suppress selenium (Se) uptake by plants, potentially creating Se deficiency in grazing animals. The effects of S on forage Se can be identified with plant analysis.

Elemental S is slow-release and must be converted by soil microorganisms to sulfate before it can be taken up by plants. Full conversion of elemental S to sulfate may take a year or more in warm, moist soils and even longer at higher elevations. Thus, elemental S fertilizers cannot supply adequate levels of S in the year of application. However, they can supply considerable S in subsequent years. Apply elemental S annually or every other year to maintain soil supply. A soil test will not measure elemental S in the soil.

Table 3.7. Micronutrient soil test values (mg/kg soil or ppm) and interpretations.[a]

Nutrient	Low	Marginal	Adequate
Zinc	below 0.8	0.8 to 1.0	over 1.0
Iron	below 3.0	3.0 to 5.0	over 5.0
Copper	below 0.2	—	over 0.2
Manganese	below 1.0	—	over 1.0
Boron	below 0.25	0.25 to 0.5	over 0.5

[a] DTPA extractable zinc, iron, copper, and manganese; hot water extractable boron.

Source: Koenig, R., M. Nelson, J. Barnhill, and D. Miner. 2002. *Fertilizer Management for Grass and Grass-legume Mixtures*. AG-FG-03. Utah State University Extension.

Micronutrients

Deficiencies of metallic micronutrients such as zinc (Zn), copper (Cu), manganese (Mn), and iron (Fe) have not been observed on irrigated pastures in the western U.S. Grasses and legumes are less sensitive to low levels of these micronutrients than are crops such as beans and corn. Only in rare cases do pastures respond to metallic micronutrient application.

Soil pH affects availability of these nutrients. As pH declines, availability of metallic micronutrients increases.

Soil test for micronutrients prior to application. If you choose to apply these micronutrients, do so on a trial basis to make sure a deficiency exists and that the response is economical.

Boron (B) deficiencies are sometimes observed in legumes growing on coarse-textured soils. If soil test results for B are below 0.25 ppm (hot water extractable method), apply 1 to 3 pounds B per acre. Do not use higher rates, as B is toxic to plants in excessive amounts.

Table 3.7 gives guidelines for interpreting micronutrient soil test results.

Plant tissue testing

Tissue testing can supplement soil tests and provide a direct measure of the nutrient status of pasture plants. If you suspect a nutrient deficiency, tissue analysis can identify the deficient nutrient.

Sample grasses and forbs separately. Collect samples for tissue analysis preferably just before heading. Samples for pasture use may be in the vegetative stage at 8 to 10 inches tall. Forage plants are naturally higher in concentrations for most nutrients at this stage than just before heading.

Randomly select about 25 plants across a typical area. Cut off the plants at 3-inch height. Do not get any soil on the plant material, as contamination will render the test meaningless. Deliver samples to the laboratory the same day, or air dry them before shipping.

For optimum production, grass clipped just before heading should contain the following minimum concentrations:

- Nitrogen: 2.0 percent
- Phosphorus: 0.25 percent
- Potassium: 1.5 percent

• Sulfur: 0.2 percent

Consult your local extension office or soil test laboratory for interpretation of tissue test results in combination with soil test results.

Manure and compost

The application of manure and compost to pastures adds some of all of the macro- and micronutrients to the soil. The nutrient composition of these materials varies greatly, so it is important to obtain analysis by a lab certified for compost and manure nutrient analysis. The results can help you determine application rates and economics of application.

Compost usually has limited amounts of available N, while manure can be rich in N. In addition to adding essential nutrients, manure and compost add organic matter, which improves soil properties such as water-holding capacity, cation exchange capacity, and soil structure.

Negative effects can include additions of salt, weed seeds (less of a problem in compost than in manure), and possible pathogens. Also, if manure covers plant leaves, yield can be reduced. Low application rates and application during the dormant season will reduce these negative effects.

General observations and recommendations

- Irrigated pastures make good use of sloping land, stony soils, and shallow soils that are unsuitable for row crops. Pastures reduce soil erosion compared to annually cropped land.
- N and P are the nutrients most needed by irrigated pastures. N and S are the most needed in central Oregon. K, S, or B application may also be needed for optimal growth. Fertilizer need is best determined by soil and plant tissue tests.
- In a grass-legume pasture, legume composition is reduced by N fertilization and increased by P addition (if these nutrients are in low supply in the soil).
- Fertilization is only one part of pasture management. Pastures are most profitable when plant selection (chapter 2), irrigation (chapter 6), and grazing or harvest techniques (chapters 14 and 15) do not limit production.
- Intensive rotational grazing distributes nutrients better in the pasture than continuous grazing, thus providing more forage and greater returns. See chapters 14 and 15 for more information.

Contact your local extension office regarding local interpretation of this information or for further information.

For more information

Acidifying Soil for Crop Production: Inland Pacific Northwest. PNW 599-E. Oregon State University Extension Service (2007). http://extension.oregonstate.edu/catalog/html/pnw/pnw599-e/

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Soil Sampling. EXT 704. University of Idaho Extension (1998). http://info.ag.uidaho.edu/resources/PDFs/EXT0704.pdf

Soil Test Interpretation Guide. EC 1478. Oregon State University (1999). http://extension.oregonstate.edu/catalog/pdf/ec/ec1478.pdf

USDA Natural Resources Conservation Service soil surveys. http://soils.usda.gov/survey/

CHAPTER 4

Pasture Renovation, Planting, and Establishment

B. McLain, S. Fransen, and G. Shewmaker

THIS CHAPTER DISCUSSES OPTIONS FOR PASTURE RENOVATION, including changing management practices to favor desirable forages, interseeding improved forages into an existing stand, and totally removing the existing vegetation and replanting. We also discuss the steps needed for successful establishment of a new pasture. Regardless of whether you opt for improving an existing pasture or replanting, you will need to improve management practices in order to most efficiently utilize available resources. Good management practices include proper fertility (chapter 3), irrigation (chapter 6), weed control (chapter 7), and grazing management (chapters 13–15). Always purchase high-quality seed. Use certified seed when available. Look for a seed tag that indicates high percentages for purity, germination, and freedom from noxious and invasive weed seeds.

Key Points

- Keeping the existing vegetation and improving management often is the most economical approach to pasture renovation. The least-cost method is to change the composition of a pasture through fertilizer management, improved irrigation, and grazing practices.
- For interseeding to succeed, competition from established plants must be eliminated.
- When replanting or planting a new pasture, a firm, fine, moist, weed-free seedbed is required.
- It is critical to set planting equipment for the proper seeding rate, depth, and distribution.
- Depending on location and environmental conditions, planting can occur in spring, late summer, fall, late fall, or early winter. Consider soil moisture (from precipitation and/or irrigation), soil temperature, soil type, weeds, and dates when killing frosts are likely to occur.
- The long-term health of a pasture depends on proper care during the establishment year. Good water management, fertility, weed control, and mowing or grazing are all important.

Improving an existing pasture versus replanting

When a pasture requires renovation, the first step is to evaluate existing pasture conditions. A site inventory and analysis (see chapter 1) will help you determine whether the existing pasture can be reclaimed or you should replant. Consider environmental conditions, water availability, forage utilization, economics, resource availability, management ability and style, and existing or future plant populations. Ask yourself the following questions:

- What are my management goals?
- Do I have a reasonable understanding of soil and species management?
- Are enough desirable plants (species) present to promote recovery without planting if proper management is applied?
- How risky is a new planting?
- What impact will disturbance of soils and plant life have on the biological health of the area?
- What is the risk of weed invasion or loss of stable soils and sensitive native plant communities, particularly on dryland pastures? Will the expected increase in forage offset these risks?

Keeping the existing vegetation and improving management practices may be the most economical approach. Replanting will require more investment in time and money. Keep in mind that it may take 3 or more years of good management to restore a pasture to a desired condition.

After careful evaluation, you may determine that replanting is the best way to improve production and meet forage requirements. Be sure to perform a complete site inventory and analysis before replanting (see chapter 1).

Improving an existing pasture

Shifts in pasture vegetation generally are associated with changes in soil properties and processes. The least-cost method of pasture renovation is to change the composition of an established pasture through fertilizer management, improved irrigation, and grazing practices. In mixed pastures, nitrogen (N) application generally favors grasses. Application of phosphorus (P) without N favors legumes. Continuous stocking will reduce sensitive plants—generally the more palatable plants—and promote resistant plants, while rotational stocking allows the palatable, more desirable plants to persist.

INTERSEEDING A LEGUME INTO GRASS

Pastures that begin as a balanced grass-legume mix often are dominated by grasses within a few years. Legumes may disappear due to one or more of the following situations:

- **Improper soil fertility**. Proper fertility is required for maintaining legumes, especially P and boron (B). Both grasses and legumes respond to added P if soil test P levels are low. However, legumes generally require higher annual P applications than grasses. Legumes are the first plants to disappear from a mixed stand when soil P levels are inadequate. Boron is also essential to keeping legumes healthy in a mixed stand, while grasses rarely respond to B applications. Soil tests are an important tool for determining nutrient application needs. See chapter 3 for more information.
- **Acidic soils**. Legumes are often more sensitive to acidic soils than grasses because the activity of nitrogen-fixing bacteria (*Rhizobium*) is reduced in acidic soils. Some pastures quickly become acidic because of improper irrigation management; overirrigation leaches bases from the root zone, increasing acidity. Use of N and sulfur (S) fertilizers may also lower soil pH in some soils. Amend acidic soils with lime every few years to buffer soil pH and maintain calcium and magnesium availability. Many soils in the Pacific Northwest are alkaline (pH is high), however, and do not require lime. Use soil tests to determine soil pH and amendment requirements. See chapter 3 for more information.
- **Lack of nodulation in the legume**. *Rhizobium* bacteria form nodules on legume roots and convert atmospheric N to a form the legume can use. Legumes depend on this N to meet their N requirements. If *Rhizobium* nodules are lacking, green (dead), or white (inactive), legumes may not obtain enough N. Grasses tend to utilize available N more efficiently than legumes, so legumes may be deficient when N levels are inadequate.

- **Inadequate recovery time after grazing or hay harvesting**. Where excellent grazing management is practiced, grasses in mixed grass-legume stands often regrow more quickly than legumes during the spring and fall. Grasses may reach a suitable height for regrazing before legumes have replenished their crown and root carbohydrates. If you delay regrazing to give the legume more time for growth, grasses become overly mature, leading to poor quality, low palatability, underutilization, and slow growth. Thus, tall legumes such as alfalfa and red clover are more difficult to maintain than shorter legumes such as white or alsike clovers.

Interseeding legumes into grass-dominated stands is difficult and often fails. For interseeding to succeed, competition from established plants must be eliminated, either chemically or culturally. Use a registered nonselective herbicide to burn down the established plants. Then use a no-till drill to plant desirable legumes and grasses directly into the sod.

Another option that works in some cases is to use grazing or clipping to reduce competition. First graze or mow the existing vegetation closely and then immediately drill the seed directly into the soil or sod. No-till drills work best. Keep the established plants short by continued grazing or close clipping until the new forages emerge. Mow as needed at an increased height to ensure that the new seedlings can compete. During the first year, graze or clip lightly to reduce competition until the new plants are well established. Manage grazing carefully to prevent overgrazing of the young, palatable legumes.

INTERSEEDING INTO ALFALFA

We do not recommend interseeding alfalfa into an alfalfa stand that is more than 1 year old. Established alfalfa plants emit compounds that are toxic to the germination and development of alfalfa seedlings. This characteristic is called "autotoxicity." To thicken an old alfalfa stand, it is better to interseed a grass such as annual or perennial ryegrass, oats, timothy, meadow brome, or orchardgrass.

One option is to interseed a cool-season grass, such as meadow brome or orchardgrass, into a thinning alfalfa stand in the late summer or early fall. Fall planting allows for establishment prior to winter dormancy. The grass is usually planted into the alfalfa after harvest to take advantage of the short stubble. Fall alfalfa growth is slow because of decreasing day length, thus allowing the grass to establish. Be sure that there will be at least 6 weeks of good growing conditions for grasses to establish before the first killing frost.

You also can interseed cool-season grasses in the early spring before alfalfa begins to grow. The grass will germinate before alfalfa breaks winter dormancy, providing time for establishment. In some areas, early-spring plantings are risky due to late hard frosts. With proper irrigation, the grass will often establish in the thinning alfalfa stand and prolong the productive life of the stand.

New plantings

SEEDBED PREPARATION

A firm, fine, moist, weed-free seedbed is required for successful establishment of the small seeds of forage grasses and legumes. The final seedbed should be firm but not hard, fine but not powdery, moist but not muddy, and clear of competitive weeds, especially perennials. A properly prepared seedbed holds moisture, helps control planting depth, and provides good seed-to-soil contact.

To prepare a pasture for planting, first kill existing vegetation with herbicides and/or tillage. Even no-till plantings require vegetation control prior to planting. Sites with serious weed problems, especially perennial weeds, may require one or more years of fallowing. Use herbicides and/or tillage to clean the field during the fallow period. See chapter 7 for weed management recommendations.

If the site has been neglected or poorly managed, it is advantageous to plant annual grain crops for one or more years before planting permanent pasture. The grain crop can reduce soil erosion and aid in weed control. It can be harvested as green forage or dry grain or tilled under as a green manure crop.

Apply recommended fertilizer and soil amendments prior to tillage so that they can be incorporated during tillage (see chapter 3). Moldboard plowing, offset disking, chisel plowing, or rototilling is required to bury surface residues and weed seed. If necessary, use a ripper or subsoiler to break up compacted soil layers. Take care not to damage underground drainage tiles or irrigation equipment.

Finally, use a harrow, roller, roller harrow, cultipacker, ground hog, or land plane to firm the seedbed. Then walk across the site to test the firmness. Your

footprints should be 0.25 to 0.5 inch deep. If they are deeper, additional mechanical firming is needed before planting.

Fields that have been fallowed or recently farmed with annual crops may require less preparation. In this case, light tillage and/or herbicide applications may be sufficient to remove weeds and volunteer plants. Under proper conditions, you can use a minimum or no-till planter to plant directly into weed-free crop stubble. This method conserves moisture, and the stubble can serve as a noncompetitive protection for new seedlings.

PLANTING METHODS

Because most forage species have small seed, proper planting depth, good seed-to-soil contact, and even distribution of seed are critical for success. In medium to heavy soils, most species should be planted 0.25 to 0.5 inch deep or less. If soil is light and sandy, plant no more than 0.75 inch deep. Small seeds require shallower planting depths than larger seeds. Plant seed mixtures to a depth that favors the smallest seed. A firm seedbed will help prevent seed from being planted too deeply.

Regardless of planting method, it is critical to set the equipment for the proper seeding rate, depth, and distribution. Follow the manufacturer's instructions for calibrating seeding rate and setting planting depth. It is wise to check seeding rate and depth in a small test strip, traveling at field speed.

An accurate way to calibrate a drill is to pull it over the test area at field speed while catching the seeds from several seed drop tubes in cups or bags. Measure the distance traveled. Weigh or count the seeds to determine the number of seeds dropped per linear foot of drill row. Compare results with table 4.1. Adjust equipment as required for the desired seeding rate.

To calibrate broadcasting equipment, count the seeds dropped per square foot and compare the number with the seed number under the column labeled "At 1 lb/acre seeds/ft^2" in table 4.1. Adjust equipment as required for the desired seeding rate.

Conventional or minimum/no-till planters

A properly maintained and calibrated drill plants seed evenly and with good seed-to-soil contact. Drills equipped with a box for small seeds, depth regulator, and press wheels give the best results (figures 4.1–4.3). The seed box should have agitators to keep seed blended and prevent bridging, allowing for an even

Figure 4.1. Example of a conventional drill with double disk openers and press wheels. (Photo by Glenn Shewmaker)

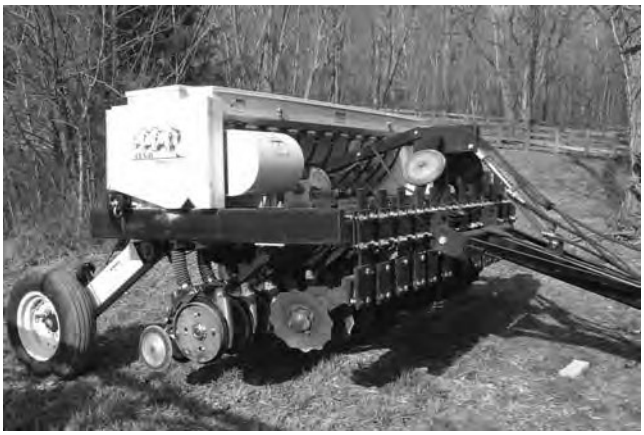

Figure 4.2. Example of a no-till drill. Front coulter disks cut sod or residue prior to seed placement by double disk openers. (Photo by Glenn Shewmaker)

Figure 4.3. Example of an ideal drill with depth-control bands on the double disk openers and press wheels that firm the soil for good seed-to-soil contact. (Photo by Glenn Shewmaker)

Table 4.1. Seeding rates of Pure Live Seed for grasses and legumes (irrigated[a] or non-irrigated with more than 18 inches annual precipitation). Use this table to calculate seeding rates for species and row spacings listed and to calibrate planting equipment.

Species	Seeds/lb	At 1 lb/acre seeds/ft^2	6-inch row[b]		12-inch row	
			lb/acre	Seeds/ft	lb/acre	Seeds/ft
GRASSES						
Brome						
Meadow	101,000	2	10	11	10	21
Mountain	80,000	2	14	15	14	29
Smooth	136,000	3	7	10	7	20
Creeping foxtail	760,000	17	3	26	3	52
Kentucky bluegrass	2,177,000	50	3	58	3	117
Orchardgrass	650,000	15	4	23	4	45
Perennial ryegrass	227,000	5	6	6	6	13
Reed canarygrass	530,000	12	4	23	4	46
Tall fescue	227,000	5	6	16	6	32
Timothy	1,200,000	28	4	57	4	113
Wheatgrass						
Intermediate	80,000	2	9	11	9	21
Tall	76,000	2	13	12	13	24
Western	114,000	3	8	10	8	20
LEGUMES						
Alfalfa	225,000	5	6	14	6	28
Birdsfoot trefoil	380,000	9	5	27	5	54
Cicer milkvetch	135,000	3	8	14	8	27
Clover						
Alsike	690,000	16	4	32	4	64
Ladino	800,000	18	3	28	3	55
White Dutch	768,000	18	3	28	3	55
Red	275,000	6	6	19	6	38
Sainfoin	22,700	1	45	16	45	31
Sweetclover	260,000	6	6	18	6	36

[a] Including subirrigated, water-spreading systems and land with limited irrigation water.

[b] For 7-inch drill rows, multiply the 6-inch row rate by 1.17.

distribution of seed. If the drill does not have press wheels or drag chains, you will need to roll or cultipack the field immediately following planting. However, planting, rolling, or cultipacking on wet soils may cause soil crusting.

Alternate-row seeding is another option when planting a legume with a grass, if your planter is so equipped. Planting legumes in alternating rows between grass rows decreases competition between the legume and the grass, thus increasing the chances of successful establishment of the mixed legume-grass stand. Alternate-row seeding is important in areas where seedling establishment is challenging and for species that compete poorly during the seedling stage.

Another option is a double-corrugated roller-planter such as the Brillion seeder. This type of planter drops the seed in front of an indented roller, which incorporates the seed and firms the soil. These planters require a very well-prepared seedbed with no surface residues. They do not perform well in sandy or very hard soils.

Broadcasting

You can broadcast seed on the soil surface with a fertilizer spinner or air applicator equipment. Broadcasting is the preferred seeding method where conditions limit the use of conventional planting equipment. Examples include rocky areas, steep slopes, and wet soils.

To ensure a good stand when broadcasting, increase the seeding rate by 30 to 100 percent. The higher rate will compensate for poorly placed seed. Ideally, broadcast half the seed over the field in one direction and the other half perpendicular or at an angle to the first pass.

Following broadcasting, immediately incorporate the seed into the soil with a roller, cultipacker, or light harrow. It is critical to cover the seed properly and firm the soil. However, make sure the seed is placed no deeper than 0.25 to 0.5 inch.

TIME OF PLANTING

Depending on location and environmental conditions, planting can occur in spring, late summer, fall, late fall, or early winter. When choosing a planting time, consider the following: soil moisture (from precipitation and/or irrigation), soil temperature, soil type, weeds, and dates when killing frosts are likely to occur. Regardless of planting time, we recommend preparing the soil well in advance so that the field is ready when the window of opportunity for planting is open.

Spring planting

Spring planting is recommended in many areas of the Northwest. Spring planting can be especially advantageous where winter annual weeds (e.g., cheatgrass, medusahead, annual rye, or broadleaf weeds) are a problem, as it allows for an additional tillage or herbicide application before planting.

Plant when established pastures begin to grow well in the surrounding area. If planting grass on sites prone to soil crusting, such as clay to clay loam soils, plant as soon as the ground is accessible to equipment.

Late-summer planting

Late summer is a good time for planting in some areas. For most of the Pacific Northwest, late-summer planting is recommended only if irrigation water is available for plant establishment. Monitor soil moisture and irrigate if moisture is inadequate to support good germination and emergence.

Most forage seedlings must be 2 to 3 inches tall (or have three or more true leaves) in order to survive killing frosts. For most grasses and legumes, this amount of growth requires at least 6 to 8 weeks of good growing weather. At high elevations, plant in early August. In warmer areas of the Pacific Northwest, planting can be done as late as September 1.

Dormant fall or winter planting

In areas with less than 12 to 14 inches of annual precipitation, late-fall dormant plantings are recommended. Dormant plantings are also recommended where soils are too wet for conventional planting equipment during most of the year. Under these conditions, planting when soils are frozen may be the only option.

Plant late enough in the fall or winter to ensure that low temperatures will delay germination. The seeds will germinate the following spring, when they can take advantage of winter soil moisture and spring precipitation. Dormant plantings are recommended for grass-only planting since legume seeds often do not survive the winter and early spring.

SEEDING RATES

Tables 4.2a through 4.2c give example seeding rates for monocultures and mixes. Recommendations vary, depending on local conditions. Contact your local university extension office or a reputable seed dealer for recommendations in your area.

Seeding rates for forages are based on Pure Live Seed (PLS) rates. You will need to adjust these rates based on the purity and germination rate of your seed. This adjustment is a two-step calculation.

1. Calculate the percentage of PLS:

$$\text{PLS} = \frac{\text{percent purity} \times \text{percent germination}}{100}$$

You can find information about percent purity and percent germination on certified seed labels. For example, if the seed label states 88 percent pure seed and 85 percent germination, the PLS is 75 percent: (88 x 85) ÷ 100 = 75.

2. Adjust the per-acre seeding rate given in Table 4.1 and Table 4.2 based on the percentage of PLS:

$$\text{adjusted seeding rate} = (\text{seeding rate} \times 100) \div \text{PLS}$$

For example, if table 4.1 or table 4.2 suggests a seeding rate of 15 pounds PLS per acre, and the PLS is 75 percent, the adjusted seeding rate is 20 pounds per acre: (15 x 100) ÷ 75 = 20.

In this situation, you would plant 20 pounds of seed per acre to attain the recommended rate of 15 pounds PLS per acre. The higher amount accounts for contaminants in the seed and less-than-perfect germination.

You can also use PLS calculations to determine the best value when comparing seed lots with different prices, purity, and germination rates.

For help calculating seeding rates, see the University of Wisconsin Extension Pasture and Hay Seeding Rate Calculator (available at http://www.uwex.edu/ces/forage/articles.htm under the "Grazing/Pasture" heading).

Legume seed inoculation

All legumes require inoculation with the proper strain of nitrogen-fixing *Rhizobium* bacteria. Some legume seed is sold pre-inoculated. Check storage conditions and the shelf life of inoculated seed to be sure inoculum is still viable. If seed is not inoculated, or if inoculum viability is in question, you will need to inoculate the seed before or during planting.

Table 4.2a. Examples of pasture seeding rates in three types of soil in areas with at least 18 inches of annual precipitation and/or irrigation (lb PLS/acre). (For mixes, choose one or two grasses and one or two legumes (optional).)

	Good/Deep			Heavy/Clay	Light/Shallow/Gravelly	
	Mix A	Mix B	Single species	Single species	Mix	Single species
GRASSES						
Perennial ryegrass	—	—	15	—	—	—
Smooth brome	—	9	—	15	9	15
Orchardgrass	5	5	—	—	5	—
Tall fescue	—	—	14	14	—	14
Meadow brome	9	—	14	—	—	—
LEGUMES						
Alfalfa	1	1	1	1	1	1
Birdsfoot trefoil	1	1	1	1	1	1
Cicer milkvetch	1	1	1	1	1	1
Red clover	1	1	1	—	—	—
White clover	1	1	1	1	—	—
Sainfoin	17	17	17	—	17	17

Notes: See page 38

Table 4.2b. Examples of pasture seeding rates in areas with a high water table and at least 18 inches of annual precipitation and/or irrigation (lb PLS/acre).

	Water table more than 20 inches below soil surface—Single species	Water table less than 20 inches below soil surface—Single species	Standing water for extended period—Single species
GRASSES			
Tall fescue	14	14	—
Tall wheatgrass	14	—	—
Creeping foxtail	—	10	10
Reed canarygrass	—	10	10
NewHy hybrid	18	—	—
Timothy	—	10	10
LEGUMES			
Alsike clover	1	1	—
Strawberry clover	1	1	1
Birdsfoot trefoil	1	1	—

Table 4.2c. Examples of pasture seeding rates in three types of soil in areas with 14 to 18 inches of annual precipitation and/or irrigation (lb PLS/acre). (For mixes, choose one or two grasses and one or two legumes (optional).)

	Good/Deep soil					Heavy/Clay soil			Light/Shallow/Gravelly soil
	Mix A	Mix B	Mix C	Mix D	Single species	Mix A	Mix B	Single species	Single species
GRASSES									
Intermediate wheatgrass	7	8	7	—	14	7	7	14	14
Tall fescue	—	—	—	—	14	—	—	14	—
Smooth brome	7	—	—	—	14	7	—	14	—
Dryland orchardgrass	—	6	—	6	—	—	—	—	—
NewHy hybrid	—	—	9	9	18	—	9	—	—
LEGUMES									
Alfalfa	1	1	1	1	1	1	1	1	1
Sainfoin	17	17	17	17	17	—	—	—	—

Notes:

- Recommendations vary greatly, depending on local conditions. Contact your local university extension office or a reputable seed dealer for specific species and seeding rate recommendations for your area.
- Rates are pounds of Pure Live Seed (PLS) per acre. See page 37 for information on how to adjust rates based on percent purity and percent germination.
- Seeding rates are based on using a properly calibrated seed planter.
- If broadcasting seed, add 30 to 100 percent more seed per acre.

Sources:

Adapted from Jensen, K.B., W.H. Horton, R. Reed, and R.E. Whitesides. 2001. *Intermountain Planting Guide*. AG510. Utah State University Extension.

Ogle, D., L. St. John, M. Stannard, and L. Holzworth. 2008. *Grass, Grass-Like, Forb, Legume, and Woody Species for the Intermountain West*. Plant Materials Technical Note No. 24. USDA Natural Resources Conservation Service. Boise, ID, Bozeman, MT, and Spokane, WA.

Table 4.3 lists several legumes and their compatible strains of *Rhizobium* bacteria. Some strains are compatible with multiple legume species. For more information about legume inoculants and application methods, see University of Idaho Extension publication CIS 838, *Inoculation of Legumes in Idaho*.

Companion crops

Companion crops (cereals or peas) can help control erosion on light soils and surface-irrigated sites. They can also improve weed control and provide additional first-year forage.

However, companion crops are usually not recommended, as they can be too competitive with forage seedlings. Direct seeding of grasses and legumes usually results in quicker establishment, higher overall yield, and a better stand over most of the stand's life.

The order of competitiveness (least to most competitive) is as follows: peas, oats, spring wheat, rye, triticale, and barley. When selecting a companion crop, choose a variety with early maturity and short to medium height to minimize competitiveness.

Plant cereal companion crops at one-fourth to one-third the normal rate. Since cereals are planted deeper than grasses or legumes, plant the companion crop before planting the forage crops. Some planters have dual seed boxes so that the companion crop and forage crop can be planted in the same operation. However, make sure the grass and legume seed is planted no deeper than 0.5 inch.

Ensure that ample moisture is available for both the companion crop and the new forage seedlings. Mow or harvest the companion crop at an early stage to reduce competition and allow new forage seedlings to establish.

Another option where erosion is a problem is to plant a cereal crop and allow it to grow about 4 to 8 inches tall. Then kill the plants with glyphosate according to label directions. Plant grasses and/or legumes directly into the stubble.

New seeding maintenance

The long-term health of a pasture depends on proper care during the establishment year. Good water management (chapter 6), fertility (chapter 3), weed control (chapter 7), and mowing or grazing are all important.

Table 4.3. Legumes and their associated *Rhizobium* bacteria inoculants.

Legume	***Rhizobium* bacteria**
Alfalfa	*Rhizobium meliloti*
Sweet clover (yellow or white)	*Rhizobium meliloti*
Alsike clover	*Rhizobium trifolii*
Red clover	*Rhizobium trifolii*
Strawberry clover	*Rhizobium trifolii*
Subterranean clover[a]	*Rhizobium trifolii*
White clover	*Rhizobium trifolii*
Field peas (Austrian, dry, green)	*Rhizobium leguminosarum*
Birdsfoot trefoil	*Rhizobium loti*
Cicer milkvetch	*Astragalus*-specific *Rhizobium*
Sainfoin	*Rhizobium* spp.

[a] Selected strains of *Rhizobium trifolii* specific for this legume species are most effective.

Mowing is the best weed-control method during the establishment year. Clipping annual weeds above the new seedlings stunts or kills weeds, thus reducing competition and allowing the forage plants to grow. Always leave 4 to 6 inches of forage stubble to sustain healthy plants and enable quicker recovery. Adequate stubble is especially important in the fall, as it provides young plants with food reserves for winter survival and spring green-up. Over time, healthy forage stands will outcompete annual weeds.

Herbicide use is limited in young stands due to unacceptable damage to new grasses and legumes. However, some herbicides are available for control of broadleaf weeds in new pastures. See chapter 7 for weed-control options.

Ideally, you should not graze new pastures for at least 1 year, but you can use the "pull test" to determine whether a new pasture is ready for grazing. Simply tug sharply on a single forage plant. If the plant pulls out, do not graze the pasture. If the forage passes the pull test, the new pasture is ready for light grazing. Do not allow grazing when the soil is saturated.

For more information

Grass, Grass-Like, Forb, Legume, and Woody Species for the Intermountain West. Plant Materials Technical Note No. 24. USDA Natural Resources Conservation Service (2008). http://www.plant-materials.nrcs.usda.gov/pubs/idpmstn7079.pdf

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Inoculation of Legumes in Idaho. CIS 838. University of Idaho Extension (1988). http://info.ag.uidaho.edu/catalog/detail.asp?IDnum=242

Pasture and Hay Seeding Rate Calculator. University of Wisconsin Extension. http://www.uwex.edu/ces/forage/articles.htm

Pasture and Hayland Renovation for Western Washington and Oregon. EB1870. Washington State University Extension (2002). http://cru84.cahe.wsu.edu/cgi-bin/pubs/EB1870.html?id=mzkqpJCN

Pasture and Range Seedings: Planning-Installation-Evaluation-Management. Plant Materials Technical Note No. 10. USDA Natural Resources Conservation Service (2008). http://www.plant-materials.nrcs.usda.gov/pubs/idpmstn6306.pdf

Pasture Management Guide: Coastal Pastures in Oregon and Washington. EM 8645. Oregon State University Extension Service (1996). http://extension.oregonstate.edu/catalog/pdf/em/em8645.pdf

Pasture Principles for Smaller Acreages. BUL 849. University of Idaho Extension (2008). http://info.ag.uidaho.edu/pdf/BUL/BUL849.pdf

CHAPTER 5

Growth, Development, and Defoliation Responses of Pasture Plants

S. Fransen and T. Griggs

PASTURES TYPICALLY PROVIDE THE LOWEST-COST SOURCE OF FORAGE (energy) in any livestock operation. Well-maintained irrigated pastures have few weeds, grow rapidly, produce high-quality herbage for high animal intake, and recover rapidly following grazing. Without periodic rest and recovery, however, the productivity of irrigated pastures is often less than their potential. The keys to having more productive land and more profit are to adopt Management-intensive Grazing (MiG) and to understand how plants grow. Then, by monitoring and managing the structure, growth stage, physiology, nutritional value, and defoliation of pasture plants, you can improve your ability to do the following:

- Predict plant responses to environmental conditions and management
- Recognize when plant growth is reduced by deficiency of a particular nutrient
- Optimize the productivity, seasonal growth distribution, nutritional value, persistence, and species composition of your pastures

In this chapter, we provide the knowledge needed to optimize pasture growth and productivity. We discuss plant structure, forage growth patterns, and the importance of energy reserves and residual leaf area for plant regrowth. Grazing guidelines based on these factors are provided for grasses, legumes, brassicas, other forbs, and mixed pastures. Other important considerations for grazing management include animal nutrition (chapter 10) and forage quality (chapter 11).

Key Points

- Understanding the positions and activities of plant growing points allows you to predict pasture growth rates, species proportions in regrowth of mixtures, and quantities of regrowth.
- Pasture growth rates vary widely across the growing season, with peak productivity in late spring to early summer.
- Forage species differ in plant structure and their response to defoliation.
- Regrowth of grazed plants requires energy from sunlight (captured by live leaves) and mobilization of stored reserves. Thus, both green leaf area and stubble are important. The relative importance of these two energy sources varies among species, with implications for target stubble heights.
- In grasses, energy reserves are stored primarily above ground in stem bases. In taprooted legumes, energy reserves are stored primarily below ground. Thus, grasses typically require higher stubble heights after grazing.

The morphological basis of defoliation management

Understanding plant structure (also called morphology) and how structure varies among species is important to grazing management. In this section, we discuss key plant structure characteristics as they relate to grazing management.

PLANT SHOOT STRUCTURE

Grasses and legumes are composed of repeating modules or subunits (phytomers). Each phytomer contains a leaf and bud attached to a node (joint) that is positioned at the base of an internode (figure 5.1). A fully developed leaf consists of a blade and sheath in grasses, or leaflets and a petiole in legumes. A shoot is a collection of phytomers, sometimes including an inflorescence. In grasses, a shoot is usually called a tiller. We will use the term shoot, however, as this term applies to both grasses and legumes.

In some cases, internodes are elongated and connected by visible, palpable nodes. Elongated internodes and intervening nodes are often referred to as "true" stem. In other cases, internodes are compressed (unelongated), and nodes can be neither seen nor felt (1A in figure 5.2). A plant with a collection of unelongated internodes and intervening nodes may be referred to as "stemless." Thus, shoots may range from having visible leaves but no visible stem to having leaves attached to an elongated stem with or without an inflorescence (figure 5.2). As shoots age, leaves die and may fall off of the lowest nodes.

The life span of a shoot is typically less than one growing season or year. Depending on the growth stage at grazing or cutting, many annual forages have little or no regrowth potential during a growing season. Most perennial pasture species, on the other hand, can have multiple growth cycles during a season. The persistence of perennial grasses and legumes over multiple seasons is based on a succession of short-lived or annual shoots. Perennials are able to live for multiple years because some of their growing points can survive the winter and resume growth during the next growing season.

MERISTEM LOCATIONS AND ACTIVITIES

Growing points, also known as meristems, are sites of cell division and growth. Meristems give rise to new leaves, stems, roots, and inflorescences, as well as to additional meristems and new shoots. There are three meristematic sources of tissue growth in grasses and legumes: apical, intercalary, and axillary meristems (figure 5.1). Each of these meristems is described below.

Meristems are important because they are the source of all plant growth. In later sections of this chapter, we will see how the positions and activities of meristems vary (depending on species, plant growth stage, and plant height) and how those differences affect grazing decisions.

Key Terms

Crown—Junction where plant shoots and roots meet, near the soil surface. A pasture plant may have a single shoot or multiple shoots arising from the same crown.

Inflorescence—Reproductive portion of a plant (flowers or seedhead). Found at the terminal ends (tops) of tillers or branches.

Long-shooted species—A species whose internodes elongate during vegetative growth.

Meristem—A growing point, or site of cell division and growth. Meristems give rise to new leaves, stems, roots, and inflorescences, as well as to additional meristems and new shoots.

Phytomer—A single module of a plant shoot. Each phytomer contains a leaf and bud attached to a node that is positioned at the base of an internode.

Shoot or tiller—A collection of phytomers, often called a tiller in grasses and a shoot or branch in legumes.

Short-shooted species—A species whose internodes do not elongate during vegetative growth.

Vernalization—Process of inducing plant flowering through environmental signals (decreasing day length and/or low temperatures) during fall or winter. Vernalized shoots flower and set seed during the following growing season.

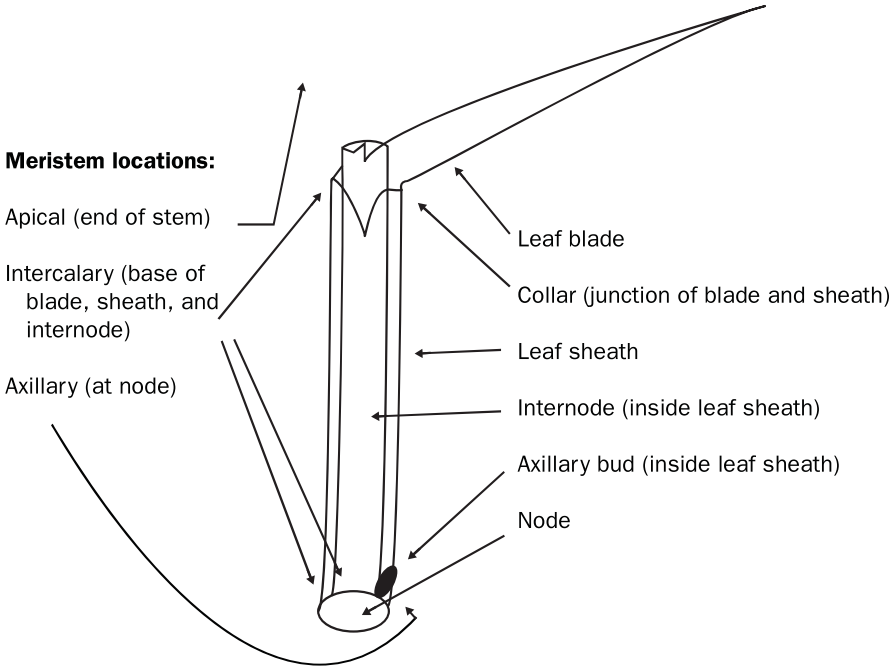

Figure 5.1. Locations of meristems and components of a grass phytomer, the repeating subunit of plant structure. A fully developed grass leaf consists of a blade and sheath joined at the collar, which forms when the leaf is fully elongated. On a legume phytomer, the leaf consists of multiple leaflets at the end of a petiole that is attached to a node.

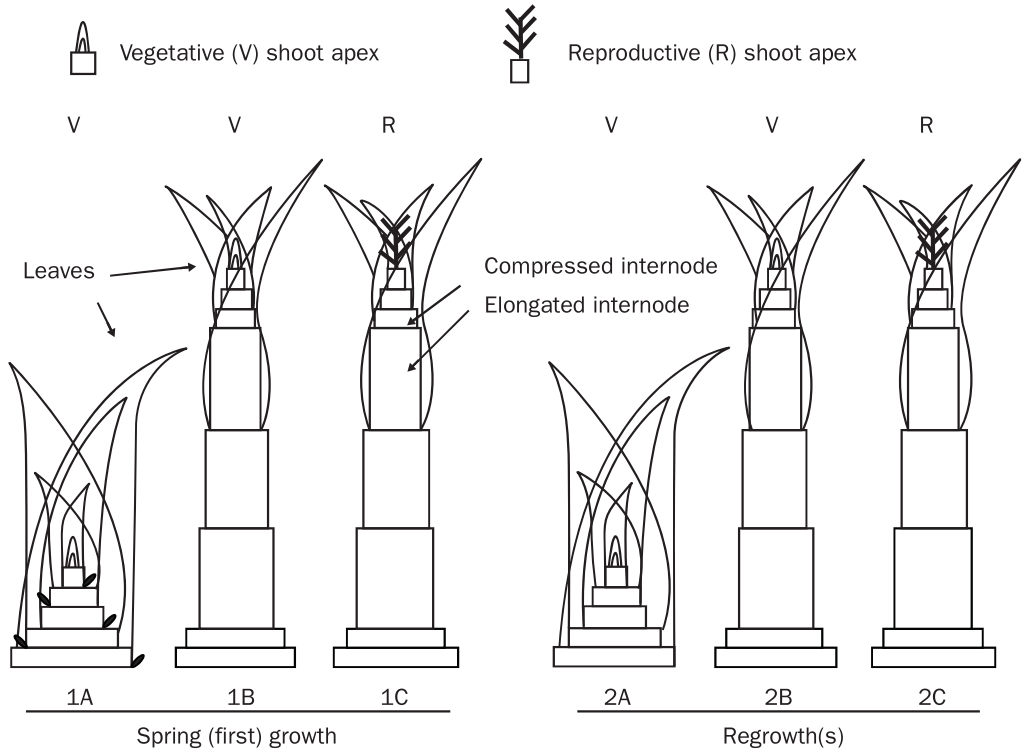

Figure 5.2. Differing growth patterns of grass tillers during spring and regrowth cycles following defoliation (V = vegetative, R = reproductive shoot apex). All shoots have axillary buds as in 1A. **Shoots 1A and 2A** are vegetative shoots of short-shooted species with a vernalization requirement for flowering. **Shoots 1B and 2B** are vegetative shoots of long-shooted species with a vernalization requirement for flowering. **Shoot 1C** is a reproductive shoot of a short- or long-shooted species that (a) formed the previous fall and has a vernalization requirement for flowering, or (b) formed in spring and has no vernalization requirement for flowering. **Shoot 2C** is a reproductive shoot of a short- or long-shooted species that formed in summer and has no vernalization requirement for flowering. **Shoots 1A and 1B** were vernalized the previous fall, survived winter, and shifted to 1C in spring. **Shoots 2A and 2B** formed during summer and remained vegetative during a regrowth cycle because they were not vernalized. If shoots **2A or 2B** did not have a vernalization requirement for flowering, they could shift to 2C.

Apical meristems

An apical meristem (also known as a shoot apex or root apex) is located at the growing end of each stem and root. Note that stolons and rhizomes are stems that grow horizontally above or below the soil surface. They have the same structure as a vertical stem, including an apical meristem at the growing end.

A vertical stem is short and remains near ground level if internodes have not elongated (1A, 2A in figure 5.2). A stem can be in a vegetative (1A, 1B, 2A, 2B) or reproductive (1C, 2C) stage, depending on the tissues produced by the apical meristem. A vegetative apical meristem produces leaves, internodes, nodes, root initials, and axillary buds below it, but does not produce inflorescences. It remains positioned above the most recently generated tissues.

Root initials are specialized meristematic cells located at the bases of internodes. They may generate so-called nodal or adventitious roots at a later date. These nodal roots form at the base of a shoot and near nodes on rhizomes and stolons. These are the meristems that allow cuttings to root after planting.

A vegetative apical meristem can continue generating leaves and other phytomer parts until it is removed by defoliation (if elevated, 1B, 2B), dies due to age or shading in a dense canopy, or shifts to reproductive status (1C, 2C). Once an apical meristem shifts to reproductive status, it produces an inflorescence and shoot growth ceases. Any replacement growth, regardless of whether the reproductive shoot is defoliated, must arise from axillary buds, as explained below.

Apical meristems also produce the other two types of meristems described below, so in a sense, apical meristems are the source of all forage plant growth; above ground, below ground, and horizontal.

Intercalary meristems

An intercalary meristem is located at the base of each leaf blade, leaf sheath, and internode (figure 5.1). These meristems allow tissues to elongate. At certain times of the year, the intercalary meristems on internodes are inactive on many species; thus, internodes remain compressed. The lowest one or more internodes (those nearest the crown) often remain unelongated throughout the life of a shoot, even if internodes above the crown eventually elongate (1B, 1C, 2B, 2C in figure 5.2).

An active intercalary meristem that remains following defoliation can continue to generate new tissue until the leaf or internode is fully expanded. Grass leaves, which differentiate blades and sheaths as they mature, can continue expanding until formation of the collar at the junction of blade and sheath (figure 5.1). This growth from intercalary meristems is easily observed in mowed lawns, where young, uncollared grass leaves continue to lengthen after their tips have been clipped off.

Axillary meristems

The axil is the angular junction at which a leaf is attached to a node. An axillary meristem (also known as a tiller bud, crown bud, or basal bud) is located in each axil (shown only in 1A in figure 5.2; assume that all shoots have them). When a shoot arises from this growing point, the axillary meristem becomes the apical meristem of the new shoot.

Axillary buds often are inactive until their parent shoot reaches maturity or until the apical meristem is removed. In many grasses and legumes, axillary buds at higher nodes remain inactive throughout the life of the shoot. Reed canarygrass is a cool-season grass that can activate upper axillary buds, often at heights of 3 or 4 feet, during summer growth. Reed canarygrass must be in a moist environment (usually without being grazed or cut for hay) in order for these new aerial shoots to form from axillary buds. These unusual new shoots are easy to miss when walking in the field, but on close inspection they look so out of place that you'll likely think you're seeing double, and you are!

If an apical meristem is removed, leaf and internode growth may continue from intercalary meristems for a limited time. However, shoot replacement (i.e., the next crop of short-lived shoots) can occur only from axillary buds.

New shoots can also emerge from axillary buds on stolons (white clover) and rhizomes (quackgrass, smooth brome, Kentucky bluegrass, and reed canarygrass), as can new roots from near nodes. This process of new shoot formation is referred to as tillering. See Briske (1991) and Manske (1998) for more information on grass developmental morphology.

Understanding forage growth patterns

Volumes have been written about plant growth and development, but if you simply understand the basics of this topic, grazing management becomes easier. The important concepts to understand relate to new shoot formation, induction of flowering, internode elongation, leaf maturity and senescence, sources of energy

for regrowth, and seasonal distribution of pasture growth. Each of these topics is discussed below.

NEW SHOOT FORMATION

Tillering, or the formation of new shoots, replaces older and dead shoots. It increases the live shoot density of plants, thereby filling gaps in the pasture canopy. In most perennial cool-season grasses, only the axillary buds at the crown region of the parent tiller form new tillers. In many legumes, tillering can occur from axillary buds at various positions at or above the crown.

Grass species vary in the timing of shoot formation:

- In many perennial grass species, new shoots form from axillary buds in spring and fall.
- In some species, such as Kentucky bluegrass, orchardgrass, perennial ryegrass, and tall fescue, new shoots form at a relatively constant rate throughout the growing season. This continuous shoot formation occurs regardless of the developmental stage or defoliation history of the parent shoots. This trait is desirable in turf and pasture grasses for continuity of growth.
- In other species, new shoots form in pulses or waves as the parent shoots reach maturity or are defoliated. This pattern of shoot development is common in taller-statured hay grasses (e.g., timothy, smooth brome, intermediate wheatgrass, and some warm-season perennial grasses such as switchgrass) and in legumes such as alfalfa.

VERNALIZATION

In many species (including most cool-season perennial grasses), environmental signals that occur during fall or winter induce plants to flower and set seed during the following growing season. This process is known as vernalization. It occurs in response to decreasing day length and/or temperature during fall or winter. Fall-planted seeds can be vernalized in some cases, but shoots are the main receptors of the winter signal.

Only shoots that are present in fall or winter can be vernalized. Those that survive until spring can then flower in response to increasing day length and/or temperature (1A and 1B become 1C in figure 5.2).

In species with a vernalization requirement, shoots that originate in spring or summer will remain vegetative and will not develop reproductively during that growing season (2A, 2B). Thus, spring-seeded plants that have a vernalization requirement will not develop seedheads during their first growing season.

Most pasture legumes do not have a vernalization requirement. They develop to reproductive stages during each spring and summer growth cycle if not defoliated.

INTERNODE ELONGATION AND REPRODUCTIVE DEVELOPMENT

In some grasses (known as short-shooted species), internode elongation coincides with a shift from vegetative to reproductive development. In other species (long-shooted species), internodes can elongate while vegetative growth continues. Legume internodes usually elongate throughout each growth cycle, regardless of their reproductive status.

Once internodes elongate, the apical meristem becomes vulnerable to removal through grazing or mechanical harvesting. *Thus, pasture plants respond differently to defoliation depending on whether internodes elongate during vegetative growth.*

Short-shooted (SS) species

Species with short shoots are not necessarily short-statured plants, but their internodes do not elongate during vegetative growth (1A, 2A in figure 5.2). Thus, their apical meristems remain protected on stemless shoots near ground level. These species are considered more defoliation-tolerant than long-shooted species.

At some point in the growing season (typically in the first growth cycle for grasses), the apical meristem of a short-shooted species may shift from vegetative to reproductive status (1A to 1C in figure 5.2). At this time, internode elongation may elevate the apical meristem, making it susceptible to removal by grazing early in the growth cycle.

Examples of short-shooted species are Kentucky bluegrass, orchardgrass, perennial ryegrass, tall fescue, and meadow brome (table 5.1).

Long-shooted (LS) species

In species with long shoots, internodes are elongated during both vegetative (1B, 2B in figure 5.2) and reproductive (1C, 2C) growth. In other words, internodes are always elongating. In the case of rhizomes and stolons, elongation is lateral.

This elongation exposes apical meristems on shoots to defoliation even if the grass is not overgrazed. These species are considered more defoliation-sensitive and must be better managed to maintain stands in pastures.

Table 5.1. Common long-shooted (LS) and short-shooted (SS) irrigated forage grasses and their growth characteristics.

Species	LS/SS	Vernalization requirement	New shoot development
Big bluestem	LS	No	Pulses
Italian (biennial) ryegrass	SS	Yes	Season-long
Indiangrass	LS	No	Pulses
Kentucky bluegrass	SS	Yes	Season-long
Meadow brome	SS	Yes	Season-long
Meadow fescue	SS	Yes	Season-long
Orchardgrass	SS	Yes	Season-long
Perennial ryegrass	SS	Yes	Season-long
Smooth brome	LS	Yes	Pulses
Switchgrass	LS	No	Pulses
Tall fescue	SS	Yes	Season-long
Timothy	LS	No	Pulses
Westerwolds (annual) ryegrass	SS	No	Season-long

The recovery rate for regrowth is slower for long-shooted grasses than for short-shooted species. Some long-shooted species, e.g., timothy, smooth brome, and alfalfa, may also have low energy reserves and a limited basal leaf area during internode elongation prior to flowering. These characteristics make these species even more sensitive to defoliation.

Other long-shooted grass species include reed canarygrass and intermediate wheatgrass. Legumes are long-shooted species.

Timing of internode elongation

On established perennial grasses (both short-shooted and long-shooted), reproductive shoots with elongated internodes tend to develop during the primary (first) growth cycle of the season (1C in figure 5.2). Growth patterns diverge as follows during subsequent regrowth cycles:

- Species with a vernalization requirement for flowering will not develop reproductively (2A, 2B). Those without a vernalization requirement may do so (2C).
- On short-shooted species, internodes will not elongate unless they become reproductive. Long-shooted species and legumes will elongate internodes in both vegetative and reproductive phases.

These differences are important because they mean that short-shooted species with a vernalization requirement will remain vegetative on stemless shoots during regrowth cycles. This growth habit means a high leaf concentration and that the apical meristem will continue to be protected from grazing throughout the growing season. Many cool-season perennial grasses fall into this category. (Timothy is an exception.)

Most perennial warm-season grasses have no vernalization requirement and tend to be long-shooted, so they develop reproductive shoots with elongated internodes during regrowth cycles. These grasses, e.g., switchgrass, big and little bluestem, and eastern gamagrass are considered short-day plants and flower in response to changes in day length.

LEAF MATURITY AND SENESCENCE

Following grazing, the intercalary meristems on the grass leaf will regrow rapidly until the collar region forms as blade and sheath elongate fully. At that time, the intercalary meristems stop growing, and the leaf has reached its maximum dry weight (yield).

As perennial forage plants grow taller and mature, upper-canopy leaves shade the lower leaves. These older, shaded leaves turn yellow and brown as they senesce (die). Some detach from lower nodes (figure 5.2), but those that remain have some capacity to store nutrients and sugars, which can be mobilized for active regrowth or winter survival. As the entire plant matures, these soluble materials are moved to the stubble and crown. Storage may be more pronounced in some grasses (e.g., timothy, smooth brome, reed canarygrass, and switchgrass) than others, but it's important for all forage grasses.

Grasses vary in how many actively growing leaves they can sustain at any time. For example, many perennial ryegrass shoots sustain only 3 leaves, while a timothy shoot may sustain more than 10 leaves at a time.

SEASONAL DISTRIBUTION OF PASTURE GROWTH

Under most conditions in the Northwest, daily pasture growth rates for cool-season grasses fluctuate widely during the growing season. As shown in figure 5.3, the pasture growth rate usually peaks as a function of temperature in late spring and declines during hotter summer temperatures.

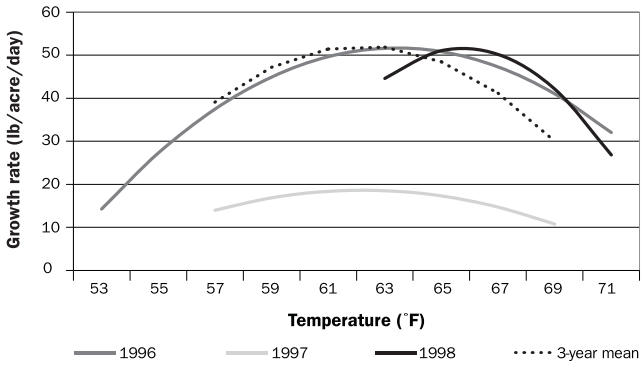

Figure 5.3. Daily growth rate of irrigated perennial cool-season grass managed as simulated grazing (Klamath Experiment Station, Oregon State University). (Source: Dovel, R.L. and J. Rainey. 1999. Pasture and hay grass variety trial, 1998. In: *Research in the Klamath Basin, 1998 Annual Report*. Special Report 1007. Agricultural Experiment Station, Oregon State University).

These growth patterns were demonstrated by a 3-year study at Klamath Falls, Oregon. Dovel and Rainey (1999) compared pasture yields of 24 cool-season perennial grasses over 3 years. Yields were lower in 1997 due to a colder spring that delayed grass growth compared to other study years. Daily growth rates in 1996 and 1998 were similar, due to more typical seasonal temperature conditions, although the spring of 1998 was wetter than normal.

Spring

During early-spring growth (i.e., when temperatures are below 60°F), grass growth is slow. Growth rates then increase during the spring flush period, as soil water is usually adequate, temperatures are optimum, a second generation of roots is growing, and grass stems are elongating.

Fertilization practices can maximize forage growth during this period. In early spring, new root growth begins underground 1 to 4 weeks before new shoots appear. These new roots have immediate access to nitrogen (N) that becomes available as soils warm and microorganisms break down organic matter. Research at Oregon State University evaluated the T-sum system of applying the first N in the spring. The T-sum system is based on accumulation of growing degree days (GDD) starting on January 1. Cool-season grass yield during the spring flush is significantly higher if N is applied when 200 GDD have accumulated, rather than by the traditional calendar date. This response is partially explained by the ability of healthy new grass roots to utilize N applied during early spring (see chapter 3 for more information).

Summer

As the growing season advances, pasture growth rates decline in response to soil water deficiency (even in some irrigated systems), high temperatures, and often lower levels of soil N. At this time, cool-season grasses are shedding roots and most species are no longer elongating stems.

By late August, early mornings become cooler, afternoons are not as hot, and day length is decreasing. These are important environmental signals to pasture plants. For the next month, these dramatic climate changes continue, and grasses begin to regrow more rapidly.

Fall and winter

In the fall, color changes in leaves are very apparent as grasses prepare for winter dormancy. Fall is considered the beginning of the perennial cool-season grass cycle because grasses produce the first generation of roots and most of their apical meristems during this time. These apical meristems develop on basal shoots that arise from axillary buds. This process often begins in September or October and continues until freeze-up. In order to initiate this process, cool-season grasses must retain enough basal leaf tissue to "see" that days are shortening. Grasses transition into root shedding during the winter dormancy period before initiating new roots the following spring.

Implications for pasture managers

By understanding these seasonal growth patterns, you can improve the uniformity of growth through the season. Some strategies include the following:

- Appropriate irrigation and fertilization—For example, you might limit phosphorus (P) and potassium (K) fertilization in spring and apply these nutrients in the early fall to stimulate apical meristem development (see chapter 3).
- Complementary use of warm-season grasses
- Greater reliance on cool-season and deeper rooted species that continue growing well at higher summer temperatures—Examples include tall fescue, alfalfa, forage plantain, and chicory.
- Proper defoliation management (see "Grazing guidelines," later in this chapter)

When the stocking rate is relatively constant throughout a grazing season, simply rotating livestock more quickly through paddocks may not prevent

reproductive development of forage plants or the accumulation of surplus spring forage. Stockpiling this spring forage for later grazing usually is not a good solution because the stockpiled forage can limit regrowth and may be of very low quality by the time it is used. Mechanical harvesting of surplus forage is an extremely effective tool for balancing seasonal forage supply and demand.

Note also that although irrigated pasture growth rates follow a predictable pattern, they can vary substantially from year to year (figure 5.3). Growth rates are a moving target that pasture managers must monitor closely. Overgrazing of irrigated pastures can easily occur if grazing is managed by the calendar or without careful observation of grasses for leaf, shoot, root, and stem development. Each year is different, and management must be adjusted to compensate for unexpected changes in weather, equipment failure, or unplanned travel by the manager.

Energy reserves and residual leaf area for regrowth

ENERGY STORAGE

Plants capture sunlight energy and carbon dioxide (CO_2) from the atmosphere and convert them to chemical energy through photosynthesis. Some of this energy is stored for later use during regrowth. Without this energy supply, pasture production cannot reach its potential. Overgrazing and mismanagement that reduce energy storage will ruin the very best pasture.

Plants store energy as various forms of carbohydrates. Structural carbohydrates (cellulose and hemicellulose) and lignin form the fibrous materials in plant cell walls. Sugars are stored temporarily in leaf tissues and then are moved overnight to longer term storage.

In grasses, long-term storage is in the bottom 3 to 6 inches of the stubble and in stolons and rhizomes. Timothy also stores energy in corms (bulb-like structures found at the base of each tiller). Only small amounts of sugar reserves are stored in the fibrous roots of grasses.

These stored carbohydrates take the form of starch (in warm-season grasses) or fructosans (in cool-season grasses). Fructosans are chains of fructose with a terminal glucose. Glucose is only about 60 percent as sweet as fructose. Thus, where fructosans are the major storage sugar in the lower portion of the plant, livestock tend to overgraze in order to eat the sweeter portions of the plant (the basal stubble).

Unlike grasses, taprooted forbs such as alfalfa, red and other clovers, sainfoin, birdsfoot trefoil, and chicory store large amounts of reserve carbohydrates in their crowns and roots. Spreading legumes such as white and kura clovers and cicer milkvetch also store energy reserves in stolons and rhizomes.

Stored sugars are in a constant state of motion. After formation and movement to storage areas, they are mobilized and used as needed by the plant for regrowth.

MAXIMIZING CARBOHYDRATE PRODUCTION AND STORAGE

Live leaf area, including the residual leaf area that remains after grazing, is required for energy capture. Thus, not every grass blade or legume leaf needs to be eaten to provide value to the pasture.

To maximize energy production and storage, you must maximize the *active* leaf area in the pasture canopy, because this is the area that produces sugar for storage. In well-managed irrigated pastures, sunlight interception is high because nearly all of the soil is covered by grass and legume leaves and basal stems. In overgrazed pastures, bare soil or weeds often intercept a large portion of the sunlight, but they don't contribute to forage yield or quality.

When other factors are not limiting, pasture growth rates are highest when the canopy leaf area intercepts approximately 95 percent of incoming sunlight energy. This means that sunlight should penetrate all the way to the soil surface on only about 5 percent of the land area. Although there is seemingly lost production potential with these gaps, they are important in the pasture canopy. If leaf area exceeds this optimum level, shading reduces productivity and tillering and increases leaf death and loss. If leaf area is much smaller, then overgrazing likely has occurred and potential pasture yield or future regrowth will be lost.

The vertical canopy structure of grass leaf blades gives them an advantage over legume leaves (which are more horizontal) in capturing sunlight. This attribute can also be a disadvantage, however, because taller leaves have a greater chance of being overgrazed if not managed correctly.

REQUIREMENTS FOR REGROWTH

Plant regrowth following defoliation—either through grazing or cutting—requires a lot of energy. There are two sources of energy for regrowth: (1) sunlight energy captured by residual leaf area, and (2) energy reserves in the stubble, crown, and roots. In general, regrowth relies mostly on energy reserves until new leaf area can capture enough sunlight to meet plant energy needs.

Species differ in their relative reliance on these energy sources, however, depending on their capacity for energy storage and their basal leaf density (table 5.2). Because sunlight capture depends on leaf density, grasses with low basal leaf density have less ability to capture sunlight following regrazing. Thus, they depend more on stored reserves. Examples include timothy, smooth brome, reed canarygrass, and bluebunch wheatgrass.

Grasses with high basal leaf density rely more on sunlight capture by residual leaves. Examples include Kentucky bluegrass, orchardgrass, perennial ryegrass, tall fescue, meadow brome, and crested wheatgrass.

Among legumes, white clover, birdsfoot trefoil, and cicer milkvetch store smaller quantities of energy during the growing season and depend more on sunlight capture by residual live leaves. Alfalfa, red clover, and sainfoin rely more on stored root reserves.

Table 5.2. Comparison of the relative dependence on different sources of energy for regrowth in common pasture grasses.

Species	Energy reserves	Sunlight capture
Bluebunch wheatgrass	x	
Crested wheatgrass		x
Kentucky bluegrass		x
Meadow brome		x
Meadow fescue		x
Orchardgrass	x	x
Perennial ryegrass	x	x
Reed canarygrass	x	
Smooth brome	x	
Tall fescue	x	x
Timothy	x	

Grazing guidelines

By understanding your grass species' regrowth requirements (reserve energy versus live leaf area) and knowing whether they are short- or long-shooted, you can assess their appropriateness for rotational versus continuous stocking and for various types of defoliation management (more frequent and severe versus less frequent and lax). This information can help you make better decisions about the following:

- The type of grazing system appropriate for your pastures
- The timing of grazing
- Targets for residual stubble after grazing
- Canopy height based on species of the pasture
- Management of mixed pastures
- Predictions of forage regrowth

Start with the following information:

- Are your species short-shooted or long-shooted? (table 5.1)
- Do they have a vernalization requirement? (table 5.1)
- What is their seasonal pattern of shoot development? (table 5.1)
- Do they depend more on energy reserves or live leaf area for regrowth? (table 5.2)
- Is the apical meristem elevated at the time of grazing? (your observation)

In this section, we'll see how you can use this information in grazing management decisions.

TIMING OF GRAZING

For well-adapted pasture grasses, such as perennial ryegrass, orchardgrass, and tall fescue, the three- to four-leaf stage is an excellent time for grazing. At this time, the pasture growth rate has been high, nutritional value is starting to decline but is still excellent, and the plant is in positive energy balance for rapid regrowth.

Research in the Pacific Northwest is limited for many taller-statured grasses such as smooth brome, timothy, and reed canarygrass. Consider grazing these species after at least the five-leaf stage.

A practical grazing example

Let's look at an example of grazing management that takes into account plant regrowth patterns. We'll assume we have a sprinkler-irrigated pasture in the Pacific Northwest (Lost Buck Ranch) and want to raise beef steers. We'll purchase steers in January and background them until the established cool-season perennial pastures are ready to graze (mid-March to mid-April). On Lost Buck's sandy soils, we will plant endophyte-free tall fescue and a grazing-type alfalfa. On the silty soils, we'll plant orchardgrass, perennial ryegrass, and annual ryegrass, plus red and white clovers. On the clayey soils, we'll consider tall fescue again, or reed canarygrass or smooth brome mixed with Kentucky bluegrass and alsike, white, and strawberry clovers.

Our pasture consists of several paddocks used in rotation. We use fencing to create the paddocks and control the steers.

The steers go from winter hay backgrounding to early-spring pasture on the sandy soils that dry out first. They will then move to the silty-soil orchardgrass-ryegrass pastures during spring flush, then onto the clayey-soil pastures during spring flush and into early summer. Then they will be rotated back to the tall fescue-alfalfa during July, as these species will have regrown well after resting. During the fall flush regrowth, the steers will return to the orchardgrass-ryegrass mix, where there should be plenty of high-quality, high-protein, digestible-fiber forage. Depending on the year, we may want to graze into early winter on the regrowth of the clayey pasture mixture, but we will make sure never to graze too low.

This is just one example of how cool-season grass and legume mixtures and rotations could be part of the Lost Buck Ranch management plan.

As we learn more about perennial warm-season grasses, these species could become an important part of the summer growth cycle. They could fill a niche when cool-season grasses become summer-dormant or have slower growth and reduced quality.

TARGETS FOR RESIDUAL STUBBLE

Rotating grazing animals before they remove excessive leaf tissue allows for a mixture of younger and older leaves to fix carbon dioxide (CO_2), promoting regrowth. For most pasture grasses, overgrazing into the stubble, i.e., the "bank account," greatly reduces stand life and pasture productivity and lengthens the time needed for regrowth before regrazing. More often than not, pasture production and quality are reduced long before they should be because the stubble height rule was violated. The result is increasing weed competition and bare soil areas.

The required stubble height for a particular species is related to the species' relative reliance on energy reserves or sunlight capture by residual leaf area for regrowth (table 5.2). Grasses that depend on stored reserves need relatively higher stubble for regrowth. Grasses that depend on sunlight capture by residual leaves may be a little more forgiving of shorter stubble heights, but they still require adequate leaf tissue to capture sunlight and form plant sugars quickly for regrowth and production. A good rule of thumb is to maintain a 3- to 4-inch stubble height for cool-season grass in irrigated pastures. Warm-season grasses require twice the stubble height (6 to 8 inches) of cool-season grasses. Stubble is also important to protect the plant crown from hoof damage and from wind and water erosion.

Taprooted legumes store considerable amounts of energy in their taproots. When grown in monocultures and allowed to store sufficient reserves between defoliations, as is typical under hay management, they can be grazed to within 1 inch of the soil surface (although a number of problems could arise from consistently managing legume pastures in this manner). When growing these species in mixtures with grasses for grazing, you must take into account the impact of defoliation on both the grasses and the legumes (see "Considerations for mixed pastures," below).

Leaving a higher stubble or residual leaf area generally allows for more frequent defoliation. By providing for higher stubble heights in your pasture management plan, you will ensure stronger stands with fewer weeds, more rapid regrowth after grazing, more consistent forage quality, and more sustainable production.

CONSIDERATIONS FOR MIXED PASTURES

To maintain productivity and desirable species proportions in a mixed pasture, grazing management—stubble height, residual leaf area, and frequency of defoliation—usually is determined by the species that is most sensitive to defoliation. For example, depending on the time of the growing season, you could graze a mixed pasture of white clover and Kentucky bluegrass or perennial ryegrass every 2 to 3 weeks to a stubble height of 1 to 2 inches or even less. (Note that such close grazing is possible only with high fertility management to keep these short-shooted grasses actively growing. Otherwise, the clover will quickly outcompete the grass in the summer, and the grass may not recover adequately in the fall.) A mixture of alfalfa and smooth brome, on the other hand, can be grazed only every 3 to 4 weeks to a stubble height of 3 to 4 inches. Frequency and severity of grazing for mixtures of red clover with orchardgrass or tall fescue would fall between these extremes.

In overgrazed pastures, desirable grasses typically are severely grazed, allowing legumes or weeds to take over the stand. Because grass leaves are more vertical than legume leaves, they are easier to graze. Additionally, livestock are attracted by the higher sugar content in grasses. Thus, when grazing a grass-legume mixture, it is important to maintain the balance of forage species.

PREDICTING REGROWTH

Your knowledge of grass growth patterns can help you predict how your pasture will respond to defoliation. First, you need to know whether your grass species are short-shooted or long-shooted and whether they have a vernalization requirement (table 5.1). Then, monitor meristem positions and activities. Is the meristem elevated? Is it vegetative or reproductive? As discussed above, when apical meristems are elevated, they may be removed during grazing, thus reducing the rate of regrowth. Once you know how each species responds to defoliation, and consider the time during the growing season, you can better forecast and budget forage growth.

For example, smooth brome is a long-shooted species with a vernalization requirement. Smooth brome shoots emerge later in spring than those of other species such as Kentucky bluegrass, requiring livestock to remain longer on winter hay rations or other feeds until the grass has adequate height and yield for grazing. Growth during the spring flush will be rapid and high-quality. Regrowth after grazing will be very slow if apical meristems were removed, because regrowth from axillary buds is relatively slow. Thus, understanding the limited regrowth potential of this species allows managers to avoid overgrazing.

In contrast, Kentucky bluegrass is a short-shooted species with a vernalization requirement. Shoots emerge relatively early in spring, and pastures are quickly carpeted in green leaves. The growth rate increases with warmer temperatures, with the highest yields occurring during the spring flush. As summer temperatures increase and irrigation continues, regrowth may slow due to temperature stress. Nonetheless, regrowth following defoliation may be faster than that of long-shooted species due to regrowth from apical and intercalary meristems.

Additional considerations for legumes and other forbs

Under appropriate environmental conditions, and depending on their proportion in mixed pastures, legumes can capture 40 to 120 pounds of N from the atmosphere per acre-year. Inoculation of legume seed with the appropriate bacteria is essential for N fixation (see chapter 4), unless these bacteria happen to be present in the soil (a risky assumption).

Legumes perform better in soils with neutral or slightly higher pH than in acidic conditions. They also require high amounts of P and K, as uptake of these macronutrients by legumes often exceeds that by cool-season grasses. In addition, soils must supply adequate boron (B) and molybdenum (Mo), both of which are important for N fixation. Amending soils as necessary can increase N fixation by legumes (see chapter 3).

Legumes differ from grasses in several other ways:

- Legumes typically have higher crude protein levels, intake potential, and rates of digestibility (see chapter 11).
- Because they have more horizontally oriented leaves, legumes capture sunlight at lower leaf area density.
- Legumes have deeper roots.
- Legumes have higher forage calcium (Ca) and magnesium (Mg) content, which can reduce the incidence of grass tetany when legumes are incorporated into grass pastures (see chapter 12).
- In the case of alfalfa, the optimum temperature for growth is higher.

- With the exception of birdsfoot trefoil, sainfoin, and cicer milkvetch, legumes can induce bloat in ruminants. Including grasses in the pasture reduces this risk (see chapter 12).
- Some legume species, such as birdsfoot trefoil and red clover, can flower prolifically and reseed themselves even under moderately heavy defoliation pressure.

Like alfalfa and red clover, forage chicory is a taprooted, summer-active perennial. During vegetative stages of development, these species usually have higher nutritional value, including mineral concentrations, than grasses. Chicory has a low-growing rosette growth habit in winter. After the establishment year, it is capable of reproductive stem development during late spring and summer growth cycles. Defoliation management should be similar to that for alfalfa.

Brassica species and hybrids present an almost overwhelming variety of morphological characteristics and growth habits. They vary widely in the time needed to reach maximum production, the proportions of stems and edible roots in their total dry matter (DM), regrowth potential, and cold tolerance.

Spring-planted brassicas can supply forage by mid- to late summer. Short-season species (including forage turnip, forage rape, stemless kale, forage radish, and Chinese cabbage x turnip hybrid) offer more summer regrowth potential than long-season species, such as swedes (fodder beets) and stemmed kale. For brassicas with summer regrowth potential, leave at least 3 to 4 inches (ideally 6 to 10 inches) of residual stubble and leaf area to support rapid recovery.

Summer-seeded brassicas can be used to extend late-fall and early-winter grazing. With the exception of summer-planted winter rape and some kales, most brassicas do not survive the winter in the northern United States. Where the crop is not expected to regrow in fall or survive the winter, fall grazing management can focus on capturing as much forage as possible without regard for residual stubble.

All brassicas have leaves with extremely high digestibility, compared to forage grasses and legumes. Swedes and turnips also develop edible roots. Digestibility of brassica forage decreases much less with plant maturity than that of grasses and legumes. It also is retained longer into winter.

Forage fiber concentrations of brassicas are much lower than those of grasses and legumes. This low fiber concentration can impair proper rumen function, making grazing animals sick, if brassicas exceed 75 percent of dietary DM. You can meet grazing animals' fiber requirements by supplying a source of fiber such as hay or interseeding brassicas with grasses.

For more information

Early Spring Forage Production for Western Oregon Pastures. EM 8852-E. Oregon State University Extension Service (2004). http://extension.oregonstate.edu/catalog/pdf/em/em8852-e.pdf

Grass Growth and Response to Grazing. Fact Sheet No. 6.108. Colorado State University Extension (1999). http://www.ext.colostate.edu/pubs/natres/06108.html

How Pasture Plants Grow. Fact Sheet PM 1791. Iowa State University Extension (1999). http://www.extension.iastate.edu/Publications/PM1791.pdf

Plant Growth and Development as the Basis of Forage Management. Fact Sheet No. 5004. West Virginia University Extension Service (1993). http://www.caf.wvu.edu/~forage/growth.htm

CHAPTER 6

Principles of Pasture Irrigation

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MUCH OF THE IRRIGATED LAND in the Pacific Northwest is devoted to pasture and hay crop production. Because of their long growing season, forage and hay crops generally use more water than other crops—about 30 inches per season for forages and 25 inches for irrigated pasture. Too much or too little irrigation reduces forage yield and stand persistence and is economically unsound. Excess irrigation leaches plant nutrients, potentially creating water-quality problems. Drought stress caused by inadequate irrigation can increase plant nitrate concentrations, creating health hazards for livestock. This chapter introduces concepts related to plant water use and water storage in the soil. We briefly discuss advantages and disadvantages of various irrigation methods, before turning to topics of irrigation management: when to irrigate and how much water to apply. Considerations for new and established pastures are included. Finally, we consider management options for water deficit situations.

Key Points

- Soil texture and depth determine the amount of water the soil can store, how much you should add per irrigation, and how often you should irrigate.
- Plant characteristics also affect irrigation planning. Know the rooting depth, evapotranspiration rates, and maximum allowable depletion of soil water for your forage species.
- The goal of irrigation is to match water application to plant water use. Various methods are available to help you determine when it's time to irrigate.
- Optimize irrigation system design and maintain equipment properly to maximize irrigation efficiency.

Function of water in plants

Plants must have water to survive and flourish. Living, active plant tissues are usually 70 to 90 percent water. Even seeds, the least active form of plants, must contain 5 to 9 percent water to be viable. Plants use water for many things. Through the support of water, leaves are held so that the maximum area is exposed to light for photosynthesis. Water also transports nutrients throughout the plant and provides evaporative cooling. Roots grow only in moist soil, and nutrients must be dissolved in water so that roots can absorb them.

Evapotranspiration

The term evapotranspiration (ET) refers to the sum of evaporation and transpiration. Evaporation is water loss from plant leaves or bare soil surfaces. Transpiration is water vapor loss through small openings in leaves called stomata. Transpiration is required for plant growth. It provides the energy to move water and dissolved nutrients from the soil into plant roots and upward through plant tissues.

ET is driven by solar energy. Energy is supplied by sunlight (solar radiation) or is transferred from another area in the form of windblown hotter or drier air. Higher solar radiation values (seen as higher air temperature and wind), greater wind speed, and lower relative humidity produce higher ET.

ET can be estimated for daily, weekly, or monthly periods. Weekly or monthly values are useful for long-term planning, but short-term variation must be considered for irrigation scheduling. Daily ET is best estimated using daily measurements of temperature, wind speed, and relative humidity. ET estimates are given as inches of water use per day. These values represent daily plant water use, not the amount of water to apply.

The AgriMet network of weather stations, operated throughout the Pacific Northwest by the U.S. Bureau of Reclamation, provides daily estimated ET for a variety of crops. There are 80 stations in Idaho, Montana, Oregon, and Washington; 2 in Nevada; and 1 in Wyoming. AgriMet information can be accessed at http://www.usbr.gov/pn/agrimet. Additional information is available in Washington through AgWeatherNet, which may be accessed at http://weather.wsu.edu.

SEASONAL ET PATTERN

As shown in figures 6.1, 6.2, and 6.3, ET rates are low early in the season, when temperatures are low and days are short. ET increases as temperature and day length increase. Maximum ET occurs with long days, peak solar radiation, and high temperatures—conditions seen during midseason. It decreases in the fall with decreasing day length and cooler temperatures.

Key Terms

Available soil water (AW)—The difference between field capacity and permanent wilting point, i.e., the amount of water stored in the soil that is either readily available or somewhat available (with yield or quality penalty) for use by plants. **Water-holding capacity (WHC)** is another term frequently used to describe this soil property. FC, PWP, AW, and WHC are all usually expressed as either percent water by volume or as inches of water per foot of soil depth.

Evapotranspiration (ET)—The sum of evaporation and transpiration. Evaporation is water loss from plant leaves or bare soil surfaces. Transpiration is water vapor loss through small openings in leaves called stomata.

Field capacity (FC)—Soil water content after the soil has been thoroughly wetted and free drainage has occurred, i.e., water content at saturation minus water that drains freely following precipitation or irrigation.

Management allowable depletion (MAD)—The maximum fraction of AW that can be used (depleted) before plant growth and yield begin to decrease. For pastures, MAD is typically 0.5 (i.e., 50 percent). Irrigation should occur at or before this level is reached.

Permanent wilting point (PWP)—The point at which soil water content is sufficiently low that permanent wilting of plants occurs. Plants will not recover even if water is applied.

Readily available water (RAW)—The portion of AW that may be used by the plant without yield or quality penalty, usually expressed in inches per foot. RAW is calculated as AW x MAD.

Seasonal ET patterns also depend on elevation and latitude. At a given latitude, peak water use is delayed as elevation increases. At a given elevation, peak water use is delayed as latitude increases. Pasture ET for Idaho, Oregon, and Washington sites is shown in figures 6.1 (low elevation), 6.2 (moderate elevation), and 6.3 (high elevation).

Curves for both long-term average and low and high year of record are given for each location. Long-term averages are useful for understanding seasonal variability and timing of peak ET. However, be careful when using averages for irrigation scheduling, since they can underestimate peak ET for many years. In figures 6.1–6.3, note the wide range of expected water use at each site.

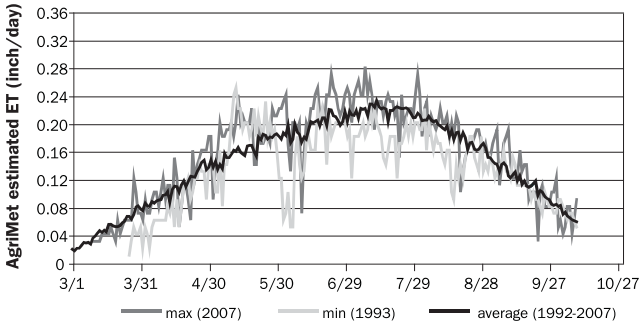

Figure 6.1a. High, low, and average AgriMet-estimated daily and seasonal ET for ***low*** elevation (elevation = 2,305 feet) at Parma, ID. (Low, high, and average seasonal ET = 27, 34, and 32 inches.)

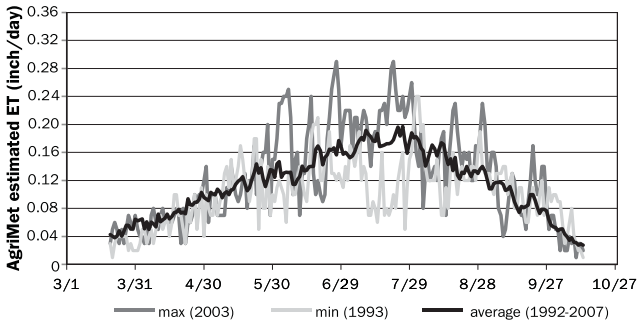

Figure 6.1b. High, low, and average AgriMet-estimated daily and seasonal ET for ***low*** elevation (elevation = 180 feet) at Forest Grove, OR. (Low, high, and average ET = 21, 26, and 24 inches.)

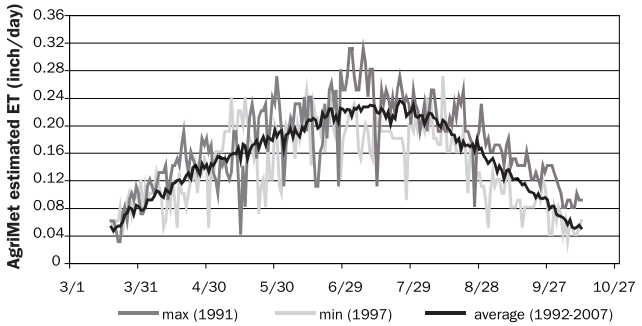

Figure 6.1c. High, low, and average AgriMet-estimated daily and seasonal ET for ***low*** elevation (elevation = 580 feet) at Legrow, WA. (Low, high, and average seasonal ET = 29, 34, and 32 inches.)

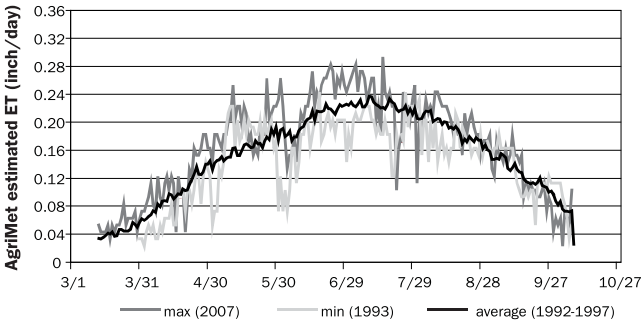

Figure 6.2a. High, low, and average AgriMet-estimated daily and seasonal ET for ***moderate*** elevation (elevation = 3,920 feet) at Twin Falls, ID. (Low, high, and average seasonal ET = 28, 34, and 32 inches.)

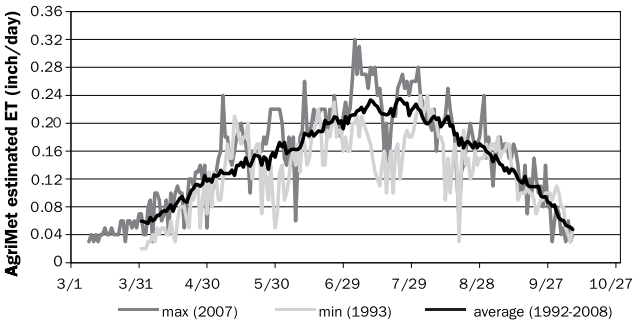

Figure 6.2b. High, low, and average AgriMet-estimated daily and seasonal ET for ***moderate*** elevation (elevation = 2,440 feet) at Madras, OR. (Low, high, and average seasonal ET = 25, 31, and 29 inches.)

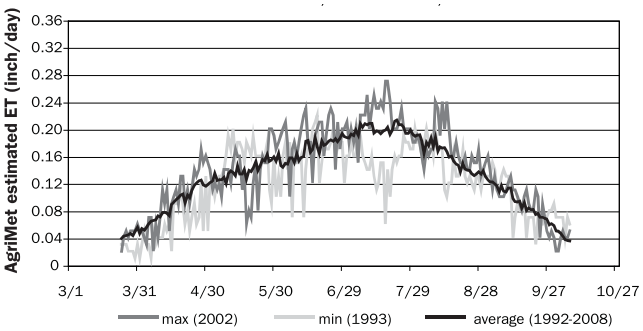

Figure 6.2c. High, low, and average AgriMet-estimated daily and seasonal ET for ***moderate*** elevation (elevation = 1,235 feet) at Omak, WA. (Low, high, and average seasonal ET = 24, 28, and 26 inches.)

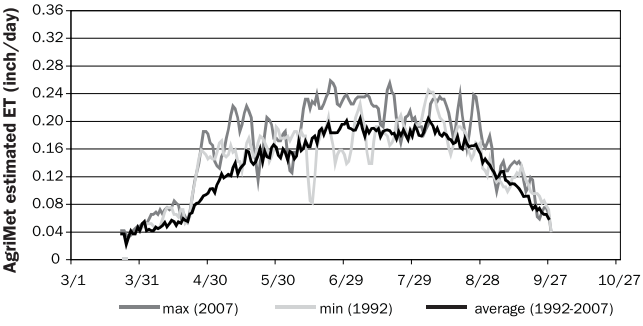

Figure 6.3a. High, low, and average AgriMet-estimated daily and seasonal ET for ***high*** elevation (elevation = 4,875 feet) at Rexburg, ID. (Low, high, and average seasonal ET = 20, 31, and 25 inches.)

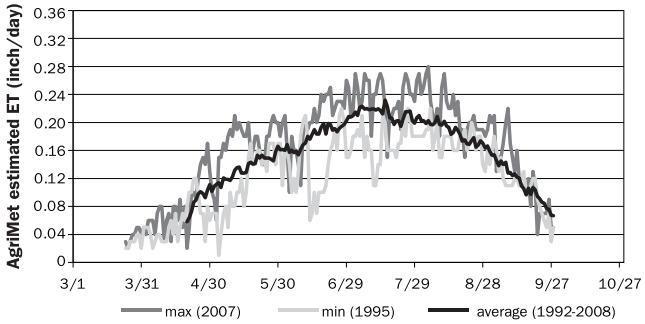

Figure 6.3b. High, low, and average AgriMet-estimated daily and seasonal ET for ***high*** elevation (elevation = 4,750 feet) at Lakeview, OR. (Low, high, and average seasonal ET = 22, 30, and 26 inches.)

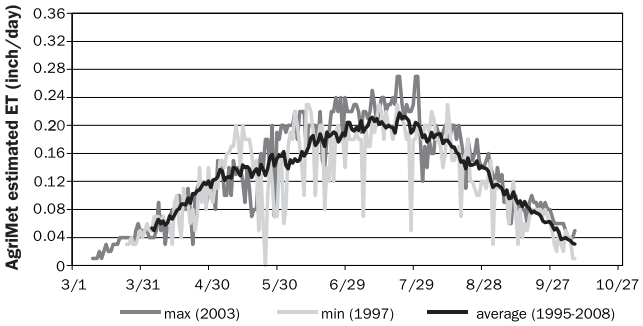

Figure 6.3c. High, low, and average AgriMet-estimated daily and seasonal ET for ***high*** elevation (elevation =1,972 feet) at Mansen, WA. (Low, high, and average seasonal ET = 24, 28, and 26 inches.)

Soil water-holding capacity and rooting depth

Each soil can hold only a certain amount of water. Following irrigation and drainage of free soil water, the soil is said to be at field capacity. If additional water is applied, it will run off the soil surface or move below the root zone and perhaps into the groundwater. Both scenarios waste water and may negatively impact water quality.

Water-holding capacity varies with soil texture. For example, clay soils can hold more water than sandy soils (see figure 6.4). Water-holding capacity also increases with increasing organic matter, while compaction reduces soil pore space and therefore reduces water-holding capacity.

Information on available water for a specific soil can be obtained from the local USDA Natural Resources Conservation Service soil survey (http://websoilsurvey.nrcs.usda.gov/app/). NRCS reports available water for each distinct soil layer (expressed as inches of water per inch of soil depth). To obtain the total water-holding capacity for a soil depth, multiply the value given times the depth in inches.

Another way to estimate water-holding capacity is to obtain a soil textural analysis. Knowing a soil's texture and organic matter content enables you to estimate water-holding capacity. Table 6.1 shows average values (expressed in inches per foot of soil depth) obtained from laboratory testing of more than 50 southern Idaho soils. In the absence of specific information, these numbers provide a reasonable estimate of water-holding capacity.

Pasture grasses have a fibrous root system with a maximum rooting depth of 2 to 3 feet, depending on species. However, in most cases, these plants extract most of their water from the upper portion of the root zone. For example, if the maximum rooting depth is 24 inches, about 40 percent of the water used comes from the top 6 inches, and about 70 percent (40 percent + 30 percent) comes from the top 12 inches.

For this type of water extraction pattern, a sample taken at about one-third of the rooting depth represents the average water content for the root zone. The amount of water removed by plant roots above and below this depth is about equal. If you only observe the top of the soil or feel around with your finger in the first inch of soil, you may not get a clear picture of how much water is really available to your plants.

It is important to note that the rooting depths given above are for deep, uniform soils with no restrictive

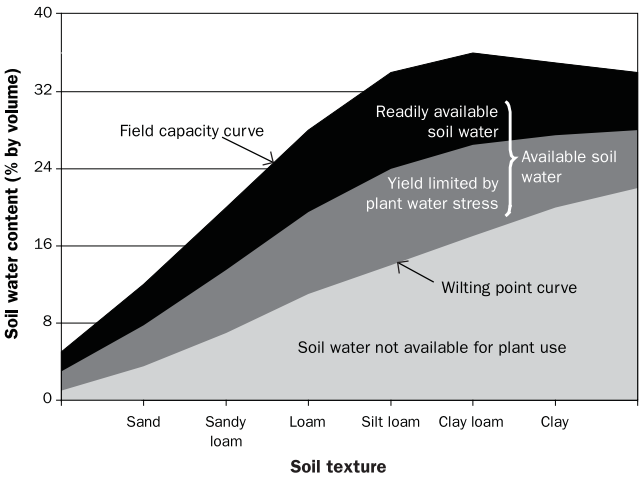

Figure 6.4. Soil water-holding relationships as a function of soil texture. Field capacity increases from sand to silt loam and then levels off. As soil texture becomes finer, the wilting point is reached at a higher soil water content. Available water (AW) is the amount of soil water held between wilting point and field capacity. Readily available water is approximately one-half of AW for pasture and alfalfa. When soil water content falls below 50 percent AW, plant stress will cause yield reduction. Individual soils may differ from this general representation.

soil layers. If a restrictive soil layer (such as a hardpan, bedrock, or previous tillage-induced layer) is near the soil surface, it will limit plant rooting depth. In some areas, a seasonally high water table limits the depth of root development.

Irrigation management can also limit root depth. For example, center pivots often apply 1 inch of water or less per revolution. On a silt loam or other medium- to heavy-textured soil, 1 inch net application of water usually wets the soil to a depth of only 12 to 18 inches. Deeper soil is not refilled. Because roots do not grow in dry soil, the irrigation system effectively limits root depth. In a sandy soil, 1 inch of water usually is adequate to rewet soil depths of 2 to 3 feet. Table 6.2 shows the relationship between amount of water applied and depth of wetting for a silt loam soil.

Table 6.1. Average water-holding capacity and water supply characteristics per 1 foot of root zone depth (assuming uniform soil properties) for common soil textures.

	Average water-holding capacity (in/ft)	Average readily available soil water (AW) (in/ft)	Average midseason return time (days)
Sand	1	0.5	2
Sandy loam	1.8	0.9	3
Silt loam	2.2 to 2.5	1.2	4
Clay	2.2	1.1	3.5

Table 6.2. Approximate quantity of water to add and resulting depth of wetting for pasture on a silt loam soil in southern Idaho.

Irrigation interval	Net midseason water required (inches)	Actual water to apply (inches)	Soil water depletion (%)	Approximate depth of wetting in silt loam soil (inches)
Daily	0.25	0.36	10	3
Every other day	0.5	0.72	21	6
Every third day	0.75	1.07	31	9
Every fourth day	1	1.43	42	12
Every fifth day	1.25	1.79	52	15

Irrigation methods

SURFACE AND SPRINKLER IRRIGATION

Border, corrugation (furrow), controlled flooding, and sprinkler irrigation can all be used on pastures. Each method is best suited to certain slope, soil, water supply, and labor supply conditions. Choose a system that permits good water management in your situation.

Surface irrigation methods such as border, furrow, gated pipe, or controlled flooding minimize equipment investment. However, these methods require more labor, have relatively low water application uniformity, and require more water than sprinkler irrigation.

Sprinkler irrigation uses limited water supplies more effectively and applies water more uniformly than surface irrigation, particularly on sloping areas. However, it requires a greater investment in equipment. Approximate costs are $200 to $300 per acre for hand lines, $400 per acre for wheel lines, and $400 to $500 per acre for pivots.

Ideally, irrigation systems should be designed to meet the anticipated peak midseason ET rate. Being able to meet pasture water needs throughout the season permits more flexibility in grazing patterns or hay harvest. It also allows deeper wetting if soil infiltration rates are adequate. In some cases, however, center pivots or other sprinkler irrigation systems cannot apply enough water at one time to meet the peak midseason ET rate.

Mini-pivots are another option for low-growing crops such as pasture or alfalfa. Since tower height and component size are less than for traditional pivots, mini-pivots require less capital investment.

LINE POD IRRIGATION

A line pod irrigation system (figure 6.5) is a low-cost, flexible plastic hose and sprinkler system that is designed for ease of moving. These systems consist of a series of durable polyethylene pods (containing the sprinkler) connected by a polyethylene pipe that delivers water between the pods. They are designed to operate under low pressure (25 to 55 pounds psi) with low per-hour application rates. The lines can be moved easily with a motorized vehicle such as an ATV. If properly designed, the system does not need to be shut off when moving the line. Line pod systems are easy to maintain and repair if needed.

Figure 6.5. Line pod system. (Photo courtesy of Mylen Bohle, Oregon State University)

These systems can be cost-effective for both small- and large-acreage operations. Although the cost of setting up a line pod system is slightly higher than that for a hand line system, labor costs are reduced in the long term.

A line pod system can operate with either Impact or Windfighter sprinkler heads. The manufacturer recommends 8 to 10 sprinkler pods per line, but the number can range from 2 to 14. Typically, pods are placed 45 to 50 feet apart on the line, but you can design your own spacing.

Application efficiency

Only a portion of the water applied through irrigation is utilized by plants. The rest is lost to evaporation, wind drift, runoff, or deep percolation. Application efficiency refers to the percentage of applied water that is stored in the root zone.

Application efficiencies are about 20 to 30 percent for wild flooding, 30 to 40 percent for furrows, 50 to 60 percent for borders, 60 to 70 percent for hand lines or wheel lines, and 80 to 85 percent for low-pressure pivots with drop nozzles. Other specialized center-pivot devices, such as bubblers or drag tubes, can improve efficiency to around 95 percent. Use these devices only on soils that can accommodate high application rates without producing surface runoff.

Because of differences in application rates and efficiency, the amount of plant-usable water applied per irrigation varies substantially among types of irrigation systems:

- Surface irrigation can apply several inches per irrigation (about 4 to 6 inches for a 12-hour set), depending on furrow flow, row spacing, and set time. About 2 to 3 inches of this water is usable.
- Set-move systems commonly apply about 1.5 to 3 inches per 12-hour irrigation (1 to 2 inches usable).
- Center-pivot and linear-move systems apply about 0.5 to 1 inch (0.4 to 0.8 inch usable), depending on water infiltration into the soil, water-holding capacity, soil depth, and speed of revolution/move.

Irrigation management

Water management is the first step toward more efficient forage production. Poor water management can dramatically reduce the benefits of other practices, including fertilization and reseeding.

Available water (AW) is a useful soil property for scheduling irrigation. Remember that AW is the difference between field capacity and the permanent wilting point—the amount of water stored in the soil that is available for use by plants—and is usually calculated per foot of soil depth. AW is a function of soil texture, structure, and organic matter. Sandy soils have low AW, and clay soils have high AW (figure 6.4 and table 6.1).

AW in the plant root zone depends on plant species and particularly the depth of plant roots. Grass roots may extend to a depth of 2 to 3 feet in deep soils. For shallow soils, however, root zone AW is limited by soil depth rather than by potential root depth. At the beginning of the growing season, the soil profile usually is moist throughout the rooting depth.

For most pasture grasses, plant growth and yield decrease when the average AW for the root zone drops below about 50 percent (when about half of the available water in the root zone has been used). In other words, management allowable depletion (MAD) is 0.5 (50 percent). Irrigation should occur at or before this level is reached.

IRRIGATION SCHEDULING

Using AW to schedule irrigation

For surface irrigation and for hand-line or wheel-line sprinkler systems, it's safe to delay irrigation until AW in the top 6 inches of soil approaches 50 percent. Be sure to start irrigating early enough to cover the field by the time the first area again needs irrigation.

With center-pivot systems, surface runoff problems limit the amount of water that can be applied at one time. Application rates are usually constrained by system design and soil characteristics. As a result, center-pivot systems are typically operated to irrigate more frequently and apply less water per irrigation than is the case with surface or other sprinkler systems. Thus, irrigation must be started at a higher level of soil water so that the amount of water applied can refill the root zone. In many cases, irrigation must begin when AW is 65 to 80 percent.

In some cases, irrigation system design limits the water application rate to less than peak ET. Designs that create a slight deficit can be satisfactory if the soil is deep enough to provide adequate water storage and allow roots to develop fully. On shallow soil, however, the system design should minimize deficits, since little stored soil water will be usable during deficit periods. If your system may not be able to meet peak water needs, monitor soil water content before the peak ET period and apply enough water to fill the soil profile well before that time.

There are two primary methods for determining when soil water content has reached the level at which irrigation is required: soil sensors and the look-and-feel method.

Soil sensors—Many types of soil water sensors are available to determine soil water content by volume or AW. Most work well if used consistently.

Look-and-feel method—Another frequently used scheduling method is to check soil feel and appearance. This method has many variations, but can be successful if used consistently. In an attempt to standardize this method, USDA-NRCS developed a simple bulletin, *Estimating Soil Moisture by Feel and Appearance* (Program Aid Number 1619), which includes photos and descriptions of several soil textures at a number of water contents. This handout is available at most USDA-NRCS offices.

Using the checkbook method and ET to schedule irrigation

Another method for scheduling irrigation is the checkbook method. This method uses estimated ET rates to match irrigation to crop water use. The goal is to irrigate to replace water lost to ET in order to minimize plant water stress.

The AgriMet and AgWeatherNet systems are excellent tools for predicting daily crop water use. Use ET estimates from these systems to estimate soil water depletion through ET. Irrigate before 50 percent of the AW is used. Practical application of ET data for irrigation scheduling is discussed in University of Idaho Extension publication CIS 1039, *Irrigation Scheduling Using Water-Use Tables*.

In this water-budget approach, water available after irrigation for plant use (e.g., readily available water) is calculated as follows:

MAD (usually 0.5) x AW (inches/foot) x root zone depth (feet)

Readily available water is reduced daily by estimated ET until all readily available water is used.

For example, assume a pasture soil has the following characteristics:

- MAD = 0.5
- AW = 2 inches per foot
- Root zone depth = 2 feet

What is the maximum depth of water that can be used before plant stress starts?

0.5 x 2 in/ft x 2 ft = 2 inches of water

If ET averages 0.25 inch per day, the readily available water would be used in 8 days:

2 inches ÷ 0.25 inch/day = 8 days

Alternatively, you could subtract the estimated daily ET (0.25 inch) from the readily available water (2 inches) each day to obtain a daily estimate of remaining readily available water. Irrigation should occur at or before the time when all readily available water is depleted.

When using ET to schedule irrigation, it is important to frequently monitor soil water content and potential ET. ET reaches its peak during the hot, dry days of midsummer. Consider crop year 2003, which had a cool spring but record heat during the summer and fall. Potential ET was extremely high—greater than 0.25 inch per day—for a long period of time (figure 6.6).

ET is also affected by plant growth. It is highest when plants are actively growing and is reduced by intense grazing and hay harvest. For example, if maximum ET is reached at a pasture height of 8 to 10 inches, it will drop when the pasture is grazed to a height of 3 to 4 inches. ET will then remain relatively constant with continued grazing in that condition. After animals are

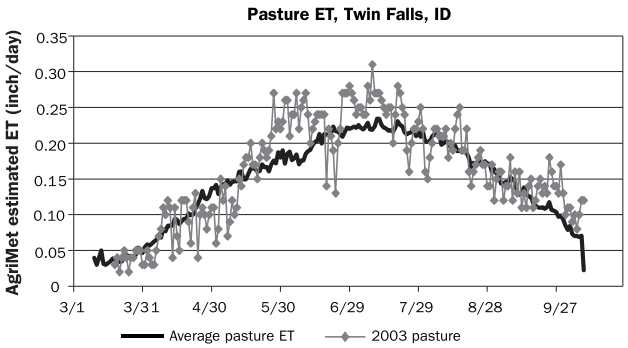

Figure 6.6. 1992–2007 mean pasture ET and 2003 pasture ET as a function of calendar date. Note the single-season variability from the long-term average. (Source: Twin Falls (Kimberly) AgriMet station)

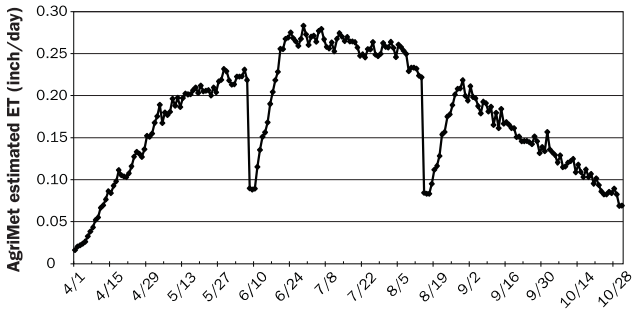

Figure 6.7. Thirty-year average ET for grass cut two times for hay as a function of calendar date. (Source: Kimberly Penman ET from J.L. Wright, Northwest Irrigation and Soils Research Laboratory)

rotated into another pasture and the pasture is irrigated, daily water use will increase during the first week of regrowth (figure 6.7). This period of reduced ET provides an opportunity to "catch up" on irrigation or to delay the next irrigation if root zone soil water content is adequate. In any case, monitoring soil water will determine when the next irrigation is needed.

Likewise, ET is reduced for about 10 days after hay is cut (figure 6.7). This reduced ET partially compensates for the fact that irrigation is not possible for the first 7 days after cutting if hay is in windrows.

For more information on the checkbook method, see Pacific Northwest Extension publication PNW 288, *Irrigation Scheduling*, or University of Idaho Extension publication CIS 1039, *Irrigation Scheduling Using Water-use Tables*.

APPLICATION RATE

Tables 6.3 and 6.4 show the amount of water required to replenish 1 foot of soil using pivot, linear, hand-line, or wheel-line systems, depending on the AW at the time of irrigation. These amounts are based on typical application efficiencies. The tables take into account evaporation, wind drift, and other losses, so the amount given is the amount to apply.

Table 6.3. Inches of water to apply to refill 1 foot of soil with a **pivot or linear irrigation system**. Quantities shown are larger than net plant water requirements to account for losses such as evaporation and wind drift.

Available soil water (%)	Heavy silt loam (WHC= 2.25 in/ft)	Light silt loam (WHC= 1.97 in/ft)	Loam (WHC= 1.41 in/ft)	Sandy loam (WHC= 1.67 in/ft)	Fine sand (WHC= 0.6 in/ft)
100	0	0	0	0	0
85	0.42	0.37	0.26	0.32	0.11
80	0.56	0.49	0.35	0.42	0.15
75	0.7	0.62	0.44	0.52	0.19
70	0.84	0.74	0.53	0.63	0.22
65	0.98	0.86	0.62	0.73	0.26
60	1.12	0.98	0.7	0.84	0.3
55	1.26	1.11	0.79	0.94	0.34
50	1.41	1.23	0.88	1.04	0.38
40	1.69	1.48	1.06	1.25	0.45
30	1.97	1.72	1.23	1.46	0.52

Note: WHC = soil water-holding capacity

Table 6.4. Inches of water to apply to refill 1 foot of soil with **hand or wheel lines**. Quantities shown are larger than net plant water requirements to account for losses such as evaporation and wind drift.

Available soil water (%)	Heavy silt loam (WHC= 2.25 in/ft)	Light silt loam (WHC= 1.97 in/ft)	Loam (WHC= 1.41 in/ft)	Sandy loam (WHC= 1.67 in/ft)	Fine sand (WHC= 0.6 in/ft)
100	0	0	0	0	0
85	0.48	0.42	0.30	0.36	0.13
80	0.64	0.56	0.40	0.48	0.17
75	0.80	0.70	0.50	0.60	0.21
70	0.96	0.84	0.60	0.72	0.26
65	1.12	0.98	0.70	0.84	0.30
60	1.29	1.13	0.80	0.95	0.34
55	1.45	1.27	0.91	1.07	0.38
50	1.61	1.41	1.01	1.19	0.43
40	1.93	1.69	1.21	1.43	0.51
30	2.25	1.97	1.41	1.67	0.60

Note: WHC = soil water-holding capacity

MANAGEMENT CONSIDERATIONS

New plantings

Irrigating before seedlings emerge often causes soil crusting. After the plants have emerged, apply light, frequent irrigations to promote root development. Keep AW above 50 percent in the top few inches of soil, but do not overwater. The root zone of new seedlings is only a few inches deep (4 to 12 inches), but withholding water will not force deeper root development because roots do not grow in dry soil.

Grazing and haying

On fine and moderate-textured soils (all but sandy or gravelly soils), grazing just after irrigating can cause damage by pugging (deep hoof penetration into excessively wet soils) and compaction. Irrigation just before hay harvest can contribute to soil compaction and crown damage by harvest equipment, and can also delay forage drying. Irrigate as soon as possible after removal of the hay or pasture crop so that rapid regrowth can occur.

Mountain meadows

High-elevation mountain meadows are typically irrigated with wild flooding or other surface irrigation methods. Good water management is more of a challenge with these systems. Continuous irrigation with spring runoff water is especially damaging to the establishment and growth of desirable forage species. Move water frequently to avoid overirrigation.

Grass-legume mixtures

Adequate early-season soil water is important for early-spring growth of both grasses and legumes. In mixed pastures, irrigation management must take into account differences in rooting depth among species. Although grasses such as orchardgrass and tall fescue can be deep rooted, most grass roots are in the surface 2 feet of soil. The root zones of white clover, red clover, birdsfoot trefoil, and alfalfa can reach about 1.5, 3, 5, and more than 5 feet, respectively. Grasses and shallow-rooted legumes need frequent, light irrigations that wet the upper 2 feet of soil. Deeper rooted crops can accommodate this frequency of wetting as well as less frequent, deeper irrigation.

Grasses require a more uniform water supply for optimum growth than do legumes. Under drought or water stress, grass production declines more than legume production. Thus, grass-alfalfa mixtures should be irrigated more often than alfalfa alone. Excess irrigation, on the other hand, will cause yellow foliage and reduced growth in alfalfa.

To optimize both grass and legume production, you must accommodate these different needs. Use light, frequent irrigations to allow plants, especially grasses, to easily extract water from the soil. Use a longer irrigation set at least twice per season to fill the entire root zone and ensure optimum growth of alfalfa.

Annual cereals

When grazing annual cereal pastures, keep the soil water level a little higher with lighter, but more frequent, irrigations. This strategy will increase forage production. Do not overirrigate, however.

Water deficit effects and limited irrigation

When the amount of water applied by irrigation is less than the amount lost by ET, deficit irrigation occurs. Water deficits can occur as a result of irrigation system design or limitations in water availability.

Most of the relevant information on dry matter yield with limited irrigation has come from line-source irrigation studies at Utah State University and USDA Agricultural Research Service at Logan, Utah. In these studies, plots were located at various distances from a solid-set system. Sprinkler spacing along the lines was 20 feet. The system was operated so that the “full-irrigation” plots (those closest to the lines) received enough water to meet crop requirements each time the system was operated. Plots farther from the lines received about 86, 69, 59, and 42 percent of full irrigation.

Winter precipitation was adequate to prevent water stress on all plots until about midseason. The timing of the onset of water stress depended on the amount of winter precipitation and subsequent spring-summer ET.

Plots were harvested for hay five or six times per year. Over a 3-year period, dry matter yield from all irrigation treatments was nearly the same until after the mid-July harvest. Irrigation for 2 years at the 40 percent level seemed to reduce yield the third year even during the non-stressed spring and early-summer period. This effect may have been related to stand loss from prolonged water stress.

Yield results for tall fescue, orchardgrass, and meadow brome are given in table 6.5. These results indicate the following:

Table 6.5. Mid- and late-season dry matter production (percent of full production) at varying levels of deficit irrigation.

	Percent of full irrigation				
Grass species	**40**	**50**	**60**	**70**	**100**
Orchardgrass[a]	17	40	64	88	100
Meadow brome[b]	44	56	68	80	100
Tall fescue[c]	23	44	66	87	100

[a] Source: Jensen, K.B., K.H. Asay, and B.L. Waldron. 2001. Dry matter production of orchardgrass and perennial ryegrass at five irrigation levels. *Crop Science* 41:479–487.

[b] Source: Jensen, K.B., B.L. Waldron, J.G. Robins, T.A. Monaco, and M.D. Peel. 2008. Breeding meadow bromegrass for forage characteristics under a line-source irrigation design. *Canadian Journal of Plant Science* 88:695–703.

[c] Source: Asay, K.H., K.B. Jensen, and B.L. Waldron. 2001. Responses of tall fescue cultivars to an irrigation gradient. *Crop Science* 41:350–357.

- After mid-July, more water meant higher yield. The yield response was linear with water added (r^2 of 92 to 94 percent). Although the response varied somewhat among species, dry matter yield was about 80 to 88 percent of maximum for 70 percent irrigation and 17 to 44 percent of maximum for 40 percent irrigation.
- Dry matter yield under deficit condition was higher for meadow brome than for other species. If periodic deficit irrigation is anticipated, meadow brome may be a good choice for a pasture or hay species.

PREPARING FOR DROUGHT

Plan ahead for short water supplies to ensure adequate forage supply to meet livestock needs. A good understanding of historical precipitation and snow pack levels, as well as of forage growth potential, will facilitate decision making.

If drought is a concern, plant drought-hardy perennial species when reseeding. On marginal pastures, plant annual forages with lower water demands and large biomass production. Or, plant winter cereals and swath graze.

To maximize pasture health during drought conditions, it is critical to maximize rooting depth. A deep root system maximizes nutrient and water uptake regardless of soil texture or irrigation system. Test soil and apply phosphorus (P) if needed to promote root growth for maximum water uptake.

It is also important to maintain the crown or stubble to store carbohydrates and capture water. Overgrazing during drought conditions damages roots, crowns, and stubble. It can reduce the rooting depth, damage the pasture for years to come, or even kill off some areas.

Bare soil creates opportunities for weeds to take over. Research has shown that weeds utilize more water than crops. Common lambsquarters required nearly 79 gallons of water to produce 1 pound of dry matter, compared to 42 gallons for corn (Washington State University Extension publication EM4856, *Water Conservation, Weed Control Go Hand in Hand*). Water utilized by an acre of lambsquarters could have produced an additional 1.9 tons of corn.

IRRIGATION MANAGEMENT DURING DROUGHT

Water management during periods of short water supply depends on the timing and rate of water availability. In some cases, water supply can meet only part of the seasonal water need, but is sufficient to meet needs completely during the period of availability. In this case, fill the plant root zone to field capacity and maintain soil water near that level as long as water is available.

For grass with a 2-foot active root zone growing on sandy loam soil, this stored soil water will provide about 1.8 inches of usable water. During periods of peak water use, the stored water will meet plant needs for an additional 7 days after water supply cutoff. Silt loam or heavier textured soils can store about 2.8 inches of usable water, enough to last up to 10 days during peak water use. After this water is utilized, the grass will become progressively stressed and go dormant. The remaining stored water is not efficiently usable by the plant.

If very minimal amounts of water are available in the fall, it is not advantageous to irrigate the pasture, start regrowth, and deplete carbohydrates going into the winter. Fall irrigation is beneficial, however, if enough water is available to bring the plants out of dormancy and grow new tillers. These new tillers will have a positive effect on the first grazing or hay harvest the following year. Likewise, if some water can be held back and stored during a drought (usually not the case), late-summer or fall green-up can be advantageous for next year's crop.

If water delivery can supply only a portion of peak need over the entire season, you have two options: (1) deficit irrigate all acres, with some corresponding reduction in production, or (2) fully irrigate the most

productive acreage and let the least productive areas go dormant. Use table 6.5 to evaluate the costs and benefits of each option.

Understanding differences in water deficit tolerance among grass species can help you maximize pasture production during drought conditions. In research in Utah, meadow brome had twice the biomass production of orchardgrass or tall fescue at 40 percent of full irrigation. Orchardgrass and tall fescue would need about 55 percent of full irrigation to achieve the same yield as that produced by meadow brome at 40 percent of full irrigation.

Considerations for forage production during drought include the following:

- Match irrigation applications to soil texture and root depth (see tables 6.3 and 6.4).
- Irrigate only the most productive pastures.
- Maintain stubble at 4 to 8 inches after grazing or hay harvest to minimize evaporative losses, capture water, and store sugars/carbohydrates.
- Maintain rest periods.
- Always sample for nitrates in drought-stressed forages (see chapter 12).
- Reduce nitrogen (N) fertilizer applications by one-half, since yield potential is limited. Lower N rates will help reduce nitrate accumulation.
- Control weeds to reduce water loss.
- Rent additional pasture.
- Match herd size to feed supply.
- Wean calves early and put cows back out on pasture so they are in better condition for winter.

Irrigation recommendations

1. KNOW YOUR SOIL TEXTURE AND DEPTH

- Determine the predominant soil texture. Most irrigation-related soil properties, such as water-holding capacity and infiltration rate, are based on soil texture.
- Determine soil water-holding capacity (how much water your soil can hold). Water-holding capacity is usually expressed in inches per inch (or foot) of soil depth. Use NRCS Soil Survey information if available. Otherwise, you can assume that usable water ranges from about 0.5 to 0.8 inch per foot for sandy soils and from 1 to 1.2 inches per foot for silt loam and heavier soils. See table 6.1.
- Know the depth to rock or restrictive layer. This depth determines maximum stored water, maximum water to add per irrigation, and frequency of irrigation.

2. KNOW YOUR PLANTS

- Estimate the rooting depth for your grass species. A rooting depth of 2 to 3 feet is common. Some deep-rooted perennial grasses can extract water from as deep as 5 feet if no hardpan or seasonally high water table is present.
- Determine the expected maximum ET based on AgriMet estimates. What are early- and late-season values?
- Know the management allowable depletion percentage (MAD) for your crop. MAD is the percentage of available water that can be used with minimal reduction in crop yield or quality. A value of 50 percent is appropriate for most grasses.

3. SAMPLE SOIL IN EARLY SPRING

Sample soil in early spring to the maximum depth of rooting to determine AW in the root zone and how much water is required to fill the root zone to field capacity. Use tables 6.3 and 6.4 as a guide. Water added in excess of this amount is wasted to deep percolation.

4. IRRIGATE EARLY TO FILL THE ROOT ZONE

Reduce pivot speed to the point of a little runoff to maximize the depth per irrigation. In deep soil, deep irrigation is important for producing healthy roots that can take advantage of the soil's water-holding capacity. Water stored in the root zone can be used for plant growth when irrigation is halted for harvesting or grazing, or when water application does not keep up with ET.

5. KNOW YOUR IRRIGATION SYSTEM!

- Know how much water you apply. Know spacing, pressure, nozzle size, and hours of set. Use an oil-filled pressure gauge and pitot tube to measure water pressure at the nozzle. For an online quick calculator to determine application rate, visit http://irrigation.wsu.edu/.

- Hand lines, wheel lines, and solid-set systems can typically meet midseason crop water demand.
- Depending on water availability and pivot design, some pivots may not be able to meet midseason ET for pasture. In this case, be sure to fill the root zone before the peak water use period.

6. OPTIMIZE SYSTEM DESIGN

A well-designed system is essential for efficient and uniform water application.

- Maintain proper system pressure. Pressure should be at least 5 psi greater than pressure regulator rating at all locations along pivot or linear laterals. On set-move or solid-set systems, nozzle pressure should be 50 to 60 psi (55 psi is best). Nozzle pressure of at least 45 psi is required for reasonable application uniformity.
- Pump inlet pipe should be one size larger than outlet pipe (for example, use 6-inch inlet and 5-inch outlet pipe).
- To minimize plugged sprinkler heads, make sure the intake pipe has a good screen.
- Install an oil-filled pressure gauge on your pump and always check the pressure. (Other types of pressure gauges wear out quickly.)

For set-move and solid-set systems:

- Know the wetting diameter of your nozzles and adjust spacing accordingly. Wetting diameter depends on nozzle diameter, angle, and pressure. Most set-move and solid-set sprinkler irrigation systems are designed to have about head-to-head coverage. For traditional impact sprinklers, this translates to a 40-foot riser spacing along the lines and 40-foot spacing between sets. For hand or wheel lines, spacing between sets is usually 50 or 60 feet. This configuration minimizes cost, but reduces water application uniformity. Some newer sprinkler head designs have a smaller wetting diameter. With these systems, you might need to reduce spacing or consider offsetting irrigation laterals. Always follow nozzle/head manufacturer recommendations.
- Make sure all nozzles on a line are the same size.
- If the pressure variation between the first and last nozzle exceeds 20 percent, use flow-control nozzles.
- Minimize use of nozzles smaller than $\frac{9}{64}$ inch. Wind effects are more severe with smaller diameter nozzles, and the wetted diameter is smaller.
- If your system has a 40-foot riser spacing, try the new Nelson Windfighter heads, which provide a larger drop size. They are promoted as being as efficient in a 10-mph wind as a traditional Rain Bird head with no wind. However, wetting diameter is slightly less, so do not use these heads on a 60-foot riser spacing without offset irrigation.
- If you reduce nozzle size to save water, you will need to adjust management and monitor your system to assure adequate water application and system efficiency.
- In general, the pump power requirement for surface water supply is about 0.5 horsepower per acre. Groundwater sources require more horsepower, depending on lift.
- In general, one wheel line is needed for 20 acres (2 wheel lines for 40 acres, etc.).
- Use self-leveling sprinkler heads.

For maximum efficiency and uniformity on center pivot and linear-move systems:

- Reduce spacing and use boom-mounted nozzles and/or rotating-type nozzles.
- Make sure all nozzles are sized properly and installed in the correct location.
- Drop the nozzles as close to the crop as possible (switch from overhead-mounted nozzles). However, if elk are a problem, you might need to locate the nozzles higher on the machine.
- Once there is substantial foliage in the pasture, each pass leaves a certain amount of water on the foliage. For grass or alfalfa hay, this amount can range from 0.05 to 0.1 inch. This water never reaches the soil and is lost to evaporation. Since both pivots and linears apply limited amounts of water per pass, this loss can be a substantial percentage of the water applied. If each pass applies 0.5 inch of water, and 0.1 inch remains on the foliage, 20 percent of the applied water never reaches the soil surface.
- Run machines as slowly as possible without causing surface runoff. This minimizes evaporative losses from the foliage, puts more of the

applied water on the soil, and moves water deeper into the soil profile. Deeper penetration in turn encourages deep rooting.

- Because both pivots and linears can usually apply a limited depth of water before surface runoff occurs, irrigation should occur when it can just refill the root zone to field capacity. Do not wait until 50 percent AW has been used or the system will not be able to refill the root zone and "keep up" with ET.

7. MAINTAIN YOUR SYSTEM IN GOOD CONDITION

A well-maintained system is essential for efficient and uniform application of irrigation water. Every extra gallon of water you pump, whether the result of leaks, worn nozzles, or excessive set time, represents a direct energy cost.

- Use an oil-filled pressure gauge and pitot tube to check pressure at the nozzles.
- Repair leaks as soon as possible.
- Nozzles enlarge and wear from use. Enlarged or worn nozzles increase pumping cost and may cause overapplication. Check nozzle sizes with drill bits of the same size.
- To ensure uniformity of water application, make sure nozzles on hand lines or wheel lines stand up straight. Properly maintain self-leveling sprinkler heads and assure that hand lines and solid-set lines are installed so that risers are vertical.
- Rubber gaskets crack with age. Replace them as needed. (Keep extras in water so they do not dry out.)
- Pump impellers occasionally wear out, so check them annually. Periodically monitor system pressure with a good-quality pressure gauge to check for leaks, worn nozzles, or impeller wear.
- Make sure pressure relief valves are working properly.

8. MANAGE THE IRRIGATION SYSTEM TO IMPROVE UNIFORMITY

- Alternate daytime and nighttime irrigation sets if possible.
- Straight-set irrigate if possible. Do not skip-set irrigate with sprinkler systems.
- Offset-irrigate every other time to increase efficiency, yield, and quality. Offsetting is especially important if you have 50- or 60-foot riser spacing, but you will see benefits even with 40-foot spacing.
- The uniformity of sprinkler irrigation is reduced dramatically when wind speed is greater than 10 mph. At just over 10 mph, efficiency is reduced by 10 percent. Higher wind speeds reduce efficiency and uniformity even more.
- Some soils (e.g., shallow or sandy soils) can be overirrigated if you irrigate longer than 6, 8, or 10 hours per set. The maximum set time depends somewhat on application rate, but mostly on water-holding capacity in the root zone (determined by soil depth, texture, and organic matter). Check that the set time is correct for the nozzle size used and that you apply only enough water to refill the root zone.
- Schedule irrigations to minimize water stress.
- Monitor soil water content by using the look-and-feel method, soil probes, gypsum blocks, Watermark sensors, tensiometers, echo meters, or other devices. Some of these devices can be connected to your computer.
- If possible, use the checkbook method, based on ET, for irrigation scheduling (http://www.usbr.gov/pn/ agrimet or http://weather.wsu.edu).
- If you are flood irrigating, try some form of "surge" irrigation to improve water application uniformity and water use efficiency. This technique alternately starts and stops water application to an irrigated area. The alternate wetting and drying advances water across the area faster, reduces overirrigation at the head end of the area, and improves irrigation uniformity. Surges can be achieved with surge control valves or by manually diverting water from one area to another and then returning to the first area.

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CHAPTER 7

Weed Management

R. Whitesides and M. Bouck

A PRODUCTIVE, WEED-FREE PASTURE IS A BEAUTIFUL SIGHT to both animal lovers and plant lovers. When pasture land is unmanaged and allowed to become overrun with weeds, forage production is reduced, often requiring the livestock producer to purchase hay. The value of the pasture and associated buildings is reduced. Poorly managed pastures on one property can reduce the value of adjacent properties as well.

Monaco et al. (2002) note that, "Almost half of the total land area of the United States is used for pasture and grazing. Nearly all of this forage land is infested with weeds, some of it seriously. Weeds interfere with grazing, lower the yield and quality of forage, increase the costs of managing and producing livestock, slow livestock gains, and reduce the quality of meat, milk, wool, and hides. Some weeds are poisonous to livestock."

This chapter introduces the concept of Integrated Weed Management, discusses weed management strategies, and provides an example of weed management in a pasture setting. We also discuss common problem areas in pastures and techniques for dealing with weeds in those areas.

Key Points

- Scouting is an essential activity to identify potential weed management problems.
- Prevention is a critical building block associated with integrated weed management.
- Integrated pasture weed management considers mechanical, cultural, biological, and chemical control methods and provides effective weed management.

What is a weed?

Plants have been classified as weeds according to many definitions. In this chapter, we define pasture weeds as plants that are growing where they are not wanted and can interfere with forage production. Weeds that infest pasture lands include trees and brush (woody plants), broadleaf plants (usually herbaceous), and undesirable grasses. Some of these plants are poisonous. In most cases, broadleaf herbaceous weeds are the most annoying. They compete with forage plants for water, space, light, and nutrients and can greatly reduce forage yield and quality.

Integrated Weed Management

Many land managers want to eradicate weeds completely—not only living weeds, but also weed parts (roots or rhizomes, for example) and all weed seeds. In almost all cases, weed eradication is not a reasonable objective. It is impossible to find all of the weed parts in a given area and equally impossible to remove all seeds. In the end, the most successful approach is to implement an integrated weed management program using all of the available weed management techniques.

The building blocks of weed management are: (1) scouting, (2) prevention, (3) mechanical practices, (4) cultural practices, (5) biological control, and (6) chemical control. The process of combining all of these practices into a comprehensive weed management program constitutes Integrated Weed Management (IWM). IWM is an achievable goal and may be more economical than any of its individual parts.

SCOUTING

Scouting is the process of taking an inventory. If you plan to use a parcel of land for grazing, it is important to identify the types of vegetation present in the pasture. Scouting identifies not only weeds but also desirable plants, both those that are abundant and those that occur in small patches. The objective is to know the species composition of the pasture—what portion is desirable grasses and legumes and what portion is composed of weedy species.

If you understand the species composition (especially weeds) of a pasture, as well as its soil, climate, intended use, and availability of irrigation water, you can make an informed choice regarding the best cropping system. In the case of an existing pasture, you must know the content of the pasture in order to decide whether it can be revived and become productive or needs to be replanted.

Scouting should take place throughout the season, since different weeds germinate and grow at different times of the year. Conduct an evaluation by "walking the field" in the spring, summer, and fall. Many landowners use global positioning systems (GPS) and geographic information systems (GIS) to conduct on-site weed mapping.

A good weed identification reference book, such as *Weeds of the West*, is invaluable in determining the weed species mix in the pasture.

PREVENTION

Of all the building blocks associated with integrated weed management, prevention is likely the most important. It is less expensive and time consuming to prevent the introduction of a weed species than it is to control or remove an established weedy species.

Perhaps the most important approach to weed prevention is to identify areas of the pasture where the worst weeds do not occur. Map the areas where these weeds are a problem and note where they are not present. Clearly identify the uninfested sites as "weed prevention areas" and make every effort to stop weeds from spreading to these areas.

Weed prevention areas should receive extra scouting and prevention efforts. If you discover a target weed in one of these areas, act immediately—while the infestation is small—to prevent the weed from becoming established. If the weed is not poisonous and is palatable to livestock (goats, sheep, or cattle), grazing is one way to control an infestation before it spreads. Biological controls are another option. See the "Biological control" section, below.

As part of an IWM program, adopt the following prevention strategies:

- Plant certified clean seed (crop seeds with known rates of germination and purity that are not contaminated with weed seeds).
- Keep equipment clean so that weed seeds or vegetative parts of weeds are not moved from a weedy location to a weed-free location. For example, clean the tines on tillers, wash mowers before moving to a new site, and keep haying equipment clean.

- Hold newly arrived animals in a dry lot for 24 to 48 hours before releasing them onto pasture.
- Avoid introducing weed seeds via contaminated manure, irrigation water, or purchased hay.
- Recognize that weed seeds can survive in the soil for years. Do not allow weeds to go to seed and recharge the soil seed bank.
- Eliminate weeds that proliferate along fencerows, parking lots, and roadsides.
- Pay particular attention to perennial weeds that spread vegetatively. Stop their spread, not just from seed, but also from underground rootstock.
- When replanting a pasture, consider rotating out of pasture for 1 or 2 years. The cleaner the field you start with, the longer the planted species will persist.

MECHANICAL PRACTICES

Most land managers are familiar with mechanical weed control practices. These methods include tillage, hand weeding, mowing, mulching, burning, and flooding. In general, these practices do not play a large role in pasture weed management. Hand weeding is an exception; although it is tedious and time consuming, it can be very successful if practiced with persistence.

Tillage is a standard technique for killing existing vegetation and leaving clean soil. This technique often uses a rototiller or tractor-mounted equipment. Cultivation is another form of tillage.

Tillage is effective at creating a clean and relatively smooth seedbed and often does a great job of controlling annual weeds. It can be effective before establishing a new pasture if the soil is inverted and weed seeds are buried so deeply that they are not in a good position to germinate.

Tillage does not work well in established pastures, except as a way to control weeds along fencerows. One disadvantage of tillage is soil disturbance, which increases the potential for soil erosion and creates an opportunity for invasive weed species to move into the disturbed area. Also, tillage brings buried seeds to the soil surface, where they can germinate. Once tillage is initiated, it often must be repeated on a regular basis to keep weeds under control.

Hand weeding is another type of mechanical practice that can be used in pasture. Unlike tillage, which does not permit selective weed control, hand weeding removes only undesirable plants. If the weed population is not too dense, this technique, although time consuming, is very effective. Pastures that are infested with curly dock (*Rumex crispus*), for example, can be cleaned of this conspicuous weed if the manager is persistent in finding and digging plants as they appear.

Mowing weeds in a newly establishing pasture can aid pasture plants by dramatically reducing competition for sunlight, water, and nutrients. In established pastures, mowing has been reported to be effective in controlling annual weeds. Weed control through mowing is successful only if annual weeds are mowed before they produce seed. If the growing point is removed by mowing, many annual plants die and do not produce seed.

Perennial plants are not easily controlled by mowing. To effectively reduce the vigor of perennial weeds, such as field bindweed, Canada thistle, and quackgrass, mowing must occur frequently. The objective is to prevent the plant from producing the above-ground leaf mass needed for photosynthesis and replenishment of energy stored in the rootstock. If mowing is frequent enough to accomplish this objective, however, it often prevents desirable plants from growing, thus weakening the entire pasture system.

In general, mowing or intense grazing pressure does not control weeds unless desirable species are healthy enough to fill in the open spots as the weeds decline.

Mulching, burning, and flooding are used in some settings, but rarely have a strong fit in pasture weed control. These methods may be successful at controlling some annual weeds, but are usually not effective against perennial weeds. Flooding that occurs during flood irrigation usually is not of long enough duration to stop weed seed germination or kill existing weeds. Also, weed seeds present in the flood water may establish in a previously uninfested area. Burning often removes only the top of weeds, allowing them to regrow from the crown.

CULTURAL PRACTICES

Cultural weed management is defined as the process of using good agronomic practices to control weeds. These practices include crop rotation; selection of appropriate forage species and varieties (chapter 2); use of proper planting dates, seeding rates, and row spacing (chapter 4); good soil fertility practices (chapter 3); and proper irrigation management (chapter 6). Cultural practices are sometimes referred to as best management practices. When pasture managers employ best practices, the control of weeds becomes part of the overall pasture management package.

Pasture grasses that can grow and compete with adapted weeds are the first line of defense against weeds. Thus, weed control is most effective if the pasture has been planted to appropriate forage species. Where soil pH and salt concentrations are high, for example, weeds can become a problem if the pasture grass species is not tolerant of these conditions.

Too often, pasture managers read about a grass or legume species that out-yields all others and decide to plant that species, regardless of whether it is well adapted to their environment. It is important to take into account the environmental factors that limit your site's ability to produce forage. Choose the most adapted species (those that will be most competitive with weeds and will tolerate limiting conditions). The best species for your site may not be the most palatable or highest yielding. See chapter 2 for more information.

Selection of planting dates will affect the weeds that are present as new pasture plants emerge. For example, you may be able to slow the reinvasion of perennial grass weeds (for example, quackgrass and Kentucky bluegrass) by planting in spring or early summer rather than in late summer. For this technique to be successful, weeds must be controlled during the preceding fall and again in spring before planting.

BIOLOGICAL CONTROL

Biological control of weeds consists of using any organism (for example, an insect or disease) to reduce or eliminate the weed population. The insect or disease that infests or attacks the weed is known as a bio-agent.

Biological control of weeds has been successful in a relatively small number of cases, most often in rangeland. Biological control in improved pastures is unlikely to provide acceptable control of the target weeds. Although biological control can be beneficial, it is not likely to be the most important weed management tool.

In improved pastures, most managers want to see a very high percentage of the weeds removed. Biological control does not always provide this level of control. The reason is that bio-agents will starve to death if their host plants are not present. If a bio-agent kills all of the host weed plants, the bio-agent will die. The weeds will then begin to re-establish from the seed reservoir in the soil, but the bio-agent will no longer be present. In order for biological control to be successful, the weed and bio-agent populations must strike an appropriate balance. If some weeds are always present, a population of the bio-agent will also be present. The weed population needed to maintain the bio-agent usually is not acceptable to pasture managers.

Management-intensive Grazing by livestock such as sheep, goats, and cattle can be a very effective way to keep non-poisonous weeds in check. However, preferential grazing can occur due to the unpalatability of the weeds. Thus, attentive observation and management of the livestock is required.

CHEMICAL WEED CONTROL

Pesticides that are used to control weeds are called herbicides. Herbicides are often classified by chemical similarities or by how they kill plants (the mode or mechanism of action). Other distinctions include:

- Systemic versus non-systemic—Systemic herbicides move from treated areas of the plant to non-treated areas, while non-systemic herbicides affect only the treated plant part.
- Selective or non-selective—Selective herbicides affect only certain weed species, while non-selective herbicides affect a broad range of species.
- Practical application—for example, pre-emergence versus post-emergence

Some non-selective herbicides are applied pre-emergence or pre-plant to desirable pasture grasses during pasture establishment and renovation. For example, when renovating a pasture, you might use glyphosate in the fall or during the growing season to take out the existing pasture and control grass weeds such as quackgrass and Kentucky bluegrass. Then, you could replant to perennial pasture using either tillage or a no-till drill. See chapter 4 for more information.

A herbicide application to control established weeds can be the first step in a successful IWM program. Herbicides alone, however, will not solve a weed problem. If the herbicide application is not followed by appropriate measures to support enhanced crop growth, the weed problem often returns the very next season.

Herbicides used in established pastures are almost always selective and usually are applied post-emergence. Many options are available. In most cases, the pasture manager wants a selective product that will kill existing herbaceous weeds (most often broadleaves) and has few, if any, restrictions regarding grazing livestock on the treated pasture.

Before applying herbicides, be sure you have identified weeds correctly to ensure that you treat the correct plant. To plan a proper control strategy, you must understand the biology of the weeds, their life cycle, and their ability to have a seed reservoir. The timing of herbicide application is essential for successful control and often dictates the rate and choice of herbicide.

Product names for herbicides and registrations change frequently. To choose the most suitable herbicide for use in an IWM program, contact your local extension educator, industry representative, or commercial pasture management service.

An example of integrated pasture weed management

Let's look at a practical example of IWM in a pasture, assuming that you want to improve yield, quality, and weed control in an existing pasture.

The first step is to take a walking tour of the pasture. Identify desirable and undesirable plants. Draw a map of the pasture and note the location of each weed infestation.

Next, ask the question, "Why is that weed growing there?" Weedy plants are opportunistic and often establish more quickly than desirable plants in disturbed sites. Look at each location where problem weeds are found. Has the area been overgrazed? Was it grazed when the field was wet, creating disturbed soil? Is the weedy location a road or access point? Is there a soil compaction problem? Are weeds most common near areas where imported hay is fed? Are weeds being introduced through the irrigation system or on machinery and equipment?

Now, evaluate what it would take to stop the introduction of weeds (prevention). A tour of neighboring properties often is necessary. If a nearby property is a source of wind-blown seed, you may need to develop a weed management area and work with your neighbor to solve the problem.

What mechanical or cultural practices may be favoring weeds over desirable crop plants? What practices can you change to reduce weed problems? For example:

- Modification of irrigation and fertilization programs to favor crop plants over weeds is an excellent way to reduce weed populations.
- Aeration of a compacted field can improve nutrient availability and crop growth, thus promoting weed control.
- Management-intensive Grazing is an excellent way to derive the most forage production from a pasture and will also aid in controlling weeds (see chapters 13–15).

A herbicide application may be needed to control existing troublesome weeds. Remember, however, that other practices will be necessary to avoid a return of the problem.

Typical problem areas in pasture

Although pasture weed control has many components, there are some common problem areas.

FENCEROWS

Livestock often do not graze under a fence, especially if the fence is electrified. Biennial or perennial species often become the dominant weeds under fences. Common biennials include common mullein, bull thistle, musk thistle, and Scotch thistle. Perennials include Canada thistle and field bindweed. These weeds do well where they are not mowed or grazed, and they easily become the dominant species in fencerows.

Use of a selective herbicide is an excellent way to remove weeds under a fence. A backpack sprayer, hand sprayer, or ATV can be used.

Some land managers use a non-selective herbicide such as glyphosate. This is sound thinking if no desirable vegetation is present. However, non-selective herbicides kill all existing vegetation and often leave an open invitation for new weeds to move into the area. If there is any merit to the existing vegetation, leave as much of it as possible, continue to irrigate and fertilize, and use a selective herbicide.

SOIL COMPACTION

Some weed species do very well in areas where soil is compacted. For example, prostrate knotweed, prostrate spurge, Russian knapweed, and common mallow tend to infest access roads and areas surrounding watering troughs. Regularly changing the location of troughs, if possible, prevents livestock from trampling all existing vegetation in one area. Field access is difficult to change, so it's best to drive in the same area

each time a vehicle enters or leaves a field. This technique confines severe compaction to a limited area, allowing you to concentrate weed control activities in a small area.

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CHAPTER 8

Insect, Mite, and Related Pests of Pacific Northwest Pastures

G. Fisher, A. Dreves, M. Bohle, and D. Hannaway

MANY SPECIES OF INSECTS AND MITES INHABIT PASTURES, but only a few are common pests. Some pests (wireworms, symphylans, slugs, and cutworms) may have developed sizable populations on the previous crop or vegetation. If not controlled by tillage or other methods, these pests can prevent establishment of newly planted pastures. Other pests can damage established pastures. These pests may fly, walk, or crawl into pastures from adjacent areas. Wind and farm machinery also move pests from field to field. Populations of insects may fluctuate widely or hardly at all through time. Populations of pests may "explode" and then very soon crash in some fields, in some seasons, on some crops, and in some years.

This chapter describes the most important pest species and suggests management strategies. Table 8.1 lists arthropod pests (insects, mites, and symphylans) and slugs that may cause problems in Pacific Northwest pastures. Not all will be present in your area. Forage species and geographical region (west or east of the Cascades) determine the potential pests in a pasture. A species' range is mainly regulated by factors such as climate, food availability, predators, parasitic insects, and natural disease.

Color plates referenced in the text are found after page 204.

Key Points

- Forage species and geographical region (west or east of the Cascades) determine the potential pests in a pasture.
- Some pests (wireworms, symphylans, slugs, and cutworms) may have developed sizable populations on the previous crop or vegetation. Control these pests by tillage, and time planting to ensure quick germination and vigorous seedling growth.
- Infestations in established pastures usually result when the adult stages of pests migrate into the pasture. Knowing what to look for, when and how to scout for pests, and where in the pasture to find them is essential to pest management and pasture productivity.

Table 8.1. Potential pasture pests in the Pacific Northwest.

Pest	Distribution[a]	Season of damage[b]
	MAY BE IN SOIL AT PLANTING	
Black cutworm	W, E	Sp, Su, F
Cranefly larvae (leather jackets)	W	W, Sp, F
Garden symphylan	W	Sp, F
Slugs (gray field, brown-banded, and European)	W	W, Sp, F
Wireworms	W, E	Sp, F, late W
	POST-EMERGENCE AND ESTABLISHED STANDS	
Primarily found in grasses and cereals		
Armyworm, *Pseudaletia unipuncta*	W	Su, F
Banks grass mite (timothy mite)	E	late Sp, Su
Bird cherry-oat aphid	W, E	F, Sp
Black grass bug	E	late Sp, Su
Chinch bug	E	Su, F
Clover mite	E	late W, Sp
Cutworms, other armyworms	W, E	Sp, Su, F
Greenbug	E	F
Plant bugs, *Irbisia* spp.	E	Sp, Su
Russian wheat aphid	E	F, Sp
Sod webworms, various species	W, E	F, W, Sp
Winter grain mite	E	W, Sp, F
Pastures that include alfalfa and/or clover		
Alfalfa and cabbage looper	W, E	Sp, early Su
Alfalfa aphid	W, E	late W, Sp, Su
Alfalfa caterpillar	E	Su
Alfalfa weevil	W (seldom), E	late Sp, Su
Army cutworm	E	late W, F
Bertha armyworm	W, E	Sp, Su
Blister beetles	E	Su
Blue alfalfa aphid	E	late W, Sp, Su
Clover aphid	W, E	late Sp, Su
Clover cutworm	E	Su
Clover leaf weevil	W, E	Sp, Su
Clover root borer	W, E	all year
Clover root curculio	W, E	Sp, Su
Lesser clover leaf weevil	W, E	Sp, Su
Meadow spittlebug	W, E	Sp
Pea aphid	W, E	late W, Sp, Su
Pea leaf weevil (seedling damage)	W, E	late W, S, F
Redbacked cutworm	E	late W, Sp
Slugs	W	W, Sp, F
Spider mites	E	late Sp, Su
Spotted alfalfa aphid	E	Su
Thrips	E	Su
Variegated cutworm	W, E	Sp, Su
Western spotted cucumber beetles	W	Sp
Other insects that can be problems in pastures		
Billbugs	W, E	Su, F
Blister beetles	E	Su
Cereal leaf beetle	W, E	Sp (larvae); F (adults)
Grasshoppers, various species	E	Su
Leafhoppers	E	late Sp, Su
Meadow spittlebug	W	Sp
Mealybugs	W (seldom), E	late W, Sp
Mosquitoes	E	late Sp, Su
Thrips	E (timothy)	Su
Western harvester ant	E	all year
White grubs (June beetles)	E	all year

[a] W = west of the Cascades; E = east of the Cascades
[b] Sp = spring; Su = summer; F = fall; W = winter

Pests that may be present in the soil at planting

Pests such as symphylans, slugs, certain cutworms, many wireworm species, and white grubs may be present in the soil in large numbers, especially if the previous crop was a perennial grass, legume, or native vegetation. No-till practices have been found to favor the development of soil pests.

- Wireworms can live in the soil and damage roots for up to 5 years before they mature into adult click beetles.
- Fields infested with the garden symphylan will always be at risk from this pest, regardless of controls taken in the past.
- Black cutworm larvae are often abundant in old pastures, grass-legume stands, canola, sugar beets, grass seed, and legume hays. Direct (no-till) seeding forage crops into these fields can be risky.
- Two species of craneflies infest grass pastures west of the Cascades. They can cause stand loss in both established pastures and new plantings.
- At least two species of slugs can seriously damage newly seeded pastures west of the Cascades.

Few cost-effective pre-plant chemical controls are available for insect pests. Growers have relied on tillage, increased seeding rates, and timing of planting to establish a stand.

Late winter or spring is generally the best time for deep plowing and disking to reduce populations of wireworms and symphylans, as these pests are in the top few inches of soil at this time. Timing is critical. Late-summer plowing, even when more than 8 inches deep, will not affect these species. At this time of the year, these pests move even deeper into the soil to seek moisture and cool temperatures.

To reduce damage from symphylans, wireworms, and seed corn maggot, time planting to ensure quick germination and vigorous seedling growth.

WIREWORMS

Wireworms are the larvae of click beetles. Several species damage pastures, particularly plantings in new ground.

Wireworms are cylindrical, slender, hard-bodied, slow-moving, yellowish-orange larvae with brown heads (plate 8.1). They vary from less than 0.25 inch to more than 1 inch long. They move up and down through the soil profile depending on soil moisture and temperature.

Larvae tunnel into seeds, roots, and crowns, commonly damaging pastures in the fall (after rains begin), late winter, and spring. Larvae may live in the soil and damage roots for 2 to 5 years before maturing to adult click beetles.

Even low densities of wireworms can cause substantial damage. Damaged seedling stands exhibit spotty emergence and stunted growth. Infested roots of grass and cereal seedlings cause stunted plants to die slowly, progressing in color from green to yellow to severe chlorosis. Damaged areas are usually patchy throughout the field or are restricted to shallow, sandy areas and ridges.

Click beetles are narrow, brown to black in color, and usually less than 0.5 inch long (plate 8.2). These beetles, when placed on their backs, will "spring" into the air with a distinct clicking sound in an attempt to return right-side up. The adult stage does not cause damage.

Detection/Scouting

Previous crop history of wireworm damage is the most reliable predictor of damage to new pastures. Detect wireworms in damaged areas by digging and screening soil. If the soil is dry, the wireworms will be as deep as the soil moisture line.

Sampling with bait stations—In the spring, when soil moisture is abundant and temperatures are mild, wireworm larvae are close to the soil surface and may come to baits buried in the soil. Bait options include potato halves or a 1:1 mixture of wheat and corn seed soaked in water for 24 hours. Bury baits 3 to 6 inches deep, mark bait stations with flags, and place a black plastic bag over each bait station. Inspect bait stations for wireworms 5 to 10 days later.

Control

Wireworm control is difficult at best. When labeled, use insecticide seed treatments and pre-plant, soil-incorporated products at planting. Plowing in late winter or spring and increased seeding rates are also used.

BLACK CUTWORM

This species and other cutworms are common pests in many areas of the Northwest. Weak pastures and new stands are most susceptible to injury.

Mature larvae may reach a little more than 1.5 inch in length. They are gray with a lighter brown stripe down the back (plate 8.3). Numerous convex granules on the skin give the larvae a shiny, "greasy" appearance. The head is dark brown or black. The pupae are brown, spindle-shaped, and about 0.75 inch long (plate 8.4). Moths are brownish-gray, with a dark spot on the top forewing and a light silvery band on the front wings (plate 8.5). The wingspan is a little less than 1.5 inch.

Moths usually begin to fly and lay eggs from mid-spring through early summer. Hundreds of eggs and females are scattered on the soil. Eggs hatch in 7 to 10 days. Small larvae feed on the foliage for a few days before molting and moving down into the soil.

After moving into the soil, cutworms feed beneath the surface by day, returning above ground at night to feed. When feeding above ground, they cut through plant leaves and stems, leaving them to wilt. Large numbers of cutworms can destroy seedling stands and reduce older stands, allowing weed encroachment.

Cutworms feed for 6 to 8 weeks and then pupate. Some may live through the winter, feeding during warm spells and pupating in the spring. Larvae can be found from late spring through early spring of the following year.

Detection/Scouting

Scout pastures for larvae from spring through fall. Wilted and cut plants and irregular holes on and around leaf margins are signs of feeding injury. Inspect fields for damaged plants and screen soil for the black larvae. Look for larvae under surface debris and in the soil at the moisture line. Inspect damaged areas at night (after 10:00 p.m.) with a flashlight to look for larvae feeding above ground on plants. Cereal bran baits with carbaryl attract and kill black cutworms and can be used in bait stations to monitor the larvae.

Control

When damaging numbers of larvae occur in a pasture, harvest hay early and then apply an insecticide if necessary.

OTHER PESTS

West of the Cascade Mountains, garden symphylans, leather jackets (larvae of craneflies), and slugs are among the most injurious pests of new pastures.

Pests occurring post-emergence and in established stands

Established pastures may develop infestations of the soil pests listed above, as well as other pests that move in following seedling development. These pests may be attracted to one or more of the pasture grass or broadleaf species, or they may be attracted first to weeds and later damage the crop. In general, legumes have different pests than do cereals and grasses.

Infestations in established pastures usually result when the adult stages of pests migrate into the pasture. Machinery, people, and animals also move pests about. Green pastures surrounded by drying vegetation can be at risk from pests such as grass bugs and grasshoppers that migrate into fields seeking green hosts.

Knowing what to look for, when and how to scout for these pests, and where in the pasture to find them is essential to pest management and pasture productivity.

MITES

Three species of mites may injure and cause economic damage to grass and cereal forages. Winter grain mite (plate 8.6) and clover mite (plate 8.7) are cool-season mites; field populations are greatest from fall through spring. Banks grass mite (plate 8.8) is a hot-season mite whose population levels peak during late spring through summer. Large populations of these three species develop readily on preferred hosts such as timothy and orchardgrass. They will also infest other grasses.

All mites feed with stylet-like mouthparts that pierce and desiccate epidermal plant cells. Large populations of mites turn leaves from a normal green color to various shades of yellow, brown, white, or silver. Webbing on leaves is produced only by Banks grass mite and two-spotted spider mite.

Winter grain mite

Detection—Inspect plants for mites and damage from late October through April. From late winter through May, damaged plants grow poorly and are noticeably chlorotic when viewed from a distance. Mites are most easily seen on the foliage in the early morning, on overcast days, on the shady side of the grass crown, and at night.

Control—Organophosphate or pyrethroid insecticides control this pest.

Clover mite

Detection—Scout from late winter through spring. This mite has been reported primarily in central Oregon, where it damages orchardgrass and timothy. These mites are extremely small—the size of a period (.)! They are light brown, and their front legs are three times as long as the other three pairs of legs. Use a 16x hand lens or microscope to verify species.

Control—Effective miticides are not yet registered for use on this pest in pasture grass.

Banks grass mite

Detection—This mite is similar in appearance and nearly indistinguishable from two-spotted spider mite. Look for chlorotic plants, mites, and webbing on leaves as they are beginning to develop in late spring. Inspect field margins; ridges; and shallow, dusty, stressed areas of fields for first signs of infestations. Use a 10x hand lens and inspect the field thoroughly throughout the season, particularly during dry, hot spells.

Control—On timothy, treat this mite with a registered miticide as populations begin to increase.

INSECTS

Other pests may occur in Pacific Northwest pastures, including various species of armyworms, cutworms, and sod webworms.

- Aphids (plates 8.9–8.12) may reach sizable numbers in late spring. However, chances are good that they will be controlled biologically by parasitic fungi (plate 8.13), small wasp parasites (plates 8.14–8.17), lady beetle larvae (plate 8.18), and flower fly larvae.
- Leafhoppers, mealybugs, and plant bugs are sporadic to common pests in eastern Oregon and Washington and in many regions in Idaho.
- Billbugs, cereal leaf beetles, and blister beetles (contaminants of baled hay) can occur and require control.

Many insect species encountered in pastures are either incidental to the crop or are beneficial predators or parasites of pests. These include small wasps, certain flies, lady beetles, and flower flies. Learn to recognize them and the roles they play in pasture pest management.

For more information

Handbook of Forage and Rangeland Insects. APS Press (2007). http://www.shopapspress.org/

Pacific Northwest Insect Management Handbook. Extension Services of Oregon State University, Washington State University, and University of Idaho (revised annually). http://uspest.org/pnw/insects

ALWAYS read and follow the instructions printed on the pesticide label. The pesticide recommendations in this publication do not substitute for instructions on the label. Due to constantly changing pesticide laws and labels, some pesticides may have been cancelled or had certain uses prohibited. Use pesticides with care. Do not use a pesticide unless both the pest and the plant, animal, or other application site are specifically listed on the label. Store pesticides in their original containers and keep them out of the reach of children, pets, and livestock. Trade names are used to simplify the information; no endorsement or discrimination is intended.

CHAPTER 9

Disease and Nematode Management

O. T. Neher

THE DEVELOPMENT AND SEVERITY of a specific disease depends mainly on three factors: environmental conditions, host susceptibility, and levels of pathogen populations. You can minimize disease spread and severity by managing these factors.

One strategy is to manipulate environmental conditions so that plant surfaces dry faster, soil is not saturated for prolonged periods, and soil is warmer at planting time. These measures reduce the likelihood of infection by many bacterial and fungal pathogens.

In addition, you can reduce host susceptibility by planting resistant varieties and promoting plant vigor. Provide adequate fertilization and irrigation, harvest at the proper time, manage diseases, and avoid injuries from farm equipment and grazing. Ask your seed sales representative or local extension educator about resistant varieties.

It is especially important to minimize the presence of the pathogen's primary inoculum (its infectious stage). Remove or burn infected plant debris or expose it to microbial activity by plowing it into the soil. Rotate with non-host crops, and use seed treatments to protect against seed- and certain soil-borne pathogens.

This chapter describes diseases of common forage species and suggests control options. Color plates referenced in the text are found after page 204.

Key Points

- Discourage bacterial and fungal diseases by managing environmental conditions (temperature and moisture around the plant and in the soil).
- Plant resistant varieties.
- Promote plant vigor through proper irrigation, fertilization, and harvest practices.
- Practice good sanitation to reduce the presence of pathogens.

Diseases of grasses

ROOT DISEASES OF GRASSES

Seed rot/Pre- and post-emergence damping-off

Distribution—Pacific Northwest

Cause—Various species of the soil-borne fungi and fungus-like organisms *Pythium* spp., *Rhizoctonia* spp., and *Fusarium* spp.

Symptoms and effects

Pre-emergence damping-off or seed rot—Seeds decay in soil, leading to poor plant emergence and reduced stands.

Post-emergence damping-off or seedling blight—Pathogens attack plants at or soon after emergence. Plants develop stem lesions at or near the soil surface. Stems become discolored and collapse. Plants die quickly, and a stand can be nearly destroyed within 2 or 3 days. Surviving plants may be weak and yield poorly.

Control—Use quality seed and a fungicidal seed treatment. Do not plant in cool soils. Plant in a good seedbed in well-drained soil. Avoid overirrigation, especially when plants are germinating or are still small.

Species affected—All grasses

Root and crown rot

Distribution—Pacific Northwest

Cause—Soil-borne fungi and fungus-like organisms such as *Fusarium* spp., *Rhizoctonia* spp., and *Pythium* spp. Crown infections are enhanced by wounds created by winter injury, livestock, insects, machinery, or desiccation (drying).

Symptoms and effects—Root symptoms vary, depending on the pathogen. The main root may be soft, tan to light brown, and stripped of lateral and hair roots (*Pythium* spp.). Roots, rhizomes, or crown tissue may show a dry, dark brown rot (*Fusarium* spp.) (plate 9.1). Roots may end in a dry, fine point with a light to dark brown discoloration (*Rhizoctonia* spp.). Foliage of affected plants may appear light green, chlorotic, or brown. Plants may be severely stunted or die completely, leaving irregular patches.

Control—Apply recommended amounts of nitrogen and phosphorus. Plant in well-drained soils and promote good root development. Avoid plant stress.

Species affected—Most grasses

Nematodes (root-lesion/root-knot)

Distribution—Pacific Northwest, with cereal root-knot nematodes in western Oregon.

Key Terms

Chlorosis—Yellowing of plant tissue.

Conidiophore—Spore-bearing structure of some fungi.

Mycelium—The vegetative part of a fungus.

Petiole—Leaf stem.

Stomata—Small openings on plant leaves, used for gas exchange.

Cause—Nematodes are microscopic worm-like organisms. *Pratylenchus* spp. (root-lesion nematodes) cause lesions by feeding on roots. *Meloidogyne* spp. cause galls on roots. Sample soil and roots and seek assistance from a nematologist to identify the species present.

Symptoms and effects—Affected plants wilt, are chlorotic, and have overall poor growth. Depending on the specific parasite, roots are severely pruned or exhibit swelling, knots, galls, or brown lesions of various sizes. Foliar and growth symptoms are worsened by stress conditions such as drought, heat, or low soil fertility.

Control—To reduce nematode populations, increase organic matter in the soil and rotate with non-host crops or trap plants. Trap crops attract nematodes, but stop the life cycle of the nematode after it penetrates the plant root. Plant resistant varieties if available.

Species affected—Most grasses. Timothy is a poor host for root-knot nematodes.

FOLIAR DISEASES OF GRASSES

Yellow dwarf

Distribution—Pacific Northwest

Cause—Barley Yellow Dwarf Virus (BYDV) is transmitted by several aphid species. The disease is more severe under cool and moist conditions.

Symptoms and effects—The most common symptom is discoloration of the leaf tip, which can turn yellow to reddish-purple. Older leaves are almost always unevenly discolored, with bright yellow blotches along the leaf margin. Symptoms can include shortened leaves or curled margins at the leaf tip. Affected leaves may die prematurely under high temperatures and water stress. Plants are stunted or dwarfed, with an underdeveloped root system that makes them more susceptible to drought stress and soil-borne pathogens. Foliar symptoms can be confused with nutrient deficiencies, aster yellows, or stress, so the presence of BYDV needs to be confirmed by laboratory testing.

Control—Control BYDV indirectly by altering the sowing date to establish plants before or after aphid flights or by controlling aphids with systemic insecticides. Provide infected plants with adequate fertilizer and water to reduce stress.

Species affected—BYDV affects more than 150 grass species, including timothy, perennial ryegrass, Kentucky bluegrass, orchardgrass, and fescues.

Brown stripe

Distribution—Pacific Northwest

Cause—*Cercosporidium graminis*, a fungal pathogen surviving in diseased plant material and debris. Infection is promoted by cool, moist weather.

Symptoms and effects—Brown to gray, elongated leaf spots appear in midspring or fall (plate 9.2). They are followed by the appearance of gray, blackish groups of spore-bearing structures (conidiophores) that extend beyond the leaf openings (stomata). Early-season infection can contribute to significant leaf loss.

Control—Chemical control may be necessary if environmental conditions are favorable for disease development. Apply foliar fungicides during stem elongation. Do not allow livestock to graze in treated areas or feed treated plant parts to livestock.

Species affected—All cool-season forage grasses

Net blotch

Distribution—Pacific Northwest

Cause—The fungal pathogens, *Drechslera* spp. (syn. *Helminthosporium* spp.), overwinter in infected plant material. They are transmitted by equipment, wind, rain, and irrigation water. Infection is favored by cool and wet conditions in the spring. Free moisture is necessary for infection.

Symptoms and effects—Initial lesions are small and water soaked, but change to reddish brown to purplish black. Lesions are oriented both parallel and crosswise to the leaf axis. As they elongate, they develop a net-like appearance ("net blotch"). Individual lesions may coalesce, and leaves may die.

Control—Avoid prolonged leaf wetness. Chemical control is suggested only for crops grown for seed production when disease pressure is high and prolonged conducive conditions are forecast. No chemical controls are available for pastures.

Species affected—Cool-season grasses

Purple eyespot

Distribution—Pacific Northwest

Cause—The fungal pathogen, *Mastigosporium rubricosum*, survives in infected leaves. Cold, wet conditions during winter and early spring favor infection.

Symptoms and effects—Initial symptoms include small, dark purple to brownish spots. Spots merge to

form elliptical lesions with gray to brownish centers and red or purple borders. Severely infected leaves may die early, and the overall quality of the crop may be reduced.

Control—Seldom needed.

Species affected—Orchardgrass, bentgrass, and timothy

Scald and leaf blotch

Distribution—Pacific Northwest

Cause—The fungal pathogens, *Rhynchosporium* spp., survive in living or dead plants. Disease development is favored by prolonged cloudy, wet, cool spring weather. Infection is followed by a latent period of 10 to 14 days before symptoms develop.

Symptoms and effects—First symptoms include oval to elongated lesions ranging in color from dark to pale to bluish gray. Lesions may appear water soaked. If infection progresses, lesions develop a light gray, tan, or white center and a dark brown edge (plate 9.3). A chlorotic region surrounds the lesion. Centers also dry out.

Control—Remove or burn diseased and dead plants to minimize primary inoculum. Harvest or graze earlier to prevent disease spread. If growing crops for seed production, apply foliar fungicides during wet conditions in the spring. No chemical controls are available for pastures.

Species affected—Orchardgrass

Rusts

Distribution—Pacific Northwest, but the incidence fluctuates yearly. Leaf rust is seldom of economic importance in Idaho.

Cause—*Puccinia* spp. can cause stripe, leaf, or stem rust. These fungal pathogens are very host-specific; they attack only one or, if an alternate host is needed, two hosts. All *Puccinia* spp. need free moisture and temperatures above 50°F to infect the host. The stripe rust pathogen, *P. striiformis*, survives on infected plants. *P. triticina*, the leaf rust pathogen, may overwinter on perennial grasses, but an alternate host (meadow rue) is necessary to complete its life cycle. Stem rust is caused by *P. graminis* subsp. *graminicola*, which survives in overwintering plants. However, the absence of alternate hosts does not translate into an absence of disease in grassy forages, because rust can overwinter in infected grasses.

Symptoms and effects

Stripe rust—Symptoms appear earlier in the season than those of leaf and stem rust. Yellow to orange pustules develop in a linear pattern on leaf blades and sheaths (plate 9.4). When infection is severe, forage yield can be reduced considerably.

Leaf rust—Small, scattered, circular to oval, orange-red pustules develop on the upper surface of leaf blades and sheaths (plate 9.5).

Stem rust—Brick-red pustules develop on all aboveground plant parts (plate 9.6). The pustules rupture the plant's epidermis, causing the lesions to appear ragged and the plant surface to feel rough. Depending on the degree of infection, pustules are scattered or coalesce, especially later in the season. Older pustules contain overwintering black spores that cause no damage to grass plants.

Control—Use resistant varieties when available. Interrupt the rust life cycle by eradicating alternate hosts. Labeled foliar fungicides can be used to control rusts.

Species affected—Orchardgrass, Kentucky bluegrass, fescues

Septoria and Stagonospora leaf spots

Distribution—Pacific Northwest

Cause—The fungal pathogens, *Septoria* spp. and *Stagonospora* spp., can survive unfavorable conditions in plant debris. Infection occurs mainly during cool, wet weather in the spring and fall, when free moisture is present on leaves.

Symptoms and effects—Infection may start near the leaf tip. Small lesions may appear as stripes, spots, or blotches. Lesions may be gray, gray-green, light or dark brown, or dark purple. Older lesions may enlarge and fade to a straw color. Leaf tips can turn chlorotic and mottle.

Control—No fungicides are labeled for control of *Septoria* spp. and *Stagonospora* spp.

Species affected—Bluegrass may be seriously damaged. Infections of tall fescue and ryegrass are rarely severe.

Slime molds

Distribution—Pacific Northwest

Cause—Slime molds are caused by myxomycetes. These organisms live in the soil or thatch, and their development is favored by wet conditions and abundant leaf litter. Their appearance on plants is not considered a disease, and only severely affected plants may show a reduced rate of photosynthesis.

Symptoms and effects—Slime molds cover leaves with a grayish, white, or purplish brown mass of small, round fruiting bodies.

Control—Not necessary.

Species affected—All grasses

Smuts and bunts

Distribution—Pacific Northwest

Cause—Head, kernel, stem, and stripe smuts, as well as common and dwarf bunts, are caused mainly by fungal pathogens belonging to the genera *Ustilago*, *Tilletia*, and *Sphacelotheca*. These pathogens may be soil-borne or seed-borne. Only the stem and stripe smuts are of relevance to forage grasses.

Symptoms and effects—The plant parts affected depend on the species of smut. *Stem smuts* produce dark brown to black masses of smut spores on stems. Plants infected with *stripe smuts* have long, narrow, grayish or black stripes on their leaves and stems. Infected plants may die, especially during the summer.

Control—Pathogen-free seeds and seed treatment with labeled fungicides may reduce the incidence of some smuts during the first year of production. Avoid high nitrogen applications, which may increase disease.

Species affected—Certain species of wheatgrass, ryegrass, and bluegrass are most commonly affected.

Snow molds/Fusarium patch

Distribution—Probably the entire Pacific Northwest

Cause—Snow molds can affect many grasses if snow cover persists for at least 100 days and soils are lightly frozen or nonfrozen. *Pink snow mold* and *Fusarium patch* describe different phases of this disease; both are caused by *Microdochium nivale*. Pink snow mold is mostly associated with snow melt, while Fusarium patch describes the occurrence of *M. nivale* without snow cover. This disease can occur year-round and is promoted by wet, cool conditions. *Gray snow mold* (also known as Typhula blight) is caused by *Typhula* spp. It can coexist with pink snow mold, but requires snow cover throughout the winter.

Symptoms and effects—*M. nivale* can cause circular patches. Under snow cover, plant leaves may exhibit a fluffy, white mycelium that turns pinkish when exposed to sunlight (plate 9.7). Symptoms caused by *Typhula* spp. become apparent at snow melt. Leaves are matted together and sometimes covered with a light to dense, white to gray mycelium. Mycelium disappears when grass dries, but leaves in infected areas become grayish to silver white and brittle.

Control—In general, avoid heavy fertilization in the fall and snow compaction. Promote fast drying and good drainage.

Species affected—Many grasses

Diseases of clover

ROOT DISEASES OF CLOVER

Damping-off and seedling blight

Distribution—Pacific Northwest

Cause—Various species of the soil-borne fungi and fungus-like organisms *Rhizoctonia* spp., *Pythium* spp., *Phytophthora* spp., and *Fusarium* spp.

Symptoms and effects—Two types of damping-off occur: pre-emergence and post-emergence.

Pre-emergence damping-off is often referred to as seed decay because poor plant emergence leads one to believe the seed decayed. This disease reduces the stand.

Post-emergence damping-off occurs while the plants are emerging or soon thereafter. A lesion develops on the stem, which becomes discolored and collapses. The plant dies quickly, and a stand can be nearly destroyed within 2 or 3 days. Surviving plants may be weak and yield poorly.

Control—Use quality seed treated with a fungicide effective against *Pythium*. Plant into a good seedbed in well-drained soil. Do not overirrigate, especially when plants are small.

Species affected—All species

Root and crown rots

Distribution—Pacific Northwest. In Idaho, these diseases are most severe from the Rupert-Burley area to western Idaho.

Cause—Depending on weather conditions, various species of soil-borne fungi and fungus-like organisms, such as *Fusarium* spp., *Rhizoctonia* spp., *Pythium* spp., and *Phoma* spp., can attack plants in all developmental stages, but are more pronounced during the second year of plant development. Crown infections are enhanced by wounds created by winter injury, root insects, livestock, machinery, frequent cutting, or desiccation.

Symptoms and effects—*Foliar symptoms* can include curled leaf edges, gray color, and wilting. Infected plants are stunted and yellowish during dry, hot conditions, and they require more frequent irrigation due to their shallow roots. *Root symptoms* include the absence of lateral and hair roots, as well as pale yellow, brown, or black streaks on and in the roots. Internal rot may be restricted or can extend over the length of the taproot (plate 9.8). Infected roots of older plants are extensively branched, resulting in shallow-rooted plants. The entire center of the crown may exhibit dry rot, leaving a whorl of buds at the extremity of the crown. Yields are reduced, and infected plants are more susceptible to cold and winter injury.

Control—Use resistant varieties when available. Improve plant health with adequate nutrients, uniform soil moisture, and recommended harvest intervals. Control root insects. Avoid damage to roots and crowns from late-fall grazing and spring harrowing.

Species affected—Most clovers; may be severe in red clover.

Sclerotinia crown rot and wilt

Distribution—Pacific Northwest

Cause—*Sclerotinia trifoliorum*, a fungus that survives as hard, black sclerotia within infected plant debris or in the soil. Sclerotia are similar in size to wheat kernels and can survive for multiple years. Infection is favored by moist, cool fall weather. Damage occurs during winter when conditions are mild or snow cover is present.

Symptoms and effects—Symptoms caused by *S. trifoliorum* begin in late fall as small, brown leaf and stem spots. Infected leaves drop and are covered with a dense, white fungal mass. The disease spreads to the crown and root system. In spring, infected crowns develop a soft, watery rot. New growth wilts, dies, and may be covered with fungus. From March to June, diseased plants occur individually or as patches in a field. In severe cases, individual patches merge and form large areas of dead plants. Stands can be reduced considerably during early spring.

Control—Plant disease-free seed and resistant varieties if available. Rotate with non-legumes for 4 years. Avoid excessive nitrogen fertilization. Plow deeply to bury sclerotia.

Species affected—All clovers

Nematodes (clover-cyst, root-knot)

Distribution—Pacific Northwest

Cause—Clover-cyst nematode (*Heterodera trifolii*) and root-knot nematode (*Meloidogyne hapla*)

Symptoms and effects—Plants look stunted. Under magnification, female clover-cyst nematodes look like miniature brown lemons attached to the root. Root-knot nematodes cause visible knots and galls on the roots.

Control—See "Root diseases" under "Diseases of grasses."

Species affected—May affect white clover and other legumes.

DISEASES AFFECTING STEMS OF CLOVER

Spring and summer black stem

Distribution—Pacific Northwest

Cause—The fungal pathogens *Phoma trifolii* and *Cercospora zebrina* survive in living hosts, on debris in the soil, and on seeds. Infection is favored by periods of cool, wet conditions during the spring and fall. Prolonged wet springs enable the fungus to be perpetuated.

Symptoms and effects—The fungi produce dark brown to black, elongated lesions on stems and leaf petioles (plate 9.9). Brown to black spots may appear on leaves, followed by yellowing and premature dying. Young shoots may be girdled. Yield and quality may be reduced. Defoliation and death of stems may occur.

Control—Plant pathogen-free seed. Rotate with a non-legume crop. Burning of residues before planting may reduce inoculum. Clip early if the disease appears to be serious.

Species affected—All *Trifolium* spp.

Northern anthracnose

Distribution—Pacific Northwest

Cause—Northern anthracnose is caused by the fungus *Kabatiella caulivorum*. This pathogen survives on crop residue and can be transmitted by seeds and the clover root borer. The disease is favored by cool, humid conditions in spring and early summer.

Symptoms and effects—Symptoms are most pronounced on stems and petioles, where enlarging dark brown to black lesions can girdle and kill the stem. Older lesions become light colored with dark margins. Leaves and flowers on infected petioles and stems wilt and bend over in a "shepherd's crook."

Control—Plant adapted or resistant varieties and pathogen-free seed. Rotate with non-host crops for at least 3 to 4 years. Use a labeled seed treatment to reduce seed-borne fungal spores.

Species affected—Many clover species

Nematodes (stem)

Distribution—Pacific Northwest

Cause—Stem nematode (*Ditylenchus dipsaci*)

Symptoms and effects—Nematodes cause swellings on the stem, leaving the plant severely stunted (plate 9.10). In heavily infected older stands, bare patches of parasitized and dying plants occur.

Control—Rotate with non-host crops for at least 3 to 4 years.

Species affected—All red clover varieties

FOLIAR DISEASES OF CLOVER

Leaf spots

Distribution—Pacific Northwest

Cause—The fungal pathogens, *Phoma* spp. and *Pseudopeziza trifolii*, overwinter in clover stubble and debris.

Symptoms and effects—Infections with *Phoma* spp. are more pronounced during wet springs, while *Pseudopeziza* can occur throughout the entire growing season. For foliar and stem symptoms of *Phoma* spp., see "Spring and summer black stem." *Pseudopeziza trifolii* can cause irregular dark brown or black spots on both the upper and lower leaf surface (plate 9.11). On petioles, spots may appear as elongated dark streaks.

Control—Plant varieties that are tolerant or resistant to *Phoma* spp. No varieties are known to be resistant to *Pseudopeziza trifolii*. Harvest or graze earlier to minimize yield loss and reduce inoculum.

Species affected—Many clover species

Powdery mildew

Distribution—Pacific Northwest

Cause—*Erysiphe polygoni*, a fungus that overwinters on clover plants and clover debris as black spore-bearing structures (cleistothecia). This pathogen is favored by relatively warm, dry days followed by cool nights.

Symptoms and effects—Small patches of fine, white to pale gray, powdery-like growth develop on the upper leaf surface (plate 9.12). The patches later enlarge and coalesce. Severely infected leaves look as if they have been dusted with white flour and eventually turn yellow and die. This disease can reduce the quality and yield of forage clover.

Control—Plant resistant varieties and apply labeled foliar fungicides to control severe infection in hay and forage crops.

Species affected—More common on red clover than on white clover

Rust

Distribution—Most northern counties in Idaho

Cause—*Uromyces trifolii-repentis*, a fungus that survives on living or dead clover leaves

Symptoms and effects—Depending on the season, symptoms vary. In the spring, small, yellow to orange-yellow, cup-like structures may form on the underside of the leaf. Later in the season, small, circular, reddish-brown pustules may develop on the underside of the leaf. Pustules may turn dark brown to black. Spring-infected leaves may become distorted, while severe late-season infection may cause leaves to turn yellow and drop. Severe infection may reduce forage yields, but infestation usually occurs too late in the season to cause measurable losses in hay yield.

Control—Plant resistant varieties.

Species affected—All clovers

MISCELLANEOUS PROBLEMS IN CLOVER

Parasitic plants

Distribution—Pacific Northwest

Cause—Parasitic plants lack chlorophyll and must obtain nutrients and water from a host. Examples include *clover broom-rape*, which attaches itself to and penetrates the roots of its host, and *dodder*, which surrounds and penetrates the host's stem.

Symptoms and effects—*Clover broom-rape* has fleshy simple or branched stems. Leaves are scale-like and yellowish-brown or purplish. Flowers are similar to snapdragons and are white to yellow-white or purplish. *Dodder* has leafless stems that encircle the host (plate 9.13). Stems range in color from white to yellow, orange, or purple. Beginning in June, they bear small, white, pinkish, or yellowish flowers in clusters.

Control—Prevent the development and spread of seeds of parasitic plants. Plant only certified seed free of dodder seed.

Species affected—All clovers

Virus diseases

Distribution—Pacific Northwest

Cause—Alfalfa Mosaic Virus, Bean Yellow Mosaic Virus, Clover Yellow Mosaic, Peak Streak, Red Clover Vein Virus, and White Clover Mosaic Virus. Some viruses are seed-borne, while others are transmitted by aphids or equipment.

Symptoms and effects—In general, virus-infected plants may exhibit a reduction in growth, vigor, and yield. Foliar symptoms range from mild to severe mottling. Discoloration appears as narrow pale to yellow areas along the veins or as large, yellowish blotches between the veins. Leaves may be deformed.

Control—Avoid exposure to insect vectors by planting crops in late summer or early fall. Eradicate alternate hosts such as volunteer clover. Separate new plantings from established legume crops. Rotate with cereals.

Species affected—All clovers

Diseases of sainfoin, cicer milkvetch, birdsfoot trefoil

Root and crown rots

Distribution—Pacific Northwest

Cause—Multiple bacterial and fungal pathogens are responsible for crown and root rot of legumes. The most important are *Erwinia* spp., *Pseudomonas* spp., and *Fusarium* spp. Research indicates that more than 50 percent of newly establishing plants are infected within 6 months.

Symptoms and effects—Foliar symptoms can include leaves with curled edges. Leaves may turn gray and wilt. Internal root symptoms may be localized or extend over the whole root, but are always expressed as light brown to black discoloration. Roots of weakened and dying plants are nearly completely rotted, preventing plants from withstanding stresses such as mowing or hot, dry conditions.

Control—See "Root diseases" under "Diseases of clover."

Species affected—Most pasture legumes

Sclerotinia crown rot and wilt

Distribution—Pacific Northwest

Cause—*Sclerotinia trifoliorum*, a fungus that survives as hard, black sclerotia within infected plant debris or in the soil. Sclerotia are similar in size to wheat kernels and can survive for multiple years. Infection is favored by moist, cool fall weather. Damage occurs during winter when conditions are mild or snow cover is present.

Symptoms and effects—See "Root diseases" under "Diseases of clover."

Control—See "Root diseases" under "Diseases of clover."

Species affected—Most pasture legumes

Stemphylium leaf spot and stem canker

Distribution—Pacific Northwest

Cause—The fungus *Stemphylium* spp. survives as black, raised structures on plant debris. It is favored by cool, wet weather. *Stemphylium* strains attacking birdsfoot trefoil do not infect other legumes.

Symptoms and effects—Foliar symptoms include reddish-brown spots on young leaves. Spots are slightly sunken and round to elongated. With age, lesions increase in size, become darker, and develop concentric zones. Stem lesions are copper colored with water-soaked margins. They may be spot-like to elongated. Plants may be partially defoliated, and stems may be girdled and killed.

Control—Plant resistant varieties if available. Harvest early if disease is severe.

Species affected—Birdsfoot trefoil only

Diseases of alfalfa

ROOT DISEASES OF ALFALFA

Aphanomyces root rot

Distribution—Pacific Northwest

Cause—*Aphanomyces* spp. overwinters in plant debris or in the soil. Soil temperatures between 61 and 82°F and water-saturated soils favor infection and disease development.

Symptoms and effects—On seedling cotyledons, tissue may become chlorotic. Roots may have a gray, water-soaked appearance and later may turn light to dark brown. Infected plants have a reduced root mass with missing or decaying nodules. Lateral roots are decayed or completely absent, and the taproot has restricted brown lesions. Foliar symptoms are similar to those caused by nitrogen deficiency, such as stunting and chlorosis.

Control—Plant resistant varieties in well-drained soils. Avoid overwatering and improve drainage. Do not plant in low spots with standing water or in areas that test positive for the pathogen.

Damping-off

Distribution—Pacific Northwest

Cause—Various species of soil-borne fungi and fungus-like organisms, such as *Rhizoctonia* spp., *Phytophthora* spp., *Pythium* spp., and *Fusarium* spp.

Symptoms and effects—See "Root diseases" under "Diseases of clover."

Control—See "Root diseases" under "Diseases of clover."

Fusarium crown rot, root rot, and wilt

Distribution—Pacific Northwest

Cause—The fungal pathogens, *Fusarium* spp., are prevalent in most fields. They attack plants stressed by other pathogens, insects, nematodes, environmental factors (heat, drought, or frost damage), physical injuries, poor drainage, or low fertility. These pathogens survive in plant tissue and debris or as resting spores in the soil, infesting the soil for several years.

Symptoms and effects—*Crown rot* is promoted by physical injuries to the crown and factors that weaken the plant. Symptoms include rot in the crown area and taproot, leading to a general decline in vigor and death. *Root symptoms* include the absence of lateral and hair roots, as well as pale yellow to brown or black streaks on and in the roots. Internal rot may be restricted or can extend over the length of the taproot. On older plants, infected roots are extensively branched, resulting in shallow-rooted plants. The entire center of the crown may exhibit dry rot, leaving a whorl of buds at the extremity of the crown. Yields are reduced, and infected plants are more susceptible to cold and winter injury.

Infected plants may exhibit partial wilting of individual shoots on one side of the plant. Wilting symptoms occur when the fungus plugs the water-conducting tissue. Leaves may wilt during the day, but recover at night. As the disease progresses, leaves develop a bleached appearance with a reddish tint. Bleaching extends to the stems. A cross section of the taproot reveals dark to brick-colored partial or complete rings, which extend through the entire root as streaks of the same color.

Control—Plant resistant varieties. Avoid stress and crown injuries from overgrazing, insects, other pathogens, or cultural practices. Improve plant health with proper fertilization and water management. Rotate with non-host crops for 3 to 4 years.

Phytophthora root rot

Distribution—Pacific Northwest

Cause—*Phytophthora megasperma* f. sp. *medicaginis*, a fungus-like organism, survives in the soil and in infected debris. Phytophthora depends on free water in the soil and is associated with poorly drained soils. Infection and disease development are favored by cool temperatures.

Symptoms and effects—Lower leaves of infected plants become yellow to reddish brown, and plants wilt under high temperatures. Regrowth is often slow after cutting. Root lesions are brown to black (plate 9.14) and may be hourglass shaped. A major diagnostic feature is the presence of yellow tissue extending through the root cortex into the xylem. Phytophthora affects the taproot at any depth, but damage is most severe above compacted soil layers where water drainage is hindered.

Control—Use resistant varieties. Plant in well-drained soils and/or promote drainage by deep tillage before planting. Adjust irrigation schedules to avoid prolonged periods of saturated soils. Rotate with non-host crops for 2 to 3 years.

Sclerotinia crown and stem rot

Distribution—Pacific Northwest

Cause—*Sclerotinia trifoliorum*, a fungus that survives as specialized black structures (sclerotia) in the soil.

Symptoms and effects—Stems and crowns are attacked during wet, cool periods or when dense foliage creates high humidity. Affected tissues develop a soft water rot with dense, white fungus on the rotted tissue. Stems wilt when the stem base or crown rots. Part of the plant or the entire plant may die.

Control—See "Root diseases" under "Diseases of clover."

FOLIAR DISEASES OF ALFALFA

Downy mildew

Distribution—Pacific Northwest

Cause—*Peronospora trifoliorum*, a fungus-like organism that survives in crown buds and shoots and as dormant spores in plant debris. Disease is favored by temperatures between 50 and 60°F and by wet or humid conditions during spring.

Symptoms and effects—Leaves and sometimes stems become diseased, but only young tissue is susceptible. New leaflets turn pale green to yellowish green (plate 9.15) and may be twisted, with margins curled downward. A delicate, violet-gray, downy growth is often abundant on the underside of infected leaflets. When the entire stem is affected, all leaves and stem tissue are yellow. Infected stems are thick but shorter than normal. Plants are defoliated. Most damage occurs during the first cutting, but the second cutting is occasionally affected.

Control—Plant resistant varieties. To protect first-season crops, use a fungicidal seed treatment. If defoliation appears imminent, harvest or graze early to save as many leaves as possible.

Leaf spots and blotches

Distribution—Pacific Northwest

Cause—Leaf spots and blotches are caused by a wide range of fungal pathogens, including *Pseudopeziza medicaginis*, *Stemphylium* spp., and *Uromyces striatus* (rust). *P. medicaginis* survives in undecomposed leaves. *Stemphylium* spp. survives as black, raised structures on plant debris and is favored by cool, wet weather.

Symptoms and effects—*P. medicaginis* can cause small, discrete, circular lesions with toothed margins (plate 9.16).

For symptoms of *Stemphylium* spp., see "Diseases of sainfoin, cicer milkvetch, birdsfoot trefoil."

Foliar symptoms of plants infected by *U. striatus* include small, circular, reddish-brown pustules. Pustules on stems are a similar color but more elongated. Infection may lead to early defoliation.

Control—Plant resistant varieties if available. Harvest early if disease is severe. Chemical control is possible.

DISEASES AFFECTING STEMS OF ALFALFA

Anthracnose

Distribution—Pacific Northwest

Cause—The fungus *Colletotrichum trifolii* survives in plant debris, in the living stem-crown junction, in the crown, or, where weather is mild, on stems. It can also be present on seeds. Disease spread is favored by warm and humid conditions.

Symptoms and effects—Symptoms vary on susceptible and resistant varieties. On susceptible varieties, stems may exhibit large, sunken lesions. These lesions are oval to diamond shaped and straw colored with brown margins (plate 9.17). Resistant varieties may exhibit small, irregular, blackish spots. In the summer and fall, lesions may enlarge, girdle, and kill the stems, creating straw-colored to white shoots. A "shepherd's crook" can be caused by girdling and sudden wilting.

Anthracnose can also cause crown rot, which may kill the plant directly or predispose it to winter injury. Symptoms include a bluish-black rot of the crown.

Control—Remove infected plant debris and clean harvest equipment. Plant resistant varieties.

Spring and summer black stem and leaf spot

Distribution—Pacific Northwest

Cause—*Phoma medicaginis* and *Cercospora medicaginis* are fungi that survive on alfalfa debris in the soil. They can also be seed-borne.

Symptoms and effects—See "Diseases affecting stems" under "Diseases of clover."

Control—See "Diseases affecting stems" under "Diseases of clover."

Bacterial wilt

Distribution—Pacific Northwest

Cause—The bacterium *Clavibacter michiganensis* subsp. *insidiosus* (syn. *Corynebacterium insidiosum*) survives in dead alfalfa tissue in the soil. Infection occurs through wounds on the roots and crown caused by mechanical injuries, soil microbes, or insects. The bacterium can be spread over long distances by hay or seed, and in the field by equipment, surface water, and cultural practices. It is also transmitted by other soil microbes, including the stem nematode and northern root-knot nematode, both of which can increase host susceptibility.

Symptoms and effects—Infected plants are stunted and yellow (plate 9.18). Shortened stems result in bunchy growth. Leaves are small and often cupped. Yellowish or brownish streaks may appear in the outer, woody tissue under the epidermis. When roots of an infected plant are cut, a yellowish or brownish ring is visible under the bark (plate 9.19).

Stands wilt and die rapidly during warm weather. Plants infected during midseason usually do not survive the winter. This disease usually affects stands 3 or more years old, although it sometimes infects younger stands.

Control—Plant resistant varieties. Promote plant health with adequate fertilization. Do not harvest when the crop is wet. Harvest young stands before old stands. Rotate with non-host crops for 3 to 4 years.

Verticillium wilt

Distribution—Pacific Northwest

Cause—*Verticillium albo-atrum*, a fungus that overwinters in plant debris and infected plants. This pathogen can be spread by insects, seed, hay, farm equipment, soil, and surface water.

Symptoms and effects—Upper leaves wilt on warm, dry days (plate 9.20) but recover at night. Early leaf symptoms include V-shaped chlorosis of the leaflet tips (plate 9.21). As the disease progresses, leaflets dry up and drop, while the stem remains green. Wilting often starts with a single stem, but eventually the whole plant wilts and dies. Infected plants usually die over the winter.

Control—Plant resistant varieties and clean seed. Rotate with non-host crops for 2 or 3 years. Minimize spread by harvesting newer plantings before older stands. Decontaminate farm equipment with a 10 percent solution of household bleach, followed by a high-pressure rinse with water or steam.

MISCELLANEOUS PROBLEMS IN ALFALFA

Nematodes (bulb and stem, root-knot, lesion)

Distribution—Pacific Northwest

Cause—Bulb and stem nematode (*Ditylenchus dipsaci*), root-knot nematode (*Meloidogyne* spp.), and lesion nematode (*Pratylenchus* spp.).

Symptoms and effects—*Bulb and stem nematode* damage is more visible and common in spring as shoots begin to grow. The optimum temperature for infection is 60 to 70°F. Infection causes swollen nodes and shortened internodes on stems, resulting in severely stunted plants. Leaves may show distortion and may turn white during warm summer weather, a condition known as "white flagging" (plate 9.22).

Plants infected with *root-knot nematodes* may become stunted. Infected roots branch excessively and have galls. Galls are small and easy to overlook if the roots are not examined closely.

Plants infected with *lesion nematodes* have no specific above-ground symptoms, but may become stunted if nematode populations are high and environmental conditions are ideal. On the roots, nematode feeding usually causes dark brown or black lesions. Feeding damage may predispose the plant to infection by other microorganisms.

Control—Plant resistant varieties. To reduce nematode populations, rotate with non-host crops for 2 to 3 years and manage weeds. Do not allow volunteer alfalfa to grow during the rotation. To reduce new infections by the stem nematode, cut hay when the top 2 to 3 inches of the soil is dry. Clean harvest equipment before moving to another field.

Alfalfa Mosaic Virus

Distribution—Pacific Northwest

Cause—Alfalfa is affected by multiple viruses. For a list of these viruses, see "Miscellaneous problems" under "Diseases of clover." Alfalfa Mosaic Virus (AMV) is of particular importance, since it appears in multiple strains. This virus is transmitted by at least 14 aphid species and affects more than 430 plant species. It can also be seed-borne and transmitted by farming equipment. It is estimated that about 80 percent of a typical

2-year-old alfalfa stand is infected with AMV, thus serving as a reservoir for new infections of other crops.

Symptoms and effects—Symptoms of AMV vary, depending on the strain. Symptoms can include light green to yellow leaf mottling (plate 9.23), leaf distortion, leaf necrosis, shoot stunting, and plant death.

Control—Plant aphid-resistant varieties to reduce localized transmission.

Winter injury

Distribution—Pacific Northwest

Cause—Winter injuries may appear in plants stressed or weakened by diseases, insects, nematodes, or problems related to soil moisture content. Plants grown on well-drained soils are less prone to damage, but moisture deficit should be avoided as well. Extremely cold soil temperatures and periods of freezing and thawing can injure the crown and roots. Desiccation can occur when roots are brought to the surface by heaving.

Symptoms and effects—Symptoms can include thin stands and plants with discolored or dead crowns and taproots.

Control—Use adapted varieties. Increase cold tolerance through proper disease management, harvest schedules, and late-fall irrigation. Adequate fertilizer applications promote high carbohydrate root reserves before the plants go dormant.

For more information

Integrated Pest Management for Alfalfa Hay. University of California-Davis, Integrated Pest Management Program, ANR Publications (1981). http://anrcatalog.ucdavis.edu/IntegratedPestManagement/3312.aspx

Online Guide to Plant Disease Control. Extension Services of Oregon State University, Washington State University, and University of Idaho (revised annually). http://ipmnet.org/plant-disease/intro.cfm

CHAPTER 10

Nutritional Needs of Grazing Animals

C. Engel, T. Fife, and J. Hall

ALL ANIMALS NEED ADEQUATE NUTRIENTS, including energy, protein, minerals, vitamins, and water. Their needs vary, however, depending on stage of production, activity level, weather, and many other factors. At the same time, nutrient levels in forages vary throughout the year. Matching animal needs to nutrient supply is a key component of success for any livestock operation.

This chapter discusses the essential nutrients needed by animals and provides guidelines for meeting the nutritional needs of several types of livestock in a pasture-based system.

Key Points

- Nutrient requirements vary by species, age, stage of production, and environmental conditions.
- Understanding nutrient requirements of grazing livestock is fundamental for allocating forage resources to meet production goals and objectives.

Essential nutrients

Essential nutrients are nutrients that are needed by all living things. Grazing livestock need carbohydrates and fat for energy, as well as protein, vitamins, minerals, and water. Animals must either consume these nutrients or produce them within the digestive system from building blocks obtained through eating, drinking, or breathing.

ENERGY

Energy is the fuel for all bodily processes—breathing, walking, eating, growth, lactation, and reproduction. Animals need more energy than any other substance, except for water. Starches, sugars, digestible fiber, fats, and excess protein are all sources of dietary energy. The primary forms of energy in forages are digestible fiber, sugars, and soluble carbohydrates (see chapter 11). Forage plants also contain limited amounts of starches and fats.

Grazing animals use energy for both maintenance and nonmaintenance functions:

- Maintenance energy is the fuel used to keep the animal alive without losing or gaining weight. Cold weather, mud, increased walking, and larger body size increase the amount of energy needed for maintenance.
- Energy above that used for maintenance is available for nonmaintenance functions—reproduction, lactation, growth, and work.

Animals are more efficient at using energy for maintenance than for nonmaintenance functions.

The energy requirements of grazing animals and the energy content of feeds are expressed in several ways:

- Digestible energy (DE) = feed energy – energy lost in the feces
- Total digestible nutrients (TDN) is similar to DE, but includes a correction for digestible protein: 2.205 lb TDN = 4.4 Mcal DE
- Metabolizable energy (ME) = DE – urinary and gaseous energy losses
- Net energy (NE) accounts for heat loss. This measure of energy can be used to determine how much energy is actually used for maintenance or retained for production. Net energy is the most accurate measure of energy because it accounts for a greater number of losses due to digestion and metabolism. Net energy is subdivided into maintenance energy and energy used for growth or lactation.

The way we express energy requirements varies, depending on livestock species. For beef cattle, sheep, and dairy cattle, TDN and NE are most common. DE is used for horses. Net energy is typically used for growing cattle and some special cow rations.

Key Terms

Average daily gain—Average daily weight gain by individual animals.

Body condition score—A method of assessing the nutritional status of livestock based on external fat cover.

Dry matter (DM)—The part of feed that is not water. Percent DM = 100% - moisture %. Feed values and nutrient requirements for ruminants are expressed on a DM basis to compensate for the large variation in moisture content of feeds. To convert "as-fed" nutrients to a dry matter basis, divide the "as-fed" nutrient value by the percent DM and multiply by 100.

ENERGY

Digestible energy (DE)—Feed energy minus energy lost in the feces.

Metabolizable energy (ME)—DE minus urinary and gaseous energy losses.

Net energy (NE)—ME minus heat loss.

PROTEIN

Crude protein (CP)— An estimate of protein content based on determination of total nitrogen (N). Calculated as 6.25 times the nitrogen content.

Nonprotein nitrogen (NPN)—Nitrogen that is not in the protein form. Can be used by rumen microorganisms to synthesize protein if adequate carbohydrates are available.

Metabolizable protein (MP)—True protein absorbed by the intestine.

Degraded intake protein (DIP)—Crude protein fraction that is degraded in the rumen and incorporated into and passes to the intestine as microbial protein to meet a portion of the MP requirement. Also known as rumen degradable protein (RDP).

Undegraded intake protein (UIP)—Crude protein fraction that is not digested in the rumen. UIP passes to the small intestine, where it can be digested and absorbed to meet a portion of the MP requirement. Also known as rumen undegradable protein (RUP) or by-pass protein.

Total digestible nutrients (TDN)—The sum of digestible crude protein, digestible nitrogen-free extract, digestible crude fiber, and 2.25 times the digestible ether extract (fat). Often calculated from ADF. Less accurate than NE for formulating diets containing both forage and grain. Most rations are now formulated using NE; however, TDN is still used to calculate beef cow rations where the diet is primarily forage.

PROTEIN

Protein is the basic component used to make all tissue (muscle, bone, skin, hair, organs) and milk. It is important not only for growth and milk production, but also for daily repair and replacement of cells and tissue. Protein is made up of amino acids.

Plant protein is a grazing animal's primary source of protein. Animals use the amino acids from digested protein to build and replace tissue.

Animals with a fully developed rumen can also use nonprotein nitrogen (NPN) to meet a portion of their protein requirement. NPN is nitrogen not in the form of amino acids, such as urea. In the presence of adequate carbohydrates, rumen microbes can use NPN to make amino acids. The ruminant animal then uses these amino acids to produce protein.

Young ruminants (those weighing less than 550 pounds) cannot effectively use NPN because their rumen is not fully developed. Nonprotein nitrogen can be toxic to young, unweaned ruminants and to nonruminants. Feed these animals only "natural" plant-based proteins that contain chains of amino acids.

Thanks to the presence of rumen microbes, ruminants (cattle and sheep) generally receive all of the essential amino acids they need as long as there is enough protein in the diet. Horses don't have a rumen. Therefore, they require a higher quality protein diet or may eat their own manure (coprophagy) to capture excreted microbial-derived protein.

Protein requirements of grazing animals and the protein content of feed are usually expressed as crude protein (CP). To estimate the protein value of a feed, use the following equation:

$$\text{crude protein} = \text{nitrogen} \times 6.25$$

Not all CP is available to ruminant animals, and CP from some feeds may not be used as efficiently as that from others. Thus, nutritionists instead often measure metabolizable protein (MP). This is the true protein absorbed by the intestine. There are two types of MP:

- Most ingested protein is digested by rumen microbes. This protein is known as degraded intake protein (DIP) or rumen degradable protein (RDP).
- Protein that is not degraded in the rumen passes to the small intestine. It is known as undegraded intake protein (UIP), rumen undegradable protein (RUP), or by-pass protein. Most protein entering the small intestine is digested and absorbed there.

MINERALS

Minerals are important for a variety of functions in the animal. Some minerals are combined with proteins to form structures such as bones and teeth. Others help transmit nerve impulses, form enzymes, or carry oxygen.

Minerals can be divided into two types: macro and micro. The macro- and microminerals important to grazing animals are listed in table 10.1. Macromineral requirements are measured in terms of ounces or grams per day. Microminerals are needed in smaller quantities—milligrams or parts per million (ppm). Microminerals are often called trace minerals.

Some minerals are stored in the animal's body. Calcium and phosphorus are stored in bones. Copper and iron are stored in the liver. Grazing animals can use these stored minerals to offset limited mineral intake for days to months. Other minerals, such as magnesium and sodium, are not readily stored in the body and must be consumed daily or every few days.

In areas with sufficient rainfall or irrigation, well-managed forages supply a large percentage of the minerals needed by grazing animals. However, soil fertility, soil pH, forage species, and forage quality all affect forage mineral content. Because the Pacific Northwest has a wide variety of soil types, forage from some areas may contain deficient or excess amounts of some minerals. Consult your local extension professional or nutritionist for assistance in developing a year-round mineral supplementation program to meet the needs of your grazing livestock.

Mineral toxicities and antagonisms

Some minerals can be toxic when ingested at high levels. The toxic concentration varies, depending on the mineral, interactions with other minerals, and the species of livestock. For example, a diet containing 40 ppm copper is fine for cattle, but copper levels above 15 ppm are toxic to sheep. Mineral requirements and toxic limits for each species are found in the *Mineral Tolerance of Animals*.

Interactions among minerals can affect mineral absorption and availability to the animal. A mineral that reduces the availability of another mineral is known as an antagonist. For example, sulfur, iron, and molybdenum can interfere with copper absorption, creating copper deficiencies even when adequate copper is available. Sulfur and molybdenum can interact to form thiomolybdenates, which impair copper availability to a greater extent than either mineral alone. Mineral antagonisms are complex and numerous. Consult a local veterinarian or nutritionist to develop strategies to compensate for mineral antagonisms.

Table 10.1. Macro- and microminerals needed by grazing animals.

Macrominerals (needed in ounce or gram amounts)	Microminerals (trace minerals, needed in milligrams or ppm amounts)
Calcium	Cobalt
Potassium	Copper
Phosphorus	Iodine
Magnesium	Iron
Sodium	Manganese
Sulfur	Molybdenum
Chloride	Selenium
	Zinc

VITAMINS

Vitamins are involved in the regulation of metabolism. They affect reproduction, skin and coat quality, and immune system function. They are needed in minute quantities, and animal requirements are not well defined. Vitamins A, D, E, and K are fat-soluble and can be stored in the animal's body. Vitamin C and the B complex vitamins are water-soluble.

Grazing animals usually get enough vitamin A and E from lush green forage, and they produce vitamin D in response to sunlight. Vitamin C and K requirements are low and are provided by the diet, so deficiencies are not a problem in most grazing animals. Rumen microbes produce all or nearly all of the B vitamins needed by ruminants. Nonruminants must consume these vitamins daily.

Vitamins can leach or be oxidized from stored forages. Thus, when vegetative forage is not available, such as in winter, vitamin A, D, and E supplementation may be needed. Vitamins can be fed daily in the mineral mix or given as an injection every 2 to 3 months.

WATER

Water is probably the most vital of the essential nutrients required by all animals. Animals require water to maintain proper bodily functions such as transporting nutrients and metabolites, digesting feed, regulating body temperature, and excreting waste and other bodily secretions. Water is the most immediately required nutrient. Animals can go without feed and other nutrients for a longer period of time than they can survive without water.

Water is lost through sweating, respiration, and urination. An animal can lose only 10 percent of its body

water before the situation becomes critical. This loss can happen in a matter of days and can result in death. Therefore, it is important to provide animals with adequate quantities of the best quality water available at all times.

Water intake is associated positively with feed intake. For livestock to eat and produce, they must meet their water intake needs. In other words, if water is limited, feed intake and production will be limited.

Animals can obtain water from three sources: drinking water, feed, and metabolism. Drinking water is the most abundant and is our focus here.

Water requirements and the ways in which animals meet those requirements vary. Requirements depend on animal species, age, and stage of production; environmental conditions; and quantity and quality of feed.

For example, milk production increases the water requirement. When the temperature is around 40°F, beef cattle need 4 to 9 gallons of water daily. At similar temperatures, a dairy cow producing 30 to 110 pounds of milk per day consumes 15 to 35 gallons of water each day. Water intake increases with increased levels of milk production.

Horses need 6 to 18 gallons of water daily, depending on size, level of activity, and stage of production. Sheep require 2 to 7 gallons of water daily.

Temperature is an important factor in determining the water requirement. Every animal has a thermal neutral zone—a range of temperatures at which it does not require energy to cool or warm itself. When the temperature is higher, more water is lost through sweat and respiration, thus increasing water requirements. For example, when air temperatures reach 90°F, a beef cow's water consumption increases to 10 to 20 gallons, depending on age and stage of production. When temperatures are around 80°F, a dairy cow consumes 8 to 47 gallons of water. Wind, rain, humidity, and other environmental factors also affect an animal's ability to control its body temperature, thus altering water requirements.

The moisture content of the feed also affects how much drinking water the animal will need. Animals grazing lush pastures in the spring require less drinking water than those grazing drier fall pastures or eating hay. Feeds higher in protein, salts, and fiber also require higher water intake to facilitate digestion and to balance body metabolites.

What is in the water is also important. Solids, salts, minerals, microorganisms, algae, protozoa, pesticides, and other chemicals can affect water palatability and animal health. Species vary in their tolerance for these compounds. Water-quality issues vary among regions and seasonally. For example, some areas of the country have problems with high-sulfate water. If the combined sulfur intake from drinking water and feed is too high, cattle can develop a neurological disorder called polioencephalomalacia.

Thus, it is important to test both feed and water. Feed and water analyses will help you optimize management decisions to meet animals' nutritional and health needs.

Nutritional needs of ruminant animals

Cattle and sheep are classified as ruminants. Ruminants have a unique, highly developed, specialized, fermentive digestive system. They can break down and utilize lower quality protein and the fibrous (cellulosic and hemicellulosic) parts of grasses, legumes, and forbs. Ruminant animals have a four-compartment stomach consisting of the rumen, reticulum, omasum, and abomasum. Each compartment performs unique and important functions in the ruminant's complex digestion process.

The rumen is the largest compartment and is often called the "fermentation vat." As this muscular "vat" contracts, it turns and mixes the ingested feed with an army of microorganisms swimming in the rumen fluid. The microorganisms attach to feed particles, helping to break down carbohydrates into the volatile fatty acids (VFA) acetate, butyrate, and proprionate. VFAs are absorbed across the rumen wall into the bloodstream and are used as the primary energy source for the animal's metabolic functions.

Microbes also break down feed-derived DIP sources. The resulting peptides, amino acids, and ammonia are either incorporated into microbial protein or absorbed as ammonia through the rumen wall into the bloodstream. This ammonia is then processed through the liver. It is later recycled back to the rumen as urea for microbial use or directed to the kidneys and excreted.

Ruminants are often referred to as foregut fermenters, as their fermentation system is located before the small intestine. This arrangement allows them to more effectively utilize microbial-derived protein. High-quality microbial protein and feed-derived protein that

escapes rumen breakdown (UIP) flow through the stomach compartments to the small intestine. There it can be absorbed and utilized to meet the animal's MP requirements.

Ruminants require at least 10 percent effective neutral detergent fiber (NDF) in their diet (as a percentage of DM) to maintain a properly functioning rumen. Abrupt changes in diet can alter the rumen environment and disrupt digestion. Microbial populations can shift to handle different diets and nutrient sources. However, this process takes time, so diets should be changed gradually.

Because ruminants effectively utilize forage as their primary nutritional resource, forage-based diets are typical. Evaluating the nutrient density of the diet and the animal's nutrient intake is important. Most producers know how much feed is offered daily. However, it is equally important to know the nutritional quality of the feed(s) and to calculate whether nutritional needs are being met.

Forage quality varies greatly throughout the growing season and from year to year, particularly on rainfed pastures and rangeland. Figure 10.1 shows the variation in crude protein (CP) over the course of the grazing season for diets selected by cattle grazing Northern Great Basin native rangeland. Harvested forages also vary greatly in nutritional composition, depending on the type of forage and the stage of maturity at harvest.

Knowing how forage quality fluctuates in your pastures and hay will help you manage your production calendar and adjust your feeding plan to meet your animals' nutrient needs. See chapter 11 for information on factors affecting forage quality and how to sample forage for nutritional analysis.

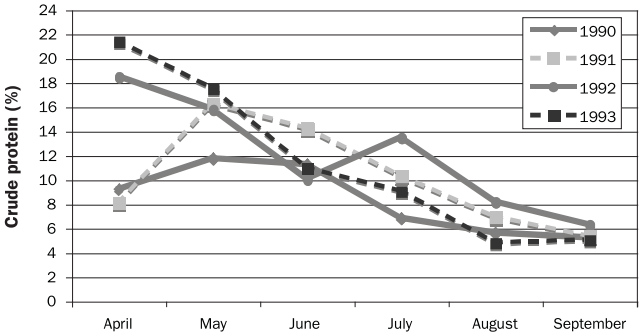

Figure 10.1. Crude protein content of diets selected by cattle grazing Northern Great Basin native rangelands over 4 consecutive years. (Source: DelCurto, T., B.W. Hess, J.E. Huston, and K.C. Olson. 2000. Optimum supplementation strategies for beef cattle consuming low-quality roughages in the western United States. J. Anim. Sci. 77:1–16)

BEEF CATTLE

The main goal of cow-calf operations is to have each cow wean a calf in a 365-day cycle. Nutritional management of the cow herd is a huge factor in reproductive success. The two most important nutrients for beef cows are protein and energy.

Mature cows

Mature cows consume 2 to 3 percent of their body weight in dry matter (DM) each day. Thus, a 1,200-pound cow consumes about 25 to 36 pounds of DM per day. However, the cow's nutritional requirements vary throughout the annual production cycle. It is important to understand this nutritional cycle in order to meet requirements efficiently and economically. Table 10.2 shows the dietary nutrient density required by a mature 1,200-pound beef cow each month, beginning with calving.

Table 10.2. Nutritional requirements of a mature 1,200-pound beef cow through a 12-month production cycle.

	Months since calving											
	1	2	3	4	5	6	7	8	9	10	11	12
Item[a]	Early lactation			Early gestation/late lactation			Midgestation			Late gestation		
DMI (lb)	27	28	28	27	27	26	24	24	24	24	24	25
TDN (% DM)	59	60	58	56	55	53	45	46	47	49	52	56
CP (% DM)	10	11	10	9	8.5	8	6	6	6.5	7	8	9
Ca (% DM)	0.29	0.31	0.29	0.26	0.24	0.22	0.15	0.15	0.15	0.26	0.25	0.25
P (% DM)	0.19	0.21	0.19	0.18	0.17	0.15	0.12	0.12	0.12	0.16	0.16	0.16

Source: Adapted from National Research Council. 1996. *Nutrient Requirements of Beef Cattle*, 7th revised edition. National Academy Press.

[a] DMI = dry matter intake, TDN = total digestible nutrients, CP = crude protein, Ca = calcium, P = phosphorus

The nutritional calendar can be divided into four 3-month periods: early lactation, early gestation/late lactation, midgestation, and late gestation.

The early lactation period—the first 3 months following calving—is when the cow's nutrient requirements are the highest. She requires a diet containing about 60 percent total digestible nutrients (TDN) and 10 to 11 percent CP.

In the West, calving typically occurs in early spring, when most beef operations are feeding harvested forages. Thus, energy or protein supplements may be needed. Alternatively, some ranchers opt for calving when pastures are available for grazing. This system can more effectively match nutrient requirements to the forage supply.

During months 4 through 6 after calving—the early gestation/late lactation period—most actively growing pastures can meet the nutrient requirements of spring-calving cows, unless forage quantity is limiting.

From month 6 through month 9 after calving—midgestation—the cow's nutrient demands are the lowest. Calves typically are weaned by this time, and the new fetus is still small and not demanding much from the cow. Cows in optimum body condition at weaning usually do well on lower quality late-season forage. Overconditioned cows can afford to lose some weight during this time.

Thinking ahead to the next breeding cycle, this period is also an excellent and economical time to put weight on thin cows and get the cow herd to a body condition score (BCS) of 5 or 6. Cows that are thin or lose excessive body condition during early lactation will not begin cycling back as quickly and may not rebreed. Research has shown that cows should have a body condition score of at least 5 (1 = emaciated and 9 = obese) at the start of the breeding season to breed back efficiently. Due to high nutrient requirements during early lactation, it will be difficult to put condition on cows after calving. Thus, body condition at the time of calving is extremely important.

During late gestation—the last 90 days before calving—the cow's protein and energy requirements steadily increase. The developing fetus and placenta are growing rapidly, and the cow is preparing for lactation. As a result of rapid fetal growth, abdominal space may be limited, and feed intake may decrease. You may need to increase dietary nutrient density to allow cows to maintain a BCS of 5 or 6 as they approach calving.

Heifers

Replacement heifers provide the greatest potential for genetic improvement in the beef herd and are a huge investment in time and resources. Attention to heifer nutrition is extremely important. A heifer needs adequate energy and protein to meet growth demands, begin producing in a timely manner, and remain in the herd for a long time.

In many production systems, heifers are expected to calve as 2-year-olds, before they have reached their mature size. A replacement beef heifer should be at 50 to 65 percent of her mature body weight at the time of breeding. By the time she calves, she should be at 70 to 85 percent of her mature body weight and have a BCS of 6.

Cattle diets have traditionally been balanced for protein based on CP content. However, as discussed above, not all protein is digested with equal efficiency. With growing cattle, such as replacement heifers and young cows, it may be important to use metabolizable protein (MP) rather than CP alone to balance protein requirements. When MP requirements are met for first-calf heifers during late gestation, even heifers in excellent body condition show reproductive improvements during the next production cycle.

Crude protein includes digested intake protein (DIP) and undigested intake protein (UIP), both of which can be used to meet the MP requirement. Rumen microbes use DIP to produce microbial crude protein, which is 64 percent digestible. UIP is approximately 80 percent digestible in the ruminant's small intestine. The amount of microbial protein produced is related to the amount of energy in the diet and can be estimated from the TDN content of the feed.

You do not need to calculate the MP value of a diet, but be aware that ignoring the type of protein offered can result in lower-than-expected performance. Some cattle, depending on age and physiological state, require both DIP and UIP. Work with a nutritionist to make sure diets are balanced for MP.

Table 10.3 shows the DM, energy (TDN), CP, MP, Ca, and P requirements of a heifer (mature weight of 1,200 pounds) during the 9 months prior to calving for the first time.

Growing cattle

For any animal, maintenance requirements must be met first. Additional nutrients must be supplied to meet production goals; in young cattle the goal is growth.

Table 10.3. Nutritional requirements of a pregnant replacement heifer with a 1,200-pound mature body weight.

	Months since conception								
Item[a]	1	2	3	4	5	6	7	8	9
DMI (lb)	19	20	20	21	22	22	23	24	24
TDN (% DM)	51	51	51	51	51	52	54	56	60
TDN (lb/day)	9.69	10.2	10.2	10.71	11.22	11.44	12.42	13.44	14.4
CP (% DM)	7.2	7.2	7.2	7.2	7.3	7.5	8	8.5	9.5
CP (lb/day)	1.368	1.44	1.44	1.512	1.606	1.65	1.84	2.04	2.28
MP (g/day)	415	425	437	457	472	501	545	613	718
Ca (% DM)	0.23	0.23	0.22	0.22	0.22	0.22	0.31	0.31	0.3
P (% DM)	0.18	0.18	0.18	0.17	0.17	0.17	0.23	0.22	0.22

Source: Adapted from National Research Council. 1996. *Nutrient Requirements of Beef Cattle*, 7th revised edition. National Academy Press.

[a] DMI = dry matter intake, TDN = total digestible nutrients, CP = crude protein, MP = metabolizable protein, Ca = calcium, P = phosphorus

Requirements for nutrients change as the animal grows and nutrients are allocated to different tissues. Nutrients typically are allocated first to skeletal structure, muscle, and connective tissues. Once those needs are met, excess nutrients are stored as fat or excreted in the urine and feces.

As long as energy intake is adequate, growing cattle deposit intramuscular fat (marbling) throughout their life. However, fat is more costly than lean tissue (muscle) in terms of energy inputs. Muscle is made up mostly of water and protein, while fat contains 2.25 times the amount of energy as protein.

Energy—Growing cattle use energy for a variety of vital functions, including regulating body temperature, other metabolic functions, and protein synthesis (growth). Energy is supplied primarily through carbohydrates and fat. In cattle, especially grazing animals, most energy comes from carbohydrates.

The average daily gains (ADG) of growing cattle depend mostly on energy intake. Therefore, given a desired rate of gain, it is important to match forage quantity and quality to the animal's needs.

Grasses have higher neutral detergent fiber (NDF) than legumes, but lower acid detergent fiber (ADF). Thus, grasses typically provide more digestible fiber and energy than legumes at a similar stage of maturity.

Table 10.4 shows energy requirements for growing cattle at several ADG. Provide supplemental nutrients if forages are limiting desired gains (see chapter 11).

Protein—Protein is required for skin, hair, hormone, and antibody production and for other vital bodily functions. Young, growing animals also need a lot of protein for muscle and tissue growth and renewal. Thus, they need a higher percentage of protein in the diet than do older animals.

The major sources of protein for grazing cattle are legumes, grasses, and supplements. Always consider forage species and time of year when grazing cattle. The type and maturity of grazed forage greatly affects whether or not grazing can meet the protein demands of growing beef cattle. During summer and fall, most forage in the Pacific Northwest matures, dries up, and has reduced feed value.

Protein requirements for growing cattle are shown in table 10.4.

Table 10.4. Nutritional requirements of growing and finishing beef cattle[a] at various average daily gains.[b]

ADG (lb/day)	TDN (% DM)	NE_m (Mcal/lb)	NE_g (Mcal/lb)	CP (% DM)	Ca (% DM)	P (% DM)
0.72	50	0.45	0.2	7.3	0.22	0.13
2.00	60	0.61	0.35	10.2	0.36	0.19
3.04	70	0.76	0.48	13.0	0.49	0.24
3.78	80	0.90	0.61	15.8	0.61	0.29

Source: Adapted from National Research Council. 1996. *Nutrient Requirements of Beef Cattle*, 7th revised edition. National Academy Press.

[a] Weighing 1,200 pounds at harvest (steers and heifers) or maturity (replacement heifers). Assumes that dry matter intake increases as animal body weight increases.

[b] ADG = average daily gain, TDN = total digestible nutrients, NE_m = net energy for maintenance, NE_g = net energy for growth, CP = crude protein, Ca = calcium, P = phosphorus

DAIRY CATTLE

Pasture can often provide dairy cattle with the nutrients needed for desired production. The performance of dairy heifers and cows on pasture depends on the pasture species, stage of maturity, grazing system, stocking rate, milk production goals, and level of supplementation. Intensely managed pastures have the potential to meet a growing replacement heifer's requirements for energy and protein, as well as a lactating cow's requirements at certain times of the year. Dairy cattle require high-quality diets for maximum milk production, however, so supplementation or additional feed is often warranted.

See tables 10.5 and 10.6 for protein and energy requirements for a growing Holstein heifer and lactating cow, respectively. The quality and quantity of forage determine whether energy and protein needs can be met. Grasses provide more energy than legumes, while legumes provide more protein. Hence a mixture of forage species will supply more of the essential nutrients.

Table 10.5. Nutritional requirements of growing Holstein heifers to achieve target average daily gain needed for mature weight of 1,496 pounds and calving at 24 months.

Item[a]	6 mo (440 lb)	12 mo (660 lb)	18 mo (990 lb)[b]
Dry matter intake (lb)	11.4	15.6	24.9
ENERGY			
ME (Mcal/day)	10.6	16.2	20.3
ME (Mcal/lb)	0.9	1	0.8
PROTEIN			
MP (% diet)	8	7.7	5.6
RDP (% diet)	9.3	9.4	8.6
RUP (% diet)	3.4	2.9	0.8
CP (% diet)	12.7	12.3	9.4
FIBER AND CARBOHYDRATES			
NDF (min %)	30 to 33	30 to 33	30 to 33
ADF (min %)	20 to 21	20 to 21	20 to 21
NFC (max %)	34 to 38	34 to 38	34 to 38

Source: Adapted from National Research Council. 2001. *Nutrient Requirements of Dairy Cattle*, 7th revised edition. National Academy Press.

[a] ME = metabolizable energy, MP = metabolizable protein, RDP = rumen degradable protein, RUP = rumen undegradable protein, CP= crude protein, NDF = neutral detergent fiber, ADF = acid detergent fiber, NFC = non-fiber carbohydrate

[b] 90 days of gestation

If the pasture includes legumes, the likelihood of meeting an animal's protein requirements increases.

For growing and lactating dairy cattle, mineral balances are extremely important. It is important to work with a nutritionist to balance the herd's mineral needs at each stage of production. Be aware of the potential for mineral toxicities and deficiencies in your region.

Calcium (Ca) and phosphorus (P) are especially important. Both are required for proper bone and structural development, milk production, and cellular functions. Both Ca and P requirements are greater for younger, growing dairy cattle than for more mature cattle.

Dairy cattle typically need supplementation with salt. Other minerals may be needed, depending on the mineral content of the forage.

Table 10.6. Nutritional requirements of a 1,496-pound lactating Holstein dairy cow at various levels of milk production.[a]

	Pounds of milk production			
Item[b]	55	77	99	120
Dry matter intake (lb)	44.7	51.9	59.2	66
Daily wt change (lb)	1.1	0.7	0.22	-0.44
Days to +/- one body condition score	221	316	1,166	544
ENERGY				
NE_L (Mcal/day)	27.9	34.8	41.8	48.3
NE_L (Mcal/lb)	0.62	0.67	0.7	0.73
PROTEIN				
MP (% diet)	9.2	10.2	11.0	11.6
RDP (% diet)	9.5	9.7	9.8	9.8
RUP (% diet)	4.6	5.5	6.2	6.9
CP (% diet)	14.1	15.2	16.0	16.7
FIBER & CARBOHYDRATES				
NDF (min %)	25 to 33	25 to 33	25 to 33	25 to 33
ADF (min %)	17 to 21	17 to 21	17 to 21	17 to 21
NFC (max %)	36 to 44	36 to 44	36 to 44	36 to 44

Source: Adapted from National Research Council. 2001. *Nutrient Requirements of Dairy Cattle*, 7th revised edition. National Academy Press.

[a] 65 months of age; 90 days in milk; milk fat = 3.5 percent, milk true protein = 3.0 percent, lactose = 4.8 percent

[b] NE_L = net energy for lactation, MP = metabolizable protein, RDP = rumen degradable protein, RUP = rumen undegradable protein, CP = crude protein, NDF = neutral detergent fiber, ADF = acid detergent fiber, NFC = non-fiber carbohydrate

Vitamins normally are not deficient in dairy cattle grazing forage. Fresh forages usually contain adequate quantities of the precursors to vitamins A and E. If cattle are fed low-quality forages that have been stored for a long time, or if they are fed very little forage, vitamin A and E supplementation may be necessary. Vitamin E is an antioxidant that decreases the incidence of mastitis.

Vitamin D is important in Ca and P absorption. Grazing dairy cattle usually manufacture enough vitamin D, as they are exposed to sunlight. However, supplementation may be beneficial just before calving, due to the high demand for Ca and P during lactation.

Rumen microbes synthesize enough vitamin K and B vitamins to meet dairy cattle demands.

Growing heifers

A growing heifer needs energy for vital functions, chemical reactions, temperature regulation, and protein synthesis. She requires protein for skin, hair, hormone, and antibody production and for muscle development. Thus, young, growing heifers need a diet with a higher percentage of protein than do older cows.

High-quality pastures in a vegetative stage can produce gains similar to those produced by high-quality harvested forages. However, lush forages with high moisture content may not meet nutrient requirements for growing heifers because of limited intake. Lower quality pastures are unlikely to meet the nutrient requirements of growing heifers. If gains are not adequate, provide supplemental hay, other harvested forages, or concentrates.

Lactating cows

Energy and protein are needed for milk production. During her first lactation, a cow also needs energy and protein for growth, although less so than during the first year. In an older cow, most of the energy and protein beyond that needed for maintenance is used for milk production. Requirements are based on the level of milk production and the percentages of fat, protein, and lactose in the milk.

Lactating cows can have difficulty meeting energy requirements because of limited intake. It is important to provide adequate nutrition to properly "transition" cows as they calve and begin milking. Otherwise, metabolic disorders can occur.

The quantity and quality of pasture forage changes significantly during the year. Therefore, you may need to supplement high-producing dairy cows with hay, other harvested forages, and/or concentrates to reach production targets. Supplementation is especially important when forage quality and quantity are low, or when high forage moisture content limits intake.

As a cow calves and begins milking, her requirements for Ca and P increase significantly, due to excretion of these minerals in milk. If a cow's diet is not adjusted to meet these increased demands, the risk of milk fever increases. Ca and P requirements continue to increase as milk production increases.

SHEEP

The nutrient requirements of sheep depend on several factors:

- Age—Lambs grow rapidly and have limited digestive tract capacity. Thus, they have higher energy requirements (as a percentage of dry matter) than do adult sheep.
- Level of exercise—In pasture and range production systems, sheep must travel to obtain feed and water. Thus, they require 10 to 100 percent more energy than sheep in drylot production systems. The magnitude of the increase depends on the severity of the terrain and the distance animals must travel.
- Weather—Temperature, wind, and humidity affect energy needs.
- Length and density of the fleece—Wool has both heat- and cold-insulating properties. The condition of the fleece affects the extent to which environmental factors influence nutrient requirements. Shorn sheep need more energy to maintain their body temperature in hot or cold conditions.
- Body condition—The greater the fat covering a ewe is carrying, the greater her level of body condition and the more nutrients it will take to maintain that body condition. Body condition often fluctuates over the season. Ewes lose weight during lactation and should regain body condition after weaning.
- Production stage of the ewe—Lactating ewes have the highest nutrient requirements.

Ewes

The reproductive stage, level of production (lambing rate), and size of the ewe (body weight) play a big part in determining the nutrient needs of a ewe (table 10.7).

Mature ewes have five stages of production: maintenance, breeding, early gestation, late gestation, and lactation. In all stages, the ewe must first meet her

maintenance requirement. Additional nutrients beyond those needed for maintenance are used for productive functions such as reproduction and lactation.

Nutrient requirements increase as the ewe moves through these five stages. The key to meeting increasing nutrient requirements is to increase feed intake. If ewes don't or can't eat more, you will need to provide a more nutrient-dense diet.

Maintenance—The maintenance period is when the ewe is dry. Her nutrient requirements are lowest at this time. Nutrients are required to maintain basic body functions (breathing, cellular turnover, etc.).

Once lambs are weaned, ewes in good body condition can make a living on mature forages or crop residues. The diet should contain about 8 percent crude protein (CP) and 53 percent total digestible nutrients (TDN). This period is an excellent time to add condition to thin ewes.

Breeding and early gestation—Beginning 2 weeks before and continuing 2 weeks into the breeding season, providing ewes with higher quality pasture or supplementing with an additional 0.75 to 1 pound of grain can increase lambing rates by 10 to 20 percent. This management practice, called flushing, increases energy intake. Flushing works best with ewes in moderate body condition and with early or out-of-season breeding programs.

Early gestation is the first 100 days of gestation. Ewe nutrient requirements during this period are similar to maintenance requirements (8 percent CP and 53 percent TDN), as fetal growth demands are not markedly elevated. However, adequate nutrition during this period is critical, as most fetal deaths are attributed to poor ewe nutrition and occur in the first 25 days of gestation.

Average-quality (8 percent CP) pastures or crop residue are excellent grazing options at this time. You may need to supplement with grass-legume hay and/or grain if forage quantity and quality are limiting.

Late gestation—Late gestation (the last 50 days of pregnancy) is a critical period for the ewe. Inadequate nutrition during the last 6 weeks of pregnancy can result in metabolic problems for the ewe, reduced milk production, and weak, unthrifty lambs. It also can dramatically reduce subsequent lamb crops.

Table 10.7. Requirements for dry matter intake, total digestible nutrients, and protein from maintenance through early lactation for ewes at three different mature body weights.[a]

	130 lb ewe					155 lb ewe					175 lb ewe				
Stage of production	**DMI[b] (lb)**	**TDN[c] (lb)**	**TDN[c] (%)**	**CP[d] (lb)**	**CP[d] (%)**	**DMI[b] (lb)**	**TDN[c] (lb)**	**TDN[c] (%)**	**CP[d] (lb)**	**CP[d] (%)**	**DMI[b] (lb)**	**TDN[c] (lb)**	**TDN[c] (%)**	**CP[d] (lb)**	**CP[d] (%)**
Maintenance	2.32	1.23	53%	0.17	7%	2.6	1.37	53%	0.19	7%	2.87	1.52	53%	0.21	7%
Breeding	2.54	1.35	53%	0.2	8%	2.87	1.52	53%	0.22	8%	3.15	1.68	53%	0.24	8%
Early gestation[e]	2.89	1.54	53%	0.23	8%	3.22	1.72	53%	0.25	8%	3.55	1.87	53%	0.28	8%
Late gestation[f]	3.59	1.9	53%	0.3	8%	3.97	2.12	53%	0.33	8%	4.37	2.32	53%	0.36	8%
Early lactation, single	3.9	2.07	53%	0.44	11%	4.32	2.29	53%	0.48	11%	4.7	2.49	53%	0.52	11%
Early lactation, twins	3.97	2.65	67%	0.59	15%	4.37	2.89	66%	0.64	15%	4.74	3.15	67%	0.69	15%
Early lactation, triplets	4.61	3.04	66%	0.72	16%	5.05	3.35	66%	0.78	16%	6.86	3.64	53%	0.89	13%

Source: Adapted from National Research Council. 2007. *Nutrient Requirements of Small Ruminants*. National Academy Press.

[a] Based on ewe weight at the time of breeding

[b] Dry matter intake

[c] Total digestible nutrients

[d] Crude protein

[e] For a ewe pregnant with a single fetus. For ewes gestating twins, increase pounds of DMI and TDN by 15 percent and CP by 20 percent.

[f] For a ewe pregnant with a single fetus. For ewes gestating twins, increase pounds of DMI by 1 percent, TDN by 26 percent, and CP by 23 percent.

Protein and energy requirements increase during this time. Fetal growth is rapid, with approximately two-thirds of total fetal weight developing during this period. As a result, rumen capacity may be limited, particularly for ewes carrying multiple fetuses. Intake may decrease, making it important to provide a nutrient-dense feed. If ewes are on pasture or crop residue at this time, you may need to provide some high-quality supplemental feed.

Lactation—A ewe's nutrient requirements are highest after lambing and during lactation. Protein requirements increase by 30 percent and energy requirements by 55 percent. Inadequate nutrition before and during lactation will result in body condition losses. Severe nutrient deficiencies result in reduced milk production, and lamb weight gains may suffer.

Milk production peaks at about 28 days of lactation and begins to decline after about 60 days. Milk production is a function of the genetic potential of the ewe, nutrient intake, and milk consumption by lambs. Ewes suckling twins produce 20 to 40 percent more milk than those suckling singles. This increased milk production increases the ewe's nutrient requirements and the quantity and quality of feed she needs (table 10.7). It often is impossible to feed a ewe suckling multiples enough to fully meet her nutrient needs. In this case, she will have to rely some on energy reserves.

Ideally, lambing should occur in the spring just as high-quality forage is ready to be grazed. Additional protein and energy supplementation may be necessary, however, depending on the quantity of forage available and the number of lambs the ewe is suckling.

Breeding rams

Maintain breeding rams in moderate body condition to optimize productivity. Poor nutrition prior to the breeding season can cause poor fertility and reduced vigor. Conversely, overconditioned rams are less efficient breeders and cost more to keep.

Even rams in good condition lose a significant amount of weight during a 45-day breeding season. Like ewes, rams can be flushed before and during the breeding season.

Assessing nutritional status

Body condition scoring (BCS) is an excellent way to assess the nutritional status of breeding ewes and rams. The five-point sheep BCS system evaluates the external fat cover over the shoulder, back, rump, and ribs. A sheep with a BCS of 1 is extremely thin, and a sheep with a BCS of 5 is extremely fat.

Ideally, rams and ewes should have a BCS of 3.5 to 4 at the start of the breeding season. Gestating ewes should have a BCS between 2.5 and 4. At lambing, ewes giving birth to singles should have a BCS of 3, and ewes giving birth to multiples should have a BCS between 3 and 4.

Detailed instructions on how to BCS sheep are found in Oregon State University Extension Service publication EC 1433, *Body Condition Scoring of Sheep*.

Lambs

Creep feeding can be an efficient way to reduce the nutrient demand on ewes nursing multiple lambs and to boost lamb gains prior to weaning. At 1 to 2 weeks of age, you can start lambs on a low-fiber creep feed containing 18 to 20 percent CP. Creep feed should contain only natural protein. Young lambs do not have a fully functioning rumen and cannot effectively utilize urea as a protein source.

Lamb diets should contain a 2:1 ratio of calcium (Ca) to phosphorus (P). Lower Ca:P ratios can lead to problems with urinary calculi (water belly).

You can finish weaned lambs on a high-concentrate diet or wean lambs onto high-quality pasture. Weaned lambs do well on actively growing, high-quality grass and grass-legume pastures. Annual pastures containing brassicas can also be an excellent nutritional base for forage-based lamb production.

Lambs weighing 40 to 70 pounds should consume a diet containing 78 percent TDN and 16 percent CP. Finishing lambs weighing 70 to 130 pounds and gaining 0.6 pound per day should consume 3 to 4 percent of their body weight daily. Their diet should contain 72 percent TDN and 14 percent CP.

Nutritional needs of horses

The horse's digestive system is unique. The foregut (mouth to small intestine) is the primary site of enzymatic digestion of non-fibrous carbohydrates, proteins, and fat. The horse's hindgut (cecum to rectum) contains an active microbial population and is the site of fermentive fiber digestion. Similar to the microbes in a cow's rumen, a horse's hindgut microbes utilize some non-fibrous and complex fibrous carbohydrates to produce volatile fatty acids (VFA). The horse then absorbs and uses these VFAs for energy. This microbial fermentation is what enables horses and ruminants to efficiently utilize forages.

Table 10.8. Recommended daily energy, protein, and mineral requirements for horses at different stages of production (mature body weight of 1,100 pounds).

Class of horse	DMI[a] (lb/day)	DE[b] (Mcal/day)	TDN[c] (lb/day)	CP[d] (lb/day)	CP[d] (%)
MATURE HORSE					
Maintenance, no work	18.0	16.7	8.4	1.4	7.8%
Moderate exercise	20.0	23.0	11.5	1.7	8.5%
Heavy exercise	25.0	27.0	13.5	1.0	7.6%
Breeding stallion	22.0	22.0	11.0	1.7	7.7%
Early pregnancy (< 5 months)	20.0	17.0	8.5	1.4	7.0%
Late pregnancy (final 90 days)	22.0	20.0	10.0	1.0	8.6%
Early lactation (1 to 2 months)	24.0	32.0	16.0	3.4	14.2%
GROWING HORSE					
6 months old	11.0	15.5	7.8	1.5	14%
12 months old	15.0	19.0	9.5	1.8	12%

Source: Adapted from National Research Council. 2007. *Nutrient Requirements of Horses*, 6th revised edition. National Academy Press.

[a] Dry matter intake (100 percent dry basis). To convert to as-fed fresh forage basis, divide by the decimal of the feed's percent dry matter (e.g., if the feed is 25 percent dry matter, and DMI is 18 pounds per day, the as-fed quantity is 72 pounds (18 ÷ 0.25 = 72).

[b] Digestible energy

[c] Total digestible nutrients, calculated as DE x (1 kg ÷ 4.4 Mcal) x 2.205 lb/kg

[d] Crude protein

The location of microbial fermentation within the digestive tract makes horses and ruminants very different, however. Because its microbial digestion occurs after the small intestine, a horse is unable to utilize much microbial protein. A horse's fermentation tract is also smaller than that of a ruminant. Thus, horses require smaller, more frequent meals and diets that contain a relatively good-quality protein source.

FEED INTAKE AND NUTRIENT REQUIREMENTS

The nutritional needs of a horse depend on several factors:

- Activity level—Working horses have greater requirements, depending on the frequency and intensity of work.
- Age—Mature horses have lower nutritional requirements than young, actively growing horses.
- Production stage—Requirements are highest during pregnancy and lactation.
- Body size—A draft horse has greater nutrient requirements than a small pony.

Table 10.8 lists the daily recommended protein and energy intake for various classes of horses.

We usually consider feeds on a dry matter (DM) basis (water removed). If a feedstuff is 90 percent DM, it contains 10 percent moisture. Most grass hays are around 90 to 95 percent DM. Dry matter in pastures can range from 30 percent in early spring to around 65 percent later in the growing season.

Horses normally consume 2 to 2.5 percent of their body weight in DM each day (100 percent dry). Intake can vary from 1.5 to 3 percent, however, depending on the horse's activity level and the quality and digestibility of the feedstuff. For example, an increase in workload or exercise can increase intake. Less digestible feeds may remain in the digestive tract for a longer time, limiting the amount and frequency of feeding. As feed quality increases, nutrient density also increases and DM intake may decline.

Diets can consist primarily of forages (hay or pasture) or a combination of forage and concentrates. Horses must consume at least 1 percent of their body weight daily in forage to maintain healthy digestive function. Their remaining nutrient requirements can be met with other feedstuffs.

Body condition scoring (BCS) is an excellent tool for evaluating plane of nutrition. On a scale of 1 to 9, a horse in good condition has a BCS of 5 or 6.

Abrupt changes in diet, such as a large increase in the amount of grain or a change from dry hay to lush pasture can harm the microbial population in the digestive tract. Horse health problems may result. When changing diet, do so gradually to give the microbial population time to adjust.

Feeding too much feed at one time can increase the risk of laminitis and colic. Feeding small amounts frequently is a good practice when supplementing diets with non-fibrous carbohydrate sources such as grain. If feeding grain, limit the amount to 0.5 percent of body weight per meal. For a 1,200-pound horse, feed no more than 6 pounds of grain at one feeding.

In addition to energy and protein, horses require macro- and microminerals. Requirements for the macrominerals calcium (Ca) and phosphorus (P) are greater when tissues and bones are actively growing, as well as during lactation. The optimum Ca:P ratio is 2:1. Supply these minerals in at least a 1:1 ratio.

Microminerals are needed in lesser amounts, but are very important. Feeds and forages supply much of the animal's requirements. Take these sources into account when providing a mineral supplement.

Some soils in the Northwest are deficient in copper, selenium, and other microminerals. In these areas, supplements should contain greater quantities of these minerals. Mineral excesses can also cause problems. Know the potential for deficiencies or excesses in your area and tailor your supplementation program accordingly.

A word of caution: ionophores, which are frequently utilized in ruminant supplementation programs, are toxic to horses.

PASTURE GRAZING

Grazing is a low-cost, healthy way to meet nutrient needs for most horses. Well-managed, actively growing pastures or good-quality hay can meet or exceed the nutritional requirements of most mature horses. (Horses that are worked or ridden often may be an exception.) Grazing horses spend more time eating than nongrazing horses and typically display less behavioral problems, such as cribbing (sucking air) and wood chewing.

A horse weighing 1,100 pounds and consuming 2 percent of its body weight in dry forage (assuming forage is 50 percent DM) consumes about 44 pounds of forage per day (as fed). To prevent damage to the pasture and reduced pasture productivity, it is important to have adequate acreage. The acreage required to effectively graze a horse depends on land productivity (i.e., forage species, rainfall amount or irrigation availability, soil type, and soil quality). See chapter 14 for determining carrying capacity and stocking rate, and chapter 16 for methods of estimating forage production, conducting a forage inventory, and forage budgeting.

Horses prefer grass, but will consume most legumes and some forbs. Common pasture grasses for horses include Kentucky bluegrass, orchardgrass, timothy, smooth brome, meadow foxtail, and endophyte-free tall fescue.

Including clovers or other legumes in the pasture mix can benefit both the horse and the pasture. Legumes provide high-quality protein and reduce the amount of nitrogen fertilizer required. Do not use alsike clover, however, as it can cause horses to be overly sensitive to sunlight.

Contrary to popular belief, the protein from legumes does not cause kidney damage to horses. Horses that consume higher protein diets may urinate more often, however, so it is important to provide unlimited access to fresh, clean water.

Horses are more selective grazers than cattle and graze longer and more frequently. This selectivity may cause "patch" grazing, as horses graze vegetative growth and leave more mature plants. They also tend to defecate in certain areas and avoid grazing in these areas.

Horses with metabolic disorders may need to be managed in a limited turnout grazing situation or with grazing muzzles. Grazing later in the evening and through the night, when soluble carbohydrate levels are lower, is another option for these horses.

For more information

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CHAPTER 11

Pasture Plant Composition and Forage Nutritional Value

T. Griggs, J. Church, and R. Wilson

FORAGE QUALITY, OR NUTRITIONAL VALUE, refers to the concentrations of fiber, energy, protein, minerals, and other nutrients in forage that impact animal performance. Pasture plants vary widely in quality, depending on their growth stage, leaf concentration, and age, as well as on environmental factors and time of year. In this chapter, we discuss plant components that determine forage quality, forage quality characteristics in pastures, factors affecting animal intake, forage sampling, and quality considerations for stockpiled forages and crop residues.

Key Points

- Pasture plant nutritional value can vary widely across a season and is more related to plant growth stage, leaf concentration, and age than to species.
- Pasture animal performance is largely a product of dry matter intake, which is influenced by forage composition. Pasture intake is a function of bite size, which depends on pasture density, pre- and post-grazing pasture height, and forage fiber and digestibility levels.
- Pasture plants in young, vegetative condition can be very high in quality, although waste of forage protein in the rumen can be high.
- For high animal performance, maximize opportunities for high intake through canopy and grazing management. Canopy management for high intake and animal performance leaves enough residual stubble and leaf area to also favor rapid pasture regrowth.
- Assessment of the consistency and composition of manure and changes in body condition can be indications of pasture nutritional value.

The nutritional basis for pasture management

Observant pasture managers are well aware that pasture-livestock systems change constantly in response to environmental and management factors. Unlike properly stored hay and silage, pasture composition and nutritional value vary over time with changing leaf and stem development, plant age, temperature, light, nutrient and water supply, and time of day. Seasonal changes in pasture growth rate add to the challenges of managing pasture quality and intake.

This constantly changing pasture environment calls for vigilance and flexibility in management. Pasture management decisions should also reflect the livestock's nutritional needs. Thus, defoliation decisions are affected not only by the plant factors described in chapter 5, but also by changes in forage nutritional value and animal intake.

It is important to understand how environmental and management factors influence forage quality. With this knowledge, you can maximize forage quality, as well as effectively allocate forage quantity and quality to meet grazing animals' needs.

How well you manage your pastures for animal nutrition will determine the level of performance achieved by your livestock. Grazing animals face the formidable task of harvesting their own feed. Their level of performance (for example, average daily gain or milk production) depends on two pasture-related factors: forage intake and forage quality. From a nutritional standpoint, two-thirds or more of the performance level of a grazing animal is a response to the level of intake, while the remainder is due to the level of forage quality.

Pasture intake is greatly affected by accessibility. Accessibility refers to sward characteristics (height, density, mass, botanical composition, and leaf and stem proportions and arrangement) that affect the amount of forage an animal can obtain in one bite. Forage quality also plays a role in determining intake, however, as high-fiber forages limit intake potential. Thus, quality considerations are critical factors in pasture management.

Knowing the nutritional value of your forages is another key to management success. Ideally, measures of a forage's nutritional value should reflect the level of performance that an animal can achieve when consuming that forage, if quantity is not limiting. In other words, forage quality measurements should represent the livestock production potential of a particular lot of forage when animals can consume as much as they want. However, such a measurement would require costly, time-consuming, feeding trials. Thus, we will describe more practical and cost-effective methods of measuring forage quality.

Key Terms

Cell contents—Highly digestible compounds; the non-fiber portion of feeds. Includes the non-structural carbohydrates (sugars and starch), protein, and soluble minerals.

Cell wall—Structural carbohydrates (cellulose and hemicellulose), pectin, lignin, silica, and minerals that are insoluble in neutral detergent solution. Also known as total fiber.

Crude protein (CP)—The total nitrogen (N) concentration in the dry matter x 6.25. This calculation treats forage N as if it were all in the form of amino acids in true protein. In reality, part of CP is non-protein N.

Neutral detergent fiber (NDF)—Cell wall components minus pectin. Used to predict forage bulkiness in the rumen and potential daily dry matter intake by ruminants.

Rumen degradable protein (RDP)—Protein that is broken down to ammonia in the rumen.

Rumen undegradable protein (RUP)—Protein that is not broken down in the rumen and can be absorbed as amino acids from the small intestine; also known as escape protein.

Total digestible nutrients (TDN)—An expression of energy availability in feed dry matter; the sum of the percentages of digestible fat x 2.25, plus digestible crude protein, plus digestible fiber, plus digestible starch and sugars.

Pasture plants vary in their water and dry matter (DM) content. Typically, water content is 70 to 85 percent, and DM content is 15 to 30 percent. To allow for a standard basis of analysis, forage nutritional value is usually expressed on an oven-dry basis.

Forage components

The chemical and physical composition of forages is commonly described using detergent analysis techniques developed by Dr. P.J. Van Soest in the 1960s. In these analyses, dry ground forage samples are boiled in detergent solutions at neutral or acid pH, then filtered to capture insoluble residues. Differences in solubility among forage components allow forage DM to be divided into two nutritionally relevant parts: plant cell wall (insoluble in neutral detergent) and cell contents (soluble in detergents). Cell wall plus cell contents equal 100 percent of DM.

CELL WALL

Cell wall materials, also known as fiber, consist of the structural carbohydrates cellulose and hemicellulose, plus pectin, lignin, silica, and minerals that are insoluble in neutral detergent solution. Lignin is an indigestible non-carbohydrate that reduces the digestibility of the structural carbohydrates to which it is linked.

Fiber supports and protects plant cells. Fiber and lignin concentrations increase with plant maturity (table 11.1), as cell walls become thicker in stemmy, older tissues. Cell wells also are thicker in grasses (particularly warm-season grasses) than in legumes.

Fiber gives bulk to the diet and is negatively correlated with feed intake (table 11.2). Fiber varies in digestibility, depending on a number of plant and environmental factors that affect lignin concentration (see "Factors influencing digestibility of fiber," below).

Table 11.1. Fiber, protein, and digestibility levels in fresh samples[a] of forage grasses and legumes at increasing stages of maturity (% of DM).[b]

Species and stage	NDF	ADF	CP	IVTDMD
PERENNIAL LEGUMES (ALFALFA, LADINO AND RED CLOVERS, BIRDSFOOT TREFOIL, ETC.)				
Vegetative	26 to 34	20 to 26	23 to 30	87 to 90
Early- to mid-bud	35 to 38	27 to 29	21 to 22	78 to 86
Early bloom	39 to 44	30 to 35	17 to 20	73 to 77
Late bloom	45 to 50	36 to 40	15 to 16	70 to 72
PERENNIAL COOL-SEASON GRASSES (ORCHARDGRASS, TALL FESCUE, SMOOTH BROMEGRASS, ETC.)				
Vegetative	38 to 48	19 to 27	20 to 26	84 to 93
Boot	49 to 59	28 to 36	14 to 19	78 to 83
Heading	60 to 64	37 to 42	11 to 13	70 to 77
Bloom (anthesis)	65 to 67	43 to 47	7 to 10	62 to 69

[a] Hay and silage samples at the same maturity stages would have somewhat higher NDF and ADF levels and somewhat lower CP and IVTDMD levels, due to harvest and storage losses.

[b] NDF = neutral detergent fiber, ADF = acid detergent fiber, CP = crude protein, IVTDMD = *In vitro* true dry matter digestibility after 48-hour incubation in rumen fluid.

Sources:

Cherney, D.J.R., J.H. Cherney, and R.F. Lucey. 1993. *In vitro* digestion kinetics and quality of perennial grasses as influenced by forage maturity. *J. Dairy Sci.* 76:790–797.

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Table 11.2. Predicted forage dry matter intake by ruminants based on forage neutral detergent fiber concentration.

Forage quality	NDF[a] (% of DM)	Daily DM intake[b] (% of body weight)
Excellent	35	3.4
	40	3
	45	2.7
Moderate	50	2.4
	55	2.2
	60	2
Poor	65	1.8

[a] NDF = neutral detergent fiber.
[b] Assumes daily NDF intake of 1.2 percent of body weight.

Source: Mertens, D.R. 2002. Physical and chemical characteristics of fiber affecting dairy cow performance. In: *Proceedings of the 2002 Cornell Nutrition Conference for Feed Manufacturers*. October 23–25. East Syracuse, NY. Cornell University, Ithaca, NY.

Cell wall materials minus pectin are collectively known as neutral detergent fiber (NDF). Although pectin is part of cell wall, it is soluble in neutral detergent and therefore is not included in NDF. In modern forage testing, NDF has replaced crude fiber as a measure of the fiber content of forages.

Another cell wall component, acid detergent fiber (ADF), is simply what remains after a sample is boiled in acid detergent solution, which removes the hemicellulose component of NDF. Acid detergent fiber is often easier to determine than NDF in routine laboratory analysis. For decades, ADF was considered a useful predictor of forage DM digestibility. The relationship between digestibility and ADF can vary widely, however, among species, cuttings, environmental conditions, and time in the growing season. More accurate indicators of digestibility are now available.

CELL CONTENTS

Cell contents are highly digestible compounds that are soluble in neutral detergent. They are the non-fiber portion of feeds: sugars and starch (both non-structural carbohydrates), protein, and soluble minerals. Although technically a part of cell wall, pectin is included in the measurement of cell contents. It has high digestibility, so from a nutritional perspective it has more in common with cell contents than with cell wall.

Cell contents are approximately 98 percent digestible to both ruminants and monogastrics (single-stomached animals), regardless of crop species, plant part, maturity stage, time of year, or environmental conditions. In other words, the nutritional value of cell contents is the same regardless of their source.

Crude protein (CP) is one of the components of cell contents and includes true protein as well as non-protein nitrogen (N). Crude protein is calculated as the total N concentration in forage DM x 6.25, which expresses plant N as if it were all in the form of amino acids in true protein.

Additional details about forage quality constituents, sampling, and analysis are provided in Ball et al. (2001), Hoffman et al. (2001), Schroeder (2004), and Shewmaker (2005).

Digestibility and energy value

Only the digestible components of forage contribute to its energy value. Cell contents are highly digestible, and cell wall (fiber) can be partially digested by ruminants through microbial fermentation in their digestive system. This digested fiber contributes to the total energy value of a feed. Thus, the nutritional value of a feed depends partly on the digestibility of its fiber.

FACTORS INFLUENCING DIGESTIBILITY OF FIBER

Unlike digestibility of cell contents, fiber digestibility varies according to crop species, plant part, maturity stage, time of year, and environmental conditions. For example, fiber digestibility is higher in leafy, younger tissues than in stemmy, older tissues. Forage fiber digestibility (NDF digestibility or NDFD) ranges from less than 40 percent for hay and straw to more than 80 percent for vegetative pasture herbage (table 11.3). Herbage produced during cool spring weather usually has higher fiber digestibility than herbage from summer growth cycles.

Digestibility of fiber ranges higher in grasses than in legumes (table 11.3). While legumes have a lower *extent* of NDF digestibility because their fiber contains more lignin than grasses, they have a higher *rate* of fiber digestibility. This means that the digestible portion of legumes breaks down more quickly in the rumen than does that of grasses. This allows a greater rate of passage of ingested legume forage through the digestive system, which explains why daily DM intake is often higher for legumes than for grasses.

See the chapter appendix for information on how digestibility is measured and calculated.

Table 11.3. Composition and digestibility of perennial forage grasses, legumes, and mixtures.[a]

Forage	NDF	CP	Ca	P	Mg	K	IVTDMD	NDFD
	(% of DM)							(% of NDF)
Legume hay	36 to 51	13 to 24	1.5	0.3	0.2	2.5	70 to 85	33 to 59
Cool-season grass hay	42 to 70	7 to 20	0.5	0.3	0.2	2	55 to 85	33 to 72
Cool-season grass pasture	38 to 62	13 to 26	0.5	0.4	0.2	3.1	82 to 91	35 to 86
Cool-season grass-legume pasture	34 to 60	17 to 26	0.9	0.4	0.2	3	77 to 93	49 to 83

[a] NDF = neutral detergent fiber, CP = crude protein, Ca = calcium, P = phosphorus, Mg = magnesium, K = potassium, IVTDMD = *in vitro* true dry matter digestibility after 48-hour incubation in rumen fluid, NDFD = neutral detergent fiber digestibility after 48-hour incubation in rumen fluid.

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Forage quality in pastures

Well-managed cool-season grass-legume pastures typically have NDF values of 35 to 50 percent. Crude protein ranges from 18 to 25 percent, and IVDMD or total digestible nutrients (TDN; see chapter appendix) is 66 to 72 percent (Muller et al., 2007; National Research Council, 2000 and 2001; Rayburn et al., 2007).

In contrast to hay diets, well-managed leafy pasture in vegetative stages presents few quality constraints to animal performance during the active growing season. Possible exceptions include inadequate levels of some minerals, excessive ruminal protein degradability, the presence of certain anti-quality compounds (see related sections below), and maturation of herbage that accumulates during the spring to early-summer growth flush if grazing animal demand is less than pasture growth rate.

On a DM basis, well-managed pasture can easily exceed high-quality grass and legume hays in terms of digestibility and CP (table 11.3). This higher quality occurs because plants in well-managed, grazed pastures are typically less mature and more leafy than those harvested for hay. Harvested hay is often allowed to grow for a longer time, since a minimum quantity of forage must accumulate to make harvest economically justifiable.

Plant growth stage, leaf concentration, plant age, and time of year are the principal factors that determine pasture forage quality. Plant species is less important. As pasture plants mature, fiber content increases and the fiber contains more lignin. Forage digestibility and intake potential decline. In other words, forage quality is lower.

Even as forage quality declines, animals can influence the quality of their diet if they can selectively graze plants or plant parts. If possible, they will choose the more nutritious forage—the leafy, green, younger tissues.

Forage quality concerns can be much greater where surplus pasture accumulates in a mature or weathered condition, in crop residues, and in forage stockpiled for extended-season grazing. Thus, it is important to minimize intake limitations to animal performance during the growing season.

DIGESTIBILITY

At equivalent stages of maturity, relative DM digestibility of forage species is as follows (in decreasing order of digestibility): brassicas ≥ legumes ≥ cool-season annual grasses > cool-season perennial grasses > warm-season annual grasses > warm-season perennial grasses. Digestibility is highest at the end of a sunny day, due to accumulation of non-structural carbohydrates from photosynthesis, and lowest in the morning, when non-structural carbohydrate levels have been reduced by plant respiration during the night. Grazing animals can therefore consume higher-energy meals during evening grazing.

PROTEIN

Pastures tend to contain high to excessive amounts of CP and rumen degradable protein (RDP). Rumen degradable protein is the fraction of total CP that is broken down to ammonia in the rumen. If the amount of ammonia in the rumen exceeds the amount needed for synthesis of microbial CP, the excess is excreted as urea in urine and feces. This excreted ammonia represents a loss of ingested N. In addition to lowering the efficiency of dietary protein utilization, this process has an energy cost to the animal and releases N to the environment. As much as 70 to 80 percent of CP in pasture herbage can be in the form of RDP, whereas an optimum dietary level for grazing animals is approximately 60 to 67 percent of CP (Muller et al., 2007).

The plant compound tannin reduces protein degradation in the rumen, thus improving protein utilization efficiency and reducing N loss. Tannin is present in sainfoin and a few birdsfoot trefoil varieties.

Other ways to improve protein utilization efficiency on pastures include the following:

- Interseed red clover, which has lower ruminal protein degradability than many other legumes.
- Provide an adequate level of dietary soluble carbohydrates in the form of young, leafy forages or supplemental concentrates in a feed dispenser. Rumen microbes use these carbohydrates as an energy source to convert ammonia to microbial CP.
- Supplement with sources of rumen undegradable protein (RUP), such as brewer's or distiller's grains, corn gluten meal, or heat-treated soybeans, if RDP is above an optimum level of 60 to 67 percent of CP. RUP is degraded to amino acids in the small intestine and absorbed.

MINERALS

Legumes typically have higher calcium, and sometimes higher magnesium, concentrations than grasses (table 11.3). Although there is wide variation among forages, locations, and times of year, common forage mineral deficiencies include phosphorus (P), magnesium (Mg), copper (Cu), zinc (Zn), and selenium (Se) for cattle. Sheep have lower Cu and Se requirements and may not require supplementation with these minerals. Supplementation should be based on forage tests and consultation with a nutritionist. While mineral concentrations in soils may not necessarily reflect those in plants, plant nutrient deficiencies that are common in some Pacific Northwest soils include P, sulfur (S), calcium (Ca) west of the Cascades, and occasionally Zn.

ANTI-QUALITY COMPOUNDS

Anti-quality compounds are plant compounds that negatively affect animal performance. Compounds of concern in pastures include the following:

- Alkaloids produced by certain genotypes of reed canarygrass and endophyte-infected ('E+') tall fescue and perennial ryegrass.
- Nitrates and prussic acid, primarily in annual species (see chapter 12).
- Phytoestrogenic compounds in some alfalfa and red and white clovers. These compounds are chemically similar to estrogen and can impair livestock reproductive performance.

Intake constraints and management in pastures

Daily DM intake (DMI) is the most important factor in determining whether an animal can meet its nutrient requirements. Thus, ensuring adequate DMI is critical to animal performance.

FORAGE QUALITY CONSTRAINTS ON INTAKE

High-fiber forages limit DM intake. As plants advance in maturity, the amount of fiber increases and the digestibility of fiber decreases (tables 11.1 and 11.3). As digestibility declines, the rate of passage through the rumen slows. The resulting gut fill causes animals to reduce their intake (table 11.2).

According to Garcia and Wright (2007), livestock grazing high-quality forages stop eating when they meet their energy requirements. Livestock grazing low-quality forages (high in fiber and low in energy) will stop eating when the rumen becomes distended, even if they have not met energy requirements. Extended periods of grazing low-quality forages that do not meet maintenance requirements will result in weight loss and a decline in body condition.

Forage NDF concentration is the primary indicator of fill effect or DM intake. Research indicates that a cow will eat a daily quantity of NDF up to approximately 1.2 percent of her body weight (Mertens, 2002). Thus, if you know forage NDF concentration and a cow's weight, you can estimate potential daily forage DM intake (DMI) as follows:

$$\text{DMI} = \frac{1.2 \times \text{body weight}}{\text{NDF \%}}$$

For example, consider a 1,000-pound cow eating hay containing 65 percent NDF (DM basis):

$$\frac{1.2 \times 1,000}{65} = 18.5 \text{ lb DMI}$$

This cow will consume 18.5 pounds of DM daily. If she is eating hay or crop residues with 90 percent DM content, she would be expected to eat 20.5 pounds of forage on an as-fed basis:

$$\frac{18.5 \text{ lb DMI}}{0.9 \text{ DM}} = 20.5 \text{ lb forage on an as-fed basis}$$

Once you know the predicted maximum DMI of your animals, you can determine whether they can consume enough forage to meet their requirements. For maximum intake, *cattle need to have access to two to three times more forage DM per day than they are expected to consume*. Tables in chapter 10 and National Research Council (1985, 2000, and 2001) give DMI requirements for various classes of livestock. If your calculated maximum DMI indicates that your animals will not meet these requirements, you'll need to provide energy and/or protein supplements. See chapter 10 for more information.

PASTURE CONSTRAINTS ON INTAKE

Actual DMI may be less than potential DMI if pasture conditions are not conducive to high intake. Daily DMI by grazing animals is a function of three things:

- Size of the individual bite (e.g., grams of DM per bite)
- Biting rate (e.g., bites per minute)
- Total daily grazing time (e.g., hours)

Multiplication of these factors yields total daily DMI.

When pasture conditions such as low sward height or density limit intake, animals can compensate to some extent by increasing their biting rate and grazing time. However, the factor most strongly related to total daily DMI is bite size. Simulating the mouth of a grazing animal by using your hand to grasp a potential bite from a pasture canopy is an easy way to rate potential bite size (e.g., is a single bite the size of a golf ball or a baseball?) and the ease or difficulty with which an animal may harvest its daily feed requirement.

Animals that obtain large bites need less grazing time to meet their nutritional requirements. Where there are few limitations to intake, animals may graze for as few as 6 to 8 hours per day. Animals that are struggling to meet requirements may graze 12 to 14 hours per day while sacrificing performance. By occasionally evaluating the amount of time livestock spend grazing, you can get a good idea of whether they are achieving their potential daily intake.

MANAGING PASTURES FOR HIGH INTAKE

Factors such as sward density, height, and leaf and stem arrangement influence bite size and intake rate. High intake requires a pasture canopy that is tall and dense enough to facilitate grazing while being young enough to be high in quality and not shade lower leaves excessively. (Shading reduces pasture growth rate.) Canopy management principles for high intake are complementary with those for rapid pasture regrowth; both are based on leaving adequate residual herbage mass and/or leaf area.

For most cool-season pastures, high intake potential results from management for high sward density. If livestock nutritional requirements are high, consider

using species with high tiller density, such as perennial ryegrass and tall fescue. If the predominant species in a pasture are bunchgrasses, consider introducing spreading grasses and legumes to fill gaps in the canopy.

Sward height is also important. For most cool-season grass-legume mixtures, optimum sward heights for high intake are in the range of 6 to 10 inches. To facilitate high intake, maintain leafy vegetative canopies up to 8 to 10 inches high and graze no closer than 3 to 4 inches, depending on plant species, livestock class, and performance targets. An 8- to 10-inch pasture height provides approximately 2,400 to 3,200 pounds of forage DM per acre to soil surface level, while a 3-inch residual height leaves about 1,000 to 1,200 pounds of forage DM per acre. Below 1,500 to 1,800 pounds of DM per acre, intake is increasingly restricted by harvesting constraints.

As discussed in chapter 14, forage utilization by high-performing livestock will be lower than that by livestock with lower performance targets; lower performing animals need less daily forage DM and therefore can graze a canopy more closely.

Pasture sampling and analysis

Knowing the nutritional content of your forages will help you ensure that animals are meeting their nutritional requirements. Pasture sampling and analysis will give you this information.

Well-managed pastures often surpass excellent hay in terms of energy and CP (table 11.3). Thus, pasture sampling and analysis is less important for young, leafy vegetation during the active growing season, *once you have adequate baseline data for your grazing season, species, and conditions.* Local Extension information may be available, or you may have to establish a database from periodic pasture sampling. Pasture quality testing is more important if forage is mature or seems to be limiting animal performance. In these situations, or to develop an appropriate database for your operation, sample each management unit for forage quality testing at the following times:

- The beginning, middle, and end of the grazing season that falls during the pasture growing season
- The beginning and end of any dormant-season grazing

Communicate with the laboratory to determine optimum sample size, sampling pattern, and sample handling and submission timing for meaningful results. As with sampling hay for forage quality analysis, each sample should be a composite of at least 20 clips representing a pasture management unit at a moment in time. It is important to obtain a sample that is representative of both the pasture and the diet of your grazing animals. Both are critical because only a small quantity of forage will be analyzed. Use a zigzag or grid sampling pattern similar to those used for soil sampling or estimating standing forage mass (see chapter 16). If you know the grazing habits of your livestock, try to sample only the material that they are likely to consume.

Each clip for a composite sample should typically be only a few tillers to a small handful, so that the final combined sample will be no larger than approximately 0.5 gallon. Laboratories that receive larger samples may dry and grind only a portion of the sample, which may not adequately represent the original sample.

Deliver fresh forage samples directly to a laboratory or place them in a refrigerator, freezer, or drying oven at 140°F (60°C) within 4 to 6 hours to minimize losses of highly digestible non-structural carbohydrates from respiration of plant tissue. Samples that sit at room temperature or higher are not just losing water! If you cannot deliver samples to a laboratory, refrigerator, freezer, or oven within 4 to 6 hours following clipping, place them in a portable cooler with ice or dry ice as they are taken, particularly during hot weather.

Forage protein, energy, and digestibility levels can be analyzed by conventional wet chemistry or near-infrared reflectance spectroscopy (NIRS), which uses the light reflectance pattern from a sample to determine chemical composition. NIRS is faster and less expensive. In some cases, it provides better repeatability of digestibility analyses based on rumen fluid, because an appropriate NIR instrument calibration equation eliminates the day-to-day variations in rumen fluid composition that can occur with wet chemistry analysis. Wet chemistry remains a stronger approach for mineral analysis, however.

Choose a laboratory approved as a provider of wet chemistry and NIRS analytical services by the National Forage Testing Association (NFTA). If the laboratory performs NIRS analyses, membership in the NIRS Forage and Feed Testing Consortium (NIRSC) may provide another level of assurance.

The most useful measurements of pasture forage quality are the following:

- Neutral detergent fiber (NDF)
- Crude protein (CP)
- Rumen degradable protein (RDP)
- *In vitro* DM digestibility (IVDMD or IVTDMD) at 24, 30, or 48 hours
- Neutral detergent fiber digestibility (NDFD) at 24, 30, or 48 hours. This is easily calculated and not an extra procedure if NDF and IVTDMD were determined.
- Total digestible nutrients (TDN) calculated from a summative equation that includes lignin- or *in vitro*-based NDF digestibility data (rather than from ADF or NDF alone)
- Calcium (Ca), P, Mg, potassium (K), and any other minerals that are commonly deficient or excessive in your area

Once you have these values, compare them to the nutritional requirements given in the tables in chapter 10 and NRC (1985, 2000, and 2001). Follow the suggestions in these sources to ensure that animals meet their nutritional needs.

You also can assess forage CP and digestibility values by monitoring manure consistency and fibrosity and body condition score of your animals. The size of residual fiber particles and extent to which manure deposits run or fold and stack is related to the indigestible fiber (and therefore digestibility) levels in the diet. Interpretive guidelines and suggestions are given in Lyons et al. (2000) and in chapter 16.

Stockpiled forages and crop residues

Stockpiling is the accumulation of late-summer and fall pasture regrowth for fall and winter grazing after the growing season ends. Stockpiled pasture, particularly tall fescue, can be higher in quality in fall than in summer. A major challenge with stockpiling cool-season pasture is that the accumulation period occurs during a time of year when growth rate is low and pasture supply may already be limited. Warm-season grasses and supplemental N fertilizer and irrigation offer some options for improving forage production in late summer.

To stockpile forage, defer grazing of a pasture, hay field, or planted crop to allow for late-season growth. The resulting forage can be grazed as a standing crop or swathed and grazed in the windrow. See chapter 14 for more information about stockpiling.

Stockpiled forages and crop residues may be lower in quality than actively growing pasture due to their greater maturity and to weather damage. These high-fiber forages may have reduced nutritional value and limit feed intake (table 11.2).

If you choose to graze crop residues and stockpiled forages, make sure livestock receive the required nutrients. Obtain a nutritional analysis of the forage (at least NDF, energy, and CP) before turning livestock out to graze. Compare test results to the nutrient requirements of the class of livestock that will be grazing the forage (see chapter 10 and National Research Council 1985, 2000, and 2001). In addition, calculate the potential DMI to determine whether the livestock can consume enough forage to meet their requirements. If you note a deficiency, provide a protein and energy supplement to meet the animals' nutritional requirements.

EFFECT OF STOCKPILING PERIOD ON YIELD AND QUALITY

To optimize forage mass and nutritive value, the length of the stockpiling period should be about 70 to 80 days. Longer growing periods increase forage mass but produce forage that is more mature, higher in fiber, and lower in digestibility and CP.

An Iowa State University study showed that a 140-day rest period produced smooth bromegrass forage with 8 percent CP and 50 percent DM digestibility. Johnston and Wand (2002) compared the quality of stockpiled forages with mid-July and mid-August initiation dates in Ontario, Canada. Forage was harvested and tested in October. The pasture that was set aside in mid-July produced forage with 10.3 percent CP and 58.5 percent TDN. The mid-August pasture tested at 14.7 percent CP and 63.4 percent TDN.

A study of smooth bromegrass at the University of Minnesota analyzed forage yield with different stockpiling periods (Cuomo et al., 2000). Stockpiling initiation dates ranged from early June to mid-August, and forage was harvested in mid-October. The early-July initiation date resulted in forage production equal to that of the early-June initiation date. Yield then declined as the initiation date progressed.

Thus, the ideal stockpiling period depends mainly on the type of livestock that will use the forage. If you want to graze dry cows or ewes in the late fall and winter, consider a longer stockpiling period to increase yield. Quality is of less concern with these classes of animals.

If your objective is to graze newly weaned calves or lambs on stockpiled forages, emphasize forage quality rather than yield. Weaned calves weighing 500 to 600 pounds need a ration containing approximately 12 to 13 percent CP (National Research Council, 2000). Lambs weighing 80 to 90 pounds need a diet containing 13 to 14 percent CP (National Research Council, 1985). For these classes of animals, consider a shorter stockpiling period. Shorter rest periods produce forage plants higher in protein and lower in fiber.

WINDROW GRAZING

Windrow grazing involves swathing an annual or perennial crop and leaving it in the field to be grazed by livestock in late fall or winter (see chapter 14). In areas with dry fall and winter conditions, the nutritive value of windrowed forages is comparable to that of baled hay. Research conducted at the University of Nebraska Gudmundsen Sandhills Laboratory compared the CP content of meadow forages cut for hay, swathed and windrowed, or left standing (Berger and Volesky, 2006). Forage was tested at monthly intervals during the fall and winter. CP content in hay and windrowed forage was stable and similar through February, while CP of standing forage declined from 10.6 percent in September to 5.7 percent in February.

Forage quality is highest, in terms of digestibility and CP, when the forage is at earlier stages of maturity at swathing. Harvest perennial grasses early enough in the growing season to allow them to regrow for a fall swathing. Plant annual crops in late spring or early summer to allow for optimum quality at swathing time.

To prevent mold from growing in the windrows, swath forage in the fall when nights are cool. If possible, make windrows high and dense; you may have to rake two windrows together. Windrows should lie parallel to the direction of the prevailing wind. Deterioration of swath quality and structure are potential problems in areas that do not have dry fall and winter conditions and dry snow.

CROP RESIDUE GRAZING

Each fall, abundant corn and cereal grain stubble is available to extend the grazing season and reduce feed costs. These crop residues may be low in quality but can be adequate for certain classes of livestock. Rasby et al. (2008) outlined the average CP and IVDMD composition of corn residue in Nebraska:

- Residual corn grain in the field: 10.2 percent CP and 90 percent IVDMD
- Leaves: 7 percent CP and 58 percent IVDMD
- Husks: 3.5 percent CP and 68 percent IVDMD
- Cobs: 2.8 percent CP and 60 percent IVDMD
- Stalks: 3.7 percent CP and 51 percent IVDMD

For comparison, typical alfalfa hay has a CP level of 18 to 20 percent and a TDN level of 60 percent.

What do these numbers mean? According to Dr. Jeff Lehmkuhler (2003), University of Kentucky Extension beef specialist, the quality of corn residues nearly meets the nutrient requirements of a dry, gestating beef cow. Nutritive value declines, however, as grazing progresses. Protein and energy supplements may be needed later in the season when the quality of corn residue is lower.

Wheat and barley residues also provide late-season grazing opportunities. The quality of cereal straw is lower than that of corn residue, with CP ranging from 3.5 to a little over 4 percent. Total digestible nutrient concentration (protein and energy) is also low (around 40 percent), and crude fiber is high (42 percent).

For more information

Forage Quality Photo Guide. Publication E-541. Texas AgriLife Extension (2000). https://agrilifebookstore.org/

Grazing Crop Residues with Beef Cattle. Publication EC278. University of Nebraska-Lincoln Extension (2008). http://www.ianrpubs.unl.edu/epublic/pages/index.jsp

Windrow Grazing. Publication G1616. University of Nebraska Cooperative Extension (2006). http://www.ianrpubs.unl.edu/sendIt/g1616.pdf

APPENDIX

Predicting Energy Value Based on Digestibility

Measurements of the energy value of a feed must be based on total DM digestibility, including digestibility of fiber. Although NDF and ADF are widely used in equations to predict forage energy value, these measurements are often inadequate for this purpose because neither accounts for the wide variation in the digestibility of forage fiber.

One of Van Soest's contributions to forage quality evaluation was a method for estimating the digestibility of fiber on the basis of lignin concentration. The ADF procedure was developed as a preparatory step in lignin analysis, but relatively few commercial forage testing laboratories complete the steps beyond ADF analysis for determination of lignin concentration.

Progressive forage testing laboratories have adopted new approaches for predicting energy availability. These techniques are based on estimates of fiber digestibility from analysis of the lignin concentration in fiber or on actual measurements of digestibility of DM and fiber in samples that are fermented in laboratory rumen fluid solutions to simulate the ruminant digestive process. The length of the fermentation period varies, depending on the class of livestock, but 48 hours has been used as a standard (Hoffman et al., 2003). Digestibility methods and expressions include:

- *In vitro* ("in glass") DM digestibility (IVDMD) and *in vitro* true DM digestibility (IVTDMD)—measurement of DM disappearance from a sample incubated in rumen fluid for a standard time period, such as 48 hours. For 48-hour fermentation, IVTDMD values are typically about 12 percentage units higher than those for IVDMD, because the two procedures treat samples differently after the fermentation period.
- Neutral detergent fiber digestibility (NDFD)—fiber digestibility expressed as a percentage of NDF (e.g., 65 percent NDFD means 65 percent of NDF is digestible).
- Digestible NDF (dNDF)—fiber digestibility expressed as a percentage of DM (e.g., 36 percent dNDF means 36 percent of DM is digestible NDF. A forage sample with 55 percent NDF and 65 percent NDFD has a dNDF concentration of 36 percent.)

Total digestible nutrients (TDN) is another common expression of forage digestible energy concentration. Its values are similar to those for IVDMD. TDN calculations that are based on ADF concentration fail to account for variations in fiber digestibility and differ widely in their prediction accuracy. A more reliable way to calculate TDN is by means of a summative equation as described in this chapter's key terms (National Research Council, 2001; Schroeder, 2004). Other expressions of available energy density, such as digestible energy (DE), net energy (NE), and metabolizable energy (ME) are calculated from TDN or from forage components in summative equations similar to the equation used to calculate TDN (National Research Council 2000 and 2001).

For purposes of classifying and marketing harvested forage, laboratories often calculate an index representing potential *daily intake of digestible DM* based on ADF and NDF values (see Schroeder, 2004). This measure is known as Relative Feed Value (RFV). In this approach, the potential daily digestible DM intake of a forage sample is rated relative to full-bloom alfalfa hay, which has a reference value of 100. Forage that is higher in quality than full-bloom alfalfa hay has an RFV greater than 100. This index suffers from the unreliability of ADF as a predictor of DM digestibility.

RFV is being replaced by Relative Forage Quality (RFQ) in modern forage analysis. RFQ is conceptually identical to RFV, but relies on estimates of fiber digestibility from measures of lignin or digestion in rumen fluid for improved estimates of digestible DM intake. Neither RFV nor RFQ is used in livestock ration formulation.

CHAPTER 12

Health Considerations for Grazing Animals

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FOR ANIMAL HEALTH PROBLEMS TO ARISE, specific conditions are required. These conditions are related to (1) the animal, (2) the "pest" (toxic plant, disease organism, parasite, etc.), and (3) the environment. Figure 12.1 illustrates this concept. The severity of a health disorder depends on both the presence and level of all three conditions.

Many factors can cause disorders in grazing animals. Disorders can be due to a single factor or to interactions among two or three factors. For example, healthy livestock can generally avoid or tolerate many plant-induced disorders if they have adequate-quality forage, clean water, proper minerals, shelter, and good fences, and if weeds, pests, and manure are managed properly. Conversely, even expensive purebred livestock or horses on a good vaccination and deworming program can succumb to a severe parasite infestation when kept in crowded conditions with inadequate forage, stagnant water, improper pest and manure management, and poorly timed drug treatment.

The first part of this chapter describes plant-induced disorders caused by physical or chemical attributes of forage and weed species. Animal diseases, external pests, and internal parasites are discussed in the second part of the chapter. The final part briefly discusses animal welfare issues.

Key Points

- Grazing animals are exposed to numerous potential health disorders on pasture. Unexpected animal health issues may emerge with more intensive utilization of pasture-based livestock systems.
- Physical or chemical attributes in some plants can injure or poison animals on pasture.
- Many animal diseases, external pests, and internal parasites can occur in grazing animals.
- Although the number and severity of these problems may seem daunting, many of these syndromes rarely occur with proper livestock and pasture management.
- Both novice and experienced graziers should be familiar with pasture animal health principles. Animals should be monitored daily and handled by safe and low-stress methods.

Forage or pasture-related disorders of grazing livestock

PHYSICAL PLANT STRUCTURES

Many plant structures can cause problems for grazing livestock. These structures include awns (hare barley, foxtail barley, needlegrass, medusahead rye, ripgut brome, downy brome, cheat), burrs (burdock, cocklebur, longspine sandbur), spines (yellow starthistle, puncturevine), and thorns (wild rose). When these plant structures become lodged in the nostrils, eyes, mouth, or digestive tract, they cause animal trauma. Infections can occur if they become embedded in tissues and form abscesses or ulcers.

Control plants with these structures using the measures discussed in chapter 7. Management information for specific weed species is available in the *Pacific Northwest Weed Management Handbook*. See the chapters on "Managing Small Pastures," "Pasture and Rangeland Weed Control," and "Control of Problem Species." Another valuable reference is *Weeds of California and Other Western States*.

PLANT-INDUCED DISORDERS

Plant-induced disorders include toxicities, digestive problems, and chemical imbalances. Toxicities caused by poisonous plants are due primarily to effects on the animal's metabolism. Examples include nitrate toxicity, prussic acid toxicity, and photosensitization. Examples of digestive and chemical imbalances include bloat and grass tetany.

Many plant-induced animal disorders occur only seasonally or sporadically. For example, toxic plant compounds vary, depending on the season. In the case of disorders such as bloat and forage mineral imbalances, both the crop (species and stage of growth) and the environment are contributing factors.

Learn to recognize the common symptoms of animals affected by these problems. Immediately remove affected animals from the pasture and provide free-choice clean water and good-quality hay. Consult with a veterinarian about treatment for severely affected animals.

Bloat

Bloat (also known as frothy bloat) can be a significant risk for cattle and sheep grazing pastures containing a high percentage of alfalfa and other legumes. Symptoms include distended rumen, labored breathing, restlessness, and frequent urination and defecation. Death

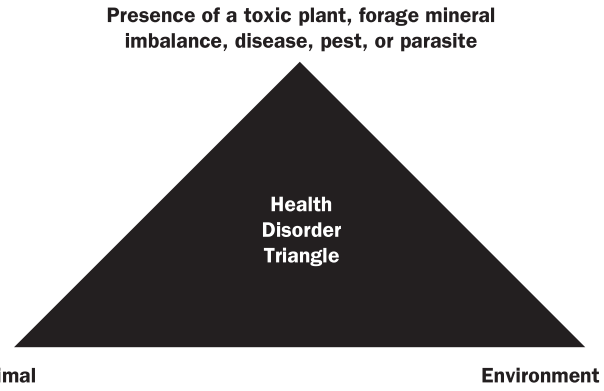

Figure 12.1. The health disorder triangle illustrates the conditions necessary for development of animal health disorders due to plant toxicities, mineral imbalances, diseases, pests, or parasites. The presence and severity of the disorder (size of the triangle) is determined by the level of each factor.

can occur rapidly. Mild "subacute" bloat (rumen distended on one side) frequently occurs. Most individuals can develop an increasing level of tolerance.

Bloat typically occurs in ruminant livestock grazing lush alfalfa or clover, but can also occur on lush grass or cereal pastures such as wheat. Consuming these forages without accompanying hay or other low-moisture forage often leads to a severe form of indigestion characterized by an abnormally high accumulation of gas. The breakdown of rapidly soluble proteins forms a stable foam over the rumen contents, reducing the animal's ability to eructate (belch). Bloat results when the animal is unable to eructate the large quantity of gases produced during rumen fermentation.

Contributing factors include:

- Forage species—Alfalfa, white clover, red clover, or wheat is often involved.
- Stage of plant growth—Bloat risk declines with plant maturity.
- Season—Bloat "storms" are more likely in the spring or fall and following rainstorms.
- Concentrations of certain soluble proteins—High nitrogen (N) fertility increases the risk.
- High rate and amount of forage intake
- Low fiber concentration
- Rumen microbial population
- Inflammation of lymph nodes between the lungs—Inflamed lymph nodes compress the esophagus.
- An inherited tendency by some animals

The complex interactions among bloat-causing factors require a number of preventive measures:

- Establish and manage pastures so that alfalfa and clover make up less than 50 percent of the forage biomass.
- Establish a non-bloating legume in pastures, such as birdsfoot trefoil, cicer milkvetch, or sainfoin.
- Allow animals to fill on dry roughage before turning out on bloat-prone pastures.
- When grazing a bloat-prone pasture, feed dry hay or windrow-graze.
- Feed antifoaming agents such as Poloxalene in a molasses-containing block.
- Move animals to a drylot or other area following heavy dew or rain.
- Immediately move distressed animals to another pasture (and possibly away from the herd).
- Consult with your veterinarian and plan ahead to be competent in handling a severe bloat event.

Grass tetany

Grass tetany (also called hypomagnesemia for "low magnesium") is a common metabolic disease of ruminants. It usually is associated with early-spring grazing of lush, grass-dominated pastures, but can occur with grazing of regrowth in intensively grazed pastures. Symptoms include nervousness, stiffness, reduced milk production, staggering, and labored breathing. These symptoms can progress to convulsions and death in as few as 6 hours. Cows or ewes following late-winter parturition are most susceptible to tetany.

Tetany occurs when an animal's level of blood magnesium (Mg) is too low. Low Mg levels in forage can be a significant contributing factor to tetany.

Magnesium is required at similar levels for both crop and livestock function. Cool-season grasses should contain at least 0.2 percent Mg on a dry weight basis. For proper sheep and cattle growth, livestock diets should contain at least 0.1 percent Mg. For lactating cows, the diet should contain more than 0.2 percent Mg.

In spring, rapidly growing plants typically have low levels of Mg and high potassium (K) concentrations (above 3 percent). Potassium reduces the absorption of Mg in forage plants and the rumen, reducing the amount of animal-available Mg.

Additional factors associated with Mg deficiency include:

- Lactation—Large quantities of calcium (Ca) and Mg are excreted in milk.
- High concentrations of crude protein (greater than 25 percent) or N (greater than 4 percent) in forage.
- High levels of N fertilization, especially during poor plant growing conditions.
- Bad weather (especially storms) or other stresses that cause livestock to go off feed for more than 24 hours.
- Interactions among the above factors, resulting in low blood Mg and Ca.

Pastures can be managed to reduce the risk of grass tetany. On first-pass pastures in the spring, a significant supply of residual growth from the previous year (or some dry hay) can reduce the risk. Split annual N and K applications to avoid high concentrations of these elements.

In extreme cases of tetany, a veterinarian can treat the affected animal with injections of magnesium sulfate or calcium gluconate.

Milk fever

Milk fever (also called hypocalcemia for "low calcium") is a metabolic disorder related to Ca availability. It occurs most frequently in females at the onset of lactation. Milk fever does not cause a fever. Symptoms include muscle weakness, fatigue, reduced milk yield, and loss of appetite. In severe cases, heart failure can occur. On early-season pastures, both plant Ca and Mg may be low, and the symptoms of milk fever may be indistinguishable from those of tetany.

Forage tissue levels of 0.3 to 0.4 percent Ca typically meet livestock Ca requirements. Comprehensive forage testing across the United States has shown that legumes typically have higher concentrations of Ca (1.4 percent) than grasses (0.6 percent). Ideally, the calcium:phosphorus ratio in the diet should be 2:1.

Supply Ca in the form of a balanced mineral meal or block prior to parturition and while livestock are on pastures. Severe cases of milk fever may require a veterinarian to provide an injection of calcium gluconate.

Winter tetany

"Winter tetany" is caused by feeding hay with excessive (or unbalanced) K levels. A "tetany risk ratio" is often used to evaluate the potential risk. If the milliequivalent (meq) ratio of K to (Ca + Mg) is above 2.2, the hay has a high risk of inducing tetany. To estimate the tetany risk ratio, obtain laboratory analyses for K, Ca, and Mg (100 percent dry matter basis). Calculate the meq values by multiplying the concentrations (percent) of K, Ca, and Mg by 255.74, 499.00, and 822.64, respectively.

For example, from a barley hay analysis, the laboratory reported that the forage contained 3.09 percent K, 0.24 percent Ca, and 0.2 percent Mg. Using the equations above, the tetany risk ratio is:

$$\frac{3.09 \times 255.74}{(0.24 \times 499.0) + (0.2 \times 822.64)} = \frac{790.2}{284.3} = 2.8$$

Since 2.8 is greater than 2.2, this hay is at risk for inducing tetany.

You can use soil or forage tissue analysis to monitor Mg concentrations. However, it may be more efficient to provide Mg in a complete mineral supplement. Begin supplementation 3 weeks before tetany is anticipated (the turnout date in some circumstances). Many mineral formulations are available. An economical choice is a 1:1:1 mixture of trace mineral salt, magnesium oxide, and cracked grain or dry molasses. Monitor mineral intake frequently. Daily consumption is required, because Mg is not stored in the body.

Nitrate toxicity

Nitrate toxicity is caused by elevated consumption of nitrate (NO_3) in pasture crops, weeds, hay, or water. Symptoms include increased heart rate, labored breathing, change in color of tissues from pink to blue, and muscle tremors. Affected animals may stagger, abort fetuses, and die within hours of ingesting toxic levels of nitrate. Gestating ruminants are very susceptible to high levels of NO_3.

In the body, nitrite (NO_2) is produced as an intermediate step in the conversion of absorbed nitrate to amino acids and protein. Nitrite (NO_2) is highly toxic and competes directly with oxygen (O_2) in the bloodstream.

A number of plant, livestock, and environmental conditions increase the likelihood of nitrate toxicity. These include:

- Stage of plant growth—Many grasses and legumes contain high levels of NO_3 during their early vegetative growth. During flowering or reproduction, nitrate is rapidly converted to plant proteins.
- Plant part—NO_3 is higher in stems than in leaves or reproductive structures. It is highest in the lower stems.
- Plant species—Certain species tend to be nitrate "accumulators," including oats and other cereals, sudangrass, and many common weeds, such as pigweed species, nightshade species, common lambsquarters, common mallow, kochia, and wild oat. These species tend to retain high levels of nitrate throughout their entire growth cycle (see table 12.1).
- The amount and availability of soil N—In intensively managed pastures, N applications must be split.
- Soil conditions—NO_3 uptake is favored by low soil temperatures and low or deficient plant levels of phosphorus (P), sulfur (S), and molybdenum (Mo).
- Drought, cloudiness, or extreme heat or cold conditions that restrict normal plant growth
- Livestock condition—NO_3 toxicity risk usually is higher for females on a low plane of nutrition, in gestation, or under other stress.
- Rapid change in the diet of gestating or stressed livestock from a low-quality roughage to a diet containing high levels of NO_3

Over time, livestock can tolerate increasingly higher levels of forage NO_3, as the rumen microflora adapt. In a managed rotational grazing system, livestock can adapt to elevated NO_3 levels multiple times during the year, including during winter when hay is fed.

Due to the potentially rapid onset of NO_3 toxicity, be careful when initiating grazing on suspect pastures, especially in the case of pregnant mares, foals, and other juvenile animals. Test forage that is likely to be high in NO_3, especially if it has been heavily fertilized with N or is drought stressed. A recently developed product (www.lallemand.com) containing high concentrations of propionic bacteria can be administered to animals before feeding high-NO_3 roughages.

Animals suspected of having NO_3 poisoning should be kept stress-free. Remove the suspect feed source from

Table 12.1. Toxicities and associated common plant species in the inland Pacific Northwest.

Impact on animal	Chemical/ symptom group	Potential plants involved
Potential for sudden death	Cyanogenic glycosides (HCN)	Sudangrass and other sorghums (*Sorghum* spp.), white clover (*Trifolium repens*), serviceberry (*Amelanchier alnifolia*), hydrangeas (*Hydrangea* spp.), flaxes (*Linum* spp.), birdsfoot trefoil (*Lotus* spp.), crabapple leaves (*Malus* spp.), lima bean (*Phaseolus lunatus*), chokecherries (*Prunus* spp.), elderberries (*Sambuccus* spp.), mountain-mahogany (*Cercocarpus montanum*), brackenfern (*Pteridium aquilinum*), arrowgrass (*Triglochin maritima*), vetch seed (*Vicia sativa*), corn (*Zea mays*)
	Nitrate toxicity	Ragweeds (*Ambrosia* spp.), pigweeds (*Amaranthus* spp.), tame oat and wild oat (*Avena* spp.), sugarbeet (*Beta vulgaris*), rape (*Brassica napus*), common lambsquarters (*Chenopodium album*), Canada thistle (*Cirsium arvense*), field bindweed (*Convolvulus arvense*), jimsonweed (*Datura stramonium*), barnyardgrass (*Echinochloa crus-galli*), sunflower (*Helianthus annuus*), barley (*Hordeum vulgare*), kochia (*Kochia scoparia*), flaxes (*Linum* spp.), mallows (*Malva* spp.), alfalfa (*Medicago sativa*), sweetclovers (*Melilotus* spp.), millets (*Pennisetum*, *Pannicum*, and *Echinochloa* spp.), smartweeds (*Polygonum* spp.), curly dock (*Rumex crispus*), Russian thistle (*Salsola kali*), feral or cereal rye (*Secale cereale*), sudangrass and sorghums (*Sorghum* spp.), nightshades (*Solanum* spp.), goldenrods (*Solidago* spp.), wheat (*Triticum aestivum*), corn (*Zea mays*)
	Toxic alkaloids	Larkspurs (*Delphinium* spp.), monkshood (*Aconitum columbianum*), poison hemlock (*Conium maculatum*), waterhemlocks (*Cicuta* spp.)
Cardiovascular system	Cardiac glycosides	Hemp dogbane (*Apocynum cannabinum*), lily-of-the-valley (*Convallaria majalis*), garden foxglove (*Digitalis purpurea*), oleander (*Nerium oleander*), milkweeds (*Asclepias* spp.), yews (*Taxus* spp.), deathcamas (*Zigadenus* spp.)
Digestive system	Excessive salivation	**Physical structures**: foxtail barley (*Hordeum jubatum*), hare barley (*Hordeum leporinum*), needlegrass (*Stipa* spp.), ripgut brome and downy brome (*Bromus* spp.), squirreltail (*Sitanion hystrix*), foxtails (*Setaria* spp.), sandbur (*Cenchrus longispinus*), medusahead rye (*Taeniatherum asperum*), burdock (*Arctium minus*), cocklebur (*Xanthium strumarium*) **Chemical irritants**: clover or alfalfa infected with *Rhizoctonia leguminicola* **Protoanemonins**: buttercups (*Ranunculus* spp.), marsh marigold (*Caltha palustris*), clematis (*Clematis* spp.), baneberry (*Actaea arguta*)
	Vomiting	Orange sneezeweed (*Dugaldia hoopesii*), Colorado rubberweed (*Hymenoxys richardsonii*), bitterweed (*Hymenoxys odorata*)
	Nightshade poisoning (steroidal glycoalkaloids causing colic, constipation, or hemorrhagic diarrhea)	Nightshades, buffalobur, horsenettle, and bull nettle (*Solanum* spp.), jimsonweed (*Datura stramonium*), deadly nightshade (*Atropa belladonna*), black henbane (*Hyoscyamus niger*), buffalobur (*Solanum rostratum*), ground cherries (*Physalis* spp.)
	Diarrhea, gastrointestinal poisoning	Yarrow (*Achillea millefloruм*), leafy spurge (*Euphorbia esula*), irises (*Iris* spp.), horsetail (*Equisetum arvense*), bitterweeds (*Helenium* spp.), tulips (*Tulipa* spp.), numerous mustards (*Brassica* spp.), rhododendrons (*Rhododendron* spp.), common boxwood (*Buxus sempervirens*), laurels (*Kalmia* spp.)
Skin and liver disorders	Primary photosensitization (directly affects skin)	Buckwheat (*Fagopyrum esculentum*), St. Johnswort (*Hypericum perforatum*)
	Secondary photosensitization (liver function damaged—compounds or their components cause secondary skin and organ disorders)	**Pyrrolizidine alkaloids**: fiddlenecks (*Amsinckia* spp.), houndstongue (*Cynoglossum officinale*), tansy ragwort and groundsels (*Senecio* spp.) **Alsike clover poisoning**: *Trifolium hybridum* **Other**: tame oat and wild oat (*Avena* spp.), rape (*Brassica rapus*), kale (*Brassica oleraceae*), sandbur (*Cenchrus longispinus*), tansy mustard (*Descurainia pinnata*), flixweed (*Descurainia sophia*), wild carrot (*Daucus carota*), milk purslane (*Euphorbia maculata*), barley (*Hordeum vulgare*), kochia (*Kochia scoparia*), cocklebur (*Xanthium strumarium*), perennial ryegrass (*Lolium perenne*), panic grasses (*Panicum* spp.), alfalfa (*Medicago sativa*), hairy vetch (*Vicia villosa*), parsnip (*Pastinaca* spp.), knotweeds (*Polygonum* spp.), buttercups (*Ranunculus* spp.), sudangrass (*Sorghum* spp.), puncturevine (*Tribulus terrestris*), clovers (*Trifolium* spp.) **Mycotoxin (aflatoxin)**: Moldy hay, straw, or grain infected with *Aspergillus* or *Penicillium* spp. **Blue-green algae poisoning in stagnant ponds**: (*Microcystis*, *Anabaena*, and *Aphanizomenon* spp.)

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Table 12.1 *continued*. Toxicities and associated common plant species in the inland Pacific Northwest.

Impact on animal	Chemical/ symptom group	Potential plants involved
Blood disorders	Red blood cell damage	Onion and wild onion (*Allium* spp.), kale, rape, and turnip (*Brassica* spp.)
	Inhibition of blood clotting	Brackenfern (thiaminase) and dicoumarol, an anticoagulant in sweetclover infected by *Aspergillus*, *Penicillium*, or *Mucor* spp.
	Goiter, hypothyroidism	**Glucosinolate poisoning**: whitetop (*Lepidium draba*), mustards (*Brassica* spp.)
Nervous system	"Locoism" alkaloids	Milkvetches (*Astragalus* spp.), point vetch (*Oxytropis* spp.)
	Essential oils, sesquiterpene lactones, or monoterpene toxins	Fringed sage (*Artemisia frigida*—horses only), big sagebrush (*Artemisia tridentata*), yellow starthistle (*Centaurea solstitialis*), Russian knapweed (*Centaurea repens*)
	Other	Horsetails (*Equisetum* spp.), sudangrass (*Sorghum* spp.), sweetpea (*Lathyrus* spp.), hemp (*Cannabis sativa*)
Kidney failure	Oxalate poisoning (sodium or potassium oxalate accumulation)	Pigweeds (*Amaranthus* spp.), sugarbeet (*Beta vulgaris*), lambsquarters (*Chenopodium album*), halogeton (*Halogeton glomeratus*), kochia (*Kochia scoparia*), sheep sorrel (*Rumex acetosella*), purslane (*Portulaca oleraceae*), curly dock (*Rumex crispus*), rhubarb (*Rheum rhaponticum*), Russian thistle (*Salsola kali*), greasewood (*Sarcobatus vermiculatus*)
Congenital defects and reproductive disorders	Abortion	Milkvetches (*Astragalus* spp.), *Oxytropis* spp., *Brassica* spp., poison hemlock (*Conium maculatum*), spotted hemlock (*Conium maculatum* vars. *angustifolia* and *bolanderi*), fescue (*Festuca* spp.), halogeton (*Halogeton* spp.), juniper (*Indigofera glomeratus* and *Juniperus* spp.), alfalfa (*Medicago sativa*), tansy (*Tanacetum* spp.), goldenrods (*Solidago* spp.), clovers, false hellebore (*Veratrum* spp.) **Pine needle abortion**: ponderosa pine (*Pinus ponderosa*) **Nitrate accumulators**: see "Nitrate toxicity," previous page
	Teratogens (cause fetal death or deformity)	Milkvetches (*Astragalus* spp.), *Oxytropis* spp., spotted hemlock (*Conium maculatum* vars. *angustifolia* and *bolanderi*), sweetpea (*Lathyrus odoratus*), lupine (*Lupinus* spp.), poppies (*Papaveraceae* spp.), *Senecio* spp., false hellebore (*Veratrum* spp.), periwinkle (*Vinca rosea*)
	Phytoestrogens (cause infertility)	Clovers (*Trifolium* spp.), alfalfa (*Medicago sativa*)
Muscle and bone system	Selenium poisoning, alkali disease	Milkvetches (*Astragalus* spp.), rayless goldenweed (*Oonopsis engelmannii*), woody aster (*Xylorrhiza glabriuscula*), white fall aster (*Aster falcatus*), prince's plume (*Stanleya pinnata*), broom snakeweed (*Gutierrezia sarothrae*), gumweed (*Grindelia* spp.), saltbush (*Atriplex* spp.), Indian paintbrush (*Castilleja* spp.), beard tongue (*Penstemon* spp.)
Plant toxins in milk	Above compounds and symptoms transferred in milk	**Pyrrolizidine alkaloids**: fiddleneck (*Amsinckia* spp.), houndstongue (*Cynoglossum officinale*), tansy ragwort and groundsels (*Senecio* spp.) **Indolizidine alkaloids**: milkvetches (*Astragalus* spp.), *Oxytropis* spp. **Glucosinolates**: whitetop (*Lepidium draba*), mustards (*Brassica* spp.)

Source: Adapted from Knight, A.P. and R.G. Walter. 2001. *A Guide to Plant Poisoning of Animals in North America*. Teton NewMedia.

the diet. If a case is severe but diagnosed early, a veterinarian can inject the affected animal with methylene blue.

Prussic acid poisoning

About 2,000 plant species produce cyanogenic glycosides (table 12.1). These compounds can cause prussic acid (hydrogen cyanide, or HCN) poisoning within 20 minutes of ingestion. HCN is released when plant cells are chewed, crushed, digested, wilted, or frozen. It is highly toxic and inhibits cells' ability to utilize oxygen.

Early symptoms of prussic acid poisoning include excitement and labored breathing. Convulsions, stupor, coma, and death follow. Chronic HCN poisoning, which is caused by sublethal doses over time, causes loss of nerve function.

This disorder is relatively rare on well-managed permanent pastures. The highest risk of HCN poisoning occurs on annual pastures containing sudangrass or sorghums (all now classified as *S. bicolor* (L.) Moench). The risk is greatest when grazing young growth or regrowth following drought or frost. High HCN levels can occur sporadically in pastures with high densities of white clover, vetch (seed), or birdsfoot trefoil, or where animals have access to arrowgrass, brackenfern, chokecherry, serviceberry, western waterhemlock, or apple trees.

In grass-legume pastures containing white clover or birdsfoot trefoil, maintain a good balance of grass and legume foliage. Follow guidelines for proper grazing heights, rest periods, and fertilizer application. Pay close attention to grazing animals in the early spring and fall.

The only treatment for HCN poisoning is injection of an appropriate antidote, such as sodium thiosulfate or sodium nitrate.

Fescue and ryegrass toxicoses

The causes of these long-known animal disorders have only recently been fully recognized. Previously referred to as "fescue foot," "summer slump," or "ryegrass staggers," these disorders are very important because of the widespread use of tall fescue and perennial ryegrass in improved pastures.

Symptoms in cattle and sheep include lack of appetite; reduced weight; low milk production; high body temperature; dull, rough haircoat or reduced wool production; excessive salivation; and reproductive problems. Under high N fertilization, affected cattle can develop fat necrosis—hard masses in the fatty tissues surrounding the intestines. This condition causes digestive problems and can interfere with calving.

In horses, mares are particularly susceptible to fescue and ryegrass toxicoses. Symptoms include prolonged gestation, difficult or abnormal labor or delivery (dystocia), retained placenta, stillborn foals, late-term abortions, and greatly reduced milk production (agalactia). Foals born to affected mares may be uncoordinated and have limited immunity to infection.

Fescue and ryegrass species live in a mutually beneficial (symbiotic) relationship with an endophytic (inside-the-plant) fungus *Neotyphodium* spp. The fungus, in combination with the plant, produces alkaloids similar to those produced by the ergot fungus. The alkaloids provide the plant with increased tolerance to numerous stresses, including drought, cold, salinity, grazing, and pests. However, they also cause animal health problems.

The fungus is seed-borne, so the major preventive measure is to establish new pastures with endophyte-free seed. Seed of endophyte-free varieties of tall fescue and perennial ryegrass is now available, as are new varieties containing novel endophytes. These endophytes convey agronomic benefits without adverse animal health effects.

When renovating an infested pasture, remove vegetation mechanically or chemically. Do not replant with fescue or ryegrass for at least one season.

Grass-legume mixes reduce the impact of the toxins. Overseeding with red or white clover can be a temporary measure to reduce animal health problems by diluting forage with a high-quality, toxin-free species.

Photosensitization

Photosensitization is induced by numerous compounds in a variety of plants (table 12.1). It resembles severe sunburn. In severe cases, the animal's skin can slough off. Light-skinned animals and white areas on multicolored livestock (e.g., Hereford cattle) are most susceptible.

In primary photosensitization, dermatitis and other skin disorders occur when plant compounds react with ultraviolet (UV) light in the animal's blood. Plants associated with primary photosensitization include tall and creeping buttercup, buckwheat, St. Johnswort, and spring parsley.

Secondary photosensitization is more common than primary photosensitization. This disorder is due to

liver disease. Numerous plant compounds, such as pyrrolizidine alkaloids, destroy liver tissue. The weakened liver cannot break down phylloerythrin (a product of chlorophyll), allowing this compound to circulate through the blood. It interacts with UV light to cause severe symptoms on nonpigmented skin. Livestock can succumb to liver damage before exhibiting skin symptoms.

Several plants contain pyrrolizidine alkaloids, including houndstongue, fiddleneck, tansy ragwort, groundsel, and other *Senecio* spp. Many other plants have been reported to induce secondary photosensitization, including oats, barley, alfalfa, alsike clover, tansy mustard, wild carrot, kochia, knotweed, and horsebrush.

Moldy hay, straw, or grain, as well as stagnant water with blue-green algae, have also been implicated in liver damage due to the presence of mycotoxins in these materials. This specialized form of secondary photosensitization causes skin reactions around the mouth and nose and is known as facial eczema. Ingestion of perennial ryegrass contaminated by sporidesmin (a toxin produced by *Pithomyces chartarum* following periods of fall drought) also causes severe dermatitis on cattle and sheep. Many of these symptoms are cured if animals are immediately removed from the source of the toxin.

Keys to avoiding toxicities

The best way to protect livestock from toxic forage is to (1) maintain healthy pastures with appropriate forage species and mixtures and (2) implement a comprehensive vegetation management program integrating cultural, chemical, physical, and biological control strategies for unwanted plant species. Steps to ensuring pasture productivity and livestock health include:

- Minimizing overgrazing
- Knowing the locations of established weed populations
- Managing weed populations to reduce size and spread
- Managing grazing timing to minimize risk

For more information, see chapter 7 of this guide, as well as the *PNW Weed Management Handbook* (http://uspest.org/pnw/weeds).

Other problems

Several other toxicities or poisonous weeds are found in the inland Pacific Northwest (table 12.1). The scientific names of species are used in table 12.1 due to variation in common names throughout the region.

Many garden crops, shrubs, trees, and weeds not normally associated with improved pastures can be toxic to livestock and companion animals. It is important to be aware of potentially toxic plants in and near your pastures. Learn to identify plants and develop an understanding of plant life stages. This knowledge will enable you to manage toxic weeds and reduce the risk of livestock becoming sick or injured.

You can find additional information in the resources listed under "For more information" at the end of this chapter and in other resources available in extension offices.

Diseases, parasites, and pests of grazing animals

Domestic livestock and horses evolved over many centuries as pastoral animals, so it is appropriate that pastures contribute significantly to their food and well-being. Over time, however, many disease organisms, internal parasites, and external pests coevolved with grazing animals. The result is wide diversity among animal diseases and pests, as well as differences in tolerance among animal species. Many diseases, parasites, and pests are listed in table 12.2.

You don't need to be able to identify all of these organisms. However, you should have some understanding of the principles of disease and pest management. Consider the "health disorder triangle" (figure 12.1) as you develop a year-round animal health management plan in concert with a qualified veterinarian. Your plan should include steps to ensure healthy pastures, good animal nutrition, and weed and pest control. Recommended control strategies for some animal diseases and pests are discussed below. Consult a veterinarian to address any herd or flock illness that occurs.

When using vaccines, drugs, and feed additives, it is important to study and follow all label instructions. For example, several very common ionophore treatments for coccidiosis, such as Bovatec and Rumensin, are toxic to horses. Deccox should not be used for lactating dairy cows or ewes.

LEPTOSPIROSIS ("LEPTO")

Lepto is a bacterial disease that can affect cattle, sheep, goats, horses, swine, dogs, wild rodents (rats and mice), and humans. Symptoms of infection include fever, jaundice, bloody urine, abortion, and death. Sheep are more tolerant than cattle or swine.

The largest incidence of human leptospirosis (Weil's disease) occurred when 61 individuals became ill after swimming in an irrigation canal contaminated by Lepto-infected cattle urine.

The causal organisms (*Leptospira* spp.) are slender, spiral bacteria with end-hook appendages. These bacteria move by swimming or writhing.

Lepto can remain at subclinical levels within a few "carriers" in a herd. The bacteria can localize in an infected animal's kidneys, where they multiply, persist, and are shed in the urine for up to several months. Disease transmission can occur through drinking water contaminated with infected urine, breeding, or close confinement of animals in pens or during shipping. An unexpected "storm" of abortions or bloody urine in calves or lambs can then occur.

Table 12.2. Common diseases, pests, and parasites of pastured animals in the Pacific Northwest.

	Cattle	Sheep and goats	Horses
DISEASES	Blackleg (B) Brucellosis (*B) BVD—bovine viral diarrhea (*V) Calf scours (diarrhea) (*B, *V, *P) Cancer eye Coccidiosis (*P) Foot-and-mouth disease (*V) Foot rot (B) IBR—infectious bovine rhinotracheitis (*V) Lepto—Leptospira (*B) Listeriosis (B) Lump jaw (B) Pinkeye (*B) Polioencephalomalacia (*B) Rabies (V, vectored by fleas) Ringworm (*F) Trichomoniasis venereal disease (*P) Vibriosis (*B) Wooden tongue (B)	Juvenile death (*B: *E. coli, Salmonella* spp., *Clostridium* spp.) Bloody scours (B: *Clostridium* spp.) Coccidiosis (*P) Contagious foot rot (*B) Pneumonia (*B, *V) Lepto—Leptospira (*B) Listeriosis (B) Pinkeye (*B, *V) Polyarthritis (*B) Rabies (V, vector) Scours (*B, *V, *P) Soremouth, contagious ecthyma pox (*V) Tetanus, lockjaw (B: *Clostridium tetani*) Toxoplasmosis (*P) Vibriosis (*B)	Equine encephalomyelitis (*V) Equine infectious anemia (*V) Equine influenza (*V) Equine rhinopnemontis, herpes (*V) Potomac (*B, vector) Rabies (V, vector) Strangles (*B) Tetanus, lumpjaw (B) Vesicular stomatitis (*V, vectored by mosquitos) West Nile virus (V, vectored by mosquitos)
*infectious B = bacteria F = fungus P = protozoa V = virus vector = transmitted by insect			
INTERNAL PARASITES (NEMATODES)	Worms—stomach Brown worm Barberpole worm Small worm Worms—intestines Thread-necked worm Hookworm Bankrupt worm Nodular worm Worms—small intestine *Cooperia* spp. Lungworm[a] Tapeworm[b] Liver fluke[a]	Worms—stomach Brown worm Barberpole worm Bankrupt worm Worms—small intestine Thread worm Thread-necked worm Hookworm *Cooperia* spp. Worms—large intestine Nodule worm Lungworm[a] Tapeworm[b] Liver fluke[a]	Worms—stomach Large strongyles (bloodworms) Worms—large bowel Small strongyles Pinworms Worms—small intestine Threadworms Worms—small intestine/lung Large roundworms[a]
Require indirect hosts: [a] Snail, slug [b] Pasture mite			
EXTERNAL PESTS	Cattle grubs Face flies Horn flies Lice Stable flies Scabies mites Spinose ear tick	Lice Mange (mites) Ticks Sheep keds Wool maggots	Bots Biting flies Lice Ticks

The carriers within a herd are persistent "shedders" of Lepto. It is unclear how these "shedders" interact with resident rodent populations, which may serve as disease reservoirs. Bacteria can survive in small streams or ponds with a neutral or alkaline pH and warm temperatures (68 to 80°F).

Annual vaccine programs for cattle typically include the bacterin specific for *L. pomona*. While these vaccines effectively reduce abortions and death, their effect on the persistent kidney infections of "shedders" is not known. Workers in dairy facilities have become infected by Lepto when milking cattle that had been vaccinated with bacterins from three *L.* spp. serotypes.

Management methods to prevent Lepto include:

- Serological testing of replacement animals
- Antibiotic treatment and initial quarantine of replacement stock
- Annual vaccines with Lepto bacterins
- Rodent control in pastures and facilities
- Fence exclosures of potentially contaminated water sources
- Separation of livestock from swine

Antibiotics such as streptomycin, chlortetracycline, and oxytetracycline can be effective treatments for Lepto if administered during early stages of infection.

Lepto is fairly rare due to a low rate of persistent shedders, the routine use of vaccines containing Lepto bacterins, and periodic antibiotic treatment.

SCOURS (DIARRHEA)

Scours occurs in both calves and lambs. Noninfectious (environmental) causes of scours include poor nutrition of the dam prior to pregnancy; limited or low-quality colostrum; and wet, cold, muddy conditions.

Several pathogens can also be involved: bacteria (*E. coli*, *Salmonella* spp., *Clostridium* spp., and others), viruses (*Rotavirus* and *Coronavirus*), protozoan parasites (*Cryptosporidium* and *Coccidia*), and fungi. In beef cattle, causal organisms also include viruses that cause health problems later in life, such as bovine virus diarrhea (BVD), infectious bovine rhinotracheitis (IBR), and coccidiosis.

A number of vaccines are available for cows or ewes during pregnancy. However, use of a single antibiotic or vaccine that targets only bacterial or viral infections is ineffective. In fact, relying solely on treatments or injections of any kind is not sufficient. Proper scours control requires a year-round prevention program that includes:

- An appropriate vaccine program
- Good nutrition of the dam
- A sanitary, dry, and warm environment after parturition
- Delivery of disease protection from the dam to the newborn via colostrum

PINKEYE

Pinkeye (infectious keratoconjunctivitis) is common in grazing animals. It is most common in sheep and goats, but also occurs in cattle.

Pinkeye leads to reduced performance but seldom causes animal mortality. Early symptoms are runny eyes and inflammation of the cornea. Affected animals are more sensitive to sunlight, dust, and pollen. Calves with pinkeye may weigh from 6 to 10 percent less at weaning than their uninfected herdmates.

Pinkeye is caused by a *Moraxella* spp. bacterial infection of the eye (*M. bovis* in cattle). Other infectious agents thought to be involved include *Chlamydia* spp., *Rickettia* spp., and some viruses. A high incidence of pinkeye in one or both eyes occurs in sheep moved or handled in dusty conditions. Pinkeye can be spread by animal-to-animal contact, by face flies, and by other insects.

Cattle herds and individual animals may be simultaneously infected with pinkeye and IBR, so a good herd health program is essential. On pastures, it may not be practical to control severe fly problems, but appropriate drenches, eartags, and dustbags can reduce flies. Antibiotics such as LA200, corticosteroids, and routine vaccination programs reduce pinkeye infections. An animal on pasture with moderate to severe pinkeye can be treated topically or injected with antibiotics. Confine the animal to a dark stall to reduce discomfort.

EXTERNAL PESTS

External pests frequently affect pastured animals (table 12.2). Numerous species of gnats, flies, lice, mites, and ticks can annoy or feed on livestock. More complicated and severe problems occur when these organisms transmit disease or spend a portion of their life cycle inside an animal as a parasite. Specialized forms of some flies infest animals in specific ways. These include the sheep ked (a wingless fly), maggots, bots, and screwworms.

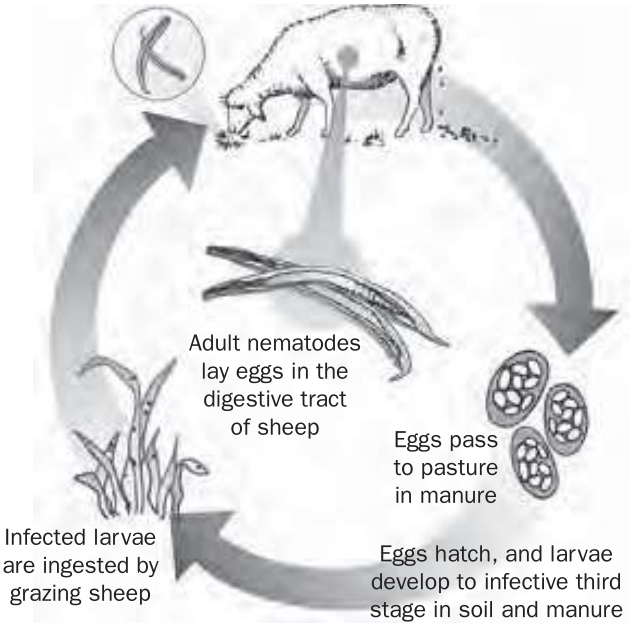

Figure 12.2. Direct life cycle of gastrointestinal nematodes in ruminants. (Source: Whittier, D. et al. 2003. *Control of Internal Parasites in Sheep*. Publication 410-027. Virginia Cooperative Extension)

Manage flies (stable, horn, and face) around animal facilities and water sources with sanitation and appropriate pesticides. Apply labeled insecticides topically as a drench, in dust bags, or in ear tags.

Specific pour-on or spray treatments are required for louse and mite control.

INTERNAL PARASITES

Many types of internal parasites are found in pastures. They are more numerous, diverse, and difficult to control in irrigated rotational grazing systems than on rangelands.

A few species of parasites cause most of the problems for grazing animals. They include nematodes ("worms"), flukes, tapeworms (table 12.2), and protozoa such as *Coccidia* (often cross-listed as a disease).

Generally, intensive grazing and best management practices for pastures do not control parasites. For example, quick rotations, high stocking density, managed grazing heights, and irrigation following grazing can promote high parasite loads in small paddocks. Thus, it is important to understand a few concepts about the life cycle of internal parasites. This knowledge will help you manage pastures and grazing to minimize parasite problems.

Stomach and gastrointestinal worms exist in ruminants and horses. In horses they are called "strongyles." Most have a simple life cycle with no intermediate host. Adult females lay eggs within the animal. The eggs drop to the ground with manure (figure 12.2) and develop into larvae. The third-instar larvae are the infective stage. Dew, splashing rain, or irrigation promote high populations of third-stage larvae on forage, where they are readily consumed.

Multiplication of worms occurs only in the pasture, not in the host. Therefore, the load of parasitic worms is directly related to the density of infective larvae in the pasture.

Keys to internal parasite management

- In general, juveniles are more susceptible to parasite infections than older animals. Beef cattle and horses generally become more tolerant to parasite infections with age, although sheep do not.
- Maintain weaned animals on separate pastures from older animals.
- Quarantine new animals.
- Deworm all animals housed together at the same time prior to turnout on pastures.
- Do not overstock pastures, as overstocking leads to overgrazing. Keep grazing heights above 3 inches.
- Sheep are particularly prone to excessively close grazing, even where other animals have urinated or defecated.
- Rotate animal species on pastures. Nematodes are generally host-specific.
- Warm and moist conditions favor worms; hot and dry conditions do not. Drag or harrow pastures during dry (spring) or hot and dry (summer) conditions.
- Routinely remove manure around stalls, bunks, water sources, and pastures.
- Apply only well-composted manure to pastures.
- Coordinate deworming treatments with the above activities.

Control of internal parasites includes elements of both livestock and pasture management. A key parasite management tool is to prevent animals from grazing near the soil surface if parasites are present on lower plant tissues or in manure. Maintain proper grazing heights (see chapters 2, 5, 11, and 13) to reduce ingestion of pests.

Various nematodes overwinter either in animal hosts or on pastures. Get help to identify specific species through fecal inspection. By identifying the species, you can determine the proper course and timing of treatment.

Anthelmintics (dewormers) are drugs labeled for control of internal parasites. Most deworming programs include both a fall and a spring treatment. This schedule is effective across multiple life cycles, allowing for treatment of multiple worm species.

Three classes of anthelmintics are used for broad-spectrum deworming programs: benzimidazoles, levamisole and related compounds, and macrocyclic lactones. The macrocyclic lactones such as Ivermectin are the newest group of compounds. Ivermectin has efficacy for numerous worms and bots. Levamisole is highly toxic to horses, so pyrantel tartrate (Strongid) is used for horses.

The following products are available. Depending on the product, pour-on, drench, oral paste, bolus, or injection formulations may be available.

- Ivermectin (Ivomec, Zimectrin) for cattle, sheep, and horses
- Moxidectin (Cydectin, Quest) for cattle and horses
- Doramectin (Dectomax) for cattle

Horse foals typically receive a stringent regimen of up to six bimonthly deworming treatments, from the age of 2 months through 12 months. Treatments rotate among Ivermectin, oxfendazole, and pyrantel pamoate.

Deworming treatments for cattle and sheep vary among regions. Develop a broad-spectrum control program appropriate for local growing conditions.

A well-planned deworming program should consider the potential for anthelmintic drug resistance. For example, the benzimidazoles are no longer effective for controlling worms in horses or sheep, but remain effective for control of tapeworm in cattle. To avoid resistance, use proper dosages and rotate drug compounds frequently.

Ethical, safe, and low-stress animal management

All livestock and horses should be treated humanely at all times, including when they are on pasture. Ideally, producers should participate in a verification or certification program (such as Beef Quality Assurance) that assures that proper animal handling, health care, and other procedures are followed.

Animals typically are more frequently observed in rotational grazing systems than when continuously grazed. In either case, you should check the condition of your animals, feed and water availability, and fences on a daily basis.

Adequate forage must be available to achieve animal production objectives, whether for maintenance or growth. Body condition scoring is a way to maintain adult horses and livestock at a healthy size (see chapter 10).

Provide adequate clean water, shade, and wind protection. Most producers also need enclosed facilities with pens, alleys, gates, and chutes for animal weighing, ear tagging, vaccinations, and other treatments. In rotational grazing systems, animals become adjusted to the routine of moving among pastures and watering sites. Thus, they can be handled with little effort or stress.

Organic, natural, and niche production systems for livestock are evolving rapidly. These systems increase the complexity of the management strategies discussed in this chapter. If you follow an organic or natural marketing program, you must follow specific certification guidelines, while still using scientific principles to address animal health issues.

For more information

Control of Internal Parasites in Sheep. Publication 410-027. Virginia Cooperative Extension (2003). http://pubs.ext.vt.edu/410/410-027/410-027.html

Cornell University Poisonous Plants Informational Database. http://www.ansci.cornell.edu/plants/

Cow-Calf Management Guide and Cattle Producer's Library. Western Beef Resource Committee (2009). http://www.csubeef.com/

Forage Information System website. Oregon State University. http://forages.oregonstate.edu/index.cfm

Online Guide to Poisonous Plants. Colorado State University. http://www.vth.colostate.edu/poisonous_plants/

Pacific Northwest Weed Management Handbook. Oregon State University, University of Idaho, and Washington State University (revised annually). http://uspest.org/pnw/weeds

Weeds of California and Other Western States. Publication 3488. University of California (2007). http://anrcatalog.ucdavis.edu/E-WeedControl/3488.aspx

Weeds of the West. Western Society of Weed Science (1996). Published by University of Wyoming. http://www.uwyobookstore.com

CHAPTER 13

Foraging Behavior and Grazing Management

K. Crane, J. Glaze, and G. Shewmaker

PASTURE MANAGEMENT CONSISTS OF STRATEGIES to optimize the productivity and harvest of forage crops. Throughout this handbook, we discuss ways to optimize harvest by grazing animals. In this chapter, we will discuss how foraging behavior of livestock influences grazing patterns in pastures. We also discuss pasture and animal management strategies that may modify foraging behavior and help you meet your management objectives.

Humans have attempted to "manage" grazing by domesticated animals for more than 10,000 years. However, our influence is relatively recent compared to the millennia of evolutionary changes and behavioral adaptations that have shaped foraging behavior.

Decisions about where to graze (distribution), what to graze (selectivity), when to graze (timing), and how much to consume (intensity) are critical to the survival of free-roaming grazers. Understanding how animal factors, pasture conditions, and management strategies can influence these decisions will improve your ability to manage grazing animals to meet your pasture management objectives.

Selective foraging patterns in pastures often result in excessive grazing on preferred areas and little or no grazing on undesirable areas. A primary challenge for grazing managers is to achieve uniform forage utilization while meeting the requirements of both grazing animals and forage plants. Meeting this challenge requires graziers to consider the complex behavioral patterns that influence how livestock approach their grazing environment.

Key Points

- Ruminants have evolved to be efficient consumers of fibrous grasses and forbs. This efficiency is influenced by the abundance, quality, and structure of forages in a pasture.
- Foraging patterns often reflect variability in the abundance, quality, structure, and palatability of forages within a pasture.
- Grazing animals have the inherent capacity to learn from their foraging experiences and to remember the consequences of previous foraging decisions.
- Animals learn from their mothers (and later from their peers) where to graze and what plants and plant parts to select for a good nutritional regime.
- Humans can positively or negatively influence animal behavior and subsequent livestock production and foraging patterns.

Influences on foraging behavior

All grazing animals inherit behavioral predispositions that influence their decisions about where, what, when, and how much to graze. However, foraging is also a learned behavior. Young animals develop foraging skills through trial and error and by watching other members of their herd. Thus, an individual animal's foraging behavior is a function of its inheritance, experience, and social learning.

INHERITED INFLUENCES

Animals probably do not inherit a picture of the ideal feed or foraging site. Instead, they inherit the ability to learn about the habitat in which they live.

- They can recognize different features and places within a pasture through their senses of sight, sound, smell, and taste.
- They can recognize and remember specific foraging habitats.
- They can associate certain habitat features with benefits (adequate nutrients, shade, water) or hazards (predators, insects, inadequate nutrients, excessive temperatures).
- They can recall the location of areas where beneficial resources or hazards were encountered.

This ability to recognize and remember habitat attributes, combined with the capacity to learn from foraging experiences, allows animals to quickly adapt to changes in their foraging environment.

EXPERIENCE

Animals learn foraging behavior from habitat cues and from the consequences of previous actions.

Habitat cues

Grazing animals learn to recognize habitat cues associated with positive consequences. This association allows them to increase the likelihood of obtaining the same benefits during future foraging bouts. Likewise, animals recognize and remember habitat cues that allowed them to avoid negative consequences such as predators, insects, and poor foraging conditions.

This consequence-based learning is termed operant conditioning. Operant conditioning accurately predicts that livestock will seek, select, and reside at foraging sites that provided positive experiences during previous foraging bouts. Conversely, it also predicts that livestock will avoid sites that were deficient in positive attributes or produced negative consequences. Previous "bad" experiences in a pasture may temporarily override good forage conditions on a particular site.

Digestive feedback

Grazing animals select or avoid specific forage plants in response to the consequences they experience from eating the plant. Animals remember and avoid forage species if consumption was followed by illness, nausea, or continued hunger. In contrast, they actively seek and consume forage plants that provided nutritional benefits. Generally, animals prefer familiar feeds to unfamiliar ones.

These behavioral adaptations are facilitated by the unique taste of different forage plants and a relationship between the flavor of a plant and its digestive consequence. In short, animals develop distaste for plants with negative digestive consequences (e.g., nausea) and prefer plants that result in positive digestive feedback (e.g., relief of hunger).

Some pastures have a mix of toxic and non-toxic plants. While animals may prefer the non-toxic plants, they may from time to time ingest small amounts of the toxic plants. Consuming these plants may or may not cause negative digestive consequences. Because the animals are exposed to the toxic plants in their normal foraging habitat, they become accustomed to them. This familiarity may cause problems if the animals are moved to an area with greater quantities of the toxic plants. Since animals prefer familiar feeds, they may be drawn to areas dominated by the familiar toxic plants. This behavior could lead to reduced animal performance due to digestive distress or even to loss of members of the herd.

SOCIAL LEARNING

Social learning provides a mechanism for the transfer of critical information among individual animals (for example, the location of preferred foods and habitats). When grazing with experienced animals (social models), naïve animals spend less time feeding and exploring, consume more forage, suffer less predation and malnutrition, and ingest fewer toxic plants than do naïve animals foraging alone.

The most important social models for a young animal are its mother and young cohorts. The predictability of annual grazing patterns in large, heterogeneous pastures is partially the result of learned behaviors

passed from mothers to their offspring. A young animal's diet and selection of feeding sites are greatly influenced by its mother's behavior. This influence is most pronounced prior to weaning.

After weaning, the behavioral patterns of young companions within the herd become increasingly important. Diet and feeding site selection patterns of the herd strongly influence the behavior of individuals. Many attempts to teach individual animals to avoid toxic plants have been thwarted when the animal observes naïve animals consuming the toxic plant and follows their lead.

Experiences by young animals influence their habitat and diet selection patterns throughout their lifetime. In fact, where an animal is raised has a much more profound influence on its foraging behavior than does the genetic makeup of its natural or foster mother. If water and forage resources are adequate, animals will remain near the location where they were reared.

Although beneficial in many ways, social learning may have negative consequences for pasture management. In some cases, very familiar (and often related) individuals form overly cohesive herds that limit exploration and prevent the uniform utilization of pastures.

Foraging site selection in the pasture

Grazing animals have choices about where to spend their time. In making those choices, they respond to internal and external stimuli. They engage in one activity (e.g., grazing, resting, or traveling) until it is no longer reinforcing; then they change their activity or location. Animals move to new habitats based on the perceived presence or prior experience of adequate forage, water, or comfortable surroundings. The value of a specific foraging site is continually evaluated in terms of its positive or negative consequences. Responses are also strongly influenced by the actions of other individuals within the herd.

Based on an animal's inherent characteristics, experience, and learned behavior, its behavior in a specific pasture is fairly predictable. Several of the factors influencing this behavior are discussed in this section.

ANIMAL ATTRIBUTES

The physical attributes of grazing animals have a profound influence on their foraging behavior. Breeds and individual animals differ with respect to how they graze, utilize feeds, and perform.

Cattle are "built to eat grass," so foraging habitats that provide ample grass are positively reinforcing and are selected by cattle. These grass-dominated sites may not meet the nutritional demands of sheep or goats, however, so these animals may avoid them in response to the negative consequences associated with malnutrition.

Physical abilities also influence foraging behavior and habitat selection. For example, individual animals and breeds vary in their ability to traverse steep terrain. Similarly, they vary in daily water requirements, allowing some animals to select foraging habitats farther from water sources.

Age and experience also affect foraging behavior. Generally, younger animals travel farther and are more likely to explore and exploit unused foraging sites. Older, more experienced animals are more proficient at locating optimal foraging habitats.

SITE CHARACTERISTICS

Grazing animals prefer some foraging sites and avoid others. As with foods, animals form likes and dislikes for foraging sites based on previous experiences and consequences. For example:

- Foraging sites that provide food, water, thermal comfort, refuge from biting insects, safety, or drug-stimulated euphoria are preferred to sites that are not associated with these positive consequences.
- Grazing animals have an affinity for sites that provide positive social interactions such as play, sexual interactions, aggressive interactions (males), and association with offspring (females).
- Animals develop an aversion for places associated with stress, fear, and inadequate nutrients. For example, livestock often develop an aversion to handling facilities and electric fences that they associate with stress and pain.

EXPLORATION

If nutritional and physiological requirements are being met, grazing animals prefer familiar foods and foraging habitats. They are more likely to "explore" new forages when they are nutritionally deficient. As pastures become depleted, livestock often expand their foraging range. Exploration of novel foods and habitats may be worth the risk during scarcity but not when nutritional needs are met.

When livestock are turned out to a new pasture, whether or not they explore depends on novelty of the new pasture, the animal's internal status, and the presence of companions. Novel habitats can result in either fear or exploration, depending on the animal's previous experience and the conditions under which animals are introduced to new pastures.

Animals are more likely to explore a new pasture if it is similar to a familiar area, if they are hungry, and if they have familiar companions. Conversely, livestock are likely to stand at the gate of a new pasture if the move was stressful, the pasture "looks" different than the previous pasture, and they have been separated from their peers.

SPATIAL MEMORY AND VISUAL CUES

Grazing animals use spatial memory to recall the location, appearance, and smell of specific habitats without the benefit of visual cues. For example, cattle can use spatial memory to relocate food in a maze. However, in natural foraging environments, animals use visual cues to enhance spatial recognition abilities. Natural features (e.g., trees, rock outcrops, waterways, terrain) and man-made structures (e.g., fences, roads, mineral/supplement sites) serve as cues to help them recognize preferred or avoided foraging habitats. In experimental observations, visual cues (e.g., traffic cones, stop signs) greatly enhance the ability of cattle to relocate and consume preferred foods.

Influencing foraging behavior to meet pasture management objectives

Pasture managers have many opportunities to influence the selection of feeding sites. By understanding how livestock foraging behaviors are created and sustained, you can alter behavioral patterns to meet pasture management objectives. We still have much to learn in this area, but someday livestock producers may uncover the secret language to instruct animals where, when, what, and how much to graze.

SELECTING FOR ANIMAL ATTRIBUTES

Generally, it's best to select breeds and animals from environments similar to your own. Animals that have performed well in one situation should perform well in similar situations. Also, match grazing animals to your foraging environment in terms of their diet selection, age, size, and seasonal nutritional requirements.

It is possible to change herd attributes by selectively breeding for individuals with desirable diet and habitat selection patterns. Likewise, when developing a herd, consider the previous foraging experience of individuals.

MANAGING FOR UNIFORM PASTURE UTILIZATION

In many cases, a key objective of pasture management is to achieve more uniform utilization across the pasture. When pastures are managed for uniform utilization, animal selectivity is reduced. As a result, individual animal production is usually lower, but production on an area basis (pounds of beef or milk per acre) usually is higher over the course of the season.

If increasing uniformity of utilization is an objective, focus on producing uniform forage conditions and providing equal access to attractive attributes from various locations within the pasture. Since animals learn to seek, select, and reside in areas that have previously provided positive experiences, it's important to maximize positive, homogeneous pasture conditions.

As a manager, you can change habitats and the cues that livestock associate with foraging consequences. It is well known that improvements in forage quality and quantity can alter grazing patterns. The location of water, protein supplements, salt/mineral sources, and human activities all influence the distribution of grazing within a pasture. If animals are not utilizing all areas of a pasture, you can try to attract them to underutilized areas with positive habitat cues (water, salt, supplement, etc.).

A dedicated livestock manager may be able to train grazing animals to more uniformly use pastures. One method is to use sensory cues to help animals locate specific habitats. For example, you can train cattle to associate specific items (e.g., discarded traffic signs, flags, posts, or pylons) with food or supplements. Then, you can use these cues to attract animals to underutilized sites. Auditory cues such as wind chimes can also help cattle find salt/mineral supplements in large pastures.

When management strategies disrupt the social hierarchy of a herd, pasture use patterns may change. One way to disrupt individual home ranges and habitat use patterns is to introduce strange animals into an established herd.

LIMITING GRAZING OF NON-DESIRABLE PLANTS

To limit animals' intake of non-desirable plants, make sure that animals' appetites are satiated before they

move to a new pasture or paddock. Since hungry animals are more likely to explore new pastures than satiated animals, moving full animals will curb the desire to explore and sample potentially toxic forages.

OVERCOMING ANIMAL AVERSIONS

To alleviate an animal's aversion to handling facilities, provide positive cues. For example, if animals resist traveling through a specific alley or lane, you might sprinkle feed throughout to draw them through the site. Likewise, if they show an aversion to handling facilities (holding pens, corrals, chutes, etc.), provide feed in these areas during non-use periods to help animals develop an affinity for the locations.

OPTIMIZING TIMING OF ANIMAL MOVES

Plants exhibit a daily cycle in their concentration of nonstructural carbohydrates (sugars, starch, and fructans). Sugars are produced during the day through photosynthesis. During the afternoon, plants can have a 15 percent higher concentration of sugars than in the morning, as well as lower neutral detergent fiber and higher yields. As animals sense these higher sugar concentrations in the afternoon, they graze for shorter periods of time, while increasing their bite size and bite rate. Generally, livestock grazing in temperate climates on continuously stocked pastures have longer afternoon grazing sessions. Grazing, ruminating, and idling times and patterns are presented in figure 13.1.

Pasture managers can impact grazing behavior by the timing of movement into new pastures or paddocks. Dairy and beef operations have benefited by allowing animals into new pastures or paddocks in the afternoon rather than in the morning. Cattle allowed into a new pasture at 7 a.m. will have to graze longer and still will not obtain as much energy as cattle allowed into a new pasture at 3 p.m. Furthermore, forage intake can be limited in the morning by higher concentrations of fiber, which result in greater rumen fill.

OPTIMIZING INTAKE RATES

Performance of high-producing livestock, such as lactating dairy cows, can be limited by forage intake. Forage intake is primarily a function of biting rate, grazing time, and dry matter (DM) intake rate:

forage intake = biting rate (bites/minute)
x grazing time (minutes/day)
x intake rate (grams DM/bite)

Cows work hard 7 days a week, 365 days a year. Their survival depends on it. They also belong to the cow union, however, and will not graze more than about 12 hours per day! They must also have time to ruminate or "chew cud," meaning they regurgitate their food and chew it again.

There is also a limit to how many bites animals can take per minute. High-producing dairy cows may have

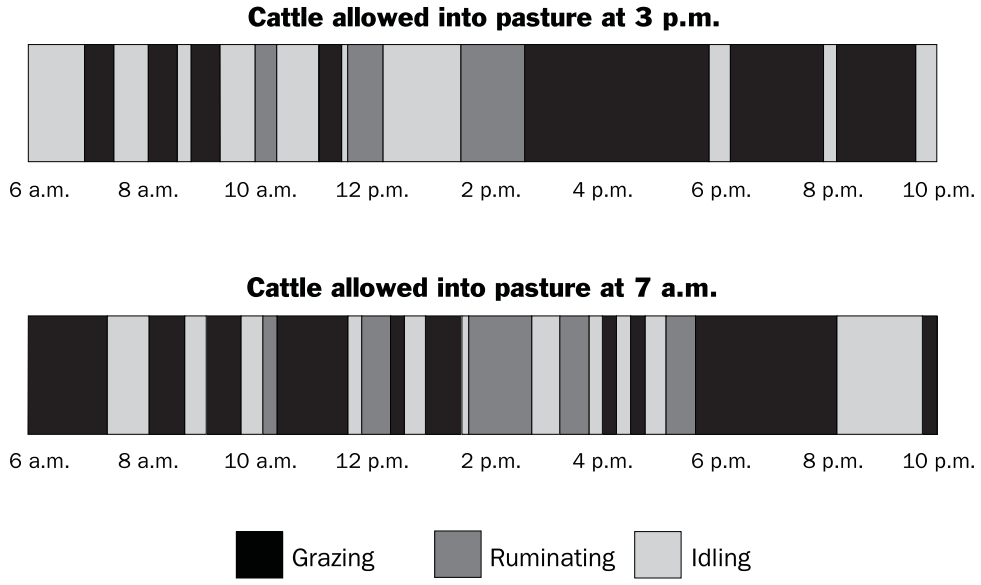

Figure 13.1. Grazing, ruminating, and idling time and pattern for cattle allowed into a new paddock at 3 p.m. or 7 a.m. (Graphic represents several studies adapted from Gregorini, P., M. Eirin, R. Refi, M. Ursino, O.E. Ansin, and S.A. Gunter. 2006. Timing of herbage allocation in strip grazing: Effects on grazing pattern and performance of beef heifers. *J. Anim. Sci.* 84:1943–1950)

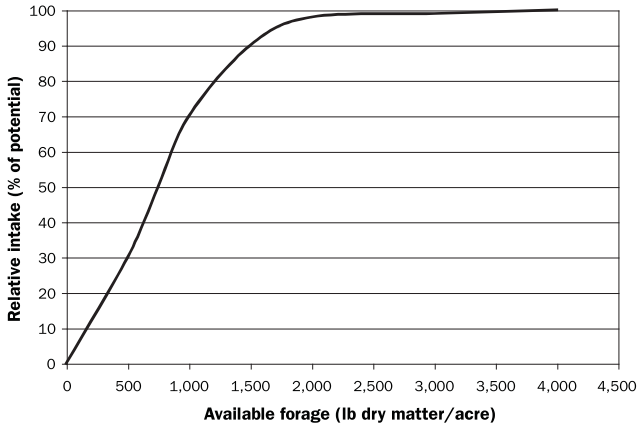

Figure 13.2. Availability of forage affects animal dry matter intake. (Adapted from Martz, F., V. Tate, and J. Gerrish. 1999. Meeting nutritional needs of livestock from pasture. In: Gerrish, J. and C. Roberts, eds. *Missouri Grazing Manual*. MU Extension, University of Missouri-Columbia)

biting rates of up to 60 bites per minute (40,000 bites per day), while low-producing cows may take only about 25,000 bites per day.

With limited grazing time and bites per minute, animals must maximize the amount of intake per bite. If they do not get enough sustenance in 12 hours, they will lose weight or exhibit decreases in production.

Sward height and mass affect bite size and intake rate. A pasture must have at least 2,000 pounds of forage DM available for an animal to realize 100 percent of its intake potential (figure 13.2). Thus, managing pastures to maintain proper sward height and density can influence grazing behavior for optimal intake. See chapter 11 for more information.

Other forage intake considerations

Your goal for grazing animals is to optimize intake. Several animal and pasture factors influence intake rates. As a manager, you can manipulate these factors to improve intake. Keep the following factors in mind.

BITE SIZE

- Bite size (grams DM per bite) has a greater influence on intake than does biting rate or grazing time.
- Bite size increases with forage quality and leaf density.
- At a feeding station, cattle graze in horizons from the top of the sward to the soil surface. Higher horizons provide deeper, heavier bites.

SWARD CHARACTERISTICS

- Optimal intake on pastures is often limited by herbage height (low vertical density). As sward height decreases, bite size declines and grazing time must increase. Conversely, intake on rangelands is limited by herbage density (low horizontal density).
- On grazed pastures, bite size and intake generally increase with forage abundance and height. However, animal gain has not been shown to increase with the height of grass. Increased forage height increases lodging and trampling and may decrease access to leaves of forage plants.
- The presence and accessibility of leaf material are both important factors in forage quality. For example, switchgrass has a lower proportion of leaves to stems than bermudagrass, but it produces better cattle gains because leaves are more accessible (taller).
- Large herbivores are at a disadvantage when grazing short swards because each bite represents a smaller portion of daily requirements.
- Animal diets are higher in quality than the overall quality of the pasture, because animals can select leaves over stems and live portions of plants over dead portions.
- Cattle will select “normal” over lodged swards, but it is possible to maintain intake rates on lodged swards.

GRAZING BEHAVIOR

- Daytime temperatures are the most important non-plant influence on grazing behavior.
- Animals on a high plane of nutrition are more selective and choose different feeds than do deficient animals.
- Grazing animals have been shown to benefit from larger group sizes (more than six animals) in terms of increased intake and greater weight gain. This improvement is attributed to decreased opportunities for exploration and other non-foraging activities.
- As the standing crop declines, grazing time per day and number of bites per minute increases.

LIMITATIONS ON INTAKE

- Fatigue may limit the amount of time a cow spends grazing to approximately 720 minutes (12 hours) per day.
- Intake on dense, productive pastures is limited by rumen capacity and feed passage through the rumen.
- High-fiber forages limit intake due to greater rumen fill.

CHAPTER 14

Grazing Systems and Methods

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THIS CHAPTER LAYS A FOUNDATION FOR GRAZING systems management. Here we focus on developing a grazing system that will help you meet your overall objectives. Chapter 15 covers the physical design of grazing cells. Chapter 16 provides tools for making day-to-day forage allocation decisions.

Key Points

- When choosing a grazing system, establish clear targets for economic returns, natural resource quality and enhancement, productivity, personal rewards, and other goals before focusing on the nuts and bolts of specific methods.
- Stocking rate is the most important aspect of grazing system planning and management. Individual animal performance and gain per land area are maximized at different stocking rates. For many livestock enterprises, the most profitable stocking rate falls between these two points. If economic returns are a priority, good decision-making and planning are essential when selecting a stocking rate.
- Grazing methods are ways to implement principles of grazing management, which are to control (1) animal grazing distribution and pasture defoliation (timing and severity), (2) forage allocation to livestock with differing requirements, (3) the balance between pasture supply and livestock demand, and (4) the length of the grazing season.

Putting pieces together to accomplish goals

As a pasture manager, you must integrate grassland and livestock resources, climate, farm and ranch infrastructure, planning, labor, and marketing opportunities to develop systems for attaining your goals. This process is both a science and an art, and it requires a combination of knowledge, forecasting, and creativity.

Grassland resources include soil, water, wildlife, and forages. Farm and ranch infrastructure includes buildings, fencing, livestock watering and handling facilities, equipment, and other capital resources. Identifying your resources should be your first step in planning a pasture-livestock system. See chapter 1 for information on how to conduct a resource inventory.

A grazing system is a planned integration of resources. The grazing system and methods you choose will determine forage and livestock production, future condition of the natural resource base, and sustainability of your enterprise. As with any complex and dynamic system, there are many ways to combine resources to reach a given set of economic, environmental, production, and lifestyle goals. They all require planning, however. Good managers are always in the planning stage! Systems that are allowed to run themselves without planning and management tend to devolve to whatever state mismanagement dictates.

A number of soil-plant-animal relationships that determine economic returns, productivity, and trends in natural resource condition are common to every grazing system. Nonetheless, each grazing system is unique. Some of the ways that grazing systems differ include the following:

- Geographic location, environment, and reliance on irrigation (e.g., coastal Washington rainfed versus southern Idaho irrigated)
- Timeline and sustainability (short-term/pay-the-bills versus long-term/sustainable)
- Intensity of management (minimal to intensive) and input usage, including seeding (low-cost versus high-input)
- Reliance on natural biological processes versus purchased inputs (conventional, natural, or organic)
- Seasonality of use (growing season, extended season, or year-long)
- Animal class and performance target (cow-calf, stocker, dairy, sheep, horse, etc.)
- Degree of control of grazing animals and defoliation (level of grazing pressure and continuous versus rotational stocking)
- Extent of mechanical harvesting of surplus forage, including swath grazing

System planning and design

There are two basic approaches to grazing system planning and design: (1) selecting, establishing, and managing appropriate forage resources for a predefined livestock class and number, and (2) fitting an appropriate livestock class, number, and management program to existing forage resources. In both cases, the manager seeks to match forage supply with livestock demand in order to meet target levels of economic and livestock performance.

Regardless of whether you are developing a pasture-livestock system for the first time or seeking to improve an existing system, it is critical to focus on what you want to accomplish before settling on the nuts and bolts of specific practices. If you thoroughly explore the following questions, grazing system design and methods should flow naturally from your answers.

- What are my primary objectives and priorities with respect to gain per land area, gain per animal, return on investment, risk management, grassland resource enhancement, lifestyle, etc.?
- Do I prefer to follow recipes, or do I enjoy challenges and figuring things out? How much complexity and management intensity am I comfortable with?
- What is the duration of anticipated management: short-, medium-, or long-term?
- Am I prepared to treat pasture as a high-value crop?
- What are the marketing opportunities and seasonal price and demand patterns for my livestock products?
- Are there soil limitations to forage production (e.g., salinity, alkalinity, sodicity, seasonal flooding, poor drainage, or poor water-holding capacity)?
- Is livestock water available, or can it be developed?
- What is the quality and availability of irrigation water?

- What is the forage production potential and seasonal growth pattern of my pasture?
- What risks, including predator pressure, are likely?
- If I use bloat-inducing legumes in pasture mixtures, is the risk acceptable? Or, must legumes be non-bloating (birdsfoot trefoil, sainfoin, and cicer milkvetch)?
- Will I have more than one class of livestock with differing nutritional requirements (e.g., cows and yearlings)?
- Can or will the number of animals change throughout the grazing season?
- When will birthing occur, and when will nutritional demands be lowest and highest? How do these dates correspond to the forage production calendar?
- How long will the grazing season be, relative to the forage production calendar? Will grazing occur only during the growing season, or will I extend the grazing season beyond the growing season?
- Is mechanical harvesting of surplus forage an option?
- If pastures will be continuously stocked, are existing forage species appropriate (e.g., Kentucky bluegrass, white clover, tall fescue, perennial ryegrass, and other short-shooted species)? Smooth bromegrass, non-grazing-type alfalfas, timothy, intermediate wheatgrass, and other long-shooted species are less appropriate for continuously stocked pastures.
- Are there agency or wildlife habitat management requirements that I must comply with? Examples include requirements for public land grazing and conservation improvement cost-sharing.

After answering these questions, you can begin to make decisions about the five major components of any grazing system:

- Target levels of individual animal performance and gain per land area
- Distribution of grazing animals and the timing, frequency, and severity of grazing—For example, you will need to decide when to begin and terminate the grazing season and how many pasture subdivisions are needed in rotationally stocked pastures.
- Stocking rate (the number of animals per grassland area for a defined time period)—Stocking rate may apply to a specific period or to the entire grazing season. Keep in mind that the grazing season may be much longer than the growing season.
- Ways to maximize the length of the grazing season to minimize costs of harvesting and feeding stored forages
- Methods of balancing forage supply and demand across the grazing season

We will begin by discussing how to choose a stocking rate. This decision is closely related to decisions about target levels of individual animal performance and gain per land area. With a stocking rate decision in hand, you will be ready to select grazing methods or practices to form the remaining components of your grazing system.

Setting stocking rate

Setting an appropriate stocking rate is probably the most important decision you will make. The success of your grazing system will depend greatly on a wise stocking rate decision. Stocking rate is typically adjusted over time on the basis of experience and changing conditions and management ability.

Two key factors to consider are annual forage production potential and the seasonal distribution of pasture growth. These factors determine the carrying capacity of your land—the maximum stocking rate that will achieve a target level of animal performance, using a specified grazing method, over a defined time period without deterioration of the ecosystem. A stocking rate that exceeds carrying capacity cannot be sustained. Note, however, that your optimal stocking rate may be lower than carrying capacity.

CALCULATING SEASONAL CARRYING CAPACITY

While an appropriate stocking rate is based on more than carrying capacity, calculating the number of animals that can be supported at their target level of animal performance is a logical starting point. This calculation is as much a planning and budgeting process as it is an end point. Excellent introductory information can be found in the local USDA Natural Resources Conservation Service (NRCS) soil survey, available from the nearest NRCS office or online (http://soils.usda.gov/survey/ includes a link to the Web Soil Survey). Soil surveys describe the potential and limitations of soils for various purposes, including pond development and crop production. They usually include pasture carrying capacity in animal-unit days (AUD) or animal-unit months (AUM) per acre-year, as well as approximate annual yields of hay crops. As a

rough approximation, local hay yields can be considered representative of annual pasture productivity.

Carrying capacity is a function of four factors: annual forage production, seasonal utilization rate, average daily dry matter (DM) intake, and length of the grazing season.

To move beyond general estimates that may be available from soil surveys, Gerrish and Morrow (1999) provide the following approach to calculating seasonal carrying capacity in pounds of live weight per acre (lb live wt/acre):

$$\text{carrying capacity} = \frac{\text{annual forage DM production} \times \text{seasonal utilization rate}}{\text{average daily DM intake} \times \text{length of grazing season}}$$

The equation contains the following factors:

- *Annual forage DM production*—The amount of forage (hay and pasture) produced over the entire grazing season (pounds of forage DM per acre), as determined by sampling and summing forage DM production from each grazing cycle throughout a growing season. (Methods are described in chapter 16.)
- *Seasonal utilization rate*—The proportion (expressed as a decimal fraction) of annual forage production used during the season. This fraction depends on the rotation frequency (table 14.1) and expected level of animal performance. If the length of the grazing period is 3 days, you can expect livestock to utilize approximately 55 percent (decimal fraction of 0.55) of annual forage production. If the grazing period is 30 days or more, you can expect livestock to utilize 30 to 35 percent of annual forage production.
- *Average daily DM intake*—The proportion (expressed as a decimal fraction) of body weight in forage DM that the animals are assumed to eat each day. Average daily DM intake is about 3.5 percent of body weight for high livestock performance, 3.0 percent for medium performance, and 2.5 percent for low performance. Decimal fractions corresponding to these percentages are 0.035, 0.03, and 0.025, respectively.
- *Length of the grazing season* (days)—the number of days in the full grazing season (determined by forage species, growing conditions, and management).

Table 14.1. Grazing duration before a rest period, number of paddocks, and seasonal utilization rate under rotational stocking.

Grazing duration (days)	Number of paddocks	Seasonal utilization rate (% of growth)
Continuous	1 pasture	30 to 35
14 or more	2 to 4	35 to 40
6 to 8	3 to 7	45 to 55
2 to 3	6 to 15	55 to 60
1	25 to 35	60 to 70
0.5	45 to 60	70 to 75

Source: Adapted from Gerrish, J. and R. Morrow. 1999. Grazier's arithmetic. In: Gerrish, J. and C. Roberts, eds. *Missouri Grazing Manual*. Publication M157. University of Missouri Extension.

Example of calculating carrying capacity

Assume that each acre in your system produces 8,280 pounds of forage DM annually, to soil surface level. You will not utilize all of this forage, because you will leave sufficient post-grazing residual herbage to provide reserve carbohydrates and/or capture sunlight to support regrowth and to allow livestock to obtain reasonable bite sizes. With a 2-day grazing period, the seasonal utilization rate is 60 percent. You expect yearling cattle to gain 1.5 to 2 pounds per head per day, requiring a daily DM intake of 3 percent of body weight. Your average grazing season starts on April 15 and ends October 1 (169 days). The seasonal carrying capacity in this case is:

$$\frac{8,280 \text{ lb forage DM/acre} \times 0.60}{0.03 \text{ lb forage DM/lb live weight} \times 169 \text{ days}}$$

$$= 980 \text{ lb live weight/acre}$$

If you put 500-pound steers on this pasture, you can stock it at two animals per acre (980 lb live weight/acre ÷ 500 lb live weight) on the first day. However, since you want the steers to gain 1.75 pounds per day, their intake will increase as they grow. By July 15, they will weigh 659 pounds [500 lb + (91 days × 1.75 lb/day)]. Thus, on July 15 they will each need 20 pounds of forage DM per day (659 lb live weight × 0.03 lb forage DM/lb live weight).

Plan conservatively by stocking your pasture at a rate suitable for the midpoint or later in the season. For example, you could set the initial stocking rate at 1.5 steers per acre (980 lb live weight/acre ÷ 660 lb live weight/steer). Grazing consultant Jim Gerrish states emphatically, "Remember, this is a guideline to help make initial stocking decisions, not a magical recipe for universal financial success!"

You also need to understand the trade-offs between individual animal performance and gain per land area. Research from multiple locations has shown that as stocking rate increases beyond light levels, individual animal performance declines because each animal has less opportunity for diet selection and high intake. At the same time, total livestock production per unit of land area increases up to a point, before decreasing at higher stocking rates. At extremely heavy grazing pressure or stocking rates, individual animal performance and gain per land area can both decline to maintenance levels or worse. This concept is illustrated in the "Mott curve" (figure 14.1), named after G.O. Mott (1960).

The Mott curve shows that *maximum individual animal performance* (which might interest a dairy producer or stocker cattle grazier) and *maximum gain per land area* (which might interest a producer who is maintaining cattle through winter) *occur at different stocking rates.* In the real world, the economically optimum stocking rate for many livestock enterprises falls between these two points. In other words, *profits are not necessarily highest with either maximum individual animal performance or maximum gain per land area*. Good decision-making and planning are therefore required if economic returns are a priority.

An example of the economic implications of stocking rate decisions is shown in table 14.2. In this example, the season-long stocking rate that yields maximum profits is lower than the stocking rate that would maximize live-weight gain per land area (20 versus 30 steers per 640 acres). Patton et al. (2008) provide similar findings for North Dakota grassland.

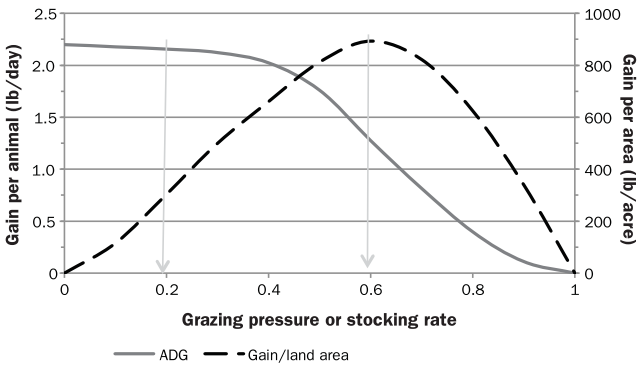

Figure 14.1. Individual animal performance (average daily gain, or ADG) and total gain per land area at increasing grazing pressures or stocking rates, ranging from very light (0) to very heavy (1). (Source: Adapted from Mott, G.O. 1960. Grazing pressure and the measurement of pasture production. *Proceedings of the 8th International Grasslands Congress*. University of Reading, England)

One of the benefits of this economic relationship is that it often leads to moderate, rather than heavy, stocking rates. By choosing a moderate stocking rate to improve potential profitability, you also reduce the risk of having to resort to crisis management after entering a drought cycle with an excessive number of cattle to support.

Stocking rate decisions are complicated by seasonal fluctuations in pasture growth rates. Across a grazing season, daily pasture growth rate typically fluctuates more than daily livestock forage demand. A stocking rate that establishes a daily livestock demand that exceeds the current pasture growth rate is unsustainable over the long term. On the other hand, a conservative stocking rate that is based on the less productive growth periods can result in accumulation of mature, low-quality forage during the spring. It is easier to deal with excessive spring growth than with problems created by overstocking, however. See the section below on "Balancing forage supply and demand across a growing season" for suggestions.

More background on the process of establishing an appropriate stocking rate is found in *Stocking Rate and Grazing Management* (publication MF-1118, Kansas State University Cooperative Extension Service).

Grazing methods or practices

After answering the questions outlined under "System planning and design" and selecting a stocking rate, you should have a general vision of your grazing system. Your next step is to choose specific grazing methods or

Table 14.2. Net revenue at increasing season-long stocking rates on 640 acres of Utah rangeland. Maximum economic return occurs at a lower stocking rate than maximum gain per section.

Steers/ 640 acres	Total gain (lb)	Total revenue ($)	Total cost ($)	Net revenue ($)
5	400	200	200	0
10	900	450	300	150
15	1,150	575	400	175
20	1,360	680	500	180
25	1,460	730	600	130
30	1,500	750	700	50
35	1,480	740	800	-60

Source: Adapted from Workman, J.P. 1986. *Range Economics*. Macmillan Co.

practices. With appropriate grazing methods, you can do the following:

- Control animal grazing distribution and pasture defoliation during both the growing season and the dormant season. Methods include continuous stocking, rotational stocking, and strip grazing.
- Allocate forage quality and quantity to livestock with differing requirements. Options include multispecies, creep, leader-follower, and limited grazing.
- Balance fluctuating pasture growth rates with livestock demand by changing the land area grazed or the number of grazing animals. Methods include early intensive stocking and buffer grazing with mechanical harvesting.
- Extend the grazing season. Possibilities include stockpiling or swathing late-summer forage or planting complementary crops for fall and winter grazing.

Each of these points is discussed below.

CONTROL OF ANIMAL DISTRIBUTION AND PASTURE DEFOLIATION

Pastures may be stocked continuously or rotationally. In continuous stocking, livestock have unrestricted access to the entire grazing area, and pasture regrowth occurs in the presence of grazing animals. In rotational stocking, livestock are moved repeatedly through a series of subdivisions known as paddocks during the growing season. Regrowth occurs during a resting period while animals are grazing other paddocks.

Continuous stocking has the advantage of lower labor requirements. Also, individual animal performance is usually higher under light to moderate continuous stocking than under rotational stocking.

Continuous stocking can create several problems, however: season-long patterns of patch overgrazing and underutilization, overconsumption by animals with only maintenance requirements (unless daily grazing time is restricted), rejection of ungrazed patches, non-uniform distribution of manure beneath shade and in other livestock gathering areas, and lower carrying capacity.

As mentioned in chapter 5, only a few, mostly short-shooted, forage species are well adapted to continuous stocking at moderate to high stocking rates. These include Kentucky bluegrass, white clover, tall fescue, bentgrass, perennial ryegrass, and grazing-type alfalfas. For any adapted pasture species, the key to pasture productivity and persistence under continuous stocking is stocking no more heavily than necessary. A moderate stocking rate will help plants maintain adequate leaf area to support plant energy requirements.

Rotational stocking has several advantages, especially with regards to pasture regrowth. Rotational stocking allows pastures to regrow to a defined growth stage, height, herbage mass, or leaf area before being regrazed. Both roots and shoots have a chance to recover between grazing periods so that plants are more likely to be in positive energy balance before being regrazed.

Most pasture plants benefit from a grazing period of no more than 3 to 5 days followed by a regrowth period of 18 to 40 days, depending on the species, time of year, and water availability. Table 14.1 shows that at least six to eight paddocks are usually needed in order to accommodate such a defoliation and regrowth schedule.

Because the utilization rate is higher (table 14.1), carrying capacity is at least 10 to 30 percent higher under rotational than under continuous stocking. Rotationally stocked animals are easier to observe for possible problems and tend to be tamer and easier to sort off of paddocks than animals under continuous stocking. With rotational stocking, animal classes with differing nutritional requirements can graze paddocks in succession. This option is discussed in the next section.

Strip grazing follows the same pattern of livestock movement as rotational stocking, but for one-time allocation of forage that is not regrowing, so animals do not return to paddocks for additional cycles of grazing. This method can be used with annual forage species or during the dormant season. Under strip grazing, animals typically graze a paddock for no more than 1 to 3 days.

ALLOCATION OF PASTURE QUALITY AND QUANTITY TO LIVESTOCK CLASSES WITH DIFFERING NUTRITIONAL REQUIREMENTS

Pasture forage varies in quality and intake potential (see chapter 11). With rotational stocking, you can match forage quality to livestock with differing nutritional requirements. One method is to allow young animals to access a pasture via a creep gate that excludes larger animals. Another is to allow animals with higher requirements to graze ahead of animals with lower requirements. This method is called leader-follower or first-last grazing. In a dairy example, a leader group of lactating cows or stocker steers would selectively graze the best one-third to one-half of a paddock

before moving to the next paddock. A follower group of dry cows and replacement heifers would then graze the remaining forage to a target residual height, mass, or leaf area. Leader-follower grazing offers perhaps the only means of simultaneously achieving high utilization and high performance for some animals.

Another approach involves mixing livestock species with differing foraging preferences, such as sheep or goats and cattle. Even when grazing simultaneously, different species select different sward constituents.

A final approach is to limit daily pasture access by animals with low nutritional requirements, such as mature pleasure horses, when the only source of feed is high-quality pasture. The result is essentially the same as that achieved by allowing young animals to creep-graze a specialty pasture while restricting access by adults. In this case, however, you are managing time instead of sward condition.

BALANCING FORAGE SUPPLY AND DEMAND ACROSS A GROWING SEASON

As a grazing manager, you must match available forage with daily livestock intake. To do so, you must allocate land areas for grazing and harvesting, while simultaneously manipulating numbers of grazing animals—all in a constantly changing environment. This task is the greatest challenge facing graziers, and success is closely related to having established an appropriate stocking rate.

If you have chosen an appropriate season-long stocking rate, pasture growth may exceed livestock demand in the spring, when pasture growth rate is highest. There are two solutions to this situation: (1) vary the stocking rate throughout the grazing season, and (2) mechanically harvest surplus spring forage.

Intensive early stocking is one example of a variable stocking rate. In this case, pastures are stocked heavily in spring when the pasture growth rate is high, and destocked as dictated by declining pasture growth rates and current market conditions.

Another option is buffer grazing. This practice involves setting aside part of a grassland area for growth and harvest of a hay or silage crop in late spring or early summer. The area is returned to grazing when pasture growth rates are lower in summer. In this approach, mechanically harvesting surplus spring forage is as much a grazing management tool as a means for providing supplemental winter feed.

If forage is in short supply during slower growth periods (hotter and cooler), you can plant complementary annual species (cereals, warm-season annual grasses, or brassicas) to boost pasture productivity at these times. For example, perennials such as tall fescue and alfalfa can augment pasture productivity during hotter parts of the season. Some warm-season grasses have potential for this purpose, but their effectiveness remains to be evaluated. Species and management options for improving seasonal distribution of forage production are provided in *Forage Utilization for Pasture-based Livestock Production* (publication NRAES-173, Cornell Cooperative Extension).

EXTENDING THE GRAZING SEASON BEYOND THE GROWING SEASON

The profitability of your business depends on minimizing costs and maximizing returns. Feed costs account for approximately 60 percent of the annual cost of owning an animal. Extending the grazing season into the winter through the use of stockpiled forages and/or crop residues can reduce harvest and feeding costs. In research at the University of Missouri, Jim Gerrish showed a cost savings of more than $1 per head for each day a cow grazes and harvests her own forage rather than being fed hay in a drylot.

Stockpiling forage

Stockpiling is the accumulation of late-summer and fall pasture regrowth for fall and winter grazing after the growing season ends. Stockpiling should not be confused with allowing spring forage that outgrew livestock demand to accumulate and be carried through the summer in a mature, low-quality condition.

To stockpile forage, defer grazing of a pasture, hay field, or planted crop for a period of time to allow for late-season growth. The resulting forage can be grazed as a standing crop or swathed and grazed in windrows.

Before planning to stockpile forage, ask yourself the following questions:

- Will irrigation or rainfall be available for regrowth?
- What forage species are best for late-season grazing?
- Should I consider windrow grazing?
- Should I use strip grazing to harvest the forage?

Each of these questions is discussed below.

Water for forage regrowth—A key to successful forage stockpiling is having irrigation or timely rainfall to allow forage regrowth during late summer and early fall. Irrigation will also allow you to plant late-seeded annual crops for later season grazing.

In low-rainfall regions, you can stockpile forage by deferring grazing during the early active growing season for utilization later in the fall and winter. Realize, however, that the nutritive quality of the forage may be low and livestock may require protein supplements, unless they are allowed to graze selectively. Only dry cows and ewes should graze this mature forage.

Forage species selection—The biggest challenge with stockpiling regrowth of cool-season perennial species is that pasture growth rates are often at a seasonal low in late summer, and livestock often require all of the current pasture growth at that time. One option is to use warm-season annual forage grasses, such as pearlmillet and sorghum x sudangrass hybrids, for more rapid growth during late summer. You also can plant winter cereals and forage brassicas in mid- to late summer for stockpiled winter forage. However, winter cereals usually provide more forage early in the following spring than in the fall of the seeding year.

In reality, any grass can be used in stockpiled forage systems, although yield and nutritive value differ among species. Robinson et al. (2007) analyzed the stockpiling characteristics of several forage species at the Brigham Young University (BYU) Agriculture Station near Spanish Fork, Utah. Among the grasses tested, tall fescue and orchardgrass produced the most dry matter while retaining forage quality. Studies at Iowa State University, University of Georgia, University of Minnesota, and in Canada also found tall fescue and orchardgrass to be the best grasses for use in stockpiled forage systems. Fall regrowth of tall fescue forage often has higher digestibility than summer growth, and tall fescue quality is retained well during fall.

Among legumes tested in the BYU study, birdsfoot trefoil showed promise. Alfalfa was not as productive as birdsfoot trefoil.

Species and management options for extending fall and winter grazing are provided in *Forage Utilization for Pasture-based Livestock Production* (publication NRAES-173, Cornell Cooperative Extension) and by Ball et al. (2008) and Boyles et al. (1998).

Grazing stockpiled forage—Graze softer grasses with less structure earlier in the fall, while retaining those with more structure and upright stature for later grazing.

Animals that are inexperienced with grazing through deep snow cover often require some time and experience to become competent at grazing stockpiled forages. Grazing can be difficult even for experienced animals if snow is crusted or icy.

One way of facilitating intake of snow-covered stockpiled forage is to swath or windrow an annual or perennial crop and leave it in the field to be grazed by livestock in late fall or winter. This practice of swath grazing maintains forage quality while reducing feeding costs. Swath grazing can reduce forage harvesting costs by as much as 60 to 75 percent compared to conventional hay harvesting methods (Berger and Volesky, 2006; Surber et al., 2001).

Where snow depths are likely to exceed 12 to 14 inches, swathing is useful for concentrating limited stockpiled forage mass so that animals can easily locate it beneath the snow. Thus, they do not have to forage as extensively to meet nutritional requirements. Animal access to swaths covered with crusted or icy snow can sometimes be improved by driving a tractor along swath edges so that a rolling tire disrupts the hard layer.

Swathing stockpiled forages is particularly beneficial where it is desirable to capture the quality of a crop canopy before excessive maturation or freezing damage occurs. Thus, it is especially useful for species that experience a deterioration in quality following freezing and weathering. Alfalfa and red clover, which lose leaves in freezing weather, are examples. Swathing can also improve accessibility of forages that would be likely to lodge in winter. Deterioration of swath structure and quality are potential problems in areas that do not have dry fall and winter conditions, including dry snow.

Grass hay crops and annually seeded forages can be used in a windrow grazing system. In a study conducted at North Dakota State University in 2006, oat hay cut in the soft dough stage worked well. Beardless barley and triticale also work well, along with some warm-season grasses such as millet, pearlmillet, and sudangrass.

Species and management options for swath grazing are discussed in *Windrow Grazing* (publication G1616, University of Nebraska-Lincoln), *Swath/Windrow Grazing: An Alternative Livestock Feeding Technique* (Montguide MT 200106 AG, Montana State University Extension Service), and Hutton et al. (2004).

Grazing system—Regardless of whether stockpiled forage is grazed as standing or swathed forage, use strip grazing and movable electric fences to ration out the pasture. This will reduce forage waste due to trampling, bedding, or soiling. Allowing livestock access to a 1- or 2-day supply of forage is ideal. If this is not possible, limit livestock to no more than a 1-week supply of forage at a time.

Waste is always an issue, however. Losses range from 5 percent (if a 1-day supply of forage is provided) to more than 30 percent (if livestock have access to a large section of stockpiled forage at one time). Keep waste in mind when deciding stocking rates.

Grazing crop residues

Crop residues are another low- to medium-quality forage source for extension of the grazing season. See chapter 11 for more information.

For more information

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CHAPTER 15

Grazing Cell Design and Installation

J. Gerrish and C. Cheyney

THE BASIC REASON FOR SUBDIVIDING PASTURES is to achieve better control of your grazing operation. The ultimate goal is to increase profit, while maintaining or improving animal and pasture health. This overall goal can include a wide range of interrelated management goals, both economic and environmental.

If you have selected a rotational grazing system (chapter 14), how well you design your grazing cell will affect whether you can achieve your goals. This chapter will introduce concepts related to grazing cell design and provide examples for irrigated pasture in the Pacific Northwest. We will also discuss fencing and stock water options and how to match your grazing system to your irrigation system.

To design and build a successful irrigated pasture management system, you must also carefully consider your available resources (see chapter 1) and understand basic principles of pasture management and livestock behavior (see chapters 13 and 14).

Key Points

- Good grazing cell design can help you meet your goals.
- Fixed grazing cell designs minimize daily labor requirements.
- Flexible grazing cell designs reduce capital costs and maximize management flexibility.
- More paddocks provide greater management opportunities and options.
- Keep travel distance to water under 1,000 feet on irrigated pastures.
- Your grazing cell design should fit with your irrigation systems.

The big questions

When beginning to plan for a Management-intensive Grazing (MiG) system, graziers often ask the following questions:

- How many paddocks do I need?
- What stocking rate is appropriate for a given grazing season?
- What stock density is appropriate for a given grazing period?
- How big should my paddocks be?

In this section, we look at how to answer these questions. Keep in mind that your answers will change over time. Growing conditions, animal needs, and your goals change through the season and from year to year. Monitor pasture conditions on a regular basis (see chapter 16), be flexible, and adapt your system as needed.

HOW MANY PADDOCKS DO I NEED?

As you consider how many paddocks you need, first ask yourself, "What do I want to accomplish?" Knowing your objectives is the first step to estimating the number of paddocks needed. Combined with understanding and experience, more pasture subdivision (more paddocks) allows you to better manage all aspects of your operation and achieve your goals.

For example, if your primary goal is to maintain plant vigor or increase legume content by resting pastures during the growing season, five or six paddocks may be adequate. If your goal is to maintain high levels of animal performance or graze year-round and eliminate hay feeding, you may need more than a hundred winter grazing strips. When grazing in the winter, splitting larger paddocks into multiple grazing strips helps to increase harvest efficiency, preserve forage quality, and maintain healthy rumen function.

The number of paddocks needed ultimately depends on the length of the grazing cycle. The grazing cycle is composed of the grazing period (when the animals are on the pasture) and the recovery period (when pasture plants are allowed to regrow). Thus, you need to determine the appropriate length of these two periods, remembering that both will change through the grazing season.

The duration of the grazing period affects many plant and animal responses, so first determine a target grazing period based on your goals. The grazing period can be several days, or it can be a fraction of a day if multiple moves are made each day.

When choosing a grazing period, consider the following:

- Your desired level of management—Grazing management choices impact pasture health and productivity, individual animal health and performance, water and nutrient cycles, and overall farm or ranch carrying capacity. Knowing how much you want or need to control these variables will help you determine the length of the grazing period. Shorter grazing periods allow more pasture subdivision and more management control.

Key Terms

Dormant season—The season when animals may harvest forage remaining after the growing season.

Grazing cell—An area of pasture managed as a planning unit from which forage is allocated to a specific group of animals for the grazing season. A grazing cell usually has permanent fence on its borders and is separated into paddocks with temporary fencing or by herding. Some grazing operations may be composed of more than one cell.

Grazing cycle—The time elapsed between the beginning of one grazing period and the beginning of the next grazing period. One grazing cycle includes one grazing period plus one rest period.

Grazing period—The time that animals are present on the paddock.

Grazing season—The total period of time during which animals may harvest standing forage from pasture. Composed of the "growing season," when temperature and moisture are conducive to plant growth, and the "non-growing season," when animals may harvest any forage remaining after the growing season.

Growing season—The time of year when temperature and moisture are conducive to plant growth.

Paddock—A subdivision of a grazing cell to which animals are confined for a grazing period (hours or days). A paddock may be of fixed or variable size.

Rest period—The grazing cycle minus the grazing period.

Seasonal utilization rate—The fraction of annual forage production that will be harvested by grazing livestock during the entire grazing season.

Stock density—The relationship between the number of animals (or live weight) and area of land at any given instant of time. May be expressed as animal units or forage intake units per unit of land area (for example, "50 animal units per acre," which is equivalent to 55,000 pounds of live weight per acre).

Stocking rate—The relationship between the number of animals (or live weight) and the grazing management unit over a specified time period. May be expressed as animal units or forage intake units over a time period per unit of land area such as "50 animal units per acre-day" (equivalent to 55,000 pounds live weight per acre-day).

Temporal utilization rate—The fraction of available forage expected to be consumed during a grazing period.

- Availability of labor for moving livestock
- Performance objectives—Shorter grazing periods are needed for high-performance animals, such as lactating dairy cows. Most pasture-based dairies utilize multiple moves per day. Longer grazing periods often work for beef cow-calf operations, ewes and lambs, and dry cow maintenance.
- Pasture growth characteristics—Consider the appropriate stubble height for your forage species (see chapter 2). If the grazing period is too long or too little stubble is left, regrowth is delayed. If the rest period is too long, forage plants become overly mature and lower in quality.

After choosing a grazing period, determine the rest time required between grazing periods, based on the time needed for pasture plants to regrow. Chapter 2 provides guidelines for many species, but rest periods are site-specific, so choose an appropriate length based on your site conditions and pasture regrowth rate.

Adding together the rest period and the grazing period gives you the length of the grazing cycle. For example, if you choose an average 3-day grazing period, and your pasture conditions require a 42-day average rest period, an average grazing cycle is 45 days.

Once you know the length of the grazing cycle, you can calculate the number of paddocks needed:

$$\text{number of paddocks} = \frac{\text{grazing period} + \text{recovery period}}{\text{grazing period}}$$

Using the 3-day example above, the grazing cell needs 15 paddocks: $(3 + 42) \div 3 = 15$

Using a 1-day example, the grazing cell would need 43 paddocks: $(1 + 42) \div 1 = 43$

Keep in mind that the length of the grazing cycle varies through the season as growing conditions and animal demands change. While the rest period may average 42 days, it may range from 20 to 60 days. For example, many pasture grasses need a longer regrowth period during the summer than during the spring. Or, if you find that livestock are grazing to your desired stubble height in a shorter period of time than expected, you may need to reduce the length of the grazing period. Chapter 16 discusses topics related to allocating forage throughout the season.

WHAT STOCK DENSITY IS APPROPRIATE?

Stock density is the number of animals or amount of live weight per acre assigned to a paddock at a given point in time. Stock density is your most powerful management tool, and knowing how to use stock density to reach your objectives is an important skill. In chapter 14, we discuss how to select a season-long stocking rate. Here we consider how to determine the appropriate stock density for a given grazing period.

Choosing an appropriate stock density is important to grazing uniformity. A low stock density permits animal selectivity and results in "patchy" grazing, leading to pastures with both undergrazed (overly mature) and overgrazed forage. A higher stock density results in more uniform utilization of pasture forage. See chapter 14 for more information.

The appropriate stock density for a particular pasture during a given grazing period depends on available forage, class of livestock, target utilization rate, daily forage intake target, and length of the grazing period. Calculate the stock density as follows:

$$\text{stock density} = \frac{\text{available forage} \times \text{temporal utilization rate}}{\text{daily DM intake} \times \text{length of grazing period}}$$

The equation contains the following factors:

- *Available forage* is the quantity of forage dry matter (DM) standing in the paddock at the start of a grazing period (expressed as pounds of forage DM per acre). See chapter 16 for information on how to estimate forage production.
- *Temporal utilization rate* is the percentage of available forage expected to be consumed during the grazing period. In most circumstances, an appropriate temporal utilization rate for irrigated pastures is 50 to 60 percent. Early-season grazing may be at only 30 to 40 percent utilization, while dormant-season grazing may be at 70 to 80 percent utilization.
- *Daily DM intake* is the amount of forage expected to be consumed by an animal (expressed as a percent of body weight—for example, 2.6 percent). The following values are general guidelines based on level of livestock performance:
  - High performance: 3.5 percent of body weight
  - Medium performance: 3 percent of body weight
  - Low performance: 2.5 percent of body weight
- *Length of grazing period* is in days.

These factors are interconnected. For example, the temporal utilization rate affects animal productivity and the required rest period for the paddock. In general, as the temporal utilization rate increases, animal performance decreases and the rest period must increase. Shorter grazing periods can partially offset these effects. On the other hand, extended rest periods reduce the number of grazing periods in the grazing season and reduce total pasture productivity.

Let's look at an example based on the following assumptions:

- Available forage is 3,000 pounds DM per acre.
- Recovery is rapid on irrigated pasture, so the temporal utilization rate can be 60 percent.
- An intake rate of 2.6 percent of body weight supports moderate production for beef cattle.
- The grazing period is 3 days.

Inserting these values into the formula, we find the appropriate stock density for this 3-day grazing period:

$$\frac{3{,}000 \text{ lb DM/acre} \times 0.60}{0.026 \text{ lb DM/lb live weight/day} \times 3 \text{ days}}$$

$$= \frac{1{,}800}{0.078} = 23{,}077 \text{ lb live weight/acre}$$

To convert stock density from pounds of live weight to number of head, we divide the live weight by the average weight of the livestock. If we are grazing 600-pound steers, the result is:

$$\frac{23{,}077 \text{ lb live weight/acre}}{600 \text{ lb/animal}} = 38.5 \text{ animals}$$

Thus, 1 acre of this pasture should support about 38 steers for a 3-day grazing period.

Note: Because plant-animal relationships limit the extent of forage utilization and rate of passage through the rumen, we cannot arbitrarily rearrange these formulas to determine the dependent parts of the equation.

HOW BIG SHOULD MY PADDOCKS BE?

Once you know your herd size (see chapter 14) and stock density for the grazing period, determining paddock size becomes relatively easy.

First, find the total herd weight. If we have 300 steers weighing on average 600 pounds:

300 hd × 600 lb/head = 180,000 lb herd weight

Then, divide the total herd weight by the target stock density:

180,000 lb ÷ 23,077 lb/acre = 7.8 acres

The appropriate paddock size is 7.8 acres.

Thus, in our 3-day example, we have determined the following:

- Number of paddocks = 15
- Stock density = 38 steers per acre for a 3-day grazing period
- Paddock size = 7.8 acres

Fixed versus flexible pasture subdivision systems

There are three keys to successful grazing management and cell design:

- Know what you are trying to accomplish.
- Realize that there is no "recipe."
- Maintain adequate flexibility to achieve your goals.

Management flexibility is a fundamental concept of MiG. The more subdivision options available, the greater the flexibility. Too much permanent subdivision can become restrictive.

There are two basic approaches to subdividing pastures. Fixed systems use permanent watering points and fencing to create multiple paddocks. Flexible systems use movable fences and water tanks within a framework of permanent fences. Mixed systems combine aspects of both approaches. For example, a grazing cell might use permanent water points and temporary fences.

Figure 15.1 illustrates a typical fixed grazing cell. The paddocks are a constant size, and the permanent stock tank is a focal point for grazing and manure deposition. Moving stock from one paddock to another is simply a matter of opening and closing gates.

Figure 15.2 shows an example of a flexible grazing cell. There are only two permanent fences in this cell: the perimeter fence and the one splitting the field in half. In this type of cell, water access points are typically spaced evenly along a pipeline. The pipeline is either buried or laid on the surface near the divider fence. A portable stock tank is moved as needed, and temporary fences create paddocks of appropriate size.

Figure 15.3 shows a mixed system. Stock tanks have been permanently installed in "water blocks" as in the fixed system in figure 15.1, but paddocks are created with temporary fences.

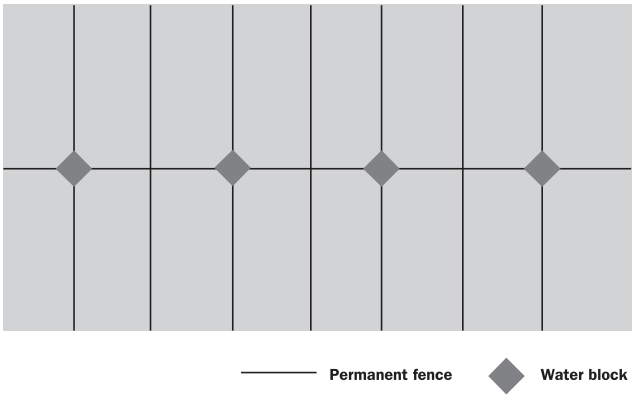

Figure 15.1. A 16-paddock fixed grazing cell. (Illustration by Jim Gerrish)

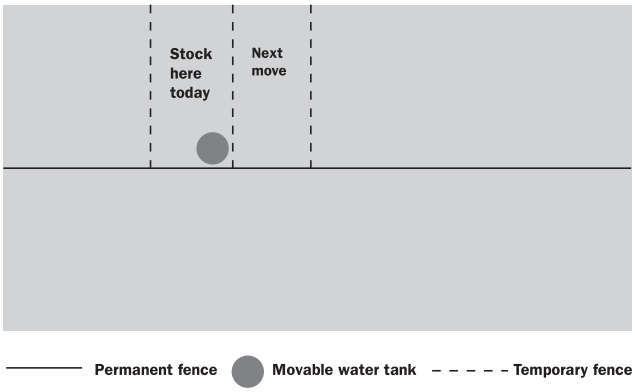

Figure 15.2. A flexible grazing cell with movable fences and stock tank. (Illustration by Jim Gerrish)

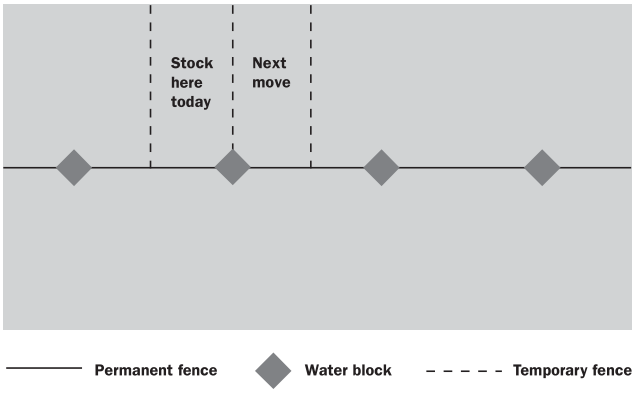

Figure 15.3. A mixed grazing cell using movable fences but permanently installed stock tanks. (Illustration by Jim Gerrish)

Advantages of a fixed system include minimal maintenance (if fencing is installed properly using quality materials) and minimal labor requirements for moving livestock. The principal disadvantage is limited management flexibility. On large operations, a relatively low per-acre or per-head capital cost is another advantage. On small operations, however, the per-acre or per-head cost can be high. The expensive parts of electric fencing are the energizer installation, end and corner assemblies, and gates. A smaller operation might have as many corners and gates as a much larger ranch, but it has fewer acres and animals over which to spread the cost.

Flexible systems have the advantages of lower capital setup costs and maximum management flexibility. Disadvantages include more daily labor for operation and maintenance. Good cell design and use of quality equipment will minimize frustration and labor requirements. Try to keep the length of movable fences to less than 1,000 feet. Many graziers use movable fence lengths of 400 to 800 feet to keep labor requirements low.

When designing your cell, look at several stock water and fence layouts before driving the first fencepost. Use aerial photos, topographic maps, and/or plat maps to evaluate different configurations. Some important things to remember are:

- The more nearly square the pastures, the less lineal fence required per acre and the more uniform the grazing.
- The location of stock water often dictates the location of fences.
- Keep the travel distance to water under 800 to 1,000 feet.
- Keep creek and river crossings to a minimum to reduce installation difficulties and maintenance demands.
- Place fences where they make sense for your management needs, not necessarily where they have been historically located.

Fencing systems

Fences allow you to manipulate both livestock and the grazing environment. They help you reach your objectives in an ever-changing ecological and economic environment. Managing a grazing cell is easier with a well-designed fencing system composed of appropriate components.

PERMANENT FENCES

In almost all situations, electrified high-tensile fences are the most economical and durable permanent fence option. For cattle, one or two wires is the norm (figure 15.4). Sheep and goats generally require more wires, with three- or four-strand fences being most common.

A permanent fence consists of one or more electrified high-tensile wires, solid end assemblies, and line posts. Wildlife should not be able to knock the wires off the line posts. Such a fence should last at least 20 to 30 years with minimal maintenance. High-quality materials and proper installation keep the lifetime fence cost low. Inexpensive, low-quality materials result in high annual repair and maintenance expenses.

Solid end and corner assemblies are critical parts of a durable fence system. You can use well-braced end posts, rock cribs, trees, or other solid objects. Floating braces provide the same strength as the common "H brace" at lower cost (figure 15.5). Most end assemblies

Figure 15.4. Typical two-wire electrified high-tensile fence with a floating brace end assembly. (Photo by Jim Gerrish)

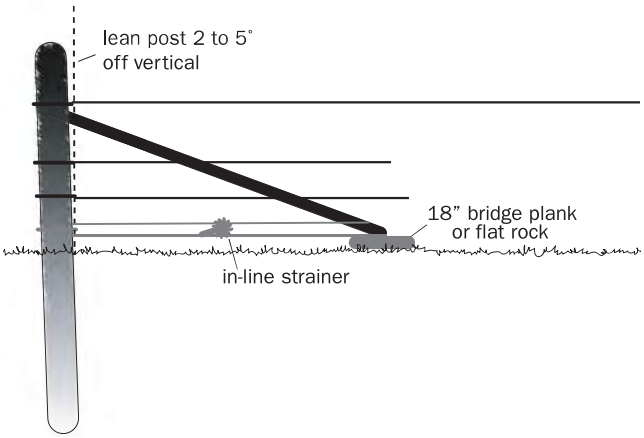

Figure 15.5. Floating brace construction. (Illustration by Jim Gerrish)

include electrified gates. For floating braces, the depth of end and corner posts should be greater than the height of the top wire. The brace post should intersect the end post no higher than two-thirds the height of the fence.

The fence-wildlife interface is an important consideration in the Pacific Northwest, where elk, moose, deer, and antelope may share the pasture with livestock. In most cases, wildlife will be in pastures during at least part of the year.

The keys to minimizing wildlife damage to fences are to build flexibility into the fence and to use appropriate wire heights. Don't think in terms of building a fence strong enough to stand up to wildlife pressure. Rather, build a fence that will flex with wildlife impact and allow animals to pass over or under the fence.

To ensure flexibility, use flexible line posts and do not overtighten fence wires. Install single-wire cattle fences at a height of 30 to 32 inches. Elk or moose are more likely to damage a taller fence, as they may hit the fence with more of their body weight. For two-wire fences, keep the bottom wire at least 18 to 20 inches high to allow antelope to pass under the wire.

It is more difficult to make three- or four-wire sheep and goat fences wildlife-friendly. Keeping the top wire under 32 inches will reduce elk damage. Cull animals that routinely jump a 32-inch fence.

TEMPORARY FENCES

Grazing management is fine tuned through the use of temporary fences. In a flexible grazing system, almost all of the paddock subdivisions are created with movable fences. You don't want pasture management to be a burden, so keep movable fence components simple and easy to use. The three basic components are the conductor, the reel, and the posts.

Polywire and polytape are the most commonly used temporary fence materials for cattle, while electric netting is often used for sheep and goats. Poly products are lightweight, easy to use, and highly effective when used appropriately.

Products differ in durability, effectiveness, and cost. The biggest factor affecting durability and effectiveness is whether the polywire is twisted or braided. Braided products offer twice the longevity of twisted polywire, as well as greater conductivity and shocking power. While braided polywire typically costs more than twisted polywire, it delivers much greater value.

Other factors affecting effectiveness and cost are the number of wire filaments and type of metal. Most products contain six to nine wire filaments. Products with more filaments of the same type of metal have greater conductivity. Conductivity is not an issue, however, unless fences exceed 1,000 feet. This is another reason to plan for temporary fence lengths under 1,000 feet.

Filaments may be stainless steel, a copper-containing alloy, or aluminum. In terms of strength (which contributes to durability), steel is the strongest, and aluminum is the weakest. Aluminum is most conductive, while steel is least conductive. Some products contain a mixture of stainless steel filaments and tin-copper alloy to provide both strength and enhanced conductivity.

Polytape is similar to polywire, but is flat instead of round. Polytape usually doesn't last as long as polywire, and standard electric fence reels hold only half as much tape as polywire.

Polytape is especially useful where high visibility is important. Potential uses include situations with high wildlife pressure or grazing horses, or where cattle without prior electric fence exposure are being trained to the idea of movable electric fencing.

When purchasing polytape, look for products with more wire filaments and a tight plastic weave. The tighter the weave, the more durable the product.

Polywire and polytape cannot be effectively coiled or stored without fence reels. One experience will convince you! A standard fence reel usually holds a little more than 1,320 feet of top-quality polywire or 660 feet of polytape, but capacity ranges from 300 feet to a half mile of polywire. Select a reel based on the job to be done; a standard quarter-mile reel is a good all-around choice. Most people find that reels that hold a half mile of polywire are unsuitable for everyday use.

Reels are either straight-crank (1:1 ratio) or geared (3:1 ratio). It's much easier to retrieve the fence conductor with a geared reel (figure 15.6). If you are managing multiple herds with frequent rotations, a geared reel will quickly pay for itself in saved labor. You will find that better quality equipment costs more, but is usually worth much more than it costs!

Lightweight, step-in posts are the easiest posts to use for temporary fencing. Look for flexible posts with a relatively small spike (to penetrate the ground easily), a step big enough to put your foot on, multiple wire attachments (so you can adjust fence height), and

Figure 15.6. Geared reel for movable polywire fences. (Photo by Jim Gerrish)

primary wire clips on the opposite side of the post from the step (to protect the installer if the fence is on).

Space posts at 40 to 100 feet depending on terrain and how well the stock are trained to electric fence. If you plan for 50-foot spacing, you usually will have enough posts on hand for your needs.

SEMIPERMANENT FENCES

Sometimes you may want to leave a fence up for several months or even a couple of years, but not long enough to justify the expense of a permanent fence. In this case, combining some of the products used for permanent and temporary fences may be the best strategy. For example, you could install a top-grade braided polywire on a more permanent post than a step-in. Such a fence can stay firmly in place for several months, but is easily removed when needed.

Stock water systems

Design a stock water system that will deliver adequate quantity and quality of water under the most challenging conditions anticipated. Calculate the herd's daily water need in a worst-case scenario; plan for the hottest day of the year and peak lactation. A dry pregnant beef cow will consume 8 to 10 gallons of water per day at 60°F. Daily water intake by beef cows increases by about 4 gallons with every 10°F increase over 60°F. Every gallon of milk produced requires about 3 gallons of water. See chapter 10 for more information on water requirements.

WATER SOURCES

Location of stock water is the most important factor determining daily livestock travel patterns and where animals spend their time. The effect of water location is particularly strong on large rangeland units, where pastures may be several thousand acres. It is also important on a 40-acre pasture with a single water source. Figure 15.7 shows utilization of a cool-season pasture. Note that pasture utilization drops dramatically as the distance to water begins to exceed 800 feet.

Stock water development is critical to a managed grazing system. When converting to MiG from continuous or slow rotational grazing systems, an important consideration is the volume of water available. With increasing stock density in a particular area, daily water demand can exceed availability. This situation often occurs where the entire pasture has been used by several continuously grazed herds, each in a separately fenced area. The water source may have been adequate for 20 head in a single herd. When five such herds are combined into a single 100-head herd, however, the water source in part of the cell may be inadequate.

A flowing stream or dugout may work when stock have access to the entire pasture. It may not be adequate, however, when pastures are subdivided, especially if the water source is near a corner or end of the pasture. With a pipeline delivery system, you can put the water where it will improve livestock distribution and pasture utilization.

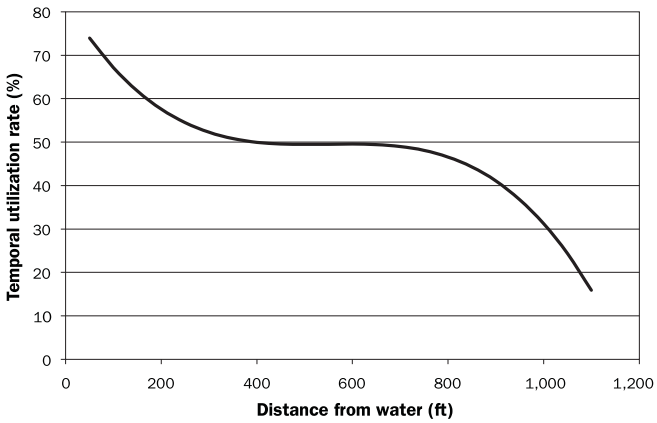

Figure 15.7. Effect of travel distance from water on temporal utilization rate. (Illustration by Jim Gerrish)

Evaluate your available water sources and design your system to optimize their use. For example, an irrigation canal or mainline can provide stock water during the irrigation season. With proper valve arrangements, other sources can use the same system to deliver water to stock tanks at other times of the year.

Water quality affects animal performance. Sheep, goats, finishing cattle, and dairy cattle are most sensitive to water quality. Wells and springs usually provide the highest quality stock water, unless groundwater is contaminated. Irrigation canals and ditches are intermediate in quality, while dugouts and ponds usually have the lowest quality water.

PIPELINES

Pipe size is the critical factor in water delivery. Even with a bigger pump, water flow will not increase if pipe size is limiting. Increasing pipe size is the most effective and economical way to increase water delivery. Doubling the pipe diameter quadruples the water flow.

The appropriate pipe size depends on the required recharge rate. Recharge rate is especially important with small, movable tanks. University extension professionals or Natural Resources Conservation Service engineers can help you determine the correct pipe size for your grazing cell. Do not try to get by with a smaller pipe because it is cheaper. In the long run it will cost more, either in lost animal performance or the expense of redoing the job.

Pipelines can be left on the surface if used only during the growing season. If they will be used year-round, bury them below the historic frost line or ensure adequate water flow throughout the winter to prevent freezing (figure 15.8). High-capacity spring developments are the best source of year-round continuously flowing water. Wells and dugouts frequently don't have enough water to support a continuously flowing system.

Figure 15.8. Laying pipeline with a ripper. (Photo by Jim Gerrish)

For over-the-surface waterlines, use high-density polyethylene (HDPE) pipe for maximum durability. HDPE pipe is burst-resistant under freezing conditions, as it can expand and contract with changing temperatures. Run the pipeline directly under a fence to prevent damage from livestock stepping on the pipe. Install water-access valves at appropriate spacing along the full length of the pipeline.

PERMANENT STOCK TANK INSTALLATIONS

There are many options for permanent livestock watering installations. Two important considerations are the number of head to be watered and the season of use. If a permanent water installation is to be used in the winter, you need to prevent freezing in the tanks and the supply line. The greater the number of livestock, the greater the demand on the water system.

You can address increased demand with a larger stock tank and/or greater recharge capacity. Graziers typically deal with larger herds by installing larger tanks. In managed grazing systems, however, the stock are likely to be closer to water, so you can use smaller tanks with higher recharge capacity. When travel distance to the tank is less than 0.25 mile, recharge rate is more important than tank size. For longer travel distances, a larger tank is more critical.

A geotextile and aggregate pad around the tank or drinker will minimize mud problems and soil damage. The pad should extend at least 8 feet from the edge of the tank and be at least 8 to 10 inches above the surrounding ground.

Water blocks allow access to a tank from several paddocks (figure 15.9). Electric gates form the sides of the water block. At a given time, three gates are closed and the fourth is open to the current paddock. Polyrope or electrified bungee are the best gate options due to their high visibility, good conductivity, and resilience to animal pressure.

A 30-foot x 30-foot water block will accommodate about 300 cow-calf pairs, as long as travel distance to water is less than 1,000 feet. Add 10 feet per side for each additional 100 head in the herd.

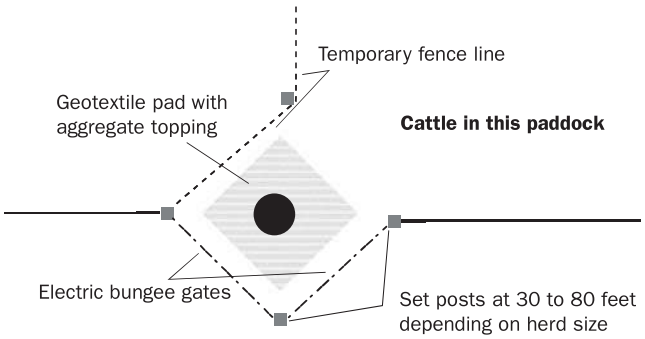

Figure 15.9. Typical water block layout for permanent stock tank installations. (Illustration by Jim Gerrish)

MOVABLE TANKS

An easily moved stock tank is key to effective use of a flexible grazing cell. High recharge capability and a relatively short travel distance make smaller tanks viable. As long as you can put water into the tank faster than livestock can drink it, the water system should work. It is possible to water 100 head of yearlings from a 20-gallon tub if the system is configured appropriately.

The key factors are:

- Adequate pipe size to allow a high flow rate
- A tank valve that delivers at least 90 percent of the pipe capacity
- Travel distance to the tank of less than 600 to 800 feet

Water delivery rate is especially critical with smaller tanks. Be sure to use an adequate pipe size and appropriate valves. Many stock tank valves have internal components that reduce the water flow to less than 30 percent of the supply line capacity. Use a full-flow valve capable of delivering at least 90 percent of its nominal size rating.

When stock travel more than 800 to 1,000 feet to water, they are more likely to travel as a larger herd. When the distance is shorter, they are more likely to travel as individuals or in small groups. This reduces crowding around the drinking facility and keeps the animals calmer. Animals are more likely to fight over drinking space and tear up facilities when they are stressed by crowding.

Fitting grazing cells to your irrigation system

Most Pacific Northwest pastures require at least some irrigation to maintain quality forage during the entire growing season. See chapter 6 for information on choosing an irrigation system. Different irrigation systems require different fence strategies.

FLOOD, FURROW, AND GATED PIPE

Surface-irrigated pastures are the most difficult to graze effectively due to the volume of water applied at a time, the propensity of livestock to trample ditches and furrows, and frequently odd-shaped pastures. Flood-irrigated pastures often must dry out before grazing begins. As a result, rest periods may be excessively long. These long return times limit pasture productivity, unless grazing periods are short and irrigation sets are applied to relatively small areas.

Flood irrigation works best with flexible grazing cells. With flexible cells, you can move fences as floodwater and soil moisture conditions change. Provide stock water through a pipeline and movable tank system, rather than allowing stock to drink from the ditches. Using ditches as the stock water source may seem economical, but it leads to serious erosion and high annual maintenance costs.

WHEEL LINES

In fields with several wheel lines, you can subdivide pasture with permanent or temporary fences. Determine subdivisions based on the area covered by each wheel line. While an area is being grazed, shut off that wheel line. To strip graze, place temporary fences perpendicular to a parked wheel line. Many graziers prefer to park the wheel line next to a permanent fence and isolate it from grazing cattle to eliminate rubbing damage.

If wheels are at least 5 feet tall, you can build permanent fence perpendicular to the wheel line. Well-trained cattle will usually stay behind a 15- to 20-inch electric fence. If the fence is built several feet from a wheel path, the wheel line can pass over the top of the fence.

LINE POD SYSTEMS

Line pod systems interface well with managed grazing, but they create some unique challenges and opportunities. Because the system is moved with an ATV, no permanent fences can be within the watering zone of each line. The most common way to set up a grazing cell on a line pod system is to fence each line's watering zone

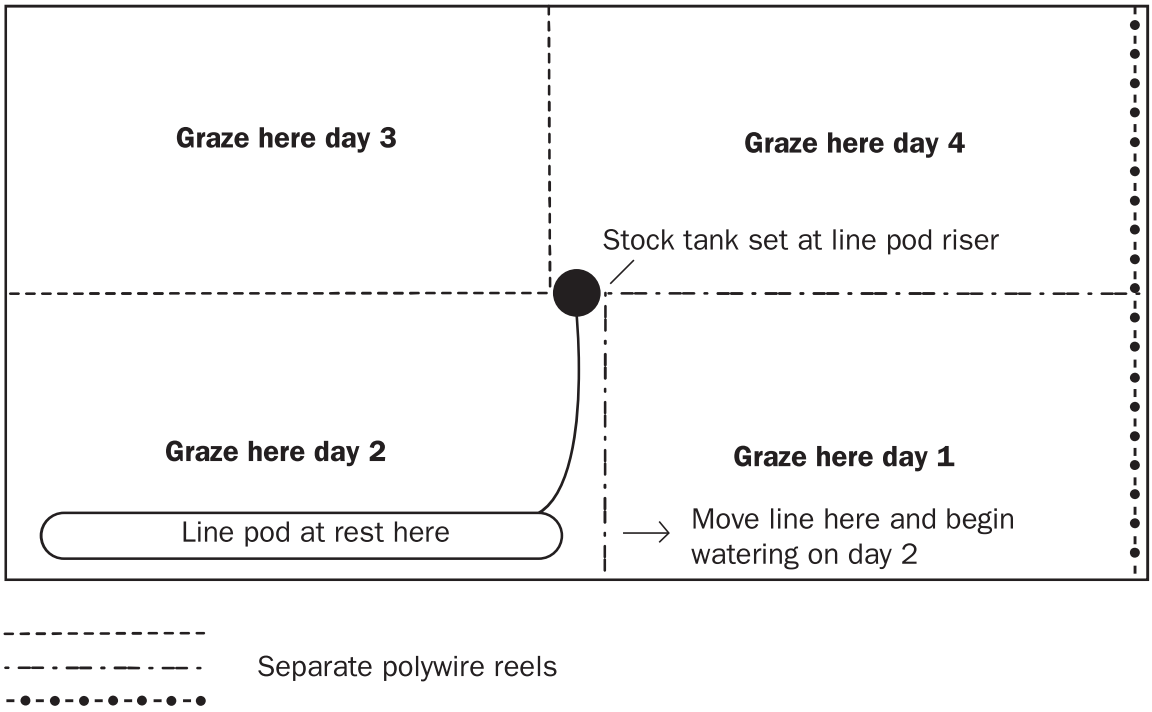

Figure 15.10. Grazing sequence around a line pod system watering zone with stock tank at the riser. (Illustration by Jim Gerrish)

as a permanent paddock and then subdivide paddocks with movable fences. The entire grazing cell may consist of repeating units of watering zones. Watering can be resumed 24 hours after grazing if the grazing sequence is well planned.

The riser that supplies the pod line can also supply stock water. Set up paddocks around this point as shown in figure 15.10.

CENTER PIVOTS

Center pivot pastures offer some of the most productive and reliable irrigated grazing. Producers sometimes view pivot grazing as challenging, as they must deal with pivot towers, availability and location of stock water, and the need to irrigate when livestock are present. However, center pivots are the easiest irrigation system to set up for MiG and the most efficient to operate.

Most paddock subdivision schemes in the past have used pie-shaped paddocks with stock water located at the pivot center. However, if permanent electric fences are used for radial subdivision, pivot towers must cross over or through the fences. This approach adds cost and complexity. Manufactured break-over posts are expensive ($15 to $50 per post). Some producers make their own posts at substantially lower cost.

As an alternative to break-over fences, mini-gates allow tower pass-through. Again, however, manufactured pass-through gates are expensive. Innovative producers have used everything from automotive radio antennas to electrified bungee cord for tower crossings.

In addition to high construction costs, these systems often result in a lack of grazing uniformity due to water placement and paddock shape.

An easier solution is to eliminate the need for towers to cross permanent fences. An increasingly popular approach is to install a permanent, nearly circular fence just off the tower track approximately midway between the pivot center and outer reach of the end gun. Temporary polyfence creates the paddocks, and towers walk over the polyfence (figure 15.11). On larger pivots, you may need to install more than one concentric fence to keep the length of temporary fences less than 800 feet.

Pivot towers can run over the top of the polywire fence as long as wheel tracks are not too deep and an underrigger is installed on the towers. If tire tracks are too deep, fill them in where fences are likely to be set up. The lead wheel of the tower must catch the top fence wire and bring it under the wheel.

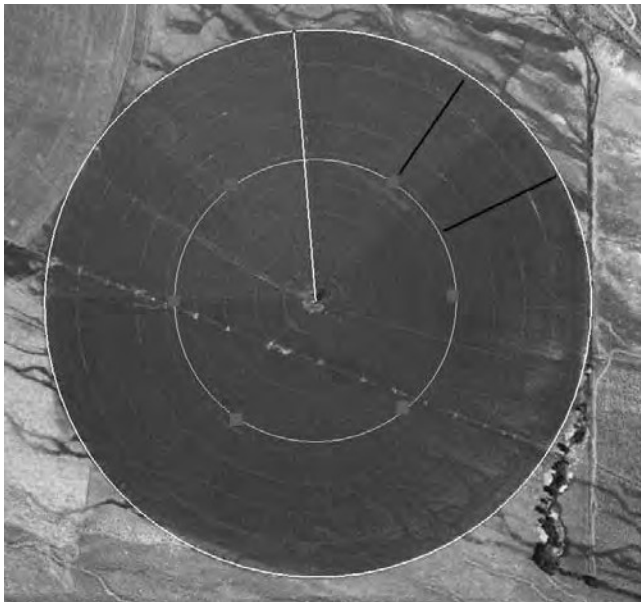

Figure 15.11. Typical center pivot grazing cell design with six water blocks on the inner circle fence. (Photo by Jim Gerrish)

Figure 15.12. PVC pipe under-rigger on a pivot tower designed to allow towers to pass over temporary fences. (Photo by Jim Gerrish))

A PVC pipe under-rigger holds the polywire down as the towers cross, thus preventing the wire from being snagged by the tower drive train or other components (figure 15.12). It also prevents grounding out the wire on metal on the tower. The leading wheel catches the polywire and pulls it down. As the wire comes up behind the rear tire, it is released.

On heavy clay or silty soils, the pivot should be dispensing water when crossing a temporary fence; otherwise the mud may not release the polywire from the trailing wheel. Where mud is a problem, another strategy is to use tread-in posts to hold the polywire down near the wheel track.

CHAPTER 16

Estimating Forage Production, Monitoring, and Evaluating the Grazing System

G. Shewmaker, B. Gillaspy, S. Fransen, T. Griggs, and L. Hooper

REGARDLESS OF WHETHER YOU HAVE CHOSEN A CONTINUOUS or rotational grazing system (chapter 14), pasture forage is the basis of your livestock-pasture system. Understanding the condition and level of production in your pastures is key to making good day-to-day grazing decisions. This chapter covers three topics:

- Methods for estimating forage production
- Examples of how to use the information in daily, weekly, and yearly planning and forage allocation decisions
- The importance of observing and recording information about pasture growth and utilization

Key Points

- By knowing the amount of forage and expected growth in your pastures, you can anticipate a forage surplus or deficit and manage proactively rather than reacting to crises.
- Inventory your forage yield per grazing paddock every 2 weeks during the growing season. During the dormant period, a monthly inventory is adequate.
- Repeated observations allow you to track trends and responses to management changes.
- With several years of data, you should be able to notice if available forage production is below or above normal for a given time of year. Then you can adjust grazing while there is still time to have an effect.

Estimating forage production

Estimating pasture production will help you make grazing management decisions. By knowing the amount of forage and expected growth, you can manage proactively, rather than reacting to crises. The goal is to effectively estimate forage availability and balance forage supply with animal requirements.

Estimates of forage production are useful for allocating paddock area or projecting carrying capacity. They are especially useful when moving into the non-growing season. Estimating forage production can help you answer the following questions:

- How large should the paddock be in order to meet my production goals and optimize uniform grazing to a predetermined height (see chapter 15)?
- When should I move the livestock to the next paddock?
- Is there enough forage in the next paddock to support the current group of animals and meet my production goals?
- Am I leaving enough residual?
- Is the regrowth rate adequate so that livestock can return to this paddock at the planned time?

As you move through the grazing season, monitor pasture growth and utilization. Monitoring enables you to fine tune paddock size, animal numbers, and grazing periods. Observe utilization daily in the current paddock, and monitor production in the last two paddocks and the next two or three paddocks. Periodically estimate the total forage in all paddocks.

With this information, you can construct a forage budget, as discussed later in this chapter. The balance sheet will help you reallocate animal numbers if needed. If forage exceeds grazing needs, or if you anticipate a need for supplemental feeding, you can plan to harvest hay.

Forage production can be estimated by several methods, each of which has advantages and disadvantages. Direct methods are more accurate, but they usually are destructive from a grazing standpoint and are time- and labor-consuming. Thus, they are not practical for inventory and monitoring purposes. Indirect methods may not be as accurate, but usually are quicker, easier, and less costly. The accuracy of indirect methods generally improves as you gain experience.

Fresh forage must be converted to a dry matter (DM) basis for most comparisons. We base our calculations on oven-dried forage.

Various direct and indirect methods are discussed below.

Key Terms

Grazing cell—An area of pasture managed as a planning unit from which forage is allocated to a specific group of animals for the grazing season. A grazing cell usually has permanent fence on its borders and is separated into paddocks with temporary fencing or by herding.

Grazing cycle—The time elapsed between the beginning of one grazing period and the beginning of the next grazing period. One grazing cycle includes one grazing period plus one rest period.

Grazing period—The time that animals are present on the paddock.

Grazing season—The total period of time during which animals may harvest standing forage from pasture. Composed of the "growing season," when temperature and moisture are conducive to plant growth, and the "non-growing season," when animals may harvest any forage remaining after the growing season.

Growing season—The time of year when temperature and moisture are conducive to plant growth.

Non-growing season—The season when animals may harvest forage remaining after the growing season.

Paddock—A subdivision of a grazing cell to which the animals are confined for a grazing period (hours or days). A paddock may be of fixed or variable size.

Rest period—The grazing cycle minus the grazing period.

Seasonal carrying capacity—The stocking rate that is economically and environmentally sustainable for a particular grazing unit over the entire grazing season.

Seasonal utilization rate—The fraction of annual forage production that will be harvested by grazing livestock during the entire grazing season.

Stocking density—The relationship between the number of animals (or live weight) and area of land at any given instant of time. May be expressed as animal units or forage intake units per unit of land area (for example, "50 animal units per acre," which is equivalent to 55,000 pounds of live weight per acre).

Stocking rate—The relationship between the number of animals (or live weight) and the grazing management unit over a specified time period. May be expressed as animal units or forage intake units over a time period per unit of land area such as "50 animal units per acre-day" (equivalent to 55,000 pounds live weight per acre-day).

Temporal utilization rate—The fraction of available forage expected to be consumed during a grazing period.

DIRECT METHODS

Converting hay yield to pasture yield

Harvesting and weighing hay from the entire paddock is the best measure of forage production. You can use this method to roughly estimate the amount of annual forage production.

Grazing is not the same as haying, however, because of different forage quality and regrowth periods. Hay is more mature than grazed forage; thus, it contains more stem and is lower quality. Continuously stocked pastures generally produce less animal days of forage than harvested hay—perhaps 15 to 35 percent less. Intensively managed pastures, on the other hand, can produce as much or more animal production as harvested hay.

Both haying and grazing animals waste some forage. Depending on stocking rate, type of grazing, and plant height at the start of grazing, waste may range from 10 to 30 percent of usable forage.

Hand clipping

Clipping, drying, and weighing samples is the most commonly used direct method of estimating forage production. The precision of hand clipping depends largely on pasture variability and sampling efficiency.

Although hand clipping is precise, it is time-consuming, which makes routine use impractical. The most practical use of hand clipping is for calibrating the indirect methods discussed below.

Collecting samples—To obtain a good estimate by hand clipping, select areas representing low, medium, and high production. Choose at least three samples from each level of production. This sample selection method assures that you will get a good estimate of overall production without having to take a large number of randomly selected samples (20 to 100). You will need a separate cloth or paper bag for each sample. Take samples as follows:

1. Use a frame of known area to surround a sample area. We prefer a 1-foot x 1-foot U-shaped frame. Place the frame on the ground by working it down through the forage. Comb tillers to either side of the frame as necessary to arrange them in their natural positions. Make sure that tillers from plants rooted outside the frame are not bent into the frame area and vice versa. It is important to clip only forage rooted inside the frame.
2. Label the first bag with location and production level.
3. Gather an easy handful of forage from inside the frame with one hand and clip parallel to the ground at 0.5 to 1 inch height (figure 16.1). Place the forage in the bag. Repeat this process for all of the forage inside the frame, collecting all of the clipped material into the bag. It is not necessary to remove dead material.
4. Move to the next sample area and repeat, using a separate bag.

Figure 16.1. Hand clipping forage within a 1-foot square frame. (Photo by Glenn Shewmaker)

Calculating forage DM per acre—Now dry and weigh the samples as follows and calculate pounds of DM per acre:

1. This example assumes weights are in pounds. If you weighed in grams, convert from grams/ft^2 to pounds/acre by multiplying by 96.
2. Dry all of the bags of forage and an empty tare bag in a convection oven at 140°F until the bags have a constant weight. (Dry and weigh the bags repeatedly until the weight does not change.)
3. Weigh each bag and sample, and then subtract the tare weight of the bag to determine forage DM weight for each bag.
4. For each level of production, find the average DM weight of the samples by adding together the weights of the samples and dividing by the number of samples.
5. Multiply the average weight for each production level by the percentage of the pasture represented by that level of production. (The sum of the three percentages must equal 100.)
6. Sum these amounts.
7. Calculate pounds of DM per acre:

$$\text{lb DM/acre} = \text{sample DM (from step 6)} \times (43{,}560 \div \text{frame size in square feet})$$

INDIRECT METHODS

There are several indirect methods of estimating forage production. In each case, forage DM weight is estimated from measurements taken in standing forage. We will present the most practical for daily use.

- Pasture sticks (rulers) measure forage canopy height.
- Rising plate and falling plate meters measure compressed forage height. This measure integrates plant density, structure, and height.
- Capacitance meters measure electrical current in forage.

Microwave oven drying

If you do not have a drying oven, you can use a microwave oven to determine DM weight.

1. For the first level of production, weigh each bag and sample, and then subtract the tare weight of the bag to determine the net fresh forage weight for each bag. Sum these fresh weights to find the total net fresh weight for this level of production.
2. Collect a small grab sample from each sample bag from this level of production. Thoroughly mix the subsamples and pull out about 0.25 lb (100 grams) of wet material. Record the exact fresh weight.
3. Cut the subsample into small pieces (smaller than 1-inch segments). Place the pieces in a microwave oven along with a glass of water to prevent fire and smoke. Dry the sample for 2 minutes, check the weight, and dry for another 30 seconds.
4. Repeat the drying for 30 seconds and weighing process until you have two successive weights that do not change. Subtract the dried tare bag weight. This is the DM weight.
5. Calculate the average DM weight for this production level:

$$\text{average DM weight} = \text{DM weight (from step 4)} \times \frac{\text{total net fresh weight (from step 1)}}{\text{fresh weight of grab sample (from step 2)}}$$

6. Repeat this process for the other two levels of production.
7. Use these average DM weights in step 5 of the hand clipping instructions on this page. Continue with steps 5–7 to calculate pounds of DM per acre.

Pasture sticks and rising plate meters are used most often. All indirect methods need to be calibrated to specific situations, including pasture species and mixes, time of year, irrigated versus rain fed, before versus after grazing, operator, etc. Calibration instructions are given in appendix A.

Pasture sticks

There are two ways to use pasture sticks. The simplest is to estimate production based on forage height alone. The second takes into account forage species and stand condition. Although the pasture stick method is fast, simple, and cheap, it is not as precise as hand clipping. Precision is increased by taking numerous measurements.

Sward height—This method works on the principle of relating sward height to yield. Therefore, you need to calculate the average pasture sward height.

1. First, walk through the paddock in a W pattern, or transect (figure 16.2), and use the ruler to determine the height below which 90 percent of the forage mass is found (figure 16.3). With a little practice, you can approximate this height visually. Initially, you may want to lower your hand into the canopy perpendicular to the ruler until you think 90 percent of the forage mass is below your hand. Do not pull the forage to its tallest height to measure it. Record the 90 percent height to the nearest 0.5 inch. In figure 16.3, the height at the bottom of the hand is 8 inches.
2. Repeat step 1 at regular intervals, for example, every 20 to 35 steps (figure 16.2). It is important to take measurements at a consistent spacing regardless of forage condition at that spot. The height of both bare spots and dense (manure-affected) spots must be recorded. Avoiding certain spots will lead to a biased calculation of average height and yield.
3. After collecting the height data, find the average height. (Add together all of the heights and divide by the number of measurements.)

If the sward height is greater than 12 to 16 inches, consider taking a hay crop. Waste from grazing probably would be excessive at this height. Cutting for hay will uniformly reduce all plants to a common residual, and most new growth will be vegetative rather than reproductive. This will allow you to better manage the paddock for grazing during the next cycle.

Generally, about 200 to 500 pounds of forage DM per acre are available per inch of sward height. For example, you might use an average yield of 300 pounds per acre per inch of sward height. In this case, to convert average sward height to yield, simply multiply sward height (inches) by 300. The result is the estimated DM yield in pounds per acre.

Sward height, species composition, and stand condition—Estimates based on sward height alone are not as accurate as those that combine height and stand condition. Stand condition is a function of stand density and vigor of desirable plants. Research in the Northwest suggests that determining whether a sward has low, medium, or high stand condition will improve the accuracy of forage yield estimates based on pasture stick measurements.

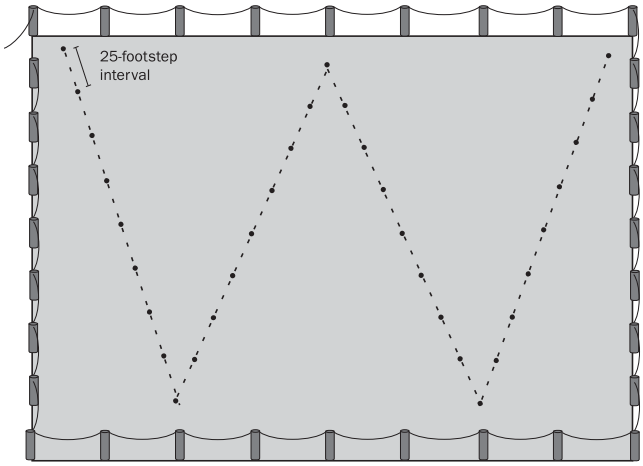

Figure 16.2. A "W" pattern for sampling pastures to minimize sampling bias.

Figure 16.3. Using a pasture stick to determine sward height. (Photo by Glenn Shewmaker)

The yield per inch of sward height measured with a pasture stick is the average weight of forage per inch. However, the center of gravity in a sward is somewhere around one-third of the total sward height. Most of the mass is in the lower 3 inches of the sward. Yield per inch also varies among grass species. Smooth brome and timothy, for example, have leaves that extend higher in the canopy than do Kentucky bluegrass and perennial ryegrass.

Table 16.1 provides estimated forage DM yields (pounds per acre per inch of sward height) based on species and stand condition. For each species and stand condition, a range of yields is given. Use a lower yield for taller swards and a higher yield for shorter swards, especially in post-grazing estimation.

The values for orchardgrass, smooth brome, and perennial ryegrass in table 16.1 are averages across the growing season. They are based on studies conducted on irrigated pastures. During 2006 and 2007, a total of 472 samples were taken at weekly intervals from May 1 to September 30. All pastures were mixes of grasses with a minor component of legumes; the dominant species is listed in table 16.1.

The values for tall fescue, Kentucky bluegrass plus white clover, red clover, alfalfa, and mixed pasture are based on values from several sites (mostly non-irrigated pastures) in the midwestern and eastern United States. Notice that the forage estimates per inch of sward height are similar regardless of longitude, latitude, or elevation, as long as adequate irrigation or precipitation is available.

Although the values in table 16.1 can give you a good starting point, you should calibrate your pasture stick to your conditions. See appendix A for instructions.

An example of using the pasture stick to determine pasture yield and forage consumed—A producer wants to determine the initial orchardgrass yield and the amount of forage consumed in a paddock. To

Table 16.1. Estimated forage dry matter yield in pounds per acre-inch measured with a pasture stick (ruler).

	Stand condition		
Forage type[a]	**Fair: 60 to 75% ground cover (lb/acre-inch)**	**Good: 75 to 90% ground cover (lb/acre-inch)**	**Excellent: >90% ground cover (lb/acre-inch)**
Orchardgrass	150 to 250	250 to 350	350 to 500
Smooth brome	150 to 200	200 to 300	300 to 400
Perennial ryegrass	150 to 250	250 to 350	350 to 500
Tall fescue	150 to 250	250 to 350	350 to 450
Kentucky bluegrass + white clover	100 to 250	250 to 350	350 to 450
Red clover or alfalfa	150 to 200	200 to 250	250 to 300
Mixed pasture	150 to 250	250 to 350	350 to 400

[a] Dominant vegetation

Table 16.2. Pasture stick measurement of orchardgrass height for estimation of yield and consumption.

Sample number	Pre-grazing plant height (inches)	Post-grazing plant height (inches)
1	8	4
2	10	4
3	9	5
4	10	3.5
5	8	3
6	11	4
7	8	3.5
8	10	4
9	8	3
10	9	2
11	10	4.5
12	8	4
13	9	3.5
14	7	4
15	9	3
16	10	4
17	8	3
18	9	4
19	10	5
20	9	3
Sum	**180**	**74**
Average height	**9**	**3.7**

estimate how much forage is consumed by the grazing animals, he needs to estimate the DM before and after each grazing event. Subtracting the post-grazing DM from the pre-grazing DM will give the actual forage consumed.

total forage consumed = pre-grazing DM
– post-grazing DM

The producer takes 20 measurements with a pasture stick before and after grazing and records the data (table 16.2). The average pre-grazing height was 9 inches, and the average post-grazing height was 3.7 inches. From table 16.1, he selects 250 pounds DM per acre-inch as the pre-grazing yield estimate and 350 pounds DM per acre-inch as the post-grazing estimate.

pre-grazing yield = 9 x 250 lb DM/acre-inch
= 2,250 lb DM/acre

post-grazing yield = 3.7 x 350 lb DM/acre-inch
= 1,295 lb DM/acre

total forage consumed = 2,250 – 1,295 lb DM/acre
= 955 lb DM/acre

Rising plate meters

This method combines plant height, structure, and density into one measurement referred to as bulk density or compressed sward height. It is more precise than the pasture stick method, but requires a greater investment in time (for calibration) and money. The meter consists of a disk or plate on a threaded (or notched) pole or rod that meshes with counter wheels to tally accumulated heights and numbers of observation points (figure 16.4). It works best on uniform, dense vegetation. It is not useful on arid rangelands.

Before data collection, set the sample counter to zero or record the number. Also record the rising plate value. Then take measurements as follows:

1. To take the first measurement, lower the meter vertically into the sward until the rod hits the ground. The plate will be held at the compressed sward height by the vegetation. Units are about 0.2 inch per click. Make sure the sample counter counts the sample.
2. Next, walk through the pasture in a W pattern and take additional readings at an interval of 25 steps (figure 16.2). Readings must be taken at a consistent interval to avoid bias. Collect at least 20 readings regardless of paddock size; more are better. With a properly calibrated meter, 30 to 50 measurements usually give a reasonable estimate of paddock production.
3. When you have finished collecting the readings, record the final plate number.
4. Calculate the average plate meter rise by subtracting the initial value from the final value and dividing by the number of samples.

The average plate rise is correlated with forage bulk density. Use the appropriate calibration formula from table 16.3 to estimate forage production. However, rising plate meters vary in size, shape, weight, and area. Because the weight and area of the disk are important in determining the compressed sward height, you should calibrate your meter to your conditions. See appendix A for instructions.

An example of using the rising plate meter to determine pasture yield and forage consumed—A producer wants to determine the initial orchardgrass yield and the amount of forage consumed in a paddock. He takes 25 measurements with a rising plate meter

Figure 16.4. Using a rising plate meter to determine compressed sward height. (Photo by Glenn Shewmaker)

Table 16.3. Calibration formula for estimating dry matter yield (pounds per acre-inch) with a rising plate meter[a] and estimated dry matter yield (pounds per acre-inch) for a falling plate meter.[b]

Forage type[c]	Calibration formula for rising plate meter (lb/acre)	Falling plate meter (lb/acre-inch)
Orchardgrass	(76 x avg RPM) + 1,087	640
Smooth brome	(103 x avg RPM) + 364	520
Perennial ryegrass	(100 x avg RPM) + 398	560

[a] Ellinbank-type constructed by the University of Missouri
[b] 3.2 pounds and 18 inches square
[c] Dominant vegetation

before and after grazing (table 16.4). The average rising plate meter (RPM) reading was 42 for the pre-grazing measurement and 17 for the post-grazing measurement. Our calibration equation for orchardgrass is: yield = (76 x avg RPM) + 1,087 (from table 16.3).

Pre-grazing yield = (76 x 42 avg RPM) + 1,087
= 4,279 lb DM/acre

Post-grazing yield = (76 x 17 avg RPM) + 1,087
= 2,379 lb DM/acre

Total forage consumed = 4,279 – 2,379
= 1,900 lb DM/acre

Table 16.4. Rising plate meter estimation of orchardgrass yield and consumption.

	Formula	Pre-grazing meter reading	Post-grazing meter reading
Initial reading		893	1,245
Final reading		1,943	1,670
Counter		25	25
Final reading – initial reading		1,050	425
Average RPM		42	17
Estimated yield (lb DM/acre)	(76 x avg RPM) + 1,087	4,279	2,379
Forage consumed (lb DM/acre)	pre-grazing DM – post-grazing DM		1,900

Figure 16.5. Using a falling plate meter to determine compressed sward height. (Photo by Glenn Shewmaker)

Falling plate meters

Falling plate meters (figure 16.5) are similar to rising plate meters. Both types of meter measure compressed sward height, structure, and stand density. Falling plate meters are less expensive, but measurements take more time because you must manually record each plot.

Falling plate meters normally consist of an 18-inch square plate with a center hole. The plate can be made of Plexiglas, cardboard, or plywood. To use the meter, push a yardstick through the center hole until it touches the ground. Then lower the plate onto the forage until the herbage supports the weight of the plate. Measure the compressed sward height by reading the yardstick at the top of the plate.

Table 16.3 provides average estimated forage DM yields (pounds per acre-inch) based on compressed sward height (inches). These estimates are based on experiments conducted in Idaho on irrigated pasture. Our falling plate meter was an 0.25-inch thick acrylic sheet measuring 18 x 18 inches. It weighed 3.2 pounds and provided compression of 1.42 pounds per square foot. With this falling plate meter, each inch of compressed height represents 520 to 640 pounds DM per acre. We recommend a lighter sheet exerting compression of about 1 pound per square foot. As with rising plate meters, you should calibrate your meter to your conditions. See appendix A for instructions.

A spreadsheet for entering data and calculating pounds DM from rising plate and falling plate meters is available from the University of Idaho on the "pastures and grazing page" at http://www.extension.uidaho.edu/forage/.

Capacitance probes

New Zealand researchers have developed an electronic capacitance meter to estimate standing forage. The meter works on the principle that electrical conductivity increases as the mass of forage increases. The computerized hand-held probe measures electrical capacitance. It then converts this value to estimated forage DM yields. Capacitance probes are not useful on rangeland.

Our research has shown no advantage of capacitance probes over pasture sticks or rising plate meters. However, they are convenient because they display estimated yield instantly. The equations used to calculate yield may not be accurate in your situation, so calibrate your probe.

Visual estimates

With training and experience using one or more of the above methods, plus a season or two of grazing observations, you may learn to visually estimate pasture forage mass. You then can estimate production as you move livestock or as part of an all-paddock inventory (recommended every 2 weeks). Sweeping your hand through the pasture canopy to sense density can add another perspective and improve your estimates of forage mass.

Your estimate likely will fall within 50 pounds per acre-inch above or below actual production (plus or minus 250 pounds per acre on 5-inch-tall pasture). This level of accuracy is sufficient for daily management decisions and adjustments based on forage and livestock responses.

Forage inventory and budgeting (the grazing wedge)

Inventory your forage yield per grazing paddock every 2 weeks during the growing season. (During the dormant period, a monthly inventory is adequate.) By knowing yield per paddock and paddock size, you can construct a forage budget. Combine your pasture inventory with pest scouting and other monitoring activities (irrigation, grazing, livestock, etc.).

Forage yield is dynamic and can be thought of in terms of a "wedge." In a rotational grazing system, the forage in a series of paddocks forms a declining pattern, or wedge, when sorted by the highest to lowest amount of available forage (figure 16.6). A grazing wedge indicates the optimum order of paddock rotation, which may not be sequential.

In figure 16.6, pasture growth is divided into three phases. Phase I (below the line at 1,250 pounds per acre) is residual or permanent base growth. Phase II (between the two lines) represents vegetative growth. This phase is suitable for grazing. Phase III (above the line at 2,750 pounds) is excess growth.

Your goal as a grazing manager is to keep forage growth in Phase II (between the lines shown in figure 16.6). Do not graze Phase I forage because this permanent base growth is needed for rapid regrowth following grazing. When forage is in Phase III, it should be cut for hay or stockpiled for later fall or winter grazing.

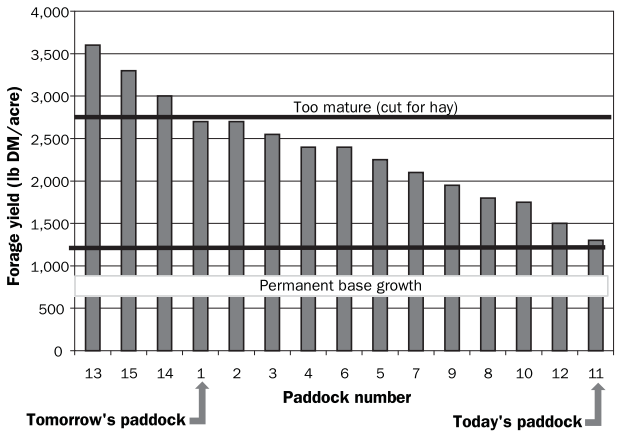

Figure 16.6. A grazing wedge.

Grazing wedge example

A producer has a grazing cell with permanent fence on borders (figure 16.6). Using temporary fence, he can easily subdivide the cell into 15 paddocks for daily moves. Grazing began on April 15 in paddock 1, and livestock were quickly rotated through all paddocks. Although the paddocks were grazed in numerical sequence during the first grazing cycle, they likely won't be grazed in the same order during all cycles.

We are now in a subsequent grazing cycle. Grazing again began in paddock 1 and has progressed through paddock 11, where the livestock are now. Paddocks 13, 14, and 15 have not been grazed during this cycle. They are in Phase III (plants are more than 10 inches tall, with more than 3,000 pounds of forage DM per acre). These paddocks should be cut for hay to improve harvest efficiency and conserve the spring growth for winter use. The next grazing paddock should be paddock 1. It has the most usable production and is on the high side of the Phase II growth curve. Regrowth should be adequate if enough residual is left.

A grazing wedge spreadsheet allowing data entry, easy sorting, and graphical display of the grazing wedge is available on the "pastures and grazing" page at http://www.extension.uidaho.edu/forage/.

It is important to estimate forage growth rates in order to anticipate a forage surplus or deficit. In paddocks

yielding from 1,200 to 3,000 pounds DM per acre, the daily growth rate may be only 40 pounds per acre with dry soil moisture conditions. With moderate soil moisture conditions, growth may be 70 pounds per acre. With higher soil moisture, growth may reach 100 pounds per acre. The growth rate for paddocks below 1,200 pounds DM per acre is much lower.

With several years of data, you should be able to notice if available forage production is below or above normal for a given time of year. Then you can adjust grazing while there is still time to have an effect. Many producers don't realize they are in trouble until it is too late to adjust the stocking rate easily. Also, if you notice a decline in production during the spring, good records will enable you to relate the change to management practices and adjust your plan.

Inventories also serve as a "reality check" if you occasionally compare estimated and actual forage production. For example, you may find that your livestock are bigger or more productive than you estimated and are consuming more than you had budgeted.

The example on page 169 shows how to use a grazing wedge.

Monitoring pasture condition

Good pasture condition is critical to a successful grazing system. Regularly monitor your forage production, livestock performance, and progress toward economic, environmental, and other goals. Pasture quality may vary greatly from one area to another, but the trend over time should show the direction in which pasture condition is moving. Pasture monitoring is a tool to help determine whether pastures need improvement and what areas need the most improvement. It can also help you evaluate results of management decisions.

The best time to monitor pastures is 15 days after a grazing period. Use the Pasture Condition and Trend Score Sheet (appendix B) to rate pastures on 10 critical pasture, grazing, and soil resource factors. The scale is 0 to 4, with 4 being the most desirable condition and 0 being least desirable. If you can't decide exactly how to rate a factor, use ½-point scores.

A single evaluation gives you a snapshot of pasture condition at a given time. Repeated observations allow you to track trends and responses to your management changes.

Monitoring animal performance

Observe livestock for amount of rumen fill, as well as when and how they are grazing, resting, and ruminating. See chapter 13 for information on grazing behavior.

We recommend monitoring what passes through the livestock as well as what animals consume. Scatology, the study of feces, can reveal a lot about whether livestock are meeting your production goals. For example, with experience you can establish a relationship between fiber in the feces and weight gain or milk production.

Scrape the surface off a dung pat with the bottom of your boot or a shovel and observe the amount and size of fiber. A high concentration of fiber in the feces indicates that forage digestibility is too low for good production. If the dung pat is still intact by the time the next grazing period begins, you will know that the livestock did not get high-quality forage during the previous grazing period.

The amount of fiber is less critical for maintenance of dry cows or horses than for growing or lactating animals. A high fiber concentration still indicates, however, that you may be grazing too high on the Phase II curve.

Allocating forage

Generally, there are two scenarios for allocating forages:

- You are using a fixed grazing system and a slow rotation and need to calculate how many days a paddock will support your herd. In this case, the paddock size is fixed, and you need to calculate the length of the grazing period.
- You are using temporary fence and allocating acreage to feed your animals for a specific number of days.

Below we discuss how to calculate a grazing period for the first scenario. See chapter 15 for a discussion of how to calculate paddock size in the second scenario.

CALCULATING LENGTH OF THE GRAZING PERIOD

When allocating forage on a day-to-day basis, you may need to adjust the average grazing period that you calculated for the season (see chapter 15). Assuming a fixed paddock size (from chapter 15) and a given herd

size (from chapter 14), the grazing period for the paddock is a function of available forage in the paddock, animal weight, and daily DM intake (as a percentage of body weight).

Begin with your estimation of total forage DM per acre from one of the methods discussed earlier in this chapter. Then calculate total forage in the paddock as follows:

total forage (lb DM/paddock)
= total forage (lb DM/acre) x paddock area (acres)

For example, if a 15-acre paddock has an estimated forage production of 2,250 pounds DM per acre:

total forage = 2,250 x 15 = 33,750 lb DM/paddock

Now calculate the available forage in the paddock. Available forage is the total forage times the desired temporal utilization rate. The temporal utilization rate is the percentage of the total forage expected to be consumed during the grazing period. In a continuous grazing system, animals use only 30 to 35 percent of the total forage. With pasture rotation, the grazing period is shortened, animals cannot be as selective, and less forage is wasted. With more than seven paddocks and daily moves, utilization rates can exceed 60 percent.

available forage (lb DM/paddock)
= total forage (lb DM/paddock)
x temporal utilization rate (%)

If the producer uses a 15-paddock rotation and knows from experience to expect a 70 percent temporal utilization rate:

available forage = 33,750 x 0.7
= 23,625 lb DM/paddock

Now choose a DM intake rate based on your desired level of animal performance. The following values are general guidelines based on level of livestock performance:

- High performance: 3.5 percent of body weight (BW)
- Medium performance: 3 percent of BW
- Low performance: 2.5 percent of BW

For example, a forage DM intake of 3.5 percent predicts that each day an animal will consume 3.5 pounds of forage DM per 100 pounds of BW. A 1,200-pound animal would be expected to consume 42 pounds of forage DM each day (1,200 x 0.035). If forage has a DM content of 25 percent, this is the equivalent of 168 pounds of standing forage (42 ÷ 0.25). Caution: if forage of appropriate quality is not sufficiently abundant, the livestock cannot attain the desired intake rate! Low-quality, high-fiber forages reduce intake. See chapters 10 and 11 for information on forage nutritional value and animal requirements.

Finally, calculate the length of the grazing period from the available forage (lb DM/paddock), the number of animals, the body weight per animal (lb), and the daily DM intake (lb DM day ÷ 100 lb BW) as follows. (Assume 110 animals).

$$\text{grazing period (days)} = \frac{\text{available forage}}{\text{\# of animals x BW/animal x daily DM intake}}$$

In this example:

$$\text{grazing period (days)} = \frac{23,625}{(110 \times 1,200) \times (3 \div 100)}$$

$$= \frac{23,625}{132,000 \times 0.03} = \frac{23,625}{3,960}$$

$$= 5.96 \text{ days}$$

The grazing period in this example is about 6 days.

For more information

University of Idaho forage web page.
http://www.extension.uidaho.edu/forage/

APPENDIX A

Calibrating Pasture Sticks, Rising Plate Meters, and Falling Plate Meters

You will need the following:

- Hand shears
- Clipping frame
- Drying oven or microwave oven
- Pasture stick (ruler), rising plate meter, or falling plate meter
- 15–20 bags labeled with sequential numbers
- Scale

PROCEDURE FOR PASTURE STICKS

1. Record the air-dry tare weight of an empty bag (Tw).
2. Begin walking through the pasture in a W pattern. After about 20 to 35 steps, measure and record sward height at the end of your toe. Place a clipping frame at the same spot and collect a hand clipping to 1 inch above ground level. Place clippings in bag #1.
3. Continue walking through the paddock in a W pattern, repeating step 2 at a fixed interval of 20 to 35 steps. If the paddock is small, take at least 15 measurements and samples. Record the sward height for each sample, and place clippings into the numbered bags in the order in which you take the samples.
4. Weigh each of the bags and samples to get the gross wet weight (GWw) of each bag.
5. Calculate the net wet weight of each bag and record it:

   NWw = GWw – Tw

6. Randomly select three of the bags.
7. Dry the three selected bags and a tare bag to get an oven-dry weight. (For information on how to dry forage, see page 164.)
8. Weigh each selected bag after drying. This is the gross dry weight (GWd).
9. Calculate percent DM content (% DM) of each selected bag:

   % DM = (GWd – Tw) ÷ (GWw – Tw) x 100

10. Calculate average percent DM of the three selected bags by summing the percent DM for the three bags and dividing by 3.
11. Calculate bag DM for each of the 15 or more samples:

    bag DM = NWw (from step 5) x average % DM (from step 10)

12. Sum all of the bag DMs to find the total sample DM.
13. Calculate pounds of DM per acre:

    lb DM/acre = total sample DM (from step 12) x (43,560 ÷ [# of samples x frame size in square feet])

    If you weighed in grams, multiply by 0.00221 to convert to pounds.

14. Calculate average sward height:

    average height (inches) = sum of individual heights (inches) ÷ number of samples

15. Determine the relationship between DM production and sward height.

    average lb DM/acre-inch = lb DM/acre (from step 13) ÷ average sward height (from step 14)

Repeat this process at least 10 times to develop a reliable relationship between sward height and DM production. You can then substitute this value for the value given for this species and pasture condition in table 16.1. Once you have determined a reliable relationship, occasional checks are recommended. Take about three samples per transect (W pattern) each time you use your pasture stick to estimate forage production. You can download a spreadsheet and example to assist in calibrating the pasture stick at http://www.extension.uidaho.edu/forage/.

PROCEDURE FOR RISING PLATE OR FALLING PLATE METERS

1. Record the tare weight of an empty bag (Tw).
2. Begin walking through the pasture in a W pattern. After about 20 to 35 steps, lower the meter onto the forage at the end of your toe and record the compressed height.
3. Place a clipping frame directly under the meter and collect a hand clipping to the 1-inch level. Place clippings in bag #1.
4. Walking through the paddock in a W pattern, repeat steps 2 and 3 at a fixed interval of 20 to 35 steps. If the paddock is small, take at least 15 measurements and samples. Record the compressed height for each sample and place clippings into the numbered bags in the order in which you take the samples.
5. Weigh each of the bags and samples to get the gross wet weight (GWw) of each bag. Record this weight for each bag.

   If you weighed in grams, multiply by 0.00221 to convert to pounds.
6. Calculate the net wet weight of each bag and record it:

   NWw = GWw – Tw
7. Randomly select three of the bags.
8. Dry the three selected bags to get an oven-dry weight. (For information on how to dry forage, see page 164.)
9. Weigh each selected bag after drying. This is the gross dry weight (GWd). Record these weights.
10. Calculate the net dry weight (NWd) of each selected bag.

    NWd = GWd – Tw
11. Calculate percent DM content (% DM) of each selected bag:

    % DM = NWd (from step 10)
    ÷ NWw (from step 6) x 100
12. Add together the percent DM (from step 11) for the three bags.
13. Divide the total found in step 12 by 3 to find the average percent DM for the three bags.
14. Calculate bag DM for each of the samples taken in step 4:

    bag DM = NWw (from step 6)
    x average % DM (from step 13)
15. Go to the University of Idaho "pastures and grazing" page (http://www.extension.uidaho.edu/forage/) and download the spreadsheet "Idaho RPM Calibration.xls." Follow instructions (mouse over the red marks on cells to see instructions). Note: Check that the number for the average RPM value in cell F4 is correct. Use the slope and intercept calculated in the spreadsheet to develop your own calibration formula. For example, if the slope is 86 and the intercept is 1,212, your calibration formula would be (86 x avg RPM) + 1,212. Substitute your calibration formula for the formula given for your forage species in table 16.3.

Repeat this process at least 10 times to develop a reliable relationship between sward height and DM production. Once you have determined a reliable relationship, occasional checks are recommended. Take about three samples per transect (W pattern) each time you use your rising or falling plate meter to estimate forage production.

APPENDIX B

Pasture Condition and Trend Score Sheet

Use this worksheet to monitor natural rainfall or irrigated pastures. You will rate pastures on 10 critical pasture, grazing, and soil factors. Use a scale of 0 to 4, with 0 being the least desirable condition and 4 being most desirable. It's best to rate pastures 10 to 15 days after grazing at about the same time each year. A single evaluation gives you a snapshot of pasture condition at a moment in time. Repeated observations allow you to track trends and responses to management changes. Following are the evaluation criteria for each factor. Feel free to use ½-point scores if you can't decide exactly how to score a factor.

1. **Plant population**—Desirable plant species are those that can best meet production needs. Desirable plant species are specific to the operation, soil conditions, and season of use. Intermediate species are those that are acceptable for the site and operation. Undesirable species are those that create more problems than they solve.
2. **Plant diversity**—Plant diversity contributes to seasonal stability of forage yield and quality. It also provides greater wildlife opportunities. Look for multiple desirable and intermediate plant species. Also look for different functional groups (e.g., cool-season vs. warm-season grasses, legumes vs. grasses, sod formers vs. bunch types). At the top of the worksheet, record the species present.
3. **Plant density**—What percentage of the soil surface is covered by desirable and intermediate plant species? You can estimate stand density either visually or by using a step-point transect line. For visual estimates, first calibrate your eye by looking at stands of known density. For the step-point method, take a predetermined number of steps and touch the ground with your pasture stick. Record whether it touches plant material or bare ground. Calculate plant density and bare ground from the total number of hits.
4. **Plant vigor**—How vigorous are the desirable and intermediate plants? Look at plant color and leaf size. Dark green indicates high vigor, while yellowing indicates low vigor. Large leaves indicate vigorous growth, while small leaves indicate stress. Presence of insect and disease damage indicates low vigor.
5. **Legumes in stand—**Legumes make valuable contributions to the pasture by increasing forage yield, quality, and nitrogen fixation. Too few or too many legumes can be undesirable. The optimal range is 40 to 60 percent. Give a lower score for legume presence above or below this range.
6. **Severity of use**—Has the pasture been grazed appropriately? Grasslands must be grazed to stay in a healthy condition. Undergrazing can be just as detrimental as overgrazing. Score appropriate grazing as 4 and give a lower score for overuse or underuse. Note whether the problem was over- or underuse.
7. **Uniformity of use**—Consider uniformity of grazing in two ways. First, is there localized spot grazing? Are there Phase I and Phase III plant growth stages side by side? Then look across the entire pasture. Are there large areas of overuse or underuse? Pasture-wide patterns are known as spatial grazing distribution.
8. **Soil resources**—Are there visible signs of soil erosion, compaction, or other degradation? Look for bare soil with rill and gully development, plant pedestaling, or hardened soil surface. This score is based on the percentage of the area affected by these factors.
9. **Undesirable canopy**—How much of the potential solar panel area of the pasture is shaded by undesirable plant species? Examples include woody brush encroachment and low-growing weeds. Annual weed cover can be seasonal but serious. Evaluate the pasture when you have a known problem.
10. **Plant residue**—Plant residue on the soil surface is an important part of the pasture ecosystem. It enhances water infiltration, moderates soil temperature, and forms the transition between plant organic matter and the mineral soil. Too little residue results in excess runoff and high soil temperatures. Too much residue can smother existing plants and inhibit seedling establishment. Give this factor a score of 4 if the amount of residue is appropriate. Give a lower score for too little or too much residue. Note whether the problem was too much or too little.

PASTURE CONDITION AND TREND SCORE SHEET

Technician:_____ Field identification:_____

Pasture condition scores:
1–8 = Very poor
9–16 = Poor
25–32 = Good
33–40 = Very good

Observation date						
Abundant desirable plant species found in the pasture:	**1**					
	2					
	3					
	4					
	5					
	6					
	7					
	8					
	9					

Category	Criteria	Score					
1) PLANT POPULATION Plant species (estimated by weight) are mostly:	desirable	4					
	intermediate	2					
	undesirable	0					
2) PLANT DIVERSITY Diversity of forage species is:	broad: > 7–9 species	4					
	medium: 4–6 species	2					
	narrow: < 3 species	0					
3) PLANT DENSITY Desirables and intermediates are:	dense: > 90%	4					
	medium: 60–70%	2					
	sparse: < 40%	0					
4) PLANT VIGOR Desirable and intermediate plants are:	strong	4					
	medium	2					
	weak	0					
5) LEGUMES IN STAND Legumes (by weight) make up:	40–60%	4					
	20–30% or > 70%	2					
	< 10% or > 90%	0					
6) SEVERITY OF USE Degree and frequency of use is:	heavy	0					
	appropriate	4					
	light	0					
7) UNIFORMITY OF USE Grazing use across the pasture is:	uniform	4					
	intermediate	2					
	spotty	0					
8) SOIL RESOURCES Amount of area affected by erosion, compaction, concentration is:	< 5%	4					
	10–15%	2					
	> 25%	0					
9) UNDESIRABLE CANOPY Percent of canopy made up by undesirables is:	< 10%	4					
	20%	2					
	> 30%	0					
10) PLANT RESIDUE Dead and decaying plant material is:	excessive	0					
	appropriate	4					
	deficient	0					
Total pasture score							

CHAPTER 17

Economics and Risk Management in Grazing Systems

W. Gray and M. Bohle

THIS CHAPTER INTRODUCES CONCEPTS AND TOOLS related to evaluating profitability of a pasture-based livestock system. We will explain:

- How to create and use an enterprise budget
- Whole-farm budgets
- Partial budgets
- Rental options
- Economic implications of carrying capacity and stock density
- Risk management

Key Points

- Enterprise budgets can help you evaluate the potential economic effects of decisions before implementing them, thus increasing the likelihood of success in your pasture-livestock operation.
- It is important to include all of your costs—not just cash expenditures—in your enterprise budgets.
- Stocking rate decisions should be based not only on a pasture resource inventory, but also on economic analysis.
- Risk management tools can help you offset some of the uncertainty inherent in farming operations.

Enterprise budgets: A tool for assessing profitability

An old adage states, "If you can't pencil a profit you aren't likely to plow one." If you evaluate the potential economic effects of decisions before implementing them, you are more likely to enjoy success and less likely to experience unforeseen negative events.

A budget is a tool for this evaluation. A budget lets you check things out first on paper and then make informed decisions about the best way to proceed. It can help you evaluate the expected profitability of an enterprise, investment, or your entire operation. It can help you get a clearer financial picture of what you want to do by "seeing" your plan on paper before committing money, time, and equipment. It can also help you evaluate whether an adjustment to your operation might be profitable. Finally, when implementing your plans, a budget enables you to compare your goals to actual results and decide whether adjustments are necessary.

Enterprise budgets are one type of budget commonly used by farm managers. An enterprise budget is an estimation of total farm or ranch revenues and expenses during one production cycle. An enterprise can be a crop such as pasture, grain, or hay, or livestock such as cattle, dairy, or sheep. Enterprise budgets are usually developed on a per-unit basis (acres, tons, head, or hundredweight) to allow comparisons among alternative enterprises.

An enterprise budget has several uses. You can use it to monitor costs of production, negotiate with a banker for a line of credit, evaluate market risk, or plan adjustments to your operation. Enterprise budgets also provide the information needed to construct three other budgets used in farm management: whole-farm budgets, partial budgets, and cash-flow budgets.

A pasture-based livestock enterprise needs three enterprise budgets: one for pasture establishment, one for pasture production, and one for grazing/livestock production.

- The establishment budget includes the costs of establishing the pasture—seed, fertilizer, irrigation, machinery, labor, etc. There is no grazing during the establishment year, so there are no returns.
- The pasture budget includes the costs of producing forage—chemical inputs, labor, irrigation, fencing, land cost, equipment, etc. The value of the forage produced represents the return on these costs.
- The grazing/livestock budget includes the cost of producing livestock—animals, feed, supplements, veterinary, labor, housing, equipment, etc. The value of the marketed livestock is the return on these costs. Note that the pasture cost developed in the pasture budget becomes a feed cost in the livestock budget.

Key Terms

Enterprise—Production of a crop or livestock commodity considered independently from other farm operations.

Enterprise budget—An estimation of total farm or ranch revenues and expenses during one enterprise production cycle. Enterprise budgets are usually developed on a per-unit basis (acres, tons, head, or hundredweight) to allow comparisons among alternative enterprises.

Gross margin—The difference between total revenues and total operating expenses for the enterprise. Gross margin represents the contribution toward payment of ownership costs and profitability.

Management charge—In academic budgets, a management charge is a charge for the owner/operator's time and skills in managing the operation. In operator's budgets, it is sometimes used as a proxy for owner's salary or living draw.

Net returns—The return to management and risk. Calculated by subtracting total operating costs and total ownership costs from total revenue. If a management charge was made in the ownership cost section, then net returns represent a return to risk. A positive return indicates the enterprise is profitable.

Operating costs—Expenses associated with the direct production of an enterprise. These costs typically vary with the size of an enterprise and are incurred only if production takes place. Feed, veterinary, irrigation, and breeding expenses are examples.

Opportunity costs—The expected return forgone by using a resource in the grazing enterprise rather than in its next most profitable use.

Ownership costs—Costs of investment in livestock, buildings, equipment, and vehicles, including depreciation, interest, taxes, and insurance. These costs are incurred regardless of whether production takes place.

Partial budget—A budget used to evaluate the effects of a minor change to the operation, such as adding more livestock or purchasing a new piece of equipment.

Revenues—Income from sales of crops, livestock, or products such as milk or wool produced by an enterprise.

Risk management—The use of tools, such as insurance and forward contracts, that reduce the impact of risk. Risk is the chance that a decision or action taken will have an adverse result. Agriculturalists must always make decisions in an environment of uncertainty and risk. Examples of risk include weather, equipment, labor, and price changes.

Whole-farm budget—An overall budget for the farm consisting of budgets for each enterprise. A whole-farm budget shows revenues and costs for the entire farm or operation. It often is an important part of an application for an operating line of credit or a loan to purchase additional assets, as it indicates total credit needs and repayment capacity of the farm.

The appendix to this chapter includes the following sample budgets:

- Budget 17.1—pasture establishment budget
- Budget 17.2—pasture budget for conventional grazing
- Budget 17.3—pasture budget for a 4-paddock rotational grazing system
- Budget 17.4—pasture budget for a 12-paddock rotational grazing system
- Budget 17.5—cow-calf budget showing example costs, such as veterinary and winter feeding
- Budget 17.6—grazing budget for conventional grazing
- Budget 17.7—grazing budget for a 4-paddock rotational grazing system
- Budget 17.8—grazing budget for a 12-paddock rotational grazing system

Your own situation will differ from these examples. As we walk through the examples, however, you can see how various costs and returns are allocated to build the budgets. You then can use the same process to construct a budget for your own enterprise, based on your best cost and revenue estimates. Sources for budgets and budgeting software are listed at the end of this chapter under "For more information."

ASSUMPTIONS FOR THE SAMPLE BUDGETS

- The 12-paddock system anticipates a Management-intensive Grazing (MiG) system with animal moves every 1 to 3 days.
- In the three pasture budgets, we assume that increasing the intensity of management increases the amount of forage produced and reduces the need for commercial weed control and fertilizer. Properly managed stock density can adequately control weeds. In addition, manure is distributed more evenly with a MiG system. More uniform manure distribution allows plants to better utilize nutrients, thus reducing fertilizer needs.
- MiG reduces equipment use. In the 4-paddock system, aerating is done only 1 in 2 years, and there is no harrowing. In the 12-paddock system, aerating is done 1 in 3 years, and no harrowing is performed.
- In all of the pasture budgets, we prorate rodent control, soil testing, and spot weed control, as these activities are not necessarily performed every year or on every acre. (Soil testing is included in the custom fertilize charge.)
- In our traditional grazing budget, the field perimeter is fenced with four-strand barbed wire. The 4-paddock and 12-paddock grazing budgets use a 4-wire electrified fence on the perimeter plus movable electrified fences to divide the pasture into grazing paddocks.

- In the conventional grazing system, a stock water tank is supplied by an existing water system. In the 4- and 12-paddock rotational systems, water is provided to stock tanks via movable water lines. Tanks are moved with the animals, and the water is supplied by an existing system.
- All pastures are sprinkler irrigated by a center pivot with surface water delivered from an irrigation district.
- Useful life of the conventional pasture is 10 years. For the 4-paddock pasture, it is 15 years, and for the 12-paddock pasture, it is 20 years. Establishment costs are amortized over these periods.

ALLOCATING COSTS AMONG ENTERPRISES

To construct individual enterprise budgets, you'll need to allocate expenses and income to specific enterprises (pasture, hay, livestock, etc.). In some cases, this is easy, as some expenses and income are clearly related to a specific enterprise. For example, the cost of replacement heifers is allocated to the livestock enterprise. You can allocate these expenses and income at the end of the year or as transactions take place. A cash journal can facilitate this process since it contains cash receipts and expenditures for the entire year.

In other cases, your expense and income records are probably on a whole-farm basis. Indirect expenses, such as fuel, repairs, and general farm labor are examples. These expenses are more difficult to allocate to individual enterprises. One option is to allocate these costs to specific enterprises based on income and expense accounts for the farm's enterprises. Another is to prorate them to enterprises using a common criterion such as machinery use records. For example, an operation might have both hay and pasture enterprises. If three cuttings are made for hay and a portion of the pasture is stockpiled for feed, the fuel cost might be allocated 75 percent to hay and 25 percent to pasture.

CALCULATING COSTS

In this section we will look at common costs associated with pasture-based livestock systems and consider how to enter them into an enterprise budget.

Costs are categorized as operating (variable) or ownership (fixed). Operating costs occur only if production takes place, and they vary with the level of production. In a pasture budget, these costs may include fertilizer, chemicals, seed, fuel, repairs, and labor. In a livestock budget, they may include feed and supplements, marketing, fuel, repairs, labor, and veterinary.

Ownership costs, often referred to as investment or fixed costs, generally do not vary during one production cycle. Ownership costs are associated with machinery, buildings, and land. These costs remain fixed even if production stops. Machinery and buildings still depreciate, taxes and insurance payments still come due, and interest on capital borrowed to purchase these assets must still be paid.

If you don't have records of repair, fuel, and lube costs, ask your county extension agricultural agent for publication PNW 346, *The Costs of Owning and Operating Farm Machinery in the Pacific Northwest*. Computer programs designed to help estimate enterprise and machinery costs are available from the University of Idaho's Agricultural Economics website (http://www.cals.uidaho.edu/aers/r_software.htm).

Operating costs

Purchased inputs—Calculation of costs for purchased inputs is relatively straightforward. Simply multiply the expected quantity of an input (fertilizer, chemicals, seed, etc.) times the projected price per unit. For example, budget 17.1 shows 70 pounds of nitrogen fertilizer applied to each acre at a cost of $0.56 per pound. This translates into a cost of $39.20 per acre (70 lb/acre x $0.56/lb).

Feed—The grazing/livestock budgets (budgets 17.6, 17.7, and 17.8) include both purchased feed and the cost of pasture developed in the pasture budget. For example, in the 4-paddock grazing example (budget 17.7), pasture costs are $256.11 per acre, and the pasture supports 1.06 head per acre for the grazing season. Thus, the pasture cost is $241.61 per head ($256.11 ÷ 1.06 head).

Labor—Another important operating cost is hired labor. Labor is used to operate machinery, irrigate fields, and do general work around the farm. Include owner-supplied labor even though it doesn't involve a direct cash outlay. In our sample budgets, we treat all labor for operating machinery and irrigating fields as hired labor and give it a value, even though some of this work is typically performed by the owner or operator. Tractor and machinery labor is based on field time and includes time for traveling to and from fields and servicing equipment. Labor costs for the conventional pasture budget (budget 17.2) are $15.13 per acre.

Table 17.1. Machinery and equipment costs per acre for pasture establishment and pasture maintenance ($/acre).[a]

Operation[b]	Depreciation	Interest	THI[c]	Repairs	Labor	Fuel/lube	Total
PASTURE ESTABLISHMENT							
Corrugator, 6-row	0.37	0.38	0.04	0.19	1.18	0.39	2.57
12-ft drill	0.64	0.81	0.09	0.41	2.42	0.80	5.17
Roller harrow, 12-ft	1.23	1.17	0.11	0.78	2.09	0.69	6.05
3-bottom plow	2.09	2.10	0.13	1.01	3.72	1.85	10.91
¾-ton pickup	0.25	0.20	0.09	0.03	0.42	0.24	1.22
4 wheeler	0.10	0.09	0.01	0.01	1.55	0.51	2.27
Total cost	4.68	4.75	0.47	2.43	11.38	4.48	28.19
PASTURE MAINTENANCE							
Spike harrow, 20-ft	0.32	0.33	0.04	0.15	1.08	0.36	2.27
¾-ton pickup	0.13	0.10	0.04	0.01	0.21	0.13	0.61
Tow sprayer–ATV	0.16	0.14	0.01	0.02	1.51	0.49	2.34
Total cost	0.61	0.57	0.09	0.18	2.80	0.98	5.22

[a] Based on summer 2009 prices.
[b] Pull implement costs include tractor.
[c] Taxes, housing, insurance

Labor costs differ among the three pasture budgets (budgets 17.2, 17.3, and 17.4), based on the need for moving cattle, fence and water maintenance, and weed control. Livestock labor costs increase as cattle are moved more often ($2.97, $3.40, and $3.83 per acre), but declining machine labor costs ($2.81, $2.30, and $1.70 per acre) partially offset these costs. Irrigation labor is the same in the three pasture budgets.

As grazing becomes more intensive, commercial fertilizer needs are reduced due to better manure distribution, and machinery costs are reduced as the need for harrowing and aeration is lessened. Spot spraying for weed control is the same in all cases, however.

Machinery repairs and fuel/lube—Typical per-acre machinery and equipment costs for pasture establishment and pasture production are shown in table 17.1. You can use the costs shown to determine costs for repairs and fuel/lube.

Operating interest charges—Total operating capital is the sum of all cash operating expenses. In budget 17.1, this includes all of the operating costs for seed, fertilizer, custom, irrigation, machinery, and labor. In this example, the total is $231.51 per acre.

In the enterprise budget, you will need to include the cost of using this capital in the enterprise. This cost is called "operating interest."

If any of this capital is borrowed from the bank, use the bank interest charge as the operating interest on that portion of the operating capital. For capital that you supply, interest is an implicit charge or opportunity cost. In this case, opportunity cost represents the expected return forgone by using the money in the grazing enterprise rather than in its next most profitable use. We use an interest rate of 7 percent to represent this cost.

All of the operating capital may not be needed for the entire year. Thus, we estimate total capital requirements for each month and then convert them to an annual basis by determining how long each expense is carried before being recovered through the sale of all or part of the enterprise's production. For example, the time period for the establishment budget is 3 months. Total annual operating capital is $231.51 per acre. At 7 percent interest for 3 months (0.25 year), this translates into an interest cost of $4.05 ($231.51 x 0.07 x 0.25). Add this interest charge of $4.05 to the cash operating expenses of $231.51 to find the "total operating costs" of $235.56.

Ownership costs

Ownership costs include depreciation, interest, property taxes, and casualty insurance. These costs generally are related to capital assets such as fencing, machinery, equipment, and buildings, which typically are owned for more than 1 year. The initial investment must be spread out, or depreciated, over the years of ownership and use.

Estimate ownership costs as described below for each machine, building, and piece of equipment in your operation. Then allocate these costs to each farm enterprise in amounts proportional to each item's use. For example, if annual ownership costs for a tractor are $2,000, and 20 percent of the tractor's use is devoted to the pasture enterprise, allocate $400 (0.2 x $2,000) to the pasture enterprise. Divide by the number of acres to get the per-acre cost for use in the enterprise budget.

Typical per-acre machinery and equipment costs for pasture establishment and pasture production are shown in table 17.1. You can use these costs to avoid having to do multiple calculations to determine costs for depreciation; interest; and taxes, housing, and insurance.

General overhead costs include professional services (legal, accounting, etc.), dues and memberships, subscriptions, general office supplies, etc.

Depreciation and interest—One type of ownership cost for any asset is depreciation. Depreciation is an accounting method that reduces the value of an asset as it gradually becomes obsolete. There are two types of depreciation: management depreciation and tax depreciation. Management depreciation accounts for the declining value of an asset over its useful life. Tax depreciation reduces the taxable value of an asset according to a schedule set by the IRS and is frequently used to minimize taxable income. When constructing an enterprise budget, we are concerned with management depreciation.

Simple straight-line depreciation is an easy way to estimate management depreciation. For example, assume you purchase an asset for $55,000 and expect it to have a $5,000 salvage value at the end of its 10-year useful life. In that case, $50,000 of capital will be used over the next 10 years. Using straight-line depreciation, that equals $5,000 per year.

Not all of the capital is recovered in 1 year. Thus, you need to calculate interest or opportunity cost on the remaining value of the asset each year. The interest amount declines each year as the asset's value declines. Table 17.2 shows depreciation and interest charges for a $55,000 machine (assuming that the machine will have a $5,000 salvage value after a useful life of 10 years). Table 17.2 uses an interest rate of 5 percent per year compounded annually.

We make no distinction between owner-supplied and borrowed capital. In most cases, however, a portion (and sometimes all) of the investment capital is owner supplied. When you use your own capital or cash to purchase capital assets, you forgo opportunities to invest that capital in other ways. For example, you could be earning interest on a mutual fund instead of investing in machinery. Treat this forgone benefit as an opportunity cost in the budgeting process. To calculate the opportunity cost when your own capital is used, you may use a lender's interest rate on assets of similar type (livestock or machinery loans for example). Some recommend adding 1 or 2 percent to that rate as a risk premium, since any debt capital will have to be repaid before you can receive repayment.

Land charge—Include an appropriate land charge as an ownership cost. If you lease farmland, include the cost of the lease or rent. If you own the land, use the interest charge on the mortgage plus land taxes and

Table 17.2. Depreciation and interest charge example.[a,b]

Year	Annual straight-line depreciation	Annual interest or opportunity cost	Depreciation + interest	Remaining value
1	$5,000.00	$2,500.00	$7,500.00	$50,000.00
2	$5,000.00	$2,250.00	$7,250.00	$45,000.00
3	$5,000.00	$2,000.00	$7,000.00	$40,000.00
4	$5,000.00	$1,750.00	$6,750.00	$35,000.00
5	$5,000.00	$1,500.00	$6,500.00	$30,000.00
6	$5,000.00	$1,250.00	$6,250.00	$25,000.00
7	$5,000.00	$1,000.00	$6,000.00	$20,000.00
8	$5,000.00	$750.00	$5,750.00	$15,000.00
9	$5,000.00	$500.00	$5,500.00	$10,000.00
10	$5,000.00	$250.00	$5,250.00	$5,000.00
Totals	$50,000.00	$13,750.00	$63,750.00	Salvage value

[a] Based on summer 2009 prices.
[b] Purchase price = $55,000
Salvage value = $5,000
Depreciable value = $50,000
Interest rate = 5%

maintenance costs. Alternatively, you can allocate an opportunity cost equal to the current long-term interest rate times its agricultural value (a value based on agricultural productivity rather than on development or other speculative values). An alternative for owned property is to use a typical lease or rental rate for similar land.

Establishment costs—A final type of cost consists of pro-rated establishment costs. Since most perennial crops have a finite life, establishment costs are typically pro-rated or amortized over the productive life of the stand. The pro-rated establishment cost is the cost of establishing the pasture divided by the expected useful life of the pasture. Costs in the establishment budget are $349.57 (round to $350) per acre. In the conventional pasture budget (budget 17.2), the expected pasture life is 10 years. Thus, the pro-rated establishment cost is $35 per acre per year ($350 ÷ 10).

Rotationally grazed pastures typically have a longer useful life than conventionally grazed pastures, so establishment costs are pro-rated over longer periods of time (budgets 17.3 and 17.4).

Total ownership costs—After allocating annual ownership costs for capital items (including land) and summing them, you can determine total ownership costs per acre. To do so, divide total ownership costs by the number of acres in the enterprise. In our conventional pasture example (budget 17.2), per-acre total ownership costs are $143.16.

Total costs

Total costs, including ownership and operating costs, are $455.72 per acre in the conventional pasture budget (table 17.2). Because some charges listed above (depreciation and the opportunity cost of capital) are not cash expenses, actual cash costs will differ.

RETURNS

Any return above total costs is considered profit or return to risk. A positive net return per acre, per pound, or per head generally indicates profit. Producers differ in their use of inputs for comparable enterprises, making some more or less profitable than others. Among your own enterprises, you can determine the most profitable enterprise (or combination of enterprises) by comparing estimates of profitability.

A zero profit for an enterprise does not imply that the enterprise is a losing proposition. A carefully constructed budget like the ones in budgets 17.1–17.4 and 17.6–17.8 accounts for all production costs, including opportunity costs. It includes all purchased operating inputs, labor (whether hired or owner supplied), capital (whether borrowed or owner supplied), and land (whether rented or owned). Even with a zero net return, the operator would earn a return on his investment in land, labor, capital, and management. The only cost not included in the budget, because it is difficult to quantify, is risk. Therefore, net return or profit in this case would be considered a return to risk.

Rent alternatives

Once you establish a pasture, you have several choices for utilizing it. You may choose to place your own livestock on the pasture and consider the cost of the pasture a feed cost in the livestock budget. Alternatively, you can rent pasture to others based on a charge per animal unit month (AUM), net weight gain, or a combination of both. If you choose to rent pasture, it is important to have a written contract at the onset of the grazing period.

PER AUM

Probably the most common way to determine pasture rent (and one that is fairly easy to calculate) is to charge per head per month. An animal unit is the amount of feed needed each month by a 1,000-pound cow with nursing calf. AUMs for other stock are based on their proportional size.

AVERAGE GAIN

Where scales are available to weigh stock in and out of the pasture, charging by rate of gain can be a good option if the livestock are well managed for good weight gain. For example, if stocker calves weigh on at 500 pounds and weigh off at 700 pounds, the net gain is 200 pounds. If the charge is $0.35 per pound of gain, rent is $70 ($0.35 x 200 lb) per head.

Although this method is not as commonly utilized in the Pacific Northwest, it sometimes is used for nontraditional grazing situations, such as grazing on organic land or grass finishing. Rents may be higher for these types of pasture to account for their extra value.

This method makes it possible to employ a performance incentive. In this case, the charge per pound of gain is based on a minimum average daily gain (ADG). If the ADG exceeds this level, a rent premium of several cents per pound is levied for the better performance.

Economic implications of stocking rate and weight gains

Calculation of the seasonal stocking rate—the number of head or total live weight that can be placed on a pasture for the entire season—is explained in chapter 14. Calculation of stocking rate for a grazing period—the number of head or total live weight that can be placed in a paddock for one grazing period—is discussed in chapter 15. Both of these decisions have economic implications.

An increase in the stocking rate can affect both the ADG of individual animals and the total gain of the herd or flock. Figure 17.1 is a "Mott curve" showing the relationship between stocking rate, average daily gain, and total gain per acre. A more detailed explanation of the Mott curve is given in chapter 14.

Some increase in competition for forage can increase ADG. Thus, as the stocking rate increases, ADG initially increases. However, as the stocking rate continues to rise, ADG will decrease as competition becomes more intense.

Total gain per acre reflects the total weight gain of the entire herd or flock. As the stocking rate increases, total gain continues to increase even after ADG begins to decrease. Eventually animals become crowded enough that total gain also decreases, but this point typically is reached later than the point at which ADG begins to decline.

Figure 17.2 shows the economic returns as total gain per acre increases. At the low stocking rate, returns are –$22.79, although gain per acre is 287 pounds. As total gains increase, net returns become positive and continue to increase until animals become crowded enough that total gains are reduced. Total gains continue to increase, but at a slower rate, and net returns fall below those at lower stocking rates.

At 2.5 animals per acre in figure 17.2, total gain per acre is nearly 720 pounds, and net returns are maximized at about $222 per acre. By increasing the stocking rate to three head per acre, total gain per acre is 754 pounds, but net returns fall to $204 per acre due to higher costs and reduced ADG. This example illustrates the point that increasing production units (livestock) will increase returns, but at some point continued increases begin to limit production and returns start to decrease. Economically, this concept is known as the law of diminishing returns.

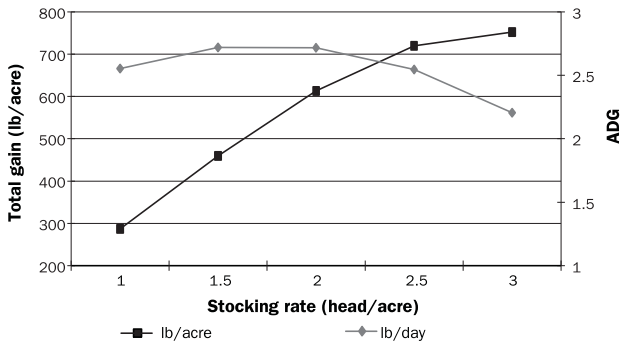

Figure 17.1. Relationship between average daily gain, total gain per acre, and stocking rate. (Data taken from Zaragoza-Ramírez, J.L., D.I. Bransby, and P.A. Duffy. 2008. Economic returns to different stocking rates for cattle on ryegrass under contract grazing and traditional ownership. In: *Southern Agricultural Economics Association Annual Meetings*. Orlando, FL. February 5–8, 2006)

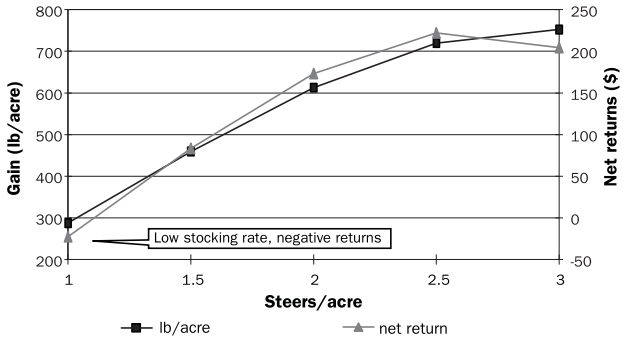

Figure 17.2. Relationship between average daily gain, total gain per acre, and net returns per acre. (Data taken from Zaragoza-Ramírez, J.L., D.I. Bransby, and P.A. Duffy. 2008. Economic returns to different stocking rates for cattle on ryegrass under contract grazing and traditional ownership. In: *Southern Agricultural Economics Association Annual Meetings*. Orlando, FL. February 5–8, 2006)

The economically optimum stocking rate varies, depending on the spread between the per-pound prices for animals at the beginning and the end of the grazing season. This spread is often termed the "buy-sell margin." Lighter weight calves typically carry higher prices per pound than heavier weight calves.

For example, the price for 500-pound calves may be $110 per hundredweight ($550 per head). At the end of the grazing period, these calves may weigh 700 pounds and market for $95 per hundredweight ($665 per head). The spread between the "in" and the "out" prices is $15 per hundredweight ($110 – $95). In another case, the 700-pound calves might market for $100 per hundredweight ($700 per head). In this case, the spread is only $10 ($110 – $100).

If the cost of production is $0.35 per pound of gain, the cost per calf is $70 (200 lb gain x $0.35 = $70). The $15 spread grosses $115 ($665 – $550) per head and nets $45 per head ($665 – [$550 + $70]). The $10 spread grosses $150 per head ($700 – $550) and nets $80 per head ($700 – [$550 + $70]).

Thus, we can see that the smaller the spread between the "in" and "out" prices, the easier it is to make the operation profitable. An enterprise budget enables you to work through the numbers in order to accurately assess profitability.

Partial budgets for minor changes

A partial budget analyzes the feasibility of a small change to a single enterprise. With a partial budget, you examine only the items affected by the change. This enables you to consider potential reductions to income and additional expenses versus potential additions to income and reduced costs. If the net effect is positive, the change should be profitable.

For example, a pasture might produce much more forage than your livestock can utilize in the spring. By mid-July, however, it might just meet their needs. You have several options for making use of the extra spring forage. You could place additional livestock (stocker calves or feeder lambs) on the pasture for 2 or 3 months in the spring, you could harvest some of the paddocks for hay or silage, or you could leave the excess growth as stockpiled feed for fall and winter use.

With a partial budget, you can evaluate these options. Temporarily renting the pasture would increase revenues, while cutting the excess forage as hay or stockpiling would add to winter feed supplies and reduce winter feed costs. Table 17.3 illustrates an example of a partial budget analysis for temporarily renting the pasture.

Table 17.3. Partial budget analysis for spring grazing additional steers.[a]

	$/unit	# units	Subtotal
1. ADDITIONAL INCOME			
Rent pasture to stockers	$16.00	20	$320.00
40 hd of 500-lb stockers for 2 months			
Equivalent to 20 AUs per month			
Total additional Income			$320.00
2. REDUCED COSTS			
None	—	—	—
Total reduced costs			—
3. REDUCED INCOME			
None	—	—	—
Total reduced income			—
4. INCREASED COSTS			
Labor	$8.50	4.5	$38.25
Portable fence for leader-follower grazing	$35.00	1	$35.00
Total increased costs			$73.25
NET IMPACT (1 + 2) – (3 + 4)			$246.75
A positive net impact means the proposed change is profitable.			
A negative net impact means the proposed change is not economic.			

[a] Based on summer 2009 prices.

Whole-farm budgeting

Whole-farm and cash-flow budgets consider expenses and revenues associated with all of the enterprises on the operation. If you raise other crops in addition to the pasture-livestock enterprise, you can combine them all into whole-farm or cash-flow budgets. These budgets give a picture of the entire operation and show the contribution of each enterprise.

Whole-farm budgets include both cash and non-cash costs (e.g., unpaid labor and depreciation). Individual enterprise budgets are a good starting point for building a whole-farm budget.

Cash-flow budgets are similar, but include only cash inflow (sales and loans to the operation) and cash outflow (payments made). Lenders often require a cash-flow budget as evidence of borrowing needs and repayment of operating lines of credit.

Managing risk

Understanding your own and your partners' attitudes toward risk will help you develop the best means to reduce risk to your operation.

The USDA crop insurance program covers pasture and range in many areas. Many livestock commodities are also covered under programs such as Adjusted Gross

Revenue (AGR) and AGR-Lite, which cover total farm revenue, including crops and livestock; Livestock Gross Margin (LGM), which covers cattle, dairy, and swine; and Livestock Risk Protection (LRP), which covers feeder cattle, fed cattle, lambs, and swine.

For specific information on covered crops or livestock and costs in your area, contact your crop insurance agent or visit the Risk Management Agency website (http://www.rma.usda.gov/). The following fact sheets are available online:

- Livestock policies: http://www.rma.usda.gov/livestock/
- Crop policies: http://www.rma.usda.gov/policies/pasturerangeforage/
- Crop policies (AGR-Lite): http://www.rma.usda.gov/policies/agr-lite.html

Forward contracting is another way to reduce risk. Forward contracting consists of selling now for later delivery. It can be done via auction (e.g., video auction) or by private treaty with individuals or companies.

When forward contracting, be careful to not contract for more than you can reasonably expect to deliver. Some contracts include language to allow for delivery of more or less product based on production conditions. As with any legal document, have your (not the buyer's) attorney look over the contract.

For more information

Computer programs to estimate enterprise and machinery costs. University of Idaho, Agricultural Economics. http://www.cals.uidaho.edu/aers/r_software.htm

Cost of production budgets and farm management software. University of Idaho, Agricultural Economics. http://www.ag.uidaho.edu/aers/resources.htm

The Costs of Owning and Operating Farm Machinery in the Pacific Northwest. PNW 346. University of Idaho Extension. http://info.ag.uidaho.edu/pdf/PNW/PNW0346/PNW0346.html

Farm management software. Washington State University. http://www.farm-mgmt.wsu.edu/Software.html

Idaho Forage Handbook, 3rd edition. BUL 547. University of Idaho, College of Agricultural and Life Sciences (2005).

USDA Risk Management Agency website. http://www.rma.usda.gov/

APPENDIX

Sample Budgets

Budget 17.1. Enterprise budget for pasture establishment (155-acre pasture).[a]

	Quantity per acre	Units	$/unit	Value per acre	Total value
VALUE OF PRODUCTION					
No grazing establishment year	0	AUM	$0.00	$0.00	$0.00
Gross returns				$0.00	$0.00
OPERATING COSTS					
Seed				$24.00	$3,720.00
Orchardgrass seed	15	lb	$1.30	$19.50	$3,022.50
Legume seed	1.5	lb	$3.00	$4.50	$697.50
Fertilizer				$39.20	$6,076.00
Dry nitrogen	70	lb	$0.56	$39.20	$6,076.00
Custom				$13.80	$2,139.00
Custom fertilize	2	acre	$6.90	$13.80	$2,139.00
Irrigation				$114.11	$17,687.05
Irrigation power–center pivot	37	acre-inch	$1.48	$54.76	$8,487.80
Water assessment	1	acre	$39.00	$39.00	$6,045.00
Irrigation repairs–center pivot	37	acre-inch	$0.55	$20.35	$3,154.25
Machinery				$6.91	$1,071.05
Fuel & lube	1	acre	$4.48	$4.48	$694.40
Repairs	1	acre	$2.43	$2.43	$376.65
Labor				$33.49	$5,190.95
Labor (irrigation)	1.1	hr	$8.50	$9.35	$1,449.25
Labor (machine)	1.34	hr	$8.50	$11.39	$1,765.45
Labor (non-machine)	1.5	hr	$8.50	$12.75	$1,976.25
Other				$4.05	$627.97
Operating interest (7%)				$4.05	$627.97
Total operating costs				$235.56	$36,512.02
Operating cost per AUM			NA		
Net returns above operating costs				($235.56)	($36,512.02)
OWNERSHIP COSTS					
General overhead		acre		$5.00	$775.00
Land rent (includes center pivot)		acre		$90.00	$13,950.00
Fence depreciation & interest		acre		$3.47	$537.85
Management charge (2% operating costs)		acre		$4.71	$730.05
Property taxes		acre		$0.00	$0.00
Taxes, housing, insurance on equipment		acre		$0.47	$72.85
Depreciation & interest on equipment		acre		$9.43	$1,461.65
Watering equipment		acre		$0.93	$144.15
Total ownership costs				$114.01	$17,671.75
Ownership cost per AUM			NA		
TOTAL COSTS				$349.57	$54,183.57
TOTAL COST PER AUM			NA		
NET RETURNS				($349.57)	($54,183.57)

[a] The costs and returns estimate shown here is representative for establishment of irrigated pasture in the Pacific Northwest in summer 2009. The pasture is sprinkler irrigated by a center pivot with surface water delivered from an irrigation district. The district charges a flat fee per acre for water.

Budget 17.2. Enterprise budget for pasture—conventional grazing (155-acre pasture).[a]

	Quantity per acre	Units	$/unit	Value per acre	Total value
VALUE OF PRODUCTION					
Forage—conventional grazing	3	AUM	$16.00	$48.00	$7,440.00
Gross returns				$48.00	$7,440.00
OPERATING COSTS					
Fertilizer				$125.70	$19,483.50
Sulfur	30	lb	$0.35	$10.50	$1,627.50
Manure/compost	5	ton	$12.00	$60.00	$9,300.00
Urea	120	lb	$0.46	$55.20	$8,556.00
Pesticide				$3.34	$517.08
2,4-D amine	0.21	qt	$4.10	$0.86	$133.45
Rodent control (1 of 3 yrs)	0.33	acre	$7.50	$2.48	$383.63
Custom				$41.80	$6,479.00
Custom haul manure	5	ton	$2.00	$10.00	$1,550.00
Custom fertilize	2	acre	$6.90	$13.80	$2,139.00
Custom aerate	1	acre	$18.00	$18.00	$2,790.00
Irrigation				$114.11	$17,687.05
Irrigation power–center pivot	37	acre-inch	$1.48	$54.76	$8,487.80
Water assessment	1	acre	$39.00	$39.00	$6,045.00
Irrigation repairs–center pivot	37	acre-inch	$0.55	$20.35	$3,154.25
Machinery				$1.16	$179.80
Fuel & lube	1	acre	$0.98	$0.98	$151.90
Repairs	1	acre	$0.18	$0.18	$27.90
Labor				$15.13	$2,345.16
Labor (irrigation)	1.1	hr	$8.50	$9.35	$1,449.25
Labor (machine)	0.33	hr	$8.50	$2.81	$434.78
Labor (livestock)	0.35	hr	$8.50	$2.97	$461.13
Other				$11.32	$1,754.52
Fence & water system repairs	1	acre	$0.75	$0.75	$116.25
Operating interest (7%)				$10.57	$1,638.27
Total operating costs				$312.56	$48,446.11
Operating cost per AUM			$104.19		
Net returns above operating costs				($264.56)	($41,006.11)
OWNERSHIP COSTS					
General overhead				$5.75	$891.25
Land rent (includes center pivot)		acre		$90.00	$13,950.00
Property taxes		acre		$0.00	$0.00
Taxes, housing, insurance on equipment		acre		$0.09	$13.95
Depreciation & interest on equipment		acre		$1.18	$182.90
4-strand barbed wire depreciation & interest		acre		$7.81	$1,210.55
Water system		acre		$0.93	$144.15
Amortized establishment cost		acre		$35.00	$5,425.00
Management charge (5% of gross returns)				$2.40	$372.00
Total ownership costs				$143.16	$22,189.80
Ownership cost per AUM			$47.72		
TOTAL COSTS				$455.72	$70,635.91
TOTAL COST PER AUM			$151.91		
NET RETURNS				($407.72)	($63,195.91)

[a] The costs and returns estimate shown here is representative for producing irrigated pasture in the Pacific Northwest in summer 2009. The pasture is sprinkler irrigated by a center pivot with surface water delivered from an irrigation district. Establishment cost is amortized over 10 years.

Budget 17.3. Enterprise budget for pasture—4-paddock grazing (155-acre pasture).[a]

	Quantity per acre	Units	$/unit	Value per acre	Total value
VALUE OF PRODUCTION					
Pasture—rotation in 4 cells	7	AUM	$16.00	$112.00	$17,360.00
Gross returns				$112.00	$17,360.00
OPERATING COSTS					
Fertilizer				$89.87	$13,930.63
Sulfur	22.5	lb	$0.35	$7.87	$1,220.63
Manure/compost	3	ton	$12.00	$36.00	$5,580.00
Urea	100	lb	$0.46	$46.00	$7,130.00
Pesticide				$3.34	$517.08
2,4-D amine	0.21	qt	$4.10	$0.86	$133.45
Rodent control (1 of 3 yrs)	0.33	acre	$7.50	$2.48	$383.63
Custom				$21.90	$3,394.50
Custom haul manure	3	ton	$2.00	$6.00	$930.00
Custom fertilize	1	acre	$6.90	$6.90	$1,069.50
Custom aerate (1 of 2 years)	0.5	acre	$18.00	$9.00	$1,395.00
Irrigation				$114.11	$17,687.05
Irrigation power–center pivot	37	acre-inch	$1.48	$54.76	$8,487.80
Water assessment	1	acre	$39.00	$39.00	$6,045.00
Irrigation repairs–center pivot	37	acre-inch	$0.55	$20.35	$3,154.25
Machinery				$0.92	$142.60
Fuel & lube	1	acre	$0.80	$0.80	$124.00
Repairs	1	acre	$0.12	$0.12	$18.60
Labor				$15.05	$2,331.98
Labor (irrigation)	1.1	hr	$8.50	$9.35	$1,449.25
Labor (machine)	0.27	hr	$8.50	$2.30	$355.73
Labor (livestock)	0.4	hr	$8.50	$3.40	$527.00
Other				$10.92	$1,692.69
Fence & water system repairs	1	acre	$2.26	$2.26	$350.30
Operating interest (7%)				$8.66	$1,342.39
Total operating costs				$256.11	$39,696.53
Operating cost per AUM			$36.59		
Net returns above operating costs				($144.11)	($22,336.53)
OWNERSHIP COSTS					
General overhead		acre		$5.75	$891.25
Land rent		acre		$90.00	$13,950.00
Property taxes		acre		$0.00	$0.00
Taxes, housing, insurance on equipment		acre		$0.28	$43.40
Depreciation & interest on equipment		acre		$4.97	$770.35
Perimeter power fence		acre		$3.47	$537.85
Portable power fence		acre		$1.19	$184.45
Water system		acre		$0.93	$144.15
Amortized establishment cost		acre		$23.30	$3,611.50
Management charge (5% of gross returns)				$5.60	$868.00
Total ownership costs				$135.49	$21,000.95
Ownership cost per AUM			$19.36		
TOTAL COSTS				$391.60	$60,697.48
TOTAL COST PER AUM			$55.94		
NET RETURNS				($279.60)	($43,337.48)

[a] The costs and returns estimate shown here is representative for producing irrigated pasture in the Pacific Northwest in 2009. The pasture is sprinkler irrigated by a center pivot with surface water delivered from an irrigation district. Establishment cost is amortized over 15 years. Intensive grazing management reduces equipment use (aerate 1 in 2 years), no harrowing, reduced fertilizer requirement.

Budget 17.4. Enterprise budget for pasture—12-paddock grazing (155-acre pasture).[a]

	Quantity per acre	Units	$/unit	Value per acre	Total value
VALUE OF PRODUCTION					
Pasture–rotation in 12 cells	13	AUM	$16.00	$208.00	$32,240.00
Gross returns				$208.00	$32,240.00
OPERATING COSTS					
Fertilizer				$28.25	$4,378.75
Urea	50	lb	$0.46	$23.00	$3,565.00
Sulfur	15	lb	$0.35	$5.25	$813.75
Pesticide				$3.34	$517.08
2,4-D amine	0.21	qt	$4.10	$0.86	$133.45
Rodent control (1 of 3 yrs)	0.33	acre	$7.50	$2.48	$383.63
Custom				$12.93	$2,004.15
Custom aerate (1 of 3 years)	0.34	acre	$18.00	$6.03	$934.65
Custom fertilize	1	acre	$6.90	$6.90	$1,069.50
Irrigation				$114.11	$17,687.05
Irrigation power–center pivot	37	acre-inch	$1.48	$54.76	$8,487.80
Water assessment	1	acre	$39.00	$39.00	$6,045.00
Irrigation repairs–center pivot	37	acre-inch	$0.55	$20.35	$3,154.25
Machinery				$0.65	$100.75
Fuel & lube	1	acre	$0.62	$0.62	$96.10
Repairs	1	acre	$0.03	$0.03	$4.65
Labor				$14.88	$2,305.63
Labor (irrigation)	1.1	hr	$8.50	$9.35	$1,449.25
Labor (machine)	0.2	hr	$8.50	$1.70	$263.50
Labor (livestock)	0.45	hr	$8.50	$3.83	$592.88
Other				$9.15	$1,418.02
Fence & water system repairs	1	acre	$2.95	$2.95	$457.25
Operating interest (7%)				$6.20	$960.77
Total operating costs				$183.31	$28,411.43
Operating cost per AUM			$14.10		
Net returns above operating costs				$24.69	$3,828.57
OWNERSHIP COSTS					
General overhead		acre		$5.75	$891.25
Land rent		acre		$90.00	$13,950.00
Property taxes		acre		$0.00	$0.00
Taxes, housing, insurance on equipment		acre		$0.05	$7.75
Depreciation & interest on equipment		acre		$0.53	$82.15
Perimeter power fence		acre		$3.47	$537.85
Portable power fence		acre		$1.19	$184.45
Water system		acre		$0.93	$144.15
Amortized establishment cost		acre		$17.50	$2,712.50
Management charge (5% of gross returns)				$10.40	$1,612.00
Total ownership costs				$129.82	$20,122.10
Ownership cost per AUM			$9.99		
TOTAL COSTS				$313.13	$48,533.53
TOTAL COST PER AUM			$24.09		
NET RETURNS				($105.13)	($16,293.53)

[a] The costs and returns estimate shown here is representative for producing irrigated pasture in the Pacific Northwest in 2009. The pasture is sprinkler irrigated by a center pivot with surface water delivered from an irrigation district. Establishment cost is amortized over 20 years. Intensive grazing management reduces equipment use (aerate 1 in 3 years), no harrowing, reduced fertilizer requirement.

Budget 17.5. Cow-calf budget (250 cows).[a]

	Production or weight per animal	Units	Total number of head/units	Price/cost per unit	Total value	Value per herd unit
VALUE OF PRODUCTION						
Steer calves	5.5	cwt	113	$105.00	$65,257.50	$261.03
Heifer calves	5	cwt	55	$100.00	$27,500.00	$110.00
Aged bull	16.5	cwt	3	$49.00	$2,425.50	$9.70
Cull cows	11	cwt	43	$44.00	$20,812.00	$83.25
Cull replacement heifer	9	cwt	10	$88.00	$7,920.00	$31.68
Gross returns					$123,915.00	$495.66
OPERATING COSTS						
Feed and forage					$68,682.55	$274.72
Feed barley		cwt	172.8	$6.50	$1,123.20	$4.49
Alfalfa grass hay		ton	434.16	$80.00	$34,732.80	$138.93
Private range		AUM	2133.6	$13.50	$28,803.60	$115.21
Crop aftermath		AUM	303	$12.00	$3,636.00	$14.54
Salt		lb	5520	$0.07	$386.95	$1.55
Marketing and handling					$6,211.36	$24.84
Checkoff/brand inspection		head	224	$2.10	$470.40	$1.88
Commission		head	56	$13.59	$761.04	$3.04
Trucking/freight (to market)		head	56	$8.57	$479.92	$1.92
Trucking to and from pasture		head	250	$18.00	$4,500.00	$18.00
Health					$4,519.44	$18.08
Veterinary medicine		$	4519.44	1	$4,519.44	$18.08
Machinery and housing					$8,348.63	$33.39
Machinery (fuel, lube, repair)		$	2516.1	1	$2,516.10	$10.06
Vehicles (fuel, repair)		$	2972.48	1	$2,972.48	$11.89
Equipment (repair)		$	758.95	1	$758.95	$3.04
Housing and improvement (repair)		$	2101.1	1	$2,101.10	$8.40
Labor					$19,210.00	$76.84
Hired labor		hr	1260	$8.50	$10,710.00	$42.84
Owner labor		hr	1000	$8.50	$8,500.00	$34.00
Interest					$5,616.03	$22.46
Operating interest (7%)					$5,616.03	$22.46
Total operating costs					$112,588.01	$450.33
OWNERSHIP COSTS						
Capital recovery					$27,595.15	$110.38
Purchased livestock					$4,444.50	$17.78
Housing and improvements					$16,350.87	$65.40
Machinery					$2,532.69	$10.13
Equipment					$2,003.98	$8.02
Vehicles					$2,263.11	$9.05
Miscellaneous					$15,736.37	$62.94
Interest on retained livestock					$12,208.00	$48.83
Taxes and insurance					$828.37	$3.31
Overhead					$2,700.00	$10.80
Total ownership costs					$43,331.52	$173.32
TOTAL COSTS					$155,919.53	$623.65
NET RETURNS					($32,004.53)	($127.99)

[a] This budget presents both the average costs and returns per cow for a 250-head cow-calf operation and the total costs and returns for the ranch in summer 2009. The forage source is private range, with hay feeding necessary in the winter.

Budget 17.6. Enterprise budget for cow-calf grazing—continuous grazing system (67 cows).[a]

	Production or weight per animal	Units	Total number of head/unit	Price/cost per unit	Value per cow	Total value	Per acre
VALUE OF PRODUCTION							
Steer calves	5.5	cwt	0.45	$102.00	$252.45	$16,914.15	$108.55
Heifer calves	5	cwt	0.216	$97.00	$104.76	$7,018.92	$45.05
Cull sales	1	all	1	$121.75	$121.75	$8,157.25	$52.35
Gross returns					$478.96	$32,090.32	$205.95
OPERATING COSTS							
Stocker or replacement purchase	0	cwt	1	$0.00	$0.00	$0.00	$0.00
Mineral		lb	22	$0.07	$1.54	$103.18	$1.99
Veterinary costs		head	1	$18.00	$18.00	$1,206.00	$23.23
Trucking		head	1	$12.00	$12.00	$804.00	$15.48
Selling costs		head	1	$17.85	$17.85	$1,195.95	$23.03
Hay & winter feed		head	1	$143.42	$143.42	$9,609.14	$185.06
Pasture operating charge		head/acre	0.43	$312.56	$726.88	$48,701.21	$56.73
Death loss (% of gross sales)		percent	$478.96	0.01	$4.79	$320.90	$6.18
Repairs			1	$0.00	$0.00	$0.00	$0.00
Fuel & lube			1	$25.00	$25.00	$1,675.00	$32.26
Interest on livestock purchase			$0.00	0.06	$0.00	$0.00	$0.00
Operating interest		percent	$949.48	0.07	$33.69	$2,257.04	$43.47
Total operating costs					$983.17	$65,872.42	$1,268.61
Net returns above operating costs					($504.21)	($33,782.10)	($650.59)
OWNERSHIP COSTS							
Machinery, equipment, vehicle depreciation, interest, taxes, insurance		head	1	$14.00	$14.00	$938.00	$18.06
Housing & improvements			1	$35.00	$35.00	$2,345.00	$45.16
Depreciation on purchased livestock			1	$9.00	$9.00	$603.00	$11.61
Pasture ownership		head/acre	0.43	$143.26	$333.16	$22,321.91	$112.53
Farm overhead expenses		head	1	$7.00	$7.00	$469.00	$9.03
Total ownership costs					$398.16	$26,676.91	$513.76
TOTAL COSTS					$1,381.33	$92,549.33	$1,782.37
NET RETURNS					($902.37)	($60,459.01)	($1,164.35)
BREAK-EVEN PRICE (STEERS)						$294.17/cwt	
BREAK-EVEN PRICE (HEIFERS)						$279.75/cwt	

[a] Based on summer 2009 prices.

Budget 17.7. Enterprise budget for cow-calf grazing—4-paddock system (four paddocks used four times in grazing season by 165 cows).[a]

	Production or weight per animal	Units	Total number of head/unit	Price/cost per unit	Value per cow	Total value	Per acre
VALUE OF PRODUCTION							
Steer calves	5.5	cwt	0.45	$102.00	$252.45	$41,654.25	$267.60
Heifer calves	5	cwt	0.216	$97.00	$104.76	$17,285.40	$111.05
Cull sales	1	each	1	$121.75	$121.75	$20,088.75	$129.06
Gross returns					$478.96	$79,028.40	$507.70
OPERATING COSTS							
Stocker or replacement purchase	0	cwt	1	$0.00	$0.00	$0.00	$0.00
Mineral		lb	22	$0.07	$1.54	$254.10	$1.63
Veterinary costs		head	1	$18.00	$18.00	$2,970.00	$19.08
Trucking		head	1	$12.00	$12.00	$1,980.00	$12.72
Selling costs		head	1	$17.85	$17.85	$2,945.25	$18.92
Hay & winter feed		head	1	$143.42	$143.42	$23,664.30	$152.03
Pasture operating charge		head/acre	1.06	$256.11	$241.61	$39,866.18	$256.11
Death loss (% of gross sales)		percent	$478.96	0.01	$4.79	$790.28	$5.08
Repairs			1	$0.00	$0.00	$0.00	$0.00
Fuel & lube			1	$25.00	$25.00	$4,125.00	$26.50
Interest on livestock purchase			$0.00	0.06	$0.00	$0.00	$0.00
Operating interest		percent	$464.21	0.07	$16.47	$2,717.55	$17.46
Total operating costs					$480.68	$79,312.67	$509.52
Net returns above operating costs					($1.72)	($284.27)	($1.83)
OWNERSHIP COSTS							
Machinery, equipment, vehicle depreciation, interest, taxes, insurance		head	1	$14.00	$14.00	$2,310.00	$14.84
Housing & improvements			1	$35.00	$35.00	$5,775.00	$37.10
Depreciation on purchased livestock			1	$9.00	$9.00	$1,485.00	$9.54
Pasture ownership		head/acre	1.06	$135.49	$127.82	$21,090.42	$135.49
Farm overhead expenses		head	1	$7.00	$7.00	$1,155.00	$7.42
Total ownership costs					$192.82	$31,815.42	$204.39
TOTAL COSTS					$673.50	$111,128.09	$713.91
NET RETURNS					($194.54)	($32,099.69)	($206.22)
BREAK-EVEN PRICE (STEERS)						$143.43/cwt	
BREAK-EVEN PRICE (HEIFERS)						$136.40/cwt	

[a] Based on summer 2009 prices.

Budget 17.8. Enterprise budget for cow-calf grazing—12-paddock system (12 paddocks used five times in grazing season by 305 cows).[a]

	Production or weight per animal	Units	Total number of head/unit	Price/cost per unit	Value per cow	Total value	Per acre
VALUE OF PRODUCTION							
Steer calves	5.5	cwt	0.45	$102.00	$252.45	$76,997.25	$497.33
Heifer calves	5	cwt	0.216	$97.00	$104.76	$31,951.80	$206.38
Cull sales	1	all	1	$121.75	$121.75	$37,133.75	$239.85
Gross returns					$478.96	$146,082.80	$943.55
OPERATING COSTS							
Stocker or replacement purchase	0	cwt	1	$0.00	$0.00	$0.00	$0.00
Mineral		lb	22	$0.07	$1.54	$469.70	$3.03
Veterinary costs		head	1	$18.00	$18.00	$5,490.00	$35.46
Trucking		head	1	$12.00	$12.00	$3,660.00	$23.64
Selling costs		head	1	$17.85	$17.85	$5,444.25	$35.16
Hay & winter feed		head	1	$143.42	$143.42	$43,743.10	$282.54
Pasture operating charge		head/acre	1.97	$183.31	$93.05	$28,380.48	$183.31
Death loss (% of gross sales)		percent	$478.96	0.01	$4.79	$1,460.83	$9.44
Repairs			1	$0.00	$0.00	$0.00	$0.00
Fuel & lube			1	$25.00	$25.00	$7,625.00	$49.25
Interest on livestock purchase			$0.00	0.06	$0.00	$0.00	$0.00
Operating interest		percent	$315.65	0.07	$10.90	$3,323.41	$21.47
Total operating costs					$326.55	$99,596.77	$643.30
Net returns above operating costs					$152.41	$46,486.03	$300.25
OWNERSHIP COSTS							
Machinery, equipment, vehicle depreciation, interest, taxes, insurance		head	1	$14.00	$14.00	$4,270.00	$27.58
Housing & improvements			1	$35.00	$35.00	$10,675.00	$68.95
Depreciation on purchased livestock			1	$9.00	$9.00	$2,745.00	$17.73
Pasture ownership		head/acre	1.97	$129.82	$65.90	$20,099.04	$129.82
Farm overhead expenses		head	1	$7.00	$7.00	$2,135.00	$13.79
Total ownership costs					$130.90	$39,924.04	$257.87
TOTAL COSTS					$457.45	$139,520.80	$901.17
NET RETURNS					$21.51	$6,562.00	$42.38
BREAK-EVEN PRICE (STEERS)						$97.42/cwt	
BREAK-EVEN PRICE (HEIFERS)						$92.64/cwt	

[a] Based on summer 2009 prices.

Glossary

Acid detergent fiber (ADF). Residue remaining after boiling a forage sample in acid detergent solution. ADF contains cellulose, lignin, and silica but not hemicellulose.

Ad libitum feeding. Daily feed offerings that allow free-will consumption, generally fed to have a daily excess of 15 percent of feed remaining.

Alternate grazing. The repeated grazing and resting of two or more pastures in succession.

Animal day. One day on a pasture by one animal. Not synonymous with animal unit day.

Animal unit (AU). One mature, nonlactating cow weighing 1,100 pounds (500 kilograms) and fed at the maintenance level, or equivalent, expressed as (body weight)$^{0.75}$. In other kinds or classes of animals, AU is based on the average daily consumption of 25 pounds of dry matter per day. Public land management agencies often use AU to refer to a 1,000-pound cow with calf, 1.4 yearling cattle, or five dry ewes.

Animal unit day (AUD). The forage required to feed an animal unit for 1 day. Generally considered to be about 25 pounds of forage dry matter. A lactating cow with calf needs about 33 pounds of forage dry matter per day.

Animal unit month (AUM). The forage required to feed an animal unit for 1 month (30 days). Not synonymous with animal month. The term AUM is commonly used in three ways: (a) in stocking rate, as in "X acres per AUM," (b) for forage allocation, as in "X AUMs in Allotment A," and (c) in utilization, as in "X AUMs taken from Unit B."

Annual. A plant that completes its life cycle from seed in one growing season.

Apical dominance. Domination and control of growth in meristematic leaves or buds on the lower stem, roots, or rhizomes by hormones produced by apical meristems on the tips and upper branches of plants, particularly woody plants.

Available forage. That portion of the forage (expressed as weight of forage per unit land area) accessible for consumption by grazing animals of a specified kind, class, gender, age, size, and physiological status. Calculated as:

available forage (lb DM/paddock)
= total forage (lb DM/acre)
x paddock area (acres/paddock)
x desired utilization (%)

Available soil water. The portion of water in a soil that can be absorbed by plant roots.

Average daily gain. Average daily weight gain by individual animals.

Band seeding. The placement of seed in rows directly above, but not in contact with, a band of fertilizer.

Biennial. A plant that requires 2 years to reach maturity or complete its life cycle. Normally produces seed in the second year and then dies.

Bloat. Excessive accumulation of gases in the rumen when gas loss through the esophagus is impaired. Causes distension of the rumen.

Body condition score. A method of assessing the nutritional status of livestock based on external fat cover.

Boot stage. The growth stage of grasses when the head is enclosed by the sheath of the uppermost leaf.

Broadcast seeding. The process of scattering seed on the soil surface before covering the seed with soil using natural or artificial means. See also drill seeding.

Browse. Leaf and twig growth of shrubs, woody vines, trees, cacti, and other non-herbaceous vegetation available for animal consumption.

C_3 photosynthesis. A metabolic pathway for carbon fixation in photosynthesis. This process converts carbon dioxide and ribulose bisphosphate (RuBP, a 5-carbon sugar) into 3-phosphoglycerate. This reaction occurs in all plants as the first step of the Calvin cycle. See "cool-season plant."

C_4 carbon fixation (photosynthesis). One of three biochemical mechanisms, along with C_3 and CAM photosynthesis, functioning in land plants to "fix" carbon dioxide for sugar production through photosynthesis. (Carbon fixation refers to the binding of gaseous molecules to dissolved compounds inside the plant.) The intermediate compounds of this process contain four carbon atoms; hence the name C_4. Found in warm-season grasses.

Canopy. The aerial portion of plants in their natural growth position; usually expressed as percent of ground occupied, or as leaf area index.

Carbohydrates, non-structural. Products of photosynthesis found in the plant in the form of solute or stored material. Examples include sugars, starch, fructosans, and hemicellulose. These compounds are readily metabolizable. Excludes structural compounds such as cellulose and lignin.

Carrying capacity. The maximum stocking rate that will achieve a target level of animal performance, using a specified grazing method, over a defined time period without deterioration of the ecosystem. (See also seasonal carrying capacity.)

Cellulose. A carbohydrate formed from glucose that is linked by beta 1,4 bonds, a major constituent of plant cell walls. A colorless solid that is insoluble in water.

Cool-season plant. Plant species that grow best during cool, moist periods of the year. Optimum temperature for growth is 59 to 77°F (15 to 25°C).

Continuous grazing. Commonly used to describe unrestricted grazing of an entire grazing unit throughout a large portion of the growing season (not a desirable grazing system). Since no animal grazes continuously, a better term is continuous stocking.

Continuous stocking. A method of grazing livestock on a given unit of land where animals have unrestricted and uninterrupted access throughout the time period when grazing is allowed.

Crown. The base of a stem where roots attach.

Crude protein (CP). An estimate of protein content based on determination of total nitrogen (N). All nitrogenous substances contained in feed stuffs (% crude protein = % N x 6.25).

Cultivar. (1) A variety, strain, or race that has originated and persisted under cultivation or was specifically developed for the purpose of cultivation. (2) For cultivated plants, the equivalent of botanical variety.

Deferred grazing. The delay of livestock grazing on an area for a period of time to provide for plant reproduction, establishment of new plants, or restoration of vigor.

Defoliation. The removal of plant leaves by grazing or browsing, cutting, chemical defoliant, or natural phenomena such as hail, fire, or frost.

Digestible dry matter (DDM). The portion of the dry matter in a feed that is digested by animals at a specified level of feed intake. Called *in vivo* DMD if determined by feeding animals in a digestion trial. Often estimated by measuring *in vitro* digestibility or *in situ* digestibility, estimated using near infrared reflectance analysis, or calculated from acid detergent fiber.

Dormancy. A period of arrested growth and development caused by physical or physiological factors.

Drill seeding. Planting seed directly into the soil with a drill, usually in rows 6 to 24 inches apart. See also broadcast seeding.

Drought. A period of dryness causing extensive damage to plant production.

Dry matter (DM). The part of feed that is not water. Percent DM = 100% – moisture %. Feed values and nutrient requirements for ruminants are expressed on a dry-matter or moisture-free basis to compensate for the large variation in moisture content of feeds commonly fed to cattle. To convert "as-fed" nutrient values to a dry-matter basis, divide the "as-fed" nutrient value by the percent dry matter and multiply by 100.

Dry matter intake (DMI). An estimate of the maximum amount of forage dry matter a cow will eat. Expressed as a percentage of body weight and calculated from NDF by: DMI (% of body weight) = 120 ÷ NDF %.

Evapotranspiration (ET). The sum of evaporation and transpiration. Evaporation is water loss from plant leaves or bare soil surfaces. Transpiration is water vapor loss through small openings in leaves called stomata.

Fertilizer. Any organic or inorganic material of natural or synthetic origin (excluding liming materials) that is added to a soil to supply one or more elements essential to plant growth.

Fiber. The cell wall portion of roughages (forages) that is low in TDN and difficult for monogastric (single-stomached) animals to digest.

Fodder. Coarse grass, such as corn or sorghum, harvested with the seed and leaves and cured for animal feeding.

Forage. Edible parts of plants, other than separated grain, that can provide feed for grazing animals or be harvested for feeding. Includes browse, herbage, and mast.

Forage allowance. The mass of forage dry matter available per animal or animal unit at a particular time; the inverse of grazing pressure.

Forage production. The weight of forage produced during a designated period of time on a given area. May be expressed as green, air-dry, or oven-dry. May specify the period of production, such as annual, current-year, or seasonal forage production.

Forb. A herbaceous non-grasslike plant that an animal may eat.

Fresh weight. The weight of plant material at the time of harvest. Also known as green weight.

Germination. The resumption of active growth by a seed. Results in rupturing of the seed coat and emergence of the radicle.

Grass. Any plant of the family Phocaea (Gramineae).

Grass tetany (hypomagnesemia). A nutritional imbalance of cattle and sheep resulting from a low level of blood magnesium. Produces staggering, convulsions, coma, and death.

Graze. To partially defoliate a plant by consumption.

Grazier. One who controls livestock grazing.

Grazing cell. An area of pasture managed as a planning unit from which forage is allocated to a specific group of animals for the grazing season. A grazing cell usually has permanent fence on its borders and is separated into paddocks with temporary fencing or by herding.

Grazing cycle. The time elapsed between the beginning of one grazing period and the beginning of the next grazing period. One grazing cycle includes one grazing period plus one rest period.

Grazing period. The time that animals are present on a paddock.

Grazing pressure. The relationship between the number of animals units (or forage intake units) and the weight of forage dry matter per unit area at a specific time; an animal-to-forage relationship.

Grazing season. The total period of time during which animals may harvest standing forage from pasture. Composed of the "growing season," when temperature and moisture are conducive to plant growth, and the "non-growing season," when animals may harvest any forage remaining after the growing season.

Grazing system. A system of grazing management that defines periods of grazing and non-grazing. Examples include deferred, deferred-rotation, rotational, rest-rotation, and short-duration grazing.

Green weight. See fresh weight.

Hardiness. The ability to survive exposure to adverse conditions.

Hay. Dried forage (grasses, alfalfa, or clovers) used for feeding farm animals.

Herbage. Leaves, stems, and other succulent plant parts upon which animals feed or forage.

Herbage allowance. Weight of forage available per animal at a specified time.

Herbicide. A chemical used for killing plants or inhibiting their growth.

Herbivore. An insect or other higher animal that subsists principally or entirely on plants or plant materials.

Herbivory. The act of eating plants or their seeds and fruits; defoliation. In most cases, the plants do not die.

Hybrid. Offspring of a cross between genetically dissimilar individuals.

In vitro. In glass; in test tubes, as in *in vitro* digestion.

In vitro digestible dry matter (IVDDM). The weight of dry matter lost upon filtration following incubation of forage in test tubes with rumen microflora. Usually expressed as a percentage: IVDDM = (weight dry matter sample – weight residue) ÷ weight dry matter sample.

In vivo. In a living organism.

Intake. The quantity of forage or feed consumed by an animal during a specified period. Usually expressed as pounds per day.

Interseeding. Seeding into established vegetation. Often involves planting seeds into the center of variably spaced, narrow seedbed strips that were prepared by mechanical or chemical methods.

Killing frost. A temperature that affects the shoot apex enough to stop growth but does not kill all of the leaves. Generally considered to be about 24°F for upright legumes with apices near the top of the canopy.

Legume. Plant member of the family Fabaceae (Leguminosae). Includes clovers, alfalfa, and similar crops that form nitrogen-fixing nodules on the roots. *Rhizobium* bacteria in the nodules use atmospheric nitrogen and convert it to a form the plant can use.

Lignin. A compound that, with cellulose, forms the cell walls of plants. Practically indigestible.

Lodging. The falling down of a crop due to stalk breakage or uprooting.

Management-intensive Grazing (MiG). A goal-driven approach to grazing management with emphasis on intensive management. Characterized by balancing animal demand with forage supply throughout the grazing season and allocating forage based on animal requirements.

Mast. Fruits and seeds of shrubs, trees, and other non-herbaceous vegetation available for animal consumption.

Meadow. An area covered with grasses and/or legumes (often native to the area) that are grown primarily for hay, but with secondary grazing.

Meristem. The tissue in all plants consisting of undifferentiated cells (meristematic cells); found in zones of the plant where growth can take place.

Minerals. Examples include calcium (Ca), phosphorus (P), magnesium (Mg), potassium (K), and sulfur (S). These minerals normally are expressed as a percentage in the feed.

Mixed grazing. Grazing by two or more species of grazing animals on the same land unit within the same grazing season, although not necessarily at the same time.

Moisture, wet basis. The weight of water in a forage sample divided by the total weight of water and dry matter.

Native plant. A plant species indigenous to an area; not introduced from another environment or area.

Naturalized plant. A plant introduced from another environment that has become established in and somewhat adapted to an area by being grown there for several generations.

Near infrared reflectance spectroscopy (NIRS). A method of forage quality analysis based on the measurement of near infrared light energy absorbed by the sample.

Net energy for gain. An estimate of the energy value of a feed calculated from the total energy content minus all loss and expense of utilization.

Neutral detergent fiber (NDF). A measurement of fiber after digesting in a nonacidic, nonalkaline detergent. Contains the fibers in ADF plus hemicellulose. Measures the structural part of the plant (cell wall), which consists of lignin, cellulose, and hemicellulose. NDF gives bulk or fill to the diet and is negatively correlated with feed intake. Because NDF can be used to predict intake, it is one of the most valuable forage analyses for dairy rations. Low NDF is usually desired. As plant maturity increases, cell wall content increases and NDF increases.

Nitrate poisoning. A serious condition resulting when an animal ingests a diet containing a high nitrate concentration. Rumen bacteria convert nitrate to nitrite. Nitrites usually are converted to other forms of nitrogen; if not, they compete with the oxygen-carrying mechanism in the blood, resulting in suffocation.

Nitrogen (N). A plant nutrient needed in large amounts by growing forages. Promotes leaf and stem growth and plant vigor. Ensures a dark, healthy, green color in grass. An important component of protein.

Nodule. A tubercle formed on legume roots by symbiotic nitrogen-fixing bacteria of the genus *Rhizobium*.

Nonprotein nitrogen (NPN). Nitrogen that is not in the form of protein. Can be used by rumen microorganisms to synthesize protein if adequate carbohydrates are available.

Overgrazing. The grazing of animals on a given area that, if continued to the end of the planned grazing period, will result in less-than-satisfactory animal performance and/or less-than-satisfactory forage production.

Overseeding. The practice of spreading seed over an existing pasture without prior seedbed preparation.

Paddock. A subdivision of the grazing cell to which animals are confined for a grazing period (hours or days). A paddock may be of fixed or variable size.

Palatability. Animal preference based on plant characteristics. Elicits a choice between two or more forages or parts of the same forage and causes selective intake.

Pasture. A fenced area of domesticated forages (usually improved) on which animals are grazed.

Pasture carrying capacity. The number of animals a given pasture will support at a given time or for a given period of time.

Pasture renovation. Improvement of a pasture by the partial or complete destruction of the sod, plus liming, fertilizing, seeding, and weed control as required to establish desirable forage plants.

Perennial. A plant or group of plants that persists for several years, usually with new growth each year.

Phosphorus (P). An element that promotes rapid growth, hastens maturity, and stimulates flower, seed, and fruit production. Required by every plant cell. Designated as P_2O_5 (phosphoric oxide, or phosphate) in fertilizer.

Photosynthesis. The plant process that produces carbohydrates from carbon dioxide, water, sunlight, and chloroplasts or chlorophyll-bearing cell granules.

Potash. Potassium oxide (K_2O). Often used interchangeably with potassium (K) in fertilizer descriptions. Potassium stimulates growth of roots and strong stems, imparts disease resistance, and improves winter survival and persistence of legumes.

Range. Land supporting indigenous vegetation that is grazed or has the potential to be grazed and is managed as a natural ecosystem.

Rangeland. Land on which the indigenous vegetation is predominately grasses, grass-like plants, forbs, or shrubs. Not a use but a type of land.

Ration. The amount of feed supplied to an animal for a specific period, usually 24 hours.

Relative feed value (RFV). An index for ranking cool-season grass and legume forages based on intake of digestible energy. RFV is calculated from ADF and NDF as follows:

$$RFV = [(1.2 \div NDF \times 0.01) \times (0.889 - (0.00779 \times ADF))] \div 1.29 \times 100$$

The higher the RFV, the better the quality. It is used to compare varieties, match hay/silage inventories to animals, and to market hay. Being replaced by Relative Forage Quality, which incorporates fiber digestibility into improved estimates of digestible energy intake.

Resistance. (1) Genetically determined traits that reduce the impacts of pest attack on a plant. (2) The ability of a plant to survive a period of stress such as drought, cold, or heat.

Respiration. The process by which tissues and organisms exchange gases with their environment. Generally associated with oxidation of sugars by plants to release energy for growth and reproduction.

Rest. The practice of leaving an area of grazing land ungrazed or unharvested for a specific period of time.

Rest period. The grazing cycle minus the grazing period.

Rhizobium. A genus of bacteria that live in symbiotic relationship with leguminous plants. Living in nodules on the legume's roots, *Rhizobium* bacteria fix nitrogen from the atmosphere and make it available to the plant.

Rhizome. An underground stem, usually horizontal, that is capable of producing new shoots and roots at the nodes.

Rotational grazing. A system of pasture utilization involving periods of heavy stocking followed by periods of rest for herbage recovery during the same season. Rotational stocking is a more appropriate term.

Rotational stocking. A grazing method that utilizes recurring periods of grazing and rest among two or more paddocks in a grazing management unit.

Roughage. Pasture, silage, hay, or other dry fodder. May be of high or low quality. Animal feeds that are usually high in fiber and relatively low in total digestible nutrients and protein.

Rumen. The first compartment of the stomach of a ruminant or cud-chewing animal, e.g., cows, sheep, deer, and elk.

Seasonal carrying capacity. The stocking rate that is economically and environmentally sustainable for a particular grazing unit for the entire grazing season.

Seasonal utilization rate. The fraction of annual forage production that will be harvested by grazing livestock during the entire grazing season.

Seed, certified. The progeny of foundation, registered, or certified seed that is handled in a way that maintains satisfactory purity, as certified by a certifying agency such as the Idaho Crop Improvement Association, Inc.

Seed inoculation. The addition of effective *Rhizobium* bacteria to legume seed prior to planting. Promotes nitrogen fixation.

Seed scarification. The act of mechanically scarring the coat of hard or impenetrable seed to permit rapid water intake and speed germination.

Seedbed preparation. Soil treatment prior to seeding to: (1) reduce or eliminate existing vegetation, (2) reduce the effective supply of weed seed, (3) modify physical soil characteristics, and (4) enhance temperature and water characteristics of the micro-environment.

Stock density (also stocking density). The relationship between the number of animals (or live weight) and area of land at any given instant of time. May be expressed as animal units or forage intake units per unit of land area (for example, "50 animal units per acre," which is equivalent to 55,000 pounds of live weight per acre).

Stocking rate. The relationship between the number of animals (or live weight) and the grazing management unit over a specified time period. May be expressed as animal units or forage intake units over a time period per unit of land area, such as "50 animal units per acre-day" (equivalent to 55,000 pounds live weight per acre-day).

Stockpiled forage. The accumulation of forage for later use.

Stolon. A trailing or creeping stem at or below the soil surface capable of rooting and sending up new shoots at the nodes.

Strip grazing. The practice of confining animals to an area of forage to be consumed in a short period of time, usually a day.

Stubble. The basal part of the stems of herbaceous plants left standing after harvest or grazing.

Sward. The grassy canopy of a pasture.

Swath. A layer of forage material left by mowing machines or self-propelled windrowers. Swaths are wider than windrows and have not been raked.

Symbiotic nitrogen fixation. The fixation of atmospheric nitrogen by *Rhizobium* bacteria growing in nodules on legume roots.

Temporal utilization rate. The fraction of available forage expected to be consumed during a grazing period.

Tiller. A branch or shoot originating at a basal node on a grass plant.

Tolerance. The ability of a resistant plant to withstand pest attack without significant yield loss, although it might express disease symptoms.

Total digestible nutrients (TDN). The sum of digestible crude protein, digestible nitrogen-free extract, digestible crude fiber, and 2.25 times the digestible ether extract (fat). Often calculated from ADF. Less accurate than net energy for formulating diets containing both forage and grain. Most rations are now formulated using net energy; however, TDN is still used to calculate beef cow rations where the diet is primarily forage.

Variety. See cultivar.

Vegetative. A term designating stem and leaf development, in contrast to flower and seed development.

Warm-season grass. A grass species that grows primarily during the warmer part of the year.

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Plate 8.1. Wireworms. (Source: Frank Peairs, Colorado State University, Bugwood.org)

Plate 8.2. Adult click beetle. (Source: Ken Gray image collection, Oregon State University)

Plate 8.3. Black cutworm and damage. (Source: Frank Peairs, Colorado State University, Bugwood.org)

Plate 8.4. Cutworm pupa. (Source: Ken Gray image collection, Oregon State University)

Plate 8.5. Black cutworm moth. (Source: Ken Gray image collection, Oregon State University)

Plate 8.6. Winter grain mite. (Source: Ken Gray image collection, Oregon State University)

Plate 8.7. Clover mite. (Source: Ken Gray image collection, Oregon State University)

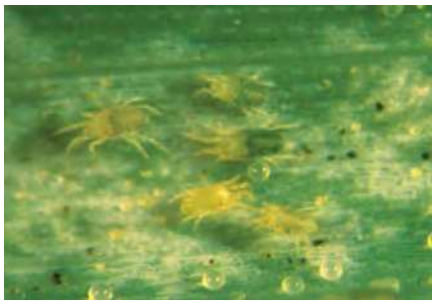

Plate 8.8. Banks grass mites. (Photo by Frank Peairs, Colorado State University)

Plate 8.9. English grain aphid. (Source: Ken Gray image collection, Oregon State University)

Plate 8.10. English grain aphid nymphs. (Source: Ken Gray image collection, Oregon State University)

Plate 8.11. Bird cherry-oat aphids. (Photo by John Obermeyer, Purdue University)

Plate 8.12. Russian wheat aphids. (Source: Frank Peairs, Colorado State University, Bugwood.org)

Plate 8.13. Parasitic fungus on aphid. (Photo by John Obermeyer, Purdue University)

Plate 8.14. Parasitized aphids. (Source: Ken Gray image collection, Oregon State University)

Plate 8.15. Golden aphid mummies parasitized by a wasp. (Photo by John Obermeyer, Purdue University)

Plate 8.16. Russian wheat aphid parasite. (Source: Frank Peairs, Colorado State University, Bugwood.org)

Plate 8.17. Parasitic wasp. (Source: Ken Gray image collection, Oregon State University)

Plate 8.18. Lady beetle larva eating aphid. (Source: Ken Gray image collection, Oregon State University)

Plate 9.1. Root rot on tall fescue. (Source: Cynthia Ocamb, Oregon State University Department of Botany and Plant Pathology, Online Guide to Plant Disease Control)

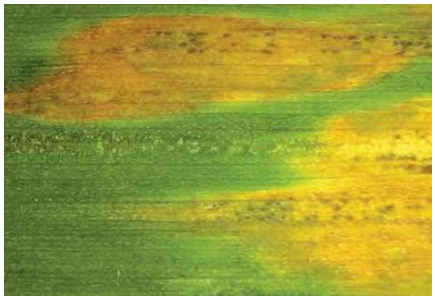

Plate 9.2. Brown stripe on orchardgrass. (Source: Oregon State University Department of Botany and Plant Pathology, Online Guide to Plant Disease Control)

Plate 9.3. Scald on barley. (Source: University of Georgia Plant Pathology Archive, University of Georgia, Bugwood.org)

Plate 9.4. Stripe rust. (Source: Howard Schwartz, Colorado State University, Bugwood.org)

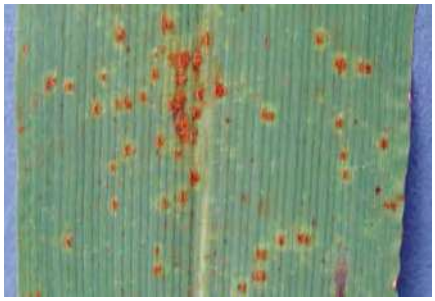

Plate 9.5. Leaf rust. (Source: Clemson University-USDA Cooperative Extension, Bugwood.org)

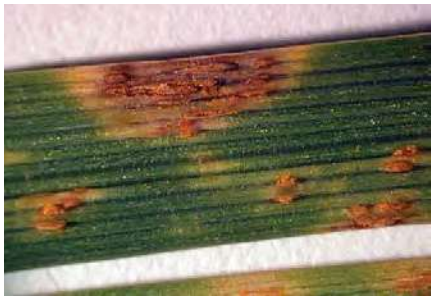

Plate 9.6. Stem rust. (Source: Cynthia Ocamb, Oregon State University Department of Botany and Plant Pathology, Online Guide to Plant Disease Control)

Plate 9.7. Snow mold. (Source: Mary Ann Hansen, Virginia Polytechnic Institute and State University, Bugwood.org)

Plate 9.8. Fusarium root and crown rot. (Source: Melodie Putnam, Oregon State University Department of Botany and Plant Pathology, Online Guide to Plant Disease Control)

Plate 9.9. Spring and summer stem rot. (Source: University of Georgia Plant Pathology Archive, University of Georgia, Bugwood.org)

Plate 9.10. Clover plants infected by the stem nematode. (Source: Paul Koepsell, Oregon State University Department of Botany and Plant Pathology, Online Guide to Plant Disease Control)

Plate 9.11. Clover leaf spot. (Source: Clemson University-USDA Cooperative Extension Slide Series, Bugwood.org)

Plate 9.12. Powdery mildew on clover. (Source: Cynthia Ocamb, Oregon State University Department of Botany and Plant Pathology, Online Guide to Plant Disease Control)

Plate 9.13. Dodder on clover. (Source: Cynthia Ocamb, Oregon State University Department of Botany and Plant Pathology, Online Guide to Plant Disease Control)

Plate 9.14. Phytophthora root and stem rot. (Source: Department of Plant Pathology Archive, North Carolina State University, Bugwood.org)

Plate 9.15. Downy mildew. (Source: Paul Koepsell, Oregon State University Department of Botany and Plant Pathology, Online Guide to Plant Disease Control)

Plate 9.16. Alfalfa leaf spot. (Source: University of Georgia Plant Pathology Archive, University of Georgia, Bugwood.org)

Plate 9.17. Anthracnose on alfalfa. (Source: Gary Munkvold, Oregon State University Department of Botany and Plant Pathology, Online Guide to Plant Disease Control)

Plate 9.18. Bacterial wilt, foliar symptoms. (Source: American Phytopathological Society Archive, American Phytopathological Society, Bugwood.org)

Plate 9.19. Bacterial wilt, root symptoms. (Source: American Phytopathological Society Archive, American Phytopathological Society, Bugwood.org)

Plate 9.20. Verticillium wilt on alfalfa. (Source: William M. Brown Jr., Bugwood.org)

Plate 9.21. Verticillium wilt on alfalfa. (Source: William M. Brown Jr., Bugwood.org)

Plate 9.22. Alfalfa plant infested with bulb and stem nematode. (Source: Oregon State University Department of Botany and Plant Pathology, Online Guide to Plant Disease Control)

Plate 9.23. Alfalfa mosaic virus. (Source: Mary Ann Hansen, Virginia Polytechnic Institute and State University, Bugwood.org)

The comprehensive resource for anyone who manages livestock on pastures in the Northwest.

Because each pasture is different, no single management recipe works in every situation. Your task as a manager is to customize a system that will enable your pastures—and your livestock—to reach their maximum production potential. ***Pasture and Grazing Management in the Northwest*** will give you the knowledge you need to succeed.

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- Detailed costs and returns estimates that you can modify for your own pasture enterprise.

The authors

Editors Glenn E. Shewmaker, University of Idaho forage specialist, and Mylen G. Bohle, Oregon State University extension agronomist, and more than 20 other experts from land-grant universities, USDA, and private industry bring together Northwest-specific information from their own research and other relevant sources.

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APPENDIX D
Biosolids Test Results

DRAFT

UMPQUA Research Company - Table Rock
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E-mail: TRLab@URCmail.net
Internet: www.umpquaresearch.com
ORELAP ID# OR100061

ANALYSIS REPORT
URC # T3L1919

North Powder, City of	Project: Waste Water	Date Reported: 01/10/24
635 3rd St.		Date Sampled: 12/19/23 10:00
North Powder, OR 97867		Date Received: 12/19/23 13:05
	Client Contact: Rick Lawyer	Sampled By: Trask Ritter

Sample Location: #1

URC Sample #: T3L1919-01

Matrix: Sludge

Inorganics

Analyte	Code	Result	Units	MRL	BML	Prepared	Analyzed	Analyst	Qualifier
SM 2540B									
*Total Solids		**2.91**	% by Weight	0.014		12/26/23	12/28/23	CAO	
SM 2540E									
*Volatile Solids		**55.6**	% by Weight (of TS)	0.466		12/26/23	12/28/23	CAO	
SM 4500 NH3 B									
*Ammonia as N		**1760**	mg/kg dry	509		12/20/23	12/21/23	JBN	
SM 4500-H B									
pH		**7.1**	pH Units			12/19/23 14:09	12/19/23	DTD	
SM 4500Norg B									
*Total Kjeldahl Nitrogen		**26600**	mg/kg dry	2510		12/20/23	12/21/23	JBN	
SM 4500P									
*Phosphorus-Total		**0.307**	% by Weight dry	0.017		12/21/23	12/21/23	JBN	
USEPA 300.0									
*Nitrite as N		ND	mg/kg dry	8.48		12/20/23 15:27	12/20/23	JBN	
*Nitrate as N		ND	mg/kg dry	33.9		12/20/23 15:27	12/20/23	JBN	

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ANALYSIS REPORT
URC # T3L1919

North Powder, City of	Project: Waste Water	Date Reported: 01/10/24
635 3rd St.		Date Sampled: 12/19/23 10:00
North Powder, OR 97867		Date Received: 12/19/23 13:05
	Client Contact: Rick Lawyer	Sampled By: Trask Ritter

Sample Location: #1 URC Sample #: T3L1919-01 Matrix: Sludge

Metals

Analyte	Code	Result	Units	MRL	BML	Prepared	Analyzed	Analyst	Qualifier
EPA 6010D									
*Arsenic		**ND**	mg/kg dry	9.21		01/03/24	01/03/24	DST	
*Cadmium		**ND**	mg/kg dry	1.84		01/03/24	01/03/24	DST	
*Chromium		**ND**	mg/kg dry	18.4		01/03/24	01/03/24	DST	
*Copper		**38.9**	mg/kg dry	18.4		01/03/24	01/03/24	DST	
*Lead		**ND**	mg/kg dry	9.21		01/03/24	01/03/24	DST	
*Mercury		ND	mg/kg dry	3.68		01/04/24	01/04/24	DST	
*Molybdenum		ND	mg/kg dry	18.4		01/03/24	01/03/24	DST	
*Nickel		**ND**	mg/kg dry	18.4		01/03/24	01/03/24	DST	
*Potassium		**0.100**	% by Weight dry	0.037		01/03/24	01/03/24	DST	
*Selenium		ND	mg/kg dry	18.4		01/03/24	01/03/24	DST	
*Zinc		**162**	mg/kg dry	36.8		01/03/24	01/03/24	DST	

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635 3rd St.		Date Sampled: 12/19/23 10:30
North Powder, OR 97867		Date Received: 12/19/23 13:05
	Client Contact: Rick Lawyer	Sampled By: Trask Ritter

Sample Location: #2 URC Sample #: T3L1919-02 Matrix: Sludge

Inorganics

Analyte	Code	Result	Units	MRL	BML	Prepared	Analyzed	Analyst	Qualifier
SM 2540B									
*Total Solids		**1.43**	% by Weight	0.015		12/26/23	12/28/23	CAO	
SM 2540E									
*Volatile Solids		**60.9**	% by Weight (of TS)	1.02		12/26/23	12/28/23	CAO	
SM 4500 NH3 B									
*Ammonia as N		**5390**	mg/kg dry	5230		12/20/23	12/21/23	JBN	
SM 4500-H B									
pH		**6.8**	pH Units			12/19/23 14:09	12/19/23	DTD	
SM 4500Norg B									
*Total Kjeldahl Nitrogen		**51600**	mg/kg dry	5190		12/20/23	12/21/23	JBN	
SM 4500P									
*Phosphorus-Total		**0.739**	% by Weight dry	0.035		12/21/23	12/21/23	JBN	
USEPA 300.0									
*Nitrite as N		ND	mg/kg dry	17.4		12/20/23 15:27	12/20/23	JBN	
*Nitrate as N		ND	mg/kg dry	69.8		12/20/23 15:27	12/20/23	JBN	

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North Powder, City of	Project: Waste Water	Date Reported: 01/10/24
635 3rd St.		Date Sampled: 12/19/23 10:30
North Powder, OR 97867		Date Received: 12/19/23 13:05
	Client Contact: Rick Lawyer	Sampled By: Trask Ritter

Sample Location: #2

URC Sample #: T3L1919-02

Matrix: Sludge

Metals

Analyte	Code	Result	Units	MRL	BML	Prepared	Analyzed	Analyst	Qualifier
EPA 6010D									
*Arsenic		**ND**	mg/kg dry	16.5		01/03/24	01/03/24	DST	
*Cadmium		**ND**	mg/kg dry	3.31		01/03/24	01/03/24	DST	
*Chromium		**ND**	mg/kg dry	33.1		01/03/24	01/03/24	DST	
*Copper		**112**	mg/kg dry	33.1		01/03/24	01/03/24	DST	
*Lead		**17.6**	mg/kg dry	16.5		01/03/24	01/03/24	DST	
*Mercury		**ND**	mg/kg dry	6.62		01/04/24	01/04/24	DST	
*Molybdenum		**ND**	mg/kg dry	33.1		01/03/24	01/03/24	DST	
*Nickel		**ND**	mg/kg dry	33.1		01/03/24	01/03/24	DST	
*Potassium		**0.241**	% by Weight dry	0.066		01/03/24	01/03/24	DST	
*Selenium		ND	mg/kg dry	33.1		01/03/24	01/03/24	DST	
*Zinc		**495**	mg/kg dry	66.2		01/03/24	01/03/24	DST	

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North Powder, OR 97867		Date Received: 12/19/23 13:05
	Client Contact: Rick Lawyer	Sampled By: Trask Ritter

Sample Location: #3 URC Sample #: T3L1919-03 Matrix: Sludge

Inorganics

Analyte	Code	Result	Units	MRL	BML	Prepared	Analyzed	Analyst	Qualifier
SM 2540B									
*Total Solids		**2.04**	% by Weight	0.014		12/26/23	12/28/23	CAO	
SM 2540E									
*Volatile Solids		**55.8**	% by Weight (of TS)	0.695		12/26/23	12/28/23	CAO	
SM 4500 NH3 B									
*Ammonia as N		**11800**	mg/kg dry	3650		12/20/23	12/21/23	JBN	
SM 4500-H B									
pH		**6.9**	pH Units			12/19/23 14:09	12/19/23	DTD	
SM 4500Norg B									
*Total Kjeldahl Nitrogen		**35700**	mg/kg dry	3620		12/20/23	12/21/23	JBN	
SM 4500P									
*Phosphorus-Total		**0.471**	% by Weight dry	0.024		12/21/23	12/21/23	JBN	
USEPA 300.0									
*Nitrite as N		**ND**	mg/kg dry	12.2		12/20/23 15:27	12/20/23	JBN	
*Nitrate as N		ND	mg/kg dry	48.7		12/20/23 15:27	12/20/23	JBN	

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635 3rd St.		Date Sampled: 12/19/23 11:00
North Powder, OR 97867		Date Received: 12/19/23 13:05
	Client Contact: Rick Lawyer	Sampled By: Trask Ritter

Sample Location: #3 URC Sample #: T3L1919-03 Matrix: Sludge

Metals

Analyte	Code	Result	Units	MRL	BML	Prepared	Analyzed	Analyst	Qualifier
EPA 6010D									
*Arsenic		**ND**	mg/kg dry	12.6		01/03/24	01/03/24	DST	
*Cadmium		**ND**	mg/kg dry	2.52		01/03/24	01/03/24	DST	
*Chromium		**ND**	mg/kg dry	25.2		01/03/24	01/03/24	DST	
*Copper		**204**	mg/kg dry	25.2		01/03/24	01/03/24	DST	
*Lead		**30.0**	mg/kg dry	12.6		01/03/24	01/03/24	DST	
*Mercury		**ND**	mg/kg dry	5.05		01/04/24	01/04/24	DST	
*Molybdenum		**ND**	mg/kg dry	25.2		01/03/24	01/03/24	DST	
*Nickel		**ND**	mg/kg dry	25.2		01/03/24	01/03/24	DST	
*Potassium		**0.262**	% by Weight dry	0.050		01/03/24	01/03/24	DST	
*Selenium		**ND**	mg/kg dry	25.2		01/03/24	01/03/24	DST	
*Zinc		**786**	mg/kg dry	50.5		01/03/24	01/03/24	DST	

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ANALYSIS REPORT
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Qualifiers and Definitions

QR-01	Sample concentrations of the Duplicate samples were less than 5 times the MRL. RPD values are not considered significant.
DET	Analyte DETECTED
ND	Analyte NOT DETECTED at or above the MRL (minimum reporting limit)
NA	Not Applicable
NR	Not Reported
dry	Sample results reported on a dry weight basis
RPD	Relative Percent Difference
MRL	Minimum Reporting Limit
MDL	Minimum Detection Limit
BML	Benchmark Level
(‡)	ORELAP Accredited Analyte
(~)	Due to rounding of individual analytes, the "total" may vary slightly from the sum of the individual analyte values.

Analytes flagged with * were subcontracted to Umpqua Research Company/MC. ORELAP ID #: OR100031

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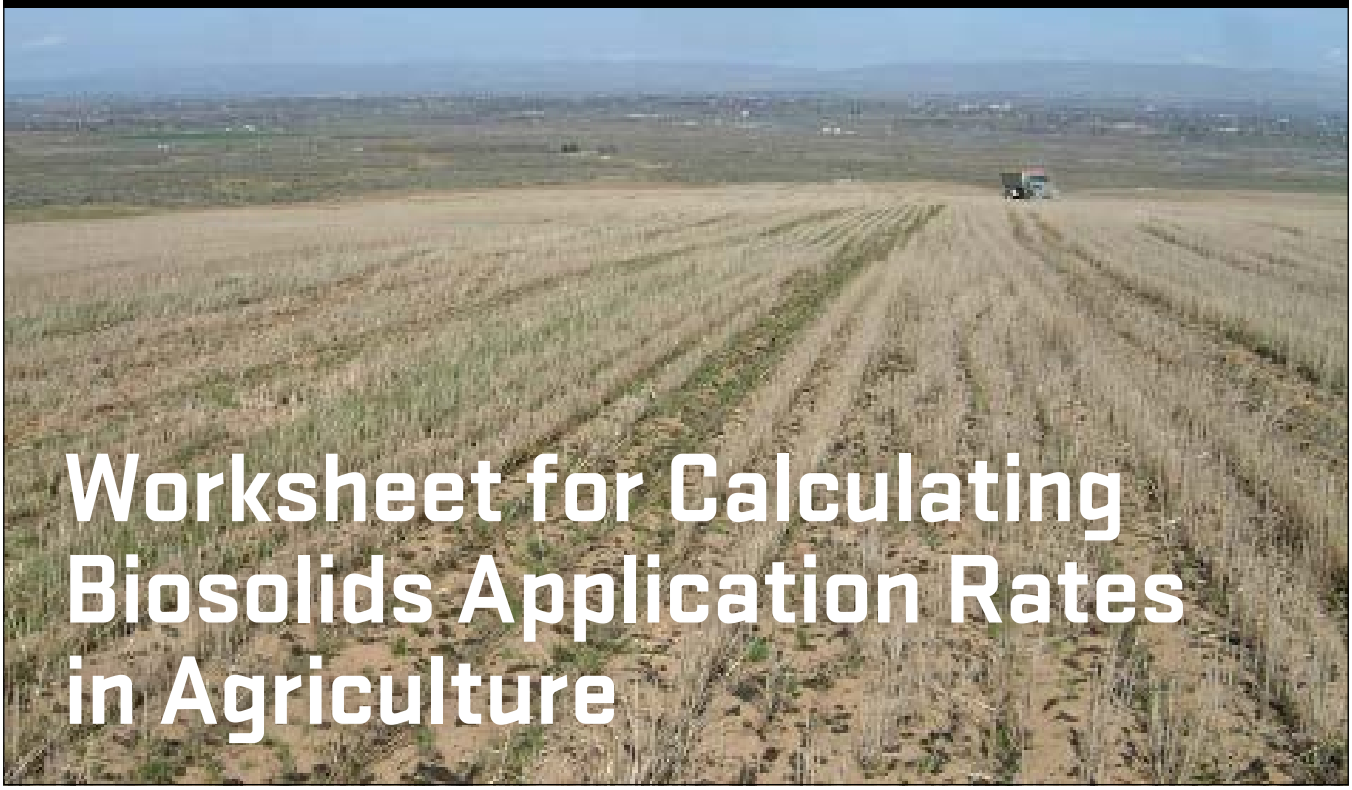
APPENDIX E
Nutrient Uptake Calculations

DRAFT

A PACIFIC NORTHWEST EXTENSION PUBLICATION



Worksheet for Calculating Biosolids Application Rates in Agriculture

Photo: Brian Campbell, Natural Selection Farms

Dan M. Sullivan, Deirdre Griffin LaHue, Biswanath Dari, Andy I. Bary and Craig G. Cogger

Biosolids are a product of municipal wastewater treatment. Raw sewage solids must be processed to meet U.S. Environmental Protection Agency standards before they can be called biosolids. Biosolids contain organic matter and nutrients that are beneficial for soil and crop productivity.

This publication focuses on matching the nitrogen (N) supplied by biosolids to the nitrogen needs of the crop. Regulatory agencies require agronomic rate calculations for most biosolids applications to cropland.

Overview: agronomic rate calculation

There are six steps to calculate the agronomic rate of a biosolids application:

1. Collect information on the site and crop, including crop N requirement.
2. Estimate the plant-available N needed from the biosolids application.
3. Collect biosolids N data.
4. Estimate plant-available N per dry ton of biosolids.
5. Calculate the agronomic biosolids application rate on a dry ton basis.
6. Convert the application rate to an "as is" basis.

In determining biosolids application rates, it's important to evaluate trace element concentrations in biosolids and the regulatory limits for trace element application (see Appendix A). However, in almost all cases, nitrogen controls the biosolids application rate.

A companion publication, *Fertilizing with Biosolids* (PNW 508), provides additional information about the value of biosolids as a fertilizer. The "For more information" section of this publication gives a summary of Pacific Northwest research and Extension publications on land application of municipal biosolids.

Dan M. Sullivan, Extension soil scientist and professor of nutrient management, and Biswanath Dari, agronomist and assistant professor, both of the Department of Crop and Soil Science, Oregon State University; Deirdre Griffin LaHue, sustainable soil management specialist and assistant professor, Andy I. Bary, senior scientific assistant, and Craig C. Cogger, Extension soil scientist (emeritus), all of the Department of Crop and Soil Sciences, Washington State University

Oregon State University • University of Idaho • Washington State University

PNW 511 • February 2021

WORKSHEET

For guidance on completing this worksheet, see "How to Use the Worksheet," starting on page 5.

Step 1. Collect site information

Soil and crop information:

Line number		Your information	Example
1.1	Soil series and texture (NRCS soil survey)	Baker, Baldlock,Haines, Powval, Umapine Silt Loam	Puyallup sandy loam
1.2	Yield goal (units/acre/year*) estimated from grower records or by agronomist**		5 tons/acre
1.3	Crop rotation (grower; e.g., wheat, fallow, wheat)	Alfalfa	perennial grass
1.4	Plant-available N needed to produce yield goal (university fertilizer/nutrient management guide; agronomist) (lb N/acre/year)	175	200 lb N/acre

Plant-available N provided by other sources:

Line number		Your calculation	Example	Unit
Pre-application testing				
1.5	Nitrate-N applied in irrigation water	0	10	lb N/acre
1.6	Preplant nitrate-N in root zone (east of Cascades)***	0	—	lb N/acre
Adjustments to typical soil N mineralization				
1.7	Plowdown of cover or green manure crop***	0	—	lb N/acre
1.8	Previous biosolids applications (see Table 1, page 7)	0	30	lb N/acre
1.9	Previous manure applications	0	—	lb N/acre
Grower information				
1.10	N applied at seeding (starter fertilizer)	0	—	lb N/acre
Total				
1.11	Total plant-available N from other sources = sum of lines 1.5 through 1.10	0	40	lb N/acre

* Yield goals may be expressed in weight (tons, pounds, etc.) or in volume (bushels).
** The American Society of Agronomy certifies professional agronomists as Certified Crop Advisors (CCAs). See https://www.certifiedcropadviser.org for more information.
*** Do not list here if these N sources were accounted for in the nitrogen fertilizer recommendation from a university fertilizer/nutrient management guide.

Step 2. Estimate the amount of plant-available N needed from biosolids

Line number		Your calculation	Example	Unit
2.1	Plant-available N needed to produce yield goal (from line 1.4)	175	200	lb N/acre
2.2	Plant-available N from other sources (from line 1.11)	0	40	lb N/acre
2.3	Amount of plant-available N needed from biosolids = line 2.1 – line 2.2	175	160	lb N/acre

Step 3. Collect biosolids data

Application information:

Line number		Your information	Example
3.1	Moisture content of biosolids	Liquid	liquid
3.2	Biosolids processing method (see Table 3, page 10)	Lagoon > 10 years	anaerobic
3.3	Method of application (surface or injected)	Surface	surface
3.4	Number of days to incorporation of biosolids	No incorporation	no incorporation
3.5	Expected application season	Summer 2024	March to September

Laboratory biosolids analysis (dry weight basis):

If your biosolids analysis is on an "as is" or wet weight basis, you will need to divide your analysis by the percent total solids (line 3.10) and multiply the result by 100 to convert to a dry weight basis.

Line number		Your calculation	Example	Unit
3.6	Total Kjeldahl N (TKN)*	37,966.67	50,000	mg/kg
3.7	Ammonium N*	6,316.67	10,000	mg/kg
3.8	Nitrate N *,**	--	not analyzed	mg/kg
3.9	Organic N*,*** = line 3.6 – line 3.7	31,650.00	40,000	mg/kg
3.10	Total solids	2.13	2.5	percent

* If your analysis is in percent, multiply by 10,000 to convert to mg/kg.
** Nitrate-N analysis required for composted or aerobically digested biosolids, but not for anaerobically digested biosolids.
*** Organic N = total Kjeldahl N – ammonium N.

Step 4. Estimate plant-available N per dry ton of biosolids

Convert biosolids N analysis to lb per dry ton:

Line number		Your calculation	Example	Unit
4.1	Total Kjeldahl N (TKN)*	75.93	100	lb N/dry ton
4.2	Ammonium N*	12.63	20	lb N/dry ton
4.3	Nitrate N*	--	not analyzed	lb N/dry ton
4.4	Organic N = line 4.1 – line 4.2	63.30	80	lb N/dry ton

*Multiply mg/kg (from lines 3.6 through 3.9) × 0.002. If your analyses are expressed in percent, multiply by 20 instead of 0.002.

Estimate inorganic N retained:

Line number		Your calculation	Example	Unit
4.5	Percent of ammonium-N retained after application (see Table 2, page 9)	55	55	percent
4.6	Ammonium-N retained after application = line 4.2 × (line 4.5 ÷ 100)	6.95	11	lb N/dry ton
4.7	Biosolids inorganic N retained = line 4.3 + line 4.6	6.95	11	lb N/dry ton

Estimate organic N mineralized:

Line number		Your calculation	Example	Unit
4.8	Percent of organic N that is plant-available in Year 1 (see Table 3, page 10)	10	35	percent
4.9	First year plant-available organic N = line 4.4 × (line 4.8 ÷ 100)	6.33	28	lb N/dry ton

Plant-available N:

Line number		Your calculation	Example	Unit
4.10	Estimated plant-available N = available inorganic N (line 4.7) + available organic N (line 4.9)	13.28	39	lb N/dry ton

Step 5. Calculate the agronomic biosolids application rate

Line number		Your calculation	Example	Unit
5.1	Amount of plant-available N needed from biosolids (from line 2.3)	175	160	lb N/acre
5.2	Estimated plant-available N in biosolids (from line 4.10)	13.28	39	lb N/dry ton
5.3	Agronomic biosolids application rate = line 5.1 ÷ line 5.2	13.18	4.1	dry ton/acre

Step 6. Convert to "as is" biosolids basis

Desired units		Your calculation	Example
Gallons per acre =	(line 5.3 ÷ line 3.10) × 24,000	148,732.64	39,400
Inches per acre =	(line 5.3 ÷ line 3.10) × 0.88	5.45	1.44
Wet tons per acre =	(line 5.3 ÷ line 3.10) × 100	619.72	164

HOW TO USE THE WORKSHEET

Step 1. Collect site information

Soil series and surface soil texture (line 1.1)

Find the location on the Natural Resources Conservation Service (NRCS) soil survey. Record the series name and surface texture of the predominant soil. NRCS soil survey data is available online at https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm.

Crop yield goal (line 1.2)

Field records are the best source for crop yield estimates. You can find proven yields for most grain farms from the local Farm Service Agency office. For most other cropping systems, grower records are the only source available. Be sure to note whether the yield records are on an "as is" or dry matter basis.

A site used repeatedly for biosolids application should have yield data collected each year. Use this accumulated data for determining crop nitrogen requirement.

Yield data is typically not available for grazed pastures because grazing animals consume the crop in the field. In these cases, omit the yield goal and go directly to line 1.4. Estimate plant nitrogen needs from the appropriate university fertilizer/nutrient management guide, based on the level of pasture management.

Crop rotation (line 1.3)

Consult with the grower and discuss possible crop rotations. Rotations that include root crops or other crops with long post-application waiting periods are not suitable for Class B biosolids application. A companion publication (*Fertilizing with Biosolids*, PNW 508) provides more information about USEPA standards for Class A and Class B biosolids.

Plant-available N needed to produce yield goal (line 1.4)

You can estimate plant-available N needs by referring to university fertilizer/nutrient management guides.

University fertilizer and nutrient management guides

Land grant universities (for example, Washington State University, Oregon State University, and the University of Idaho) publish fertilizer and nutrient management guides that estimate plant-available N needs. Use the guide most appropriate for the site and crop. For major crops, guides may cover irrigated or rainfed (dryland) cropping and different geographic areas. Don't use guides produced for irrigated sites when evaluating dryland sites. When appropriate guides do not exist, consult university Extension agronomists/

soil scientists or professional agronomists (Certified Crop Advisors) who have expertise working within the cropping system.

Nitrogen fertilizer application rates listed in the fertilizer/nutrient management guides are based on field trials conducted under the specified climate and cultural conditions. Growth trial results are averaged over a variety of soil types and years. Note that guide recommendations are not the same as crop uptake. This is because the guides account for N available from mineralization of soil organic matter and the efficiency of N removal by the crop.

The N rate recommended in fertilizer/nutrient management guides assumes average yields, good management practices, and removal of N from the field through crop harvest or grazing. In terms of satisfying crop N needs, plant-available N from biosolids application is considered equal to fertilizer N.

Agronomist calculations

Because of the general nature of university fertilizer and nutrient management guides, it may be worthwhile to have a professional agronomist calculate how much plant-available N is needed for a specific field. The American Society of Agronomy certifies professional agronomists as Certified Crop Advisors (CCAs). See https://www.certifiedcropadviser.org for more information.

Always use the same method to calculate the N requirements. You will need to document your reasons for using agronomist calculations instead of the university guide.

Photo: Andy Bary, ©Washington State University

Dewatered biosolids stockpile at field application site

Plant-available N provided by other sources (lines 1.5 to 1.11)

To make sure there isn't too much nitrogen applied to a crop, you must determine how much nitrogen comes from sources other than biosolids and soil organic matter. These sources of N are grouped into three categories in the worksheet:

- Plant-available N estimated by pre-application testing
- Adjustments to typical soil organic N mineralization (usually obtained from an agronomist)
- Information supplied by the grower

N estimated by pre-application testing (lines 1.5 to 1.6)

Irrigation water

Since the amount of nitrate-N in irrigation water varies, it should be determined by water testing. Irrigation water containing 5 mg nitrate-N per liter will contribute 1.1 pounds of nitrogen per acre-inch applied; irrigation water containing 10 mg nitrate-N per liter will contribute 2.3 pounds of N per acre-inch.

Preplant nitrate-N in the root zone (east of Cascades)

You can estimate the preplant nitrate-N in the root zone by testing the soil in early spring. Sample in 1-foot increments to a depth of at least 2 feet.

Some university fertilizer/nutrient management guides use preplant soil nitrate-N when calculating N fertilizer application rates. If you use these guides, don't count soil test nitrate-N in our worksheet—it has already been accounted for in the recommended fertilizer N rate prescribed in the university fertilizer/nutrient management guide.

In dryland cropping systems, soil testing below 3 feet is used to assess long-term N management. Accumulation of nitrate below 3 feet indicates that past N applications were not efficiently utilized by the crop. However, soil nitrate-N below 3 feet is typically not included as a credit when making a N fertilizer recommendation.

Adjustments to typical soil N mineralization (lines 1.7 to 1.9)

Nitrogen mineralization is the release of nitrogen from organic forms to plant-available inorganic forms (ammonium and nitrate). Soil organic matter supplies plant-available N through mineralization, but this is accounted for in the university fertilizer/nutrient

management guides. Sites with a history of cover crops, biosolids applications, or manure applications supply more plant-available N than do sites without a history of these inputs, and biosolids recommendations must be adjusted based on this additional supply of N.

Plowdown of cover crops

Cover crops are not removed from the field, but are recycled back into the soil. You can get an estimate of the total N contributed by estimating the biomass dry matter (lb per acre) and the nitrogen concentration (percent total) in the cover crop. Plant-available N provided by a cover crop typically ranges from 10 to 40 percent of the total N contained in aboveground cover crop biomass. Consult *Estimating Plant-Available Nitrogen Release from Cover Crops* (PNW 636) for more information.

Previous biosolids applications

Previous biosolids applications contribute to plant-available nitrogen in the years after the initial application. In the worksheet, they are considered as "N from other sources." We estimate that 8, 3, 1, and 1 percent of the organic N *originally applied* mineralizes in Years 2, 3, 4, and 5, respectively, after application (Table 1). After Year 5, biosolids N is considered part of "stable" soil organic matter and is not included in calculations.

In using Table 1, consider the following example. Suppose:

- You applied biosolids with an average organic N content of 30,000 mg/kg
- Applications were made the previous 2 years
- The application rate was 4 dry tons per acre

Table 1 gives estimates of nitrogen credits *in terms of the organic N originally applied*. Look up 30,000 mg/kg under Year 2 and Year 3 columns in the table. The table estimates 4.8 lb plant-available N per dry ton for year 2, and 1.8 lb plant-available N for year 3 (two-year credit of 6.6 lb N per dry ton). To calculate the N credit in units of lb per acre, multiply your application rate (4 dry ton per acre) by the N credit per ton (6.6 lb N per dry ton). The N credit is 26.4 lb plant-available N per acre.

Previous manure applications

Previous manure applications contribute to plant-available nitrogen in a similar manner to previous biosolids applications. To estimate this contribution, consider field history (manure type, application rate, and date of application). The Extension publication *Fertilizing with Manure and Other Organic Amendments* (PNW 533) provides plant-available N estimates.

Information supplied by the grower (line 1.10)

N applied at seeding

Some crops need a starter fertilizer (N applied at seeding) for best growth. These fertilizers usually supply N, P, and S. Examples are 16-20-0, 10-34-0. Starters are usually applied at rates that supply 10 to 30 lb N per acre. Enter all N supplied by starter fertilizer on line 1.10 in the worksheet.

Table 1. Estimated nitrogen credits for previous biosolids applications at a site

	Years after biosolids application			
	Year 2	Year 3	Year 4 and 5	Cumulative (Years 2, 3, 4, and 5)
	Percent of organic N applied first year			
	8	3	1	13
Biosolids organic N as applied (mg/kg dry weight basis)	**Plant-available N released (lb N per dry ton)**			
10,000	1.6	0.6	0.2	2.6
20,000	3.2	1.2	0.4	5.2
30,000	4.8	1.8	0.6	7.8
40,000	6.4	2.4	0.8	10.4
50,000	8.0	3.0	1.0	13.0
60,000	9.6	3.6	1.2	15.6

Photo: Brian Campbell, Natural Selection Farms

Dewatered biosolids application to dryland wheat during fallow

Step 2. Estimate plant-available N needed from biosolids

Next you will estimate the amount of plant-available N the biosolids must provide. This is the difference between the total plant-available N needed to produce the yield goal and the plant-available N from other sources.

Step. 3. Collect biosolids data

To make the calculation, managers will need the following analyses:

- Total Kjeldahl N (TKN)
- Ammonium-N (NH_4-N)
- Nitrate-N (NO_3-N; composted or aerobically digested biosolids only)
- Percent total solids

If your laboratory results are on an "as is" or wet weight basis, you must convert them to a dry weight basis. To convert from an "as is" to a dry weight basis, divide your analysis by the percent solids in the biosolids and multiply the result by 100. Total Kjeldahl N includes over 95 percent of the total N in biosolids. In using the worksheet, we will assume that total Kjeldahl N equals total N.

Ammonium-N usually makes up most of the inorganic N present in biosolids. Depending on your laboratory, results for ammonium-N may be expressed as either ammonia-N (NH_3-N) or ammonium-N (NH_4-N). Make sure that the laboratory determines ammonium-N on a fresh (not dried) biosolids sample. The ammonium-N present in fresh biosolids is lost as gaseous ammonia when biosolids are dried.

There may be significant amounts of nitrate in aerobically digested biosolids or in composts. There is little nitrate in anaerobically digested biosolids; therefore, nitrate analysis is not needed for these materials.

Determine biosolids organic N by subtracting ammonium-N from total Kjeldahl N (line 3.6 minus line 3.7). Percent total solids analyses are used to calculate application rates. Biosolids applications are calculated as the dry weight of solids applied per acre (e.g., dry tons per acre).

Step 4. Estimate plant-available N per dry ton of biosolids

The estimate of plant-available N per dry ton of biosolids includes:

- Some of the ammonium-N
- All of the nitrate-N
- Some of the organic N

Inorganic N retained (lines 4.5 to 4.7)

Ammonium-N (lines 4.5 to 4.6)

Under some conditions, ammonium is readily transformed to ammonia and lost as a gas. This gaseous ammonia loss reduces the amount of plant-available N supplied by biosolids. The following section explains the factors used to estimate ammonia-N retained in plant-available form after application.

Biosolids processing

The following types of biosolids processing cause most of the ammonia-N to be lost as ammonia gas or converted to organic forms before application:

- Drying beds
- Alkaline stabilization at pH 12
- Composting

Application method

Ammonia loss occurs only with surface application. Injecting liquid biosolids eliminates most ammonia loss, since the injected liquid is not exposed to the air. Surface applications of liquid biosolids lose less ammonia than do dewatered biosolids. For liquid biosolids, the ammonia is less concentrated and is held as NH_4^+ on negatively-charged soil surfaces after the liquid contacts the soil.

Ammonia loss is fastest just after application to the field. As ammonia is lost, the remaining biosolids are acidified—that is, each molecule of NH_3 lost generates H^+ (acidity). Acidification gradually slows ammonia loss.

Biosolids that remain on the soil surface will eventually reach a pH near 7, and further ammonia losses will be small. Ammonia loss takes place very rapidly after application, with most of the loss occurring during the first two days after application.

Time to soil incorporation

Tillage to cover biosolids can reduce ammonia loss by adsorption of ammonium-N onto soil particles.

Table 2 estimates the amount of ammonium-N retained after field application. To use this table, you will need information on biosolids stabilization processes, method of application (surface or injected), and the number of days to soil incorporation.

Nitrate-N (line 4.3)

We assume 100 percent availability of biosolids nitrate-N.

Organic N mineralized (lines 4.8 to 4.9)

Biosolids organic N, which includes proteins, amino acids, and other organic N compounds, is not available to plants at the time of application. Plant-available N is released from organic N through microbial activity in soil. This process is called mineralization. It is more rapid in soils that are warm and moist, and is slower in soils that are cold or dry. Biosolids organic N mineralization rates in soil also depend on the treatment plant processes that produced the biosolids.

Use Table 3 (page 10) to estimate biosolids mineralization rates based on processing. Use the middle of the range presented, unless you have information specific to the site or biosolids that justify using higher or lower values within the range.

Photo: City of Portland, Bureau of Environmental Services

Spring grass growth on dryland pasture following dewatered biosolids application (top) vs. no biosolids (bottom)

Step 5. Calculate the agronomic biosolids application rate

Perform this calculation using the results of the previous sections, as shown in lines 5.1 through 5.3.

Step 6. Convert agronomic biosolids application rate to "as is" basis

Use the appropriate conversion factors (given in Table 4, page 10) to convert to gallons, acre-inches, or wet tons per acre.

Table 2. Estimates of ammonium-N retained after biosolids application

	Surface-applied			Injected
	Liquid biosolids	Dewatered biosolids	Composted, air-dried, or heat-dried biosolids	All biosolids
Time to incorporation by tillage	**Ammonium-N retained (percent of applied)**			
Incorporated immediately	95	95	100	100
After 1 day	70	50	100	100
After 2 days	60	30	100	100
No incorporation	55	20	100	100

Table 3. First year mineralization estimates for organic N in biosolids

Processing	First-year organic N mineralization rate (percent of organic N)
Fresh*	
Anaerobic digestion, liquid or dewatered	30–40
Aerobic digestion, liquid or dewatered	30–40
Drying bed	30–40
Heat-dried	30–40
Lagoon	
Less than 6 months	30–40
6 months to 2 years	20–25
2 to 10 years	10–20
More than 10 years	5–10
Composting	0–10
Blends and soil products	†

*"Fresh" includes all biosolids that have not been stabilized by long-term storage in lagoons or composting.

†Because blends (with woody materials) and soil products that contain biosolids vary widely in composition and age depending on intended use, available N may vary widely among products. For blends, available N can be estimated through laboratory incubation studies.

Table 4. Conversion factors

1%	=	10,000 mg/kg or ppm 20 lb/ton
1 mg/kg	=	1 ppm 0.0001 % 0.002 lb/ton
1 wet ton	=	1 dry ton ÷ (percent solids × 0.01)
1 dry ton	=	1 wet ton × (percent solids × 0.01)
1 acre-inch	=	27,000 gallons

Other considerations for calculations

Small acreage sites without a reliable yield history

Some communities apply biosolids to small acreages managed by part-time farmers. In many of these cases, there is no reliable yield history for the site, and the goal of management is not to make the highest economic returns. You can be sure of maintaining agronomic use of biosolids nitrogen on these sites by applying at a rate substantially below that estimated for maximum yield.

Equipment limitations at low application rates

At some low-rainfall dryland cropping locations east of the Cascades, the agronomic rate calculated with the worksheet will be lower than can be spread with manure spreaders (usually 2 to 3 dry tons per acre). At these locations, you may be able to apply the dewatered biosolids at the equipment limit, but check with your permitting agency for local requirements.

Appendix A: Cumulative loading of trace elements

Under EPA regulations (40 CFR Part 503.13), managers must maintain records on cumulative loading of trace elements only when bulk biosolids do not meet EPA Exceptional Quality Standards for trace elements (Table 5). Contact your regulatory agency for details on record keeping if your biosolids do not meet the standards in Table 5.

Table 5. Trace elements concentration limits for land application

Element	Symbol	Concentration limit	
		Exceptional quality standard (EPA Table 3)* (mg/kg)	Ceiling limit (EPA Table 1)* (mg/kg)
Arsenic	As	41	75
Cadmium	Cd	39	85
Copper	Cu	1,500	4,300
Lead	Pb	300	840
Mercury	Hg	17	57
Molybdenum	Mo	**	75
Nickel	Ni	420	420
Selenium	Se	100	100
Zinc	Zn	2,800	7,500

Source: EPA 40 CFR Part 503

*EPA Table 3 and Table 1 refer to tables in EPA biosolids rule (40 CFR Part 503).

**Molybdenum concentration standard level is under review by the EPA.

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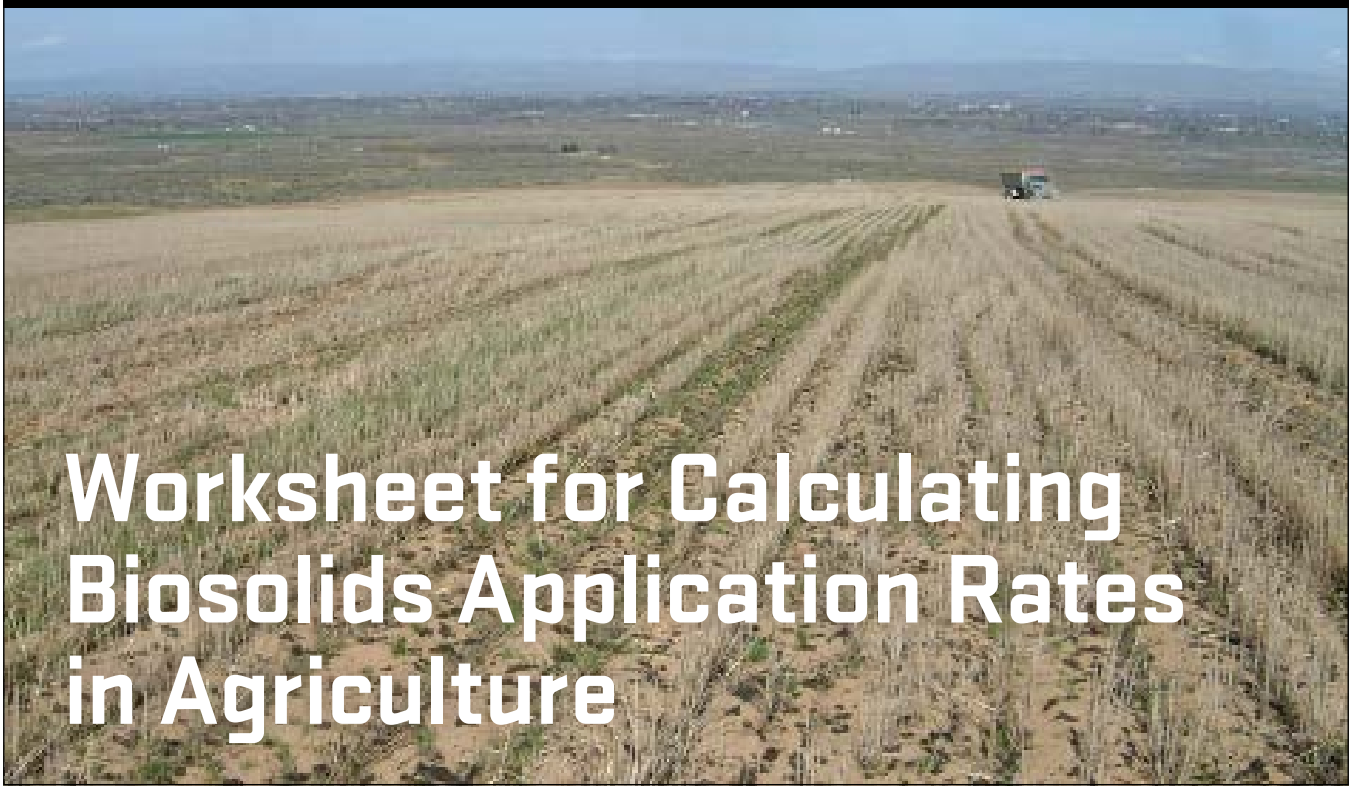

Worksheet for Calculating Biosolids Application Rates in Agriculture

Photo: Brian Campbell, Natural Selection Farms

Dan M. Sullivan, Deirdre Griffin LaHue, Biswanath Dari, Andy I. Bary and Craig G. Cogger

Biosolids are a product of municipal wastewater treatment. Raw sewage solids must be processed to meet U.S. Environmental Protection Agency standards before they can be called biosolids. Biosolids contain organic matter and nutrients that are beneficial for soil and crop productivity.

This publication focuses on matching the nitrogen (N) supplied by biosolids to the nitrogen needs of the crop. Regulatory agencies require agronomic rate calculations for most biosolids applications to cropland.

Overview: agronomic rate calculation

There are six steps to calculate the agronomic rate of a biosolids application:

1. Collect information on the site and crop, including crop N requirement.
2. Estimate the plant-available N needed from the biosolids application.
3. Collect biosolids N data.
4. Estimate plant-available N per dry ton of biosolids.
5. Calculate the agronomic biosolids application rate on a dry ton basis.
6. Convert the application rate to an "as is" basis.

In determining biosolids application rates, it's important to evaluate trace element concentrations in biosolids and the regulatory limits for trace element application (see Appendix A). However, in almost all cases, nitrogen controls the biosolids application rate.

A companion publication, *Fertilizing with Biosolids* (PNW 508), provides additional information about the value of biosolids as a fertilizer. The "For more information" section of this publication gives a summary of Pacific Northwest research and Extension publications on land application of municipal biosolids.

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PNW 511 • February 2021

WORKSHEET

For guidance on completing this worksheet, see "How to Use the Worksheet," starting on page 5.

Step 1. Collect site information

Soil and crop information:

Line number		Your information	Example
1.1	Soil series and texture (NRCS soil survey)	Baldlock,Haines, Stanflow-Umapine, Umapine Silt Loam	Puyallup sandy loam
1.2	Yield goal (units/acre/year*) estimated from grower records or by agronomist**		5 tons/acre
1.3	Crop rotation (grower; e.g., wheat, fallow, wheat)	Pasture	perennial grass
1.4	Plant-available N needed to produce yield goal (university fertilizer/nutrient management guide; agronomist) (lb N/acre/year)	75	200 lb N/acre

Plant-available N provided by other sources:

Line number		Your calculation	Example	Unit
Pre-application testing				
1.5	Nitrate-N applied in irrigation water	0	10	lb N/acre
1.6	Preplant nitrate-N in root zone (east of Cascades)***	0	—	lb N/acre
Adjustments to typical soil N mineralization				
1.7	Plowdown of cover or green manure crop***	0	—	lb N/acre
1.8	Previous biosolids applications (see Table 1, page 7)	0	30	lb N/acre
1.9	Previous manure applications	0	—	lb N/acre
Grower information				
1.10	N applied at seeding (starter fertilizer)	0	—	lb N/acre
Total				
1.11	Total plant-available N from other sources = sum of lines 1.5 through 1.10	0	40	lb N/acre

* Yield goals may be expressed in weight (tons, pounds, etc.) or in volume (bushels).
** The American Society of Agronomy certifies professional agronomists as Certified Crop Advisors (CCAs). See https://www.certifiedcropadviser.org for more information.
*** Do not list here if these N sources were accounted for in the nitrogen fertilizer recommendation from a university fertilizer/nutrient management guide.

Step 2. Estimate the amount of plant-available N needed from biosolids

Line number		Your calculation	Example	Unit
2.1	Plant-available N needed to produce yield goal (from line 1.4)	75	200	lb N/acre
2.2	Plant-available N from other sources (from line 1.11)	0	40	lb N/acre
2.3	Amount of plant-available N needed from biosolids = line 2.1 – line 2.2	75	160	lb N/acre

Step 3. Collect biosolids data

Application information:

Line number		Your information	Example
3.1	Moisture content of biosolids	Liquid	liquid
3.2	Biosolids processing method (see Table 3, page 10)	Lagoon > 10 years	anaerobic
3.3	Method of application (surface or injected)	Surface	surface
3.4	Number of days to incorporation of biosolids	No incorporation	no incorporation
3.5	Expected application season	Summer 2024	March to September

Laboratory biosolids analysis (dry weight basis):

If your biosolids analysis is on an "as is" or wet weight basis, you will need to divide your analysis by the percent total solids (line 3.10) and multiply the result by 100 to convert to a dry weight basis.

Line number		Your calculation	Example	Unit
3.6	Total Kjeldahl N (TKN)*	37,966.67	50,000	mg/kg
3.7	Ammonium N*	6,316.67	10,000	mg/kg
3.8	Nitrate N *,**	--	not analyzed	mg/kg
3.9	Organic N*,*** = line 3.6 – line 3.7	31,650.00	40,000	mg/kg
3.10	Total solids	2.13	2.5	percent

* If your analysis is in percent, multiply by 10,000 to convert to mg/kg.
** Nitrate-N analysis required for composted or aerobically digested biosolids, but not for anaerobically digested biosolids.
*** Organic N = total Kjeldahl N – ammonium N.

Step 4. Estimate plant-available N per dry ton of biosolids

Convert biosolids N analysis to lb per dry ton:

Line number		Your calculation	Example	Unit
4.1	Total Kjeldahl N (TKN)*	75.93	100	lb N/dry ton
4.2	Ammonium N*	12.63	20	lb N/dry ton
4.3	Nitrate N*	--	not analyzed	lb N/dry ton
4.4	Organic N = line 4.1 – line 4.2	63.30	80	lb N/dry ton

*Multiply mg/kg (from lines 3.6 through 3.9) × 0.002. If your analyses are expressed in percent, multiply by 20 instead of 0.002.

Estimate inorganic N retained:

Line number		Your calculation	Example	Unit
4.5	Percent of ammonium-N retained after application (see Table 2, page 9)	55	55	percent
4.6	Ammonium-N retained after application = line 4.2 × (line 4.5 ÷ 100)	6.95	11	lb N/dry ton
4.7	Biosolids inorganic N retained = line 4.3 + line 4.6	6.95	11	lb N/dry ton

Estimate organic N mineralized:

Line number		Your calculation	Example	Unit
4.8	Percent of organic N that is plant-available in Year 1 (see Table 3, page 10)	10	35	percent
4.9	First year plant-available organic N = line 4.4 × (line 4.8 ÷ 100)	6.33	28	lb N/dry ton

Plant-available N:

Line number		Your calculation	Example	Unit
4.10	Estimated plant-available N = available inorganic N (line 4.7) + available organic N (line 4.9)	13.28	39	lb N/dry ton

Step 5. Calculate the agronomic biosolids application rate

Line number		Your calculation	Example	Unit
5.1	Amount of plant-available N needed from biosolids (from line 2.3)	75	160	lb N/acre
5.2	Estimated plant-available N in biosolids (from line 4.10)	13.28	39	lb N/dry ton
5.3	Agronomic biosolids application rate = line 5.1 ÷ line 5.2	5.65	4.1	dry ton/acre

Step 6. Convert to "as is" biosolids basis

Desired units		Your calculation	Example
Gallons per acre =	(line 5.3 ÷ line 3.10) × 24,000	63,742.56	39,400
Inches per acre =	(line 5.3 ÷ line 3.10) × 0.88	2.34	1.44
Wet tons per acre =	(line 5.3 ÷ line 3.10) × 100	265.59	164

HOW TO USE THE WORKSHEET

Step 1. Collect site information

Soil series and surface soil texture (line 1.1)

Find the location on the Natural Resources Conservation Service (NRCS) soil survey. Record the series name and surface texture of the predominant soil. NRCS soil survey data is available online at https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm.

Crop yield goal (line 1.2)

Field records are the best source for crop yield estimates. You can find proven yields for most grain farms from the local Farm Service Agency office. For most other cropping systems, grower records are the only source available. Be sure to note whether the yield records are on an "as is" or dry matter basis.

A site used repeatedly for biosolids application should have yield data collected each year. Use this accumulated data for determining crop nitrogen requirement.

Yield data is typically not available for grazed pastures because grazing animals consume the crop in the field. In these cases, omit the yield goal and go directly to line 1.4. Estimate plant nitrogen needs from the appropriate university fertilizer/nutrient management guide, based on the level of pasture management.

Crop rotation (line 1.3)

Consult with the grower and discuss possible crop rotations. Rotations that include root crops or other crops with long post-application waiting periods are not suitable for Class B biosolids application. A companion publication (*Fertilizing with Biosolids*, PNW 508) provides more information about USEPA standards for Class A and Class B biosolids.

Plant-available N needed to produce yield goal (line 1.4)

You can estimate plant-available N needs by referring to university fertilizer/nutrient management guides.

University fertilizer and nutrient management guides

Land grant universities (for example, Washington State University, Oregon State University, and the University of Idaho) publish fertilizer and nutrient management guides that estimate plant-available N needs. Use the guide most appropriate for the site and crop. For major crops, guides may cover irrigated or rainfed (dryland) cropping and different geographic areas. Don't use guides produced for irrigated sites when evaluating dryland sites. When appropriate guides do not exist, consult university Extension agronomists/

soil scientists or professional agronomists (Certified Crop Advisors) who have expertise working within the cropping system.

Nitrogen fertilizer application rates listed in the fertilizer/nutrient management guides are based on field trials conducted under the specified climate and cultural conditions. Growth trial results are averaged over a variety of soil types and years. Note that guide recommendations are not the same as crop uptake. This is because the guides account for N available from mineralization of soil organic matter and the efficiency of N removal by the crop.

The N rate recommended in fertilizer/nutrient management guides assumes average yields, good management practices, and removal of N from the field through crop harvest or grazing. In terms of satisfying crop N needs, plant-available N from biosolids application is considered equal to fertilizer N.

Agronomist calculations

Because of the general nature of university fertilizer and nutrient management guides, it may be worthwhile to have a professional agronomist calculate how much plant-available N is needed for a specific field. The American Society of Agronomy certifies professional agronomists as Certified Crop Advisors (CCAs). See https://www.certifiedcropadviser.org for more information.

Always use the same method to calculate the N requirements. You will need to document your reasons for using agronomist calculations instead of the university guide.

Photo: Andy Bary, ©Washington State University

Dewatered biosolids stockpile at field application site

Plant-available N provided by other sources (lines 1.5 to 1.11)

To make sure there isn't too much nitrogen applied to a crop, you must determine how much nitrogen comes from sources other than biosolids and soil organic matter. These sources of N are grouped into three categories in the worksheet:

- Plant-available N estimated by pre-application testing
- Adjustments to typical soil organic N mineralization (usually obtained from an agronomist)
- Information supplied by the grower

N estimated by pre-application testing (lines 1.5 to 1.6)

Irrigation water

Since the amount of nitrate-N in irrigation water varies, it should be determined by water testing. Irrigation water containing 5 mg nitrate-N per liter will contribute 1.1 pounds of nitrogen per acre-inch applied; irrigation water containing 10 mg nitrate-N per liter will contribute 2.3 pounds of N per acre-inch.

Preplant nitrate-N in the root zone (east of Cascades)

You can estimate the preplant nitrate-N in the root zone by testing the soil in early spring. Sample in 1-foot increments to a depth of at least 2 feet.

Some university fertilizer/nutrient management guides use preplant soil nitrate-N when calculating N fertilizer application rates. If you use these guides, don't count soil test nitrate-N in our worksheet—it has already been accounted for in the recommended fertilizer N rate prescribed in the university fertilizer/nutrient management guide.

In dryland cropping systems, soil testing below 3 feet is used to assess long-term N management. Accumulation of nitrate below 3 feet indicates that past N applications were not efficiently utilized by the crop. However, soil nitrate-N below 3 feet is typically not included as a credit when making a N fertilizer recommendation.

Adjustments to typical soil N mineralization (lines 1.7 to 1.9)

Nitrogen mineralization is the release of nitrogen from organic forms to plant-available inorganic forms (ammonium and nitrate). Soil organic matter supplies plant-available N through mineralization, but this is accounted for in the university fertilizer/nutrient

management guides. Sites with a history of cover crops, biosolids applications, or manure applications supply more plant-available N than do sites without a history of these inputs, and biosolids recommendations must be adjusted based on this additional supply of N.

Plowdown of cover crops

Cover crops are not removed from the field, but are recycled back into the soil. You can get an estimate of the total N contributed by estimating the biomass dry matter (lb per acre) and the nitrogen concentration (percent total) in the cover crop. Plant-available N provided by a cover crop typically ranges from 10 to 40 percent of the total N contained in aboveground cover crop biomass. Consult *Estimating Plant-Available Nitrogen Release from Cover Crops* (PNW 636) for more information.

Previous biosolids applications

Previous biosolids applications contribute to plant-available nitrogen in the years after the initial application. In the worksheet, they are considered as "N from other sources." We estimate that 8, 3, 1, and 1 percent of the organic N *originally applied* mineralizes in Years 2, 3, 4, and 5, respectively, after application (Table 1). After Year 5, biosolids N is considered part of "stable" soil organic matter and is not included in calculations.

In using Table 1, consider the following example. Suppose:

- You applied biosolids with an average organic N content of 30,000 mg/kg
- Applications were made the previous 2 years
- The application rate was 4 dry tons per acre

Table 1 gives estimates of nitrogen credits *in terms of the organic N originally applied*. Look up 30,000 mg/kg under Year 2 and Year 3 columns in the table. The table estimates 4.8 lb plant-available N per dry ton for year 2, and 1.8 lb plant-available N for year 3 (two-year credit of 6.6 lb N per dry ton). To calculate the N credit in units of lb per acre, multiply your application rate (4 dry ton per acre) by the N credit per ton (6.6 lb N per dry ton). The N credit is 26.4 lb plant-available N per acre.

Previous manure applications

Previous manure applications contribute to plant-available nitrogen in a similar manner to previous biosolids applications. To estimate this contribution, consider field history (manure type, application rate, and date of application). The Extension publication *Fertilizing with Manure and Other Organic Amendments* (PNW 533) provides plant-available N estimates.

Information supplied by the grower (line 1.10)

N applied at seeding

Some crops need a starter fertilizer (N applied at seeding) for best growth. These fertilizers usually supply N, P, and S. Examples are 16-20-0, 10-34-0. Starters are usually applied at rates that supply 10 to 30 lb N per acre. Enter all N supplied by starter fertilizer on line 1.10 in the worksheet.

Table 1. Estimated nitrogen credits for previous biosolids applications at a site

	Years after biosolids application			
	Year 2	Year 3	Year 4 and 5	Cumulative (Years 2, 3, 4, and 5)
	Percent of organic N applied first year			
	8	3	1	13
Biosolids organic N as applied (mg/kg dry weight basis)	**Plant-available N released (lb N per dry ton)**			
10,000	1.6	0.6	0.2	2.6
20,000	3.2	1.2	0.4	5.2
30,000	4.8	1.8	0.6	7.8
40,000	6.4	2.4	0.8	10.4
50,000	8.0	3.0	1.0	13.0
60,000	9.6	3.6	1.2	15.6

Photo: Brian Campbell, Natural Selection Farms

Dewatered biosolids application to dryland wheat during fallow

Step 2. Estimate plant-available N needed from biosolids

Next you will estimate the amount of plant-available N the biosolids must provide. This is the difference between the total plant-available N needed to produce the yield goal and the plant-available N from other sources.

Step. 3. Collect biosolids data

To make the calculation, managers will need the following analyses:

- Total Kjeldahl N (TKN)
- Ammonium-N (NH_4-N)
- Nitrate-N (NO_3-N; composted or aerobically digested biosolids only)
- Percent total solids

If your laboratory results are on an "as is" or wet weight basis, you must convert them to a dry weight basis. To convert from an "as is" to a dry weight basis, divide your analysis by the percent solids in the biosolids and multiply the result by 100. Total Kjeldahl N includes over 95 percent of the total N in biosolids. In using the worksheet, we will assume that total Kjeldahl N equals total N.

Ammonium-N usually makes up most of the inorganic N present in biosolids. Depending on your laboratory, results for ammonium-N may be expressed as either ammonia-N (NH_3-N) or ammonium-N (NH_4-N). Make sure that the laboratory determines ammonium-N on a fresh (not dried) biosolids sample. The ammonium-N present in fresh biosolids is lost as gaseous ammonia when biosolids are dried.

There may be significant amounts of nitrate in aerobically digested biosolids or in composts. There is little nitrate in anaerobically digested biosolids; therefore, nitrate analysis is not needed for these materials.

Determine biosolids organic N by subtracting ammonium-N from total Kjeldahl N (line 3.6 minus line 3.7). Percent total solids analyses are used to calculate application rates. Biosolids applications are calculated as the dry weight of solids applied per acre (e.g., dry tons per acre).

Step 4. Estimate plant-available N per dry ton of biosolids

The estimate of plant-available N per dry ton of biosolids includes:

- Some of the ammonium-N
- All of the nitrate-N
- Some of the organic N

Inorganic N retained (lines 4.5 to 4.7)

Ammonium-N (lines 4.5 to 4.6)

Under some conditions, ammonium is readily transformed to ammonia and lost as a gas. This gaseous ammonia loss reduces the amount of plant-available N supplied by biosolids. The following section explains the factors used to estimate ammonia-N retained in plant-available form after application.

Biosolids processing

The following types of biosolids processing cause most of the ammonia-N to be lost as ammonia gas or converted to organic forms before application:

- Drying beds
- Alkaline stabilization at pH 12
- Composting

Application method

Ammonia loss occurs only with surface application. Injecting liquid biosolids eliminates most ammonia loss, since the injected liquid is not exposed to the air. Surface applications of liquid biosolids lose less ammonia than do dewatered biosolids. For liquid biosolids, the ammonia is less concentrated and is held as NH_4^+ on negatively-charged soil surfaces after the liquid contacts the soil.

Ammonia loss is fastest just after application to the field. As ammonia is lost, the remaining biosolids are acidified—that is, each molecule of NH_3 lost generates H^+ (acidity). Acidification gradually slows ammonia loss.

Biosolids that remain on the soil surface will eventually reach a pH near 7, and further ammonia losses will be small. Ammonia loss takes place very rapidly after application, with most of the loss occurring during the first two days after application.

Time to soil incorporation

Tillage to cover biosolids can reduce ammonia loss by adsorption of ammonium-N onto soil particles.

Table 2 estimates the amount of ammonium-N retained after field application. To use this table, you will need information on biosolids stabilization processes, method of application (surface or injected), and the number of days to soil incorporation.

Nitrate-N (line 4.3)

We assume 100 percent availability of biosolids nitrate-N.

Organic N mineralized (lines 4.8 to 4.9)

Biosolids organic N, which includes proteins, amino acids, and other organic N compounds, is not available to plants at the time of application. Plant-available N is released from organic N through microbial activity in soil. This process is called mineralization. It is more rapid in soils that are warm and moist, and is slower in soils that are cold or dry. Biosolids organic N mineralization rates in soil also depend on the treatment plant processes that produced the biosolids.

Use Table 3 (page 10) to estimate biosolids mineralization rates based on processing. Use the middle of the range presented, unless you have information specific to the site or biosolids that justify using higher or lower values within the range.

Photo: City of Portland, Bureau of Environmental Services

Spring grass growth on dryland pasture following dewatered biosolids application (top) vs. no biosolids (bottom)

Step 5. Calculate the agronomic biosolids application rate

Perform this calculation using the results of the previous sections, as shown in lines 5.1 through 5.3.

Step 6. Convert agronomic biosolids application rate to "as is" basis

Use the appropriate conversion factors (given in Table 4, page 10) to convert to gallons, acre-inches, or wet tons per acre.

Table 2. Estimates of ammonium-N retained after biosolids application

	Surface-applied			Injected
	Liquid biosolids	Dewatered biosolids	Composted, air-dried, or heat-dried biosolids	All biosolids
Time to incorporation by tillage	**Ammonium-N retained (percent of applied)**			
Incorporated immediately	95	95	100	100
After 1 day	70	50	100	100
After 2 days	60	30	100	100
No incorporation	55	20	100	100

Table 3. First year mineralization estimates for organic N in biosolids

Processing	First-year organic N mineralization rate (percent of organic N)
Fresh*	
Anaerobic digestion, liquid or dewatered	30–40
Aerobic digestion, liquid or dewatered	30–40
Drying bed	30–40
Heat-dried	30–40
Lagoon	
Less than 6 months	30–40
6 months to 2 years	20–25
2 to 10 years	10–20
More than 10 years	5–10
Composting	0–10
Blends and soil products	†

*"Fresh" includes all biosolids that have not been stabilized by long-term storage in lagoons or composting.

†Because blends (with woody materials) and soil products that contain biosolids vary widely in composition and age depending on intended use, available N may vary widely among products. For blends, available N can be estimated through laboratory incubation studies.

Table 4. Conversion factors

1%	=	10,000 mg/kg or ppm 20 lb/ton
1 mg/kg	=	1 ppm 0.0001 % 0.002 lb/ton
1 wet ton	=	1 dry ton ÷ (percent solids × 0.01)
1 dry ton	=	1 wet ton × (percent solids × 0.01)
1 acre-inch	=	27,000 gallons

Other considerations for calculations

Small acreage sites without a reliable yield history

Some communities apply biosolids to small acreages managed by part-time farmers. In many of these cases, there is no reliable yield history for the site, and the goal of management is not to make the highest economic returns. You can be sure of maintaining agronomic use of biosolids nitrogen on these sites by applying at a rate substantially below that estimated for maximum yield.

Equipment limitations at low application rates

At some low-rainfall dryland cropping locations east of the Cascades, the agronomic rate calculated with the worksheet will be lower than can be spread with manure spreaders (usually 2 to 3 dry tons per acre). At these locations, you may be able to apply the dewatered biosolids at the equipment limit, but check with your permitting agency for local requirements.

Appendix A: Cumulative loading of trace elements

Under EPA regulations (40 CFR Part 503.13), managers must maintain records on cumulative loading of trace elements only when bulk biosolids do not meet EPA Exceptional Quality Standards for trace elements (Table 5). Contact your regulatory agency for details on record keeping if your biosolids do not meet the standards in Table 5.

Table 5. Trace elements concentration limits for land application

Element	Symbol	Concentration limit	
		Exceptional quality standard (EPA Table 3)* (mg/kg)	Ceiling limit (EPA Table 1)* (mg/kg)
Arsenic	As	41	75
Cadmium	Cd	39	85
Copper	Cu	1,500	4,300
Lead	Pb	300	840
Mercury	Hg	17	57
Molybdenum	Mo	**	75
Nickel	Ni	420	420
Selenium	Se	100	100
Zinc	Zn	2,800	7,500

Source: EPA 40 CFR Part 503

*EPA Table 3 and Table 1 refer to tables in EPA biosolids rule (40 CFR Part 503).

**Molybdenum concentration standard level is under review by the EPA.

For more information

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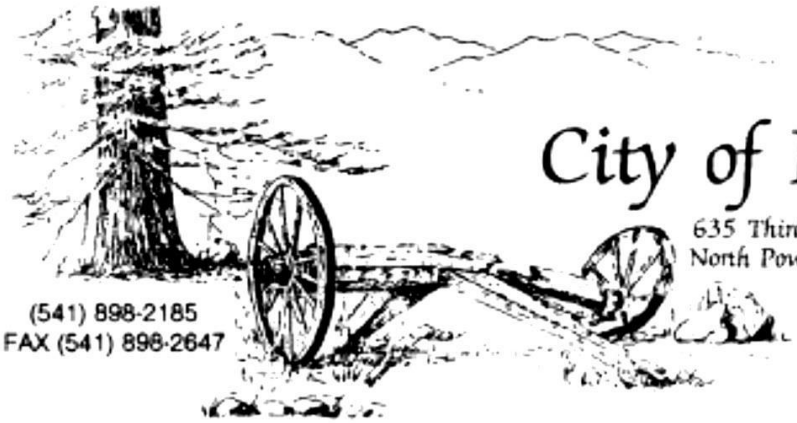
APPENDIX F
Example Notification Letter

DRAFT



City of North Powder

635 Third Street — P.O. Box 309
North Powder, Oregon 97867-0309

(541) 898-2185
FAX (541) 898-2647

Date

Address

RE: Proposed Application of Biosolids as Fertilizer Amendment

The City of North Powder has applied to the Oregon Department of Environmental Quality (DEQ) to land-apply biosolids on a property near you. The property currently proposed to receive the biosolids is located at Township 6 South, Range 39 East, Sections 23 and 26, Tax Lots 800 and 900. Please see the attached map.

Biosolids are a byproduct of domestic wastewater treatment that contain valuable nutrients. Various processes stabilize the biosolids, kill harmful bacteria, and control odors. The treated biosolids are frequently used instead of chemical fertilizers and, because many of the nutrients in the biosolids are less mobile in the soil, they are absorbed by the plants and are less likely to adversely affect our water resources. Additionally, the biosolids improve soil tilth and water-holding capacity and provide micronutrients not found in most chemical fertilizers.

The reuse of biosolids is regulated by the U.S. Environmental Protection Agency and the DEQ to protect public health and the environment. The DEQ inspects each proposed field and must approve the site prior to application. As part of this approval, the DEQ establishes buffer zones from sensitive areas such as wells, streams, roads, houses, etc.

Enclosed is a DEQ biosolids fact sheet. If you have any questions about the City of North Powder's biosolids program, please contact City Hall (541-443-2811). You may also learn more about the DEQ Biosolids Program on their website at: https://www.oregon.gov/deq/wq/programs/Pages/Biosolids.aspx

If you are not the resident or occupant of the property adjacent to this site but are the owner, please notify anyone who resides at this property of this proposed activity.

Sincerely,

CITY OF NORTH POWDER, OREGON

By_____

500 0 500

SCALE IN FEET

LEGEND

- PARCEL BOUNDARY
- BIOSOLIDS LAND APPLICATION SITE

Site 1

Site 2

Site 3

Site 4

Powder River

North Powder River

BIDWELL RD.

WASTEWATER TREATMENT FACILITY

237

Source: Esri, Maxar, Earthstar Geographics, IGN, and the GIS User Community

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anderson perry

CITY OF
NORTH POWDER, OREGON
SITE AUTHORIZATION DOCUMENTATION

BIOSOLIDS LAND APPLICATION SITES

FIGURE
3

Fact Sheet

Biosolids: A Beneficial Resource

Background

Biosolids are the nutrient-rich organic solids that are derived from the treatment of domestic wastewater at municipal wastewater facilities. Once biosolids have been treated to meet state and federal regulations, they can be beneficially used for land application or, in some cases, sold or given away like compost.

Recognizing the value of biosolids

Since 1978, DEQ has addressed the need to effectively manage the beneficial use of biosolids. Oregon's policy supports the land application of treated domestic wastewater biosolids, biosolids-derived products and domestic septage when managed in a manner that protects public health and maintains or improves environmental quality.

What is regulated?

The land application of biosolids, biosolids-derived products and domestic septage is a highly regulated practice. Regulatory requirements are established under Oregon Administrative Rules chapter 340, division 50. The state rules incorporate most of the federal technical biosolids regulations, including requirements for pathogen reduction, vector attraction reduction, and limits for trace pollutants. Monitoring is also required for several nutrients.

How biosolids are used

Land applying biosolids can have several benefits. The organic matter in biosolids can improve the quality and overall characteristics of cultivated soil. The additional nutrients provided by biosolids can improve plant growth. Approximately 95% of biosolids generated in Oregon are land applied on DEQ-approved sites for agricultural purposes such as hay and pasture. In 2001, biosolids from 108 domestic wastewater treatment facilities were land applied on 18,618 acres, which is about 0.11% of all Oregon land in farms. Biosolids are also used for silvicultural and horticultural activities. DEQ works with wastewater treatment facilities to ensure that management of biosolids and land application activities are adequately addressed through a National Pollutant Discharge Elimination System (NPDES) or Water Pollution Control Facility (WPCF) permit, a biosolids management plan, and site authorization letters. Good agronomic practices and site management activities ensure the protection of public health and the environment.

Land application of biosolids at an Oregon farm.

Biosolids Management Plans

Facilities are required to manage and operate their biosolids operations under a biosolids management plan. These plans are specific to each facility and are considered an extension of the facility's NPDES or WPCF permit. Together with a facility's permit and land application site authorizations, the plan provides assurance that biosolids processing and management activities are addressed in a comprehensive manner and problems with compliance are minimized. Plans must be current and on file with the permit. Each site used for land application of biosolids must be authorized by DEQ before use. Prior to authorizing a land application site, a facility must submit specific site information to DEQ for evaluation, and then DEQ will conduct a field visit. Notification to neighbors about the land application activity is also required. Any site that may be sensitive to residential housing or have runoff potential will be subject to a public comment process.

State rules also outline best management practices regarding use limitations, criteria for site selection and approval, and application.

For more information

For program information, please contact the program coordinator. For specific wastewater treatment facility and land application site information, please contact the appropriate regional specialist (list at right).

Alternative formats

Documents can be provided upon request in an alternate format for individuals with disabilities or in a language other than English for people with limited English skills. To request a document in another format or language, call DEQ in Portland at 503-229-5696, or toll-free in Oregon at 1-800-452-4011, ext. 5696; or email deqinfo@deq.state.or.us.

State of Oregon
Department of Environmental Quality

Biosolids Program
700 NE Multnomah St., Suite 600
Portland, OR 97232
Phone: 503-229-5696
800-452-4011
Fax: 503-229-6762
Contact: Pat Heins
www.oregon.gov/DEQ

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DEQ is a leader in restoring, maintaining and enhancing the quality of Oregon's air, land and water.

Last updated: 9/25/18
By: Pat Heins