DEQ Water Quality Division

State of Oregon
Department of Environmental Quality

Northern Malheur County Groundwater Management Area BMP Implementation Report

December 29, 2003

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State of Oregon
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Introduction

The Northern Malheur County Groundwater Management Area (NMC GWMA) was declared in 1989 after widespread groundwater nitrate contamination was identified that had resulted primarily from nonpoint source activities. Oregon DEQ and a citizen's advisory committee (Northern Malheur County Groundwater Management Committee) created an Action Plan for restoring the groundwater nitrate concentrations to acceptable levels. The Action Plan identifies specific "measures" to gauge the success of groundwater restoration activities in the area.

This report describes information related to the implementation of best management practices (BMPs) that have occurred through the efforts of growers, agricultural equipment suppliers, educational institutions, and government agencies in northern Malheur County, Oregon. These BMPs are being implemented as part of a program designed to improve groundwater quality conditions in the area. This report is a companion to the December 2003 "Northern Malheur County Groundwater Management Area Trend Analysis Report" which describes the analysis of groundwater quality data from the area. These two reports are summarized in a third document titled "Evaluation of Northern Malheur County Groundwater Management Area Action Plan Success" dated December 2003.

Purpose of the Study

The purpose of this report is to provide a discussion of the implementation of BMPs in the Groundwater Management Area (GWMA) and to evaluate whether or not the fourth measure of Action Plan success (i.e., the one stating that "other indicators of progress" be implemented) has been met. BMP implementation is one way of gauging the success of the Northern Malheur County Groundwater Management Area Action Plan.

Conclusions

Based on the information presented in this report, the following conclusions have been made.

- The fourth measure of Action Plan success (i.e., the one stating that "other indicators of progress" be implemented) has been met. Documentation of BMP implementation from 1997 to the present is needed to confirm the continued implementation of BMPs.
- There is a strong local commitment to maintain and expand the implementation of BMPs so that economic and environmental benefits can be realized and maintained.
- The factors limiting widespread BMP implementation are very real and difficult to overcome.
- Continued education and research into new technologies and practices are necessary to maintain and build upon the successes realized to date.

Recommendations

Based on the conclusions presented above, the following recommendations are made. These recommendations are grouped according to the responsible parties.

Groundwater Management Committee, Malheur County SWCD, NRCS, FSA, Malheur and Owyhee Watershed Councils, and Oregon State University

- As available and appropriate, provide financial and technical support to assist in the implementation of established BMPs and continued research to identify additional appropriate BMPs in the GWMA.
- Seek to educate growers and other citizens about factors related to groundwater contamination.
- Encourage projects such as deep soil sampling to evaluate changes in the amount and movement of nitrate within the unsaturated zone.

- Develop and maintain documentation of the extent to which the other indicators of progress identified in the Action Plan have been implemented since 1997.

DEQ
- As available and appropriate, provide financial and technical support to assist in the implementation of established BMPs and continued research to identify additional appropriate BMPs in the GWMA.
- Encourage projects such as deep soil sampling to evaluate changes in the amount and movement of nitrate within the unsaturated zone.

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1.0 INTRODUCTION

The Northern Malheur County Groundwater Management Area (NMC GWMA) was declared in 1989 after widespread groundwater nitrate contamination was identified that had resulted primarily from nonpoint source activities. Oregon DEQ and a citizen's advisory committee created an Action Plan for restoring the groundwater nitrate concentrations to acceptable levels. The Action Plan identifies specific "measures" to gauge the success of groundwater restoration activities in the area. Some of these measures of Action Plan success are related to the implementation of groundwater quality best management practices (BMPs).

This report provides information related to the implementation of groundwater quality BMPs that have occurred through the efforts of growers, agricultural fertilizer suppliers, educational institutions, and government agencies in northern Malheur County, Oregon. These BMPs are being implemented as part of a program designed to improve groundwater quality conditions in the area. Much of the information included in this report is from the Ontario Hydrologic Unit Area (HUA) Final Report 1990 - 1997. Additional information in this report was provided by the Oregon State University Malheur Experiment Station, the Malheur County Soil & Water Conservation District, the Malheur Watershed Council, and the Owyhee Watershed Council. This report is a companion to the December 2003 "Northern Malheur County Groundwater Management Area Trend Analysis Report" which describes the analysis of groundwater quality data from the area. These two reports are summarized in a third document titled "Evaluation of Northern Malheur County Groundwater Management Area Action Plan Success" dated December 2003.

This section of the report provides information on the establishment of the Northern Malheur County Groundwater Management Area, what BMPs are, the purpose of this report, and ways to measure success of the Northern Malheur County Groundwater Management Action Plan.

1.1 Establishment of Northern Malheur County Groundwater Management Area

Oregon's Groundwater Protection Act of 1989 requires the Oregon Department of Environmental Quality (DEQ) to declare a Groundwater Management Area (GWMA) if area-wide groundwater contamination, caused primarily by nonpoint source pollution, exceeds certain trigger levels.

Nonpoint source pollution of groundwater results from contaminants coming from diffuse land use practices, rather than from discrete sources such as a pipe or ditch. The contaminants of nonpoint source pollution can be the same as from point source pollution, and can include sediment, nutrients, pesticides, metals, and petroleum products. The sources of nonpoint source pollution can include construction sites, agricultural areas, forests, stream banks, roads, commercial areas, industrial areas, and residential areas.

The Groundwater Protection Act also requires the establishment of a local Groundwater Management Area Committee comprised of affected and interested parties. The committee works with and advises the state agencies that are required to develop an action plan that will reduce groundwater contamination in the area.

The Northern Malheur County GWMA was declared in 1989 after groundwater contamination was identified in an 115,000-acre area in the northeastern portion of the county where land use is dominated by agriculture. Its boundary starts at the mouths of the Malheur and Owyhee Rivers where they converge with the Snake River and extends to the uppermost irrigation canals. The approximate location of the Northern Malheur County GWMA is indicated in Figure 1-1. Major roads and water bodies within the GWMA are identified in Figure 1-2.

Groundwater samples from private water wells identified nitrate contamination and the presence of the pesticide Dacthal[1] and its breakdown products (hereafter known as DCPA & metabolites). Traditional fertilizer and agricultural chemical application practices are believed to be the main source of the contamination. Other possible sources of nitrate identified in northern Malheur County include residential lawn care, on-site sewage systems (i.e., septic tanks), and confined animal

[1] Dacthal is a trade name for dimethyl tetrachloroterephthalate (DCPA). Dacthal is the term used in the Action Plan and on analytical reports.

feed lot operations. It should be noted that the analytical method used consistently throughout the associated groundwater sampling program does not distinguish between DCPA and its metabolites (i.e., one value representing the sum of the parent and daughter products is reported). However, when a different analytical technique was occasionally used, it was determined that DCPA was not detected but its metabolite(s) were detected. Therefore, concentrations reported as "DCPA & metabolites" are likely representative of only the metabolite(s).

Sampling confirmed that most of the contaminated groundwater is present in the shallow alluvial sand and gravel aquifer which receives a large proportion of its recharge from canal leakage and irrigation water. Therefore, the shallow aquifer is the focus of the Northern Malheur County Groundwater Management Action Plan, hereafter referred to as the Action Plan (Malheur County Groundwater Management Committee, 1991).

The Northern Malheur County Groundwater Management Committee, the Technical Advisory Subcommittee, and representatives from the DEQ, the Oregon Department of Agriculture (ODA), the Oregon Water Resources Department (OWRD), the Oregon Department of Human Services (formerly known as the Oregon Health Division (OHD), and Oregon State University (OSU) conducted an 18-month effort ending with the approval of the Action Plan which is aimed at reducing groundwater contamination in the GWMA.

The Action Plan includes detailed information on water quality, identification of contaminant sources, and recommendations for implementation of BMPs to improve groundwater quality. This approach allows farmers to customize a sequence or system of available BMPs to their individual farm operations. The Committee chose to implement the Action Plan on a voluntary basis recognizing that individuals, businesses, organizations, and governments will, if given adequate information and encouragement, take positive actions and adopt or modify practices and activities to reduce contaminant loading to groundwater.

1.2 Purpose Of This Report

The purpose of this report is to provide a discussion of the implementation of BMPs in the GWMA and to evaluate whether or not the fourth measure of Action Plan success (i.e., the one stating that "other indicators of progress" be implemented) has been met. As discussed in Section 1.4, BMP implementation is one way of gauging the success of the Action Plan. The Action Plan is available at http://www.deq.state.or.us/wq/groundwa/NMalheurGWMgmtArea.htm

1.3 What are BMPs?

The following discussion of BMPs is taken from the Oregon Department of Agriculture, Natural Resources Division, Water Quality Program website http://www.oda.state.or.us/nrd/water_quality/bmp.html. The website also provides "a collection of BMP publications gathered from Cooperative Extension Service web sites here in the Northwest, as well as throughout the United States. This collection is by no means all inclusive of every BMP that exists. Rather, it is intended to show the range and types of BMPs that are available and how different states have approached common nonpoint source pollution issues." Readers desiring more information are encouraged to visit the website.

> Best Management Practices (BMPs) are techniques used to control the generation or delivery of potential pollutants from agricultural activities, while maintaining profitable crop and livestock production.
>
> BMPs can be managerial (rotational grazing, fertilizer or pesticide management, conservation tillage, etc.), vegetative (filter strips, grassed waterways, cover crops, etc.) or structural (animal waste lagoons, terraces, sediment basins, fencing, etc.). While the vast array of BMPs are important, good management is vital to effectively reduce agricultural nonpoint source pollution.
>
> The installation or use of a single BMP is rarely sufficient to control the pollutant of concern. Combinations of BMPs that control the same pollutant are generally most effective. These combinations or systems of BMPs can be specifically tailored for particular agricultural and environmental conditions, as well as for a particular pollutant. In general, systems of BMPs are required to effectively control

pollutant sources in critical areas. A BMP system is any combination of BMPs used together to comprehensively control a pollutant from the same source and same cause.

Transport of agricultural pollutants to surface and ground water can be controlled by:

- Minimizing pollutant load at the source;
- Retarding the transport of the pollutant, either by reducing water and pollutant transported, or through chemical or biological transformation; or
- Remediating or intercepting the pollutant before it reaches the water resource

An individual BMP can only control a pollutant at its source, during transport, or at the water's edge. Systems of BMPs are generally more effective in controlling the pollutant since they can be used at two or more points in the pollutant delivery pathway. For example, the objective of many agricultural nonpoint source pollution projects is to reduce the loss of soil from cropland. A system of BMPs can be designed to help reduce soil detachment, thus limiting the potential for soil to erode, and also reducing off-site transport of eroded soil. Conservation tillage systems can be used to reduce the amount of on-site soil loss. Field borders can be used to reduce sediment transport, and sediment retention basins can be used to intercept the sediment.

Sometimes one BMP cannot be used without an accompanying BMP. For example, if it is necessary to fence cows out of a stream and there are no alternative water sources, watering devices must be installed. This type of BMP system is an example of a necessary diversified BMP system.

There is no single "best" BMP system to control a particular pollutant. Rather the BMP system should be determined based on the type of pollutant; the source of the pollutant; the site-specific agricultural, climatic, and environmental conditions; the economic situation of the farm operator; the experience of the system designers; and the acceptability of alternative BMPs to the producer. A system of BMPs designed to address a specific pollutant from a particular source must comprehensively address the pollution problem.

BMP systems are more effective at controlling agricultural nonpoint source pollution than are individual BMPs because BMP systems minimize the impact of a pollutant at the source, during the transport process, and through remediation or interception. However, systems of BMPs constitute only part of an effective land treatment strategy for an overall basin agricultural water quality management plan. In order for a land treatment strategy to be really effective, properly designed BMP systems must be placed in the correct locations in the watershed (critical areas) and the extent of land treatment must be sufficient to achieve water quality improvements.

Because financial resources are generally limited, BMP system implementation should be prioritized. Systems of BMPs should first be implemented at the locations in the critical area that contribute the largest proportion of the pollutant of concern. The remaining critical area locations can then be treated with BMP systems as feasible, based on availability of funds and practicality.

1.4 Measures Of Action Plan Success

The Action Plan specifies four specific ways to gauge success. Three of these are related to water quality trends (i.e., changes in groundwater quality over time) in response to adoption of BMPs. The fourth measure of success involves the adoption of BMPs (i.e., “other indicators of progress”).

According to these criteria, the Action Plan will be considered successful if:

(1) a trend analysis indicates, at a 75% confidence level, that the level of the nitrate monitoring data for the entire management area is 7 mg/l; or

(2) a trend analysis indicates, at an 80% confidence level, that nitrate levels will reach 7 mg/l by July 1, 2000; or

(3) a statistically significant downward trend can be demonstrated at the 80% confidence level; or

(4) other indicators show progress toward this goal. Other indicators of progress may include but are not limited to the following:

- number of producers adopting farm plans;
- an increase in utilization of soil testing to improve fertilization practices;
- an increase in efficiency of nitrogen fertilizer application: timing, placement, form, & rate;
- an increase in irrigation efficiency, reducing deep percolation;
- a vadose zone drilling project demonstrating decrease in concentrations of nitrate;
- number of water quality practices being applied; and
- Ontario Hydrologic Unit Area reports and evaluations of progress and effectiveness.

The first three measures of success (i.e., those related to water quality trends) are discussed in the companion document titled “Northern Malheur County Groundwater Management Area Trend Analysis Report”. The fourth measure of success (i.e., the other indicators of progress) is discussed in this report. The success of the Action Plan as a whole is discussed in the document titled “Evaluation of Northern Malheur County Groundwater Management Area Action Plan Success”.

2.0 RECENT CHANGES IN MALHEUR COUNTY FARMING PRACTICES

Many changes have occurred in farming practices in Malheur County since the early 1980s. Some of these changes are identified as measures of Action Plan success described in Section 1.4 and are discussed in Section 3.0. Other changes that have occurred are not specifically identified as measures of Action Plan success. This section of the report provides an outline of recent changes in Malheur County farming practices. As time and resources allow, details will be added to the outline to fully describe the range of activities implemented by the Malheur County agricultural community to improve surface water and groundwater quality.

2.1 Agricultural Practices in the Early 1980's

2.1.1 Water and Soil Use Practices

- Soil preparation and cultivation practices
- Spring preparation and bedding of land
- Surface irrigation systems of concrete ditches, siphon tubes
- Lack of weed screens, laser leveling, gated pipe, etc.
- Foundations of irrigation scheduling

2.1.2 Fertilizer Use

- Use of fixed formulas: fertilizer application based on standard average formulas, not soil analysis
- Fertilizer rates were determined by the growers financial condition and yield aspirations, not based on carefully identified crop needs.
- Fall application of fertilizer
- University fertilizer guides were based on yield maximization with little consideration for off site effects.

2.1.3 Fate of Crop Residues

- Alfalfa seed screenings
- Potato waste
- Cull onions
- Mushroom compost

2.1.4 Labor considerations

- Onion weed control
- Harvesting onions

2.1.5 Contradictions and problems

2.2 Research and Demonstrations Conducted

2.2.1 Irrigation Management

2.2.1.1 Efficiency of furrow irrigation and irrigation induced erosion

- Laser leveling
- Straw mulch
- Gated pipe
- Surge irrigation
- PAM
- Sedimentation basins and pump back systems
- Turbulent fountain weed screens

2.2.1.2 Irrigation scheduling

- Monitoring equipment
- Potatoes
- Onions
- Poplars
- Evapotranspiration
- Extension of soil moisture monitoring to growers and its automation

2.2.1.3 Changes in irrigation systems

- Sprinkler irrigation
- Drip irrigation

2.2.2 Nutrition Management

2.2.2.1 Fertilizer timing

- Fall applications
- Split side-dressed applications

2.2.2.2 Fertilizer rates and the residual effects from the previous crop

- Onions
- Potatoes
- Examining fertilizer rates on a systematic basis
  - Wheat
  - Sugar beets
  - Onions

2.2.2.3 GIS/GPS soil sampling and placement of fertilizer

2.2.2.4 Nitrogen fertilizer guides

2.2.2.5 Recycling Crop Residues

- Alfalfa seed screenings
- Potato waste and onion sludge
- Cull onions
- Mushroom compost

2.2.3 Cultural Practices

2.2.3.1 Tillage Practices

- Fall bedding
- Reduced tillage

2.2.3.2 Weed Control

- Treatments compatible with fall bedding
- Dacthal Replacement

2.2.3.3 Reductions in Hand Labor

2.3 Implementation of New Practices

3.0 INDICATORS OF PROGRESS

This section of the report provides a summary of the BMPs implemented in the Northern Malheur County GWMA that are protective of groundwater quality. As indicated in Section 1.4, the success of the Action Plan can be measured in ways other than the evaluation of groundwater quality numbers. Advances in these "other indicators of progress" reflect the positive effects of BMP implementation and education. Some of this progress is documented in the Ontario Hydrologic Unit Area (HUA) Final Report 1990 - 1997 and summarized below. In addition to the information documented in the HUA Report, other efforts by local growers, suppliers, and agency personnel are also summarized below. Additional documentation of BMP implementation from 1997 to the present is needed.

In summary, major changes in agricultural practices have occurred since groundwater contamination was identified in the Malheur River area in the late 1980s. The method of nitrogen application in this area has been changed. Reduced nitrogen loading has been accomplished by changes in the timing and the application of nitrogen as well as the rate of application. Plant tissue and soil sampling have also played a major role in modifying practices for the application of nitrogen by enabling the producers to apply only the amount of nutrient needed and only when that nutrient is needed. Changes in irrigation management practices have also occurred that increase the protection of groundwater quality.

Table 3-1 identifies the extent of specific BMPs implemented between 1990 and 1997 for groundwater protection, surface water protection, erosion protection, irrigation water management, and animal waste management. Specific details regarding "other indicators of progress" identified in the Action Plan are as follows.

3.1 Number of Producers Adopting Farm Plans

Water quality farm plans are viewed as a set of progressive steps utilizing BMPs that lead to implementation of a Resource Management System. Plans are periodically reviewed and updated to include the newest BMPs available. Nearly all water quality plans written in the HUA include irrigation water management, nutrient management, and pesticide management as basic plan recommendations. Additional practices are included on a case-by-case basis and plans are tailored to individual farm requirements.

The number of water quality farm plans completed through the seven-year period of the HUA project and beyond indicates continued interest and involvement by the local growers. The total number of plans completed is as follows: 9 plans by 1991, 39 plans by 1992, 69 plans by 1993, 98 plans by 1994, 121 plans by 1995, 146 plans by 1996, and 156 plans by 1997. The 157 plans completed by 1997 represent approximately 44,000 acres, or about 28% of the total irrigated acres in the GWMA.

From 1997 through 2000, 65 new water quality farm plans were completed (averaging 12 to 15 per year). From 2001 through 2003, 40 new water quality farm plans were completed.

3.2 Improvements in Nutrient Management

Nitrogen fertilizing practices have changed in Malheur County. These changes have come about due to the research and outreach / demonstration projects completed by the OSU Malheur Experiment Station (MES), the OSU Cooperative Extension Service (CES), Malheur County Soil & Water Conservation District (SWCD), National Resource Conservation Service (NRCS), the Malheur Watershed Council, the Owyhee Watershed Council, United States Department of Agriculture programs such as Environmental Quality Improvement Program (EQIP) administered by the Farm Service Agency (FSA) and NRCS, and others. The economics of fertilization and the cooperation of the local fertilizer dealers have played important roles in these changes. These changes would not have occurred without cooperative financial and educational help from many partners, includingEPA, DEQ, CES, MES, ODA, SWCD, (FSA, NRCS, the watershed councils, and the local fertilizer dealers.

Table 3-1
Implementation of BMPs Within the Ontario HUA (FY 1990 – 1996)
Northern Malheur County GWMA BMP Implementation Report

Best Management Practice	Extent of Implementation	Protective of Groundwater	Protective of Surface Water	Protective Against Erosion	Irrigation Water Mgt Practice	Animal Waste Mgt Practice
Conservation Cropping Sequence	27,576 acres	✓	✓	✓		
Grasses & Legumes in Rotation	1,231 acres	✓	✓	✓		
Irrigation Water Management	46,891 acres	✓	✓	✓	✓	
Pasture / Hay Land Management	676 acres	✓	✓	✓		
Pasture / Hay Land Planting	285 acres	✓	✓	✓		
Nutrient Management	44,010 acres	✓	✓			
Waste Utilization	1,670 acres	✓				✓
Soil Testing	35,595 acres	✓	✓			
Fertilizer Application Timing	21,324 acres	✓	✓			
Tissue Analysis	19,098 acres	✓				
Split Application of Nitrogen	15,125 acres	✓	✓			
Banding of Nutrients	7,625 acres	✓	✓			
Surge Irrigation	160 acres	✓	✓	✓	✓	
Irrigation Scheduling	18,053 acres	✓	✓		✓	
Sprinkler Irrigation	6,737 acres	✓	✓	✓	✓	
Filter Strip	618 acres		✓	✓		
Tail Water Recovery System	16 systems		✓	✓	✓	
Irrigation Land Leveling	1,587 acres	✓	✓	✓	✓	
Straw Mulching	5,490 acres		✓	✓	✓	
Polyacrylamide (PAM)	16,725 acres		✓	✓		
Sediment Basins	8 basins			✓		
Irrigation Water Conveyance – Ditches	117,646 feet			✓	✓	
Irrigation Water Conveyance - Pipe	373,178 feet			✓	✓	
Structures for Water Control	330 structures				✓	
Bubblers	386 structures				✓	
Waste Management System	11 systems					✓
Waste Storage Structure	4 structures					✓
Waste Treatment Lagoon	2 lagoons					✓
Waste Storage Pond	5 ponds					✓

The improvements in nutrient management can be summarized as reducing the amount of nitrogen fertilizer used, budgeting the nitrogen, and utilizing deep-rooted crops planted in rotation with shallow-rooted crops (Shock et al. 1993, 1988a, 2000a). A brief description of each practice follows:

(1) Reducing the amount of nitrogen fertilizer used – The amount of nitrogen fertilizer can be reduced through determination and utilization of optimal:

- timing,
- placement, and
- rate of fertilizer application.

(2) Budgeting the nitrogen – Budgeting the nitrogen allows a better match of the amount applied to the amount used by the crop. To do this, the growers incorporate:

- soil testing results,
- plant tissue testing results, and
- nitrogen mineralization into the budget.

(3) Utilizing deep rooted crops – Utilizing deep rooted crops (e.g., sugar beets and wheat after onions and potatoes) allows the deeper rooted crops to recover residual soil nitrate and mineralized nitrogen.

Specific examples of nutrient management BMPs for locally grown crops are as follows:

- *Nitrogen Applications for Potatoes* –
  - Sample soil to determine the nitrogen fertilizer deficiency to produce the crop.
  - Apply the balance of nutrients that the soil test results indicate is required to meet the total uptake of the crop.
  - Nitrogen fertilizer shall not be applied after the last day of June during a growing season, unless the crop has been shown to be nitrogen deficient.
  - Potato plant nitrogen status is typically determined by petiole analyses.
  - Total nitrogen fertilizer applied during a given growing season shall not exceed 200 pounds of active nitrogen per acre, unless the crop has been shown to be nitrogen deficient.
  - Crop rotation patterns shall restrict potato production to a maximum of once every three years.
- *Nitrogen Applications For Onions* –
  - Sample soil to determine the fertilizer deficiency to produce the crop.
  - Between planting and 125 days after planting, apply the nitrogen fertilizer deficiency, as determined by the soil test.
  - Nitrogen fertilizer shall not be applied after the last day of July in a particular growing season, unless the crop has been shown to be nitrogen deficient.
  - Onion plant nitrogen status is typically determined by root nitrate content.
  - Total nitrogen fertilizer applied during a given growing season shall not exceed 300 pounds of active nitrogen per acre, unless the crop has been shown to be nitrogen deficient.
  - Crop rotation patterns should restrict onion production to a maximum of two out of every four years.
- *Nitrogen Applications For Sugar Beets* –
  - Sample soil to a minimum of 3 feet or hard pan to determine the fertilizer deficiency to produce the crop.

- If the soil test indicates the available nitrogen is less than the recommended rate of 8 lbs nitrogen per ton of beets anticipated at harvest, apply the amount of nitrogen to reach the recommended rate.
- Petiole sampling and testing will be performed periodically during the growing season to manage nitrogen applications.
- Total nitrogen fertilizer applied during a given growing season shall not exceed 300 pounds of active nitrogen per acre, unless the crop has been shown to be nitrogen deficient.
- Crop rotation patterns shall restrict beet production to a maximum of once every three years.

- Nitrogen fertilizer should only be applied in the spring or during the growing season.
- When using water run nitrogen, the nitrogen in the irrigation tail water needs to be minimized.

Very little, if any, nitrogen is now applied in the fall because fall nitrogen is more apt to be leached and interfere with crop seeding establishment. Soil samples are now commonly analyzed prior to any fertilization application; and the amount of residual soil nitrate and ammonium is factored into the total amount of fertilizer to be applied to the next crop. Fertilizer applications are typically applied in the spring, with a split application starting in March and ending in July. After the plants reach a prescribed size maturity, tissue samples are taken to see if more nutrients are needed for the plant to continue to be productive through full maturity. Petiole samples are taken from pototo and sugar beet, root samples are taken from onion, and flag leaf samples are taken from wheat.

One objective of the Ontario HUA was to reduce the nitrogen application by 20%. The Ontario HUA Final Report indicates that nitrogen application rates had been reduced by 1997, but not by the 20% goal. The report also indicates nitrogen is being applied more efficiently and at rates closer to plant needs. Since 1990, information and education activities targeting awareness of how much nitrogen is needed for crops as well as more efficient application methods have resulted in dramatic increases in practices such as soil testing, petiole testing, side dressing, banding, split applications and converting from fall to spring nitrogen applications. Field acres where nutrient management practices are being applied steadily increased throughout the seven-year period of the HUA project from less than 5,000 in 1991 to over 44,000 acres by 1997; representing approximately 28% of the 157,000 acres in the HUA.

3.3 Reduction of DCPA Application

There are more than 750,000 acres of irrigated cropland in the Treasure Valley, an area along the Snake River watershed that covers part of southwestern Idaho and southeastern Oregon that includes the GWMA. Onion is one of the most important irrigated crops in this valley. Onions compete poorly with weeds, and efficient weed control is essential to maintain an economically viable onion industry. DCPA is an effective herbicide to control weeds in onion fields and was commonly used throughout the GWMA (Shock et al., 2001). DCPA metabolites, however, have been found in shallow aquifers underlying parts of the intensively farmed areas of Malheur County, Oregon (Bruch, 1986; Parsons and Witt, 1988).

All pesticides sold or distributed in the U.S. must be registered by the United States Environmental Protection Agency (EPA), based on scientific studies showing that they can be used without posing unreasonable risks to people or the environment. Because of advances in scientific knowledge, the law requires that pesticides that were registered before November 1, 1984 be re-registered to ensure that they meet the current, more stringent, standards.

DCPA was first registered as a pesticide in the U.S. in 1958 as a selective preemergence herbicide for weed control on turf grasses. Following a June 1987 evaluation, EPA issued a Registration Standard for DCPA in June 1988. Based on human health risk assessment calculations summarized in the November 1998 DCPA Reregistration Eligibility Decision document, EPA concluded that “DCPA and its metabolites do not currently pose a significant cancer or chronic non-cancer risk from non-turf uses to the overall U.S. population from exposure through contaminated drinking water”.

One objective of the Ontario HUA was to reduce DCPA application by 30%. Surveys conducted by the Malheur Extension Service show that this goal was met by the end of 1997. Even without a product to substitute for DCPA, it was possible to lower the amount of chemical loading by banding DCPA in a narrow band directly where the onions would grow, rather than broadcasting DCPA over the entire soil surface. The area of soil between the banded DCPA did not need the product because weeds were controlled there by cultivation.

DCPA was applied much more efficiently by banding instead of broadcasting. Banding the herbicide generally cut the application rate by two-thirds and reduced the potential leaching to groundwater. Growers were quick to adopt the banding of DCPA because costs were reduced with no loss in weed control. Early after the declaration of the GWMA, one third of growers using DCPA were banding the product on the uncultivated parts of the bed, saving two-thirds of the DCPA expense (Jensen and Simko, 1991).

Due to concerns about residues of DCPA & metabolites in surface water and sediment runoff from furrow-irrigated crop land, as well as through deep percolation through the soil profile, intensive studies were conducted to trace the fate of DCPA & metabolites losses with banding or broadcast of DCPA. This work was conducted in 1991, with results distributed to the growers at that time and documented in Shock et al., (1998b). Without straw mulch, DCPA & metabolites in transported sediment was 33% less when banded than when broadcast; and 41% less in surface water runoff. For both banded and broadcast applications, straw mulch reduced DCPA & metabolites losses in transported sediment by about 90%. Straw mulch also reduced DCPA & metabolite losses in surface water runoff by 30% for banded application and by 50% for broadcast application. The benefits of straw mulch were primarily through reductions in soil erosion and runoff volume.

Conclusions from these studies included that omitting DCPA or banding DCPA during onion production immediately reduced the losses of DCPA residues through downward leaching or runoff. Additional research at the MES demonstrated that other products with shorter half-lives could control weeds in onions on a wide range of sites at lower cost (Stanger and Ishida, 1990, 1993). The use of DCPA was no longer necessary. With the registration of pendimethalin (sold under the trade name of Prowl) in about 1993 or 1994, growers rapidly switched to pendimethalin because it was lower in cost, more effective, and did not have the undesirable environmental effects of DCPA. DCPA inventories in Malheur County were depleted by the 1998-growing season. No DCPA was applied in Malheur County during the 1999 growing season (Shock, 2000). As indicated above, DCPA is still available for use. It is unlikely that local growers will return to the widespread use of DCPA.

Instrumental in the changes were the "on farm" demonstrations by Lynn Jensen of OSU Cooperative Extension, who demonstrated the general effectiveness of pendimethalin and its ability to control dodder. The work conducted by Jensen and Stanger was supported by the Idaho Eastern-Oregon Onion Committee. Both the adoption of banding over broadcasting DCPA and the substitution of pendimethalin for banded DCPA took place at the voluntary initiative of growers (Shock et al., 2001).

3.4 Improvements in Irrigation Management

More effective irrigation practices have been implemented and more effective irrigation structures have been constructed. The benefits of these improvements are being seen in the reduced amounts of nitrogen applications and greater savings in water use The new and more effective irrigation practices have had a measurable impact on chemical use and the reduced amount of water usage (Feibert et al., 1995, 1998; Shock et al 2000b 2002a; Shock and Klauzer, 2003). As drip irrigation continues to increase in this area, even better results will likely be realized.

The improvements in irrigation management that are protective of groundwater quality can be grouped into two related categories: irrigation induced erosion BMPs and irrigation system conversion. Specific examples of irrigation management BMPs are discussed below. Additional information on these BMPS is available at the

Oregon State University Malheur Experiment Station website http://www.cropinfo.net/bestpractices/Malcountybmp.html. In addition, a July 2001 OSU Extension Service publication titled "Strategies for Reducing Irrigation Water Use" is included as Attachment 2 (Jensen and Shock, 2001).

A wide array of practices has been investigated in an effort to improve the efficiency of furrow irrigation and reduce irrigation induced erosion. Many of these practices are protective of both surface water quality and groundwater quality. There has also been a consistent effort to encourage the conversion to more efficient methods and types of irrigation. Irrigating more efficiently both conserves water and protects water quality. The promoted changes include:

- *Irrigation Water Management (IWM)* – IWM is the process of determining and controlling the volume, frequency, and application rate of irrigation water in a planned efficient manner. The correct application of IWM requires knowledge, skills, and desire to determine when irrigation water should be applied, crop usage, soil type, and weather conditions. IWM is applicable to all irrigated lands and is applied as part of a conservation management system to support desired crop response, optimize use of available water supplies, minimize irrigation induced soil erosion, decrease non-point source pollution of surface and ground water resources manage salts in crop root zone , and manage the air soil or plant micro-climate.
- *Laser leveling fields* – The use of laser leveling[2] produces a more level field than traditional surveying and leveling techniques. MES experiments have shown that fields with slopes of 0.6 to 0.7 or more feet per hundred feet require too much water to irrigate and result in excessive runoff and soil erosion. Fields with slightly irregular slopes can have flat areas where water accumulates, infiltrates, and results in leaching of nutrients to groundwater.
- *Gated pipe and concrete ditches* – The use of gated pipe[3] and concrete ditches allow more uniform irrigation at many sites. These practices can conserve water and prevent deep leaching.
- *Straw mulch* – Because the use of straw mulch in irrigation furrows can help control soil erosion and water runoff, (as well as greatly improve yields), it is protective of surface water quality (Shock et al., 1997). The effects on groundwater quality can be positive, neutral, or negative depending on how it is used. Straw mulch can help reduce deep percolation of irrigation water when straw is used only at the bottom of the field or in the part of an uneven field subject to erosion. In these cases, the use of straw mulch can dramatically reduce the time necessary to uniformly irrigate the field with surface irrigation, thus reducing the potential for deep percolation and leaching of nutrients to groundwater. The development of mechanical straw mulching devices by members of the local community has made the use of straw mulch economically feasible.
- *Polyacrylamide (PAM)* – PAM is a synthetic water-soluble polymer than when added to irrigation water is can be highly effective in reducing soil erosion off of fields and can increase water infiltration into irrigated furrows, thus making it protective of surface water quality. (Nishihara and Shock, 2002a). The infiltration rates (and thus the effects on groundwater quality) can be positive, neutral, or negative depending on how it is used. In fields with uneven slope, surface irrigation without PAM leads to erosion in the steeper parts of each furrow; cutting a deep narrow channel at the bottom of the furrow. This narrow furrow delays water percolation, which usually results in a longer irrigation set time for the entire field thus increasing the potential for deep percolation. When PAM is used, the water does not

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[2] Laser leveling is a method of leveling a field that utilizes a laser beam and a rotating mirror to produce a plane of light. This plane is the reference point for the leveling process. Usually, a tractor is equipped with a sensor that reads the beam and tells the operator the elevation of the equipment in relation to the reference point. Most systems are automated and control the elevation of the cutting blade. When the tractor encounters a high spot the blade is lowered, removing soil; and when a low spot is encountered the blade is raised, letting soil spill out, filling the hole.

[3] Gated pipe is irrigation pipe with holes cut in it and "gates" covering the holes. The gates are set open, closed, or somewhere in between depending on the amount of water needed at a particular location. Water flows out the pipe (past the gate) and down the furrow.

cut as deep a channel in the steeper parts of the field, so the water is applied with greater uniformity. Having a more uniform water application also reduces excess water infiltration thus reducing the potential to leach nutrients to groundwater.

- *Surge irrigation* – The use of surge irrigation[4] can reduce irrigation costs through lower water use and reduced labor to irrigate. It also reduces the total amount of irrigation water applied, as well as the amount of water and sediment lost at the end of each furrow while maintaining yields. Having a more uniform water application also reduces excess water infiltration thus reducing the potential to leach nutrients to groundwater (Nishihara and Shock, 2002b).
- *Drip irrigation* – The use of drip irrigation[5] can greatly assist the efficient use of water and water quality protection. A well designed drip irrigation system or subsurface drip irrigation system will lose practically no water to runoff, deep percolation or evaporation. Irrigation scheduling can be precisely managed to meet crop demands, holding the promise of increased crop yields and quality while conserving water and protecting surface water quality and groundwater quality. MES has shown subsurface drip irrigation to be a cost effective way to grow onions while using much less water (Feibert et al, 1995) (greatly reducing deep percolation) and about half as much fertilizer as on furrow irrigated onions (Shock and Klauzer, 2003). Currently there are about 2,000 acres of drip irrigated onions and alfalfa seed in the GWMA. Smaller acreages of potatoes, carrot seed, onion seed, and alfalfa for forage are being tried (Shock et al., 2003).
- *Irrigation scheduling* – The use of irrigation scheduling[6] can also aid the efficient use of water, and protect surface water and groundwater quality. Local growers, with assistance from the Malheur County Cooperative Extension &, SWCD, and MES commonly use irrigation criteria (i.e., daily soil water potential[7] and evapotranspiration[8] data) determined for potatoes, onions, and poplar trees by the MES in drip irrigated fields and sprinkler irrigated fields.(Eldredge et al., 1992, 1996; Shock et al 1998b, 2000b, 2002b).
- *Conversion from flood irrigation to sprinkler irrigation* – The use of sprinkler irrigation can reduce water use and allow more efficient irrigation applications. When properly managed, a well designed sprinkler irrigation system will lose practically no water to runoff or deep percolation. It is important to note that flood to sprinkler irrigation conversion can be expensive, especially if power is required to pump irrigation water. Some systems can be set up for gravity flow, greatly decreasing the operating cost. It is also important to note that sprinkler irrigation will not work on all fields or for all crops. Sometimes the layout of a field or property is odd-shaped, causing difficulties in applying a sprinkler system. The presence of utility poles, roads, waterways, or buildings can also make this conversion difficult. Sprinkler irrigation may also cause disease problems in some crops because the foliage is kept wet. The benefits of converting from flood to sprinkler irrigation is probably greatest on steeper fields, where efficient irrigation is most difficult and the risk of irrigation induced soil erosion is the greatest. The conversion of potato irrigation systems from furrow to sprinkler irrigation is expensive, but results in improved tuber grade and processing quality (Shock et. al., 1988).

[4] Surge irrigation uses a surge controller butterfly valve placed in the center of the top of a field with gated pipe leading out of the valve in both directions along the top of the field. The valve works by oscillating water from one side of the valve to the other at pre-determined intervals. The alternating flow of water on each side of the valve causes an intermittent wetting and soaking cycle in the irrigated furrow. This cycling causes soil particles to settle to the bottom of the furrow and reduces the water intake rate of the soil. With a reduced intake rate, each surge of water advances farther down the furrow giving the field a more uniform water application while requiring less water for an adequate irrigation.
[5] Drip irrigation is the slow release of water through drip tube or tape to a very specific area near the plants root system. When the drip tape is buried, the method is known as subsurface drip irrigation.
[6] Irrigation scheduling means applying the required amount of water at the required time.
[7] Soil water potential is the force necessary to remove water from soil and is an expression of the energy level of water in the soil system. The amount of water in a given volume of soil is known as the soil water content.
[8] Evapotranspiration is the loss of water from soil to the atmosphere by both evaporation and by transpiration from growing plants.

One example of the effectiveness of the adoption of these practices is in the amount of erosion reduction. The 1997 Ontario HUA Final Report indicates that approximately 45,000 tons of soil was kept on fields during 1992 through 1997.

3.5 Information and Education Activities

Since 1990, much effort has gone into providing information and education to support the groundwater quality effort. The cooperation of local groups, agencies, and a large portion of the individual producers have increased the knowledge and, therefore, the practices that continue to improve water quality. During the past decade, numerous grower and commodity meetings were attended by personnel from the CES, MES, NRCS, and the SWCD. CES and MES personnel have made presentations to growers and meeting attendees on nitrogen management, irrigation practices, and the uses of irrigation water management tools. The information and education activities conducted during the Ontario HUA project included 37 presentations at local grower meetings, 48 presentations at professional meetings, 51 presentations at community and civic meetings, 27 tours, 5 demonstration projects, and 117 publications and research papers. Presentations, tours, demonstrations, and publications have continued. Many of the past and current reports related to water quality are now published on the web.

Over 200 growers, agency personnel and groups have attended the MES tour featuring BMPs for improved water quality. These educational tours are held on a county basis yearly with many smaller tours also given yearly. In addition, NRCS and the SWCD staff attended the Snake-Payette HUA Water Quality Tour.

Water quality presentations have been made by local residents at venues such as the Lion's Club, Kiwanis, Chambers of Commerce and the American Association for Retired Persons (AARP). SWCD staff have maintained a Water Quality Booth at the Malheur County Fair each year and offered free well water testing for nitrates and information on local water quality concerns and solutions.

Many educational workshops are held each year. The CES has held many pesticide workshops for local growers. The SWCD has held Irrigation Water Monitoring Workshops for the Watermark Grower Program. The MES, SWCD, NRCS, CES and a local grower attended the Northwest Water Quality and Agriculture Conference in Yakima, Washington and gave a presentation on Malheur County's Integrated Approach to Water Quality Protection. The SWCD, CES, and a local irrigation district representative gave a televised class at OSU on BMPs that conserve water. The SWCD manager also gave a presentation at Lewis and Clark School of Environmental Law on water quality BMPs and the structure and function of the water quality interagency team.

MES has given many presentations. Some include (1) Precision Irrigation Scheduling with Granular Matrix Sensors on Watermark Data Logging Systems for Evapotranspiration Measurement at the International Conference on Evapotranspiration and Irrigation Scheduling, (2) Efficient Irrigation Scheduling given to the Oregon Experience at the 11th Annual Maine Potato Conference and Trade Exhibit, (3) What Growers Need to Know about Drip Irrigation in a conference with Idaho Department of Water Resources, and (4) Nitrogen Management for Sugar Beets for the White Satin Fieldman/Growers meeting.

Community education has consisted of weekly / bi-weekly Ag Hotlines in a local newspaper (The Argus Observer). Newsletters were received by more than 2,000 landowners and operators in Malheur County. Speech contests and poster contests have been held annually with participation from area schools. The winning speeches and posters were also published in the local newspaper.

A specific example of the information and educational activities is the Watermark sensor program where soil moisture probes are used to assist farmers with irrigation scheduling decisions. The SWCD installs and reads the sensors six days a week. The moisture levels are then graphed and provided to the farmer. The NRCS and the SWCD visit the farmers on their farm to assist with interpreting the graphed data and to discuss irrigation water management. Irrigation scheduling using Watermark sensors was highly refined and this effort has provided calibrations and methods which are used in in other watersheds around the world. (Shock et al., 1998d; Shock, 2003).

In summary, sufficient progress has been made over the past decade on these "other indicators of progress" identified in the Action Plan to conclude the fourth measure of Action Plan success has been met. to date and such efforts need to continue. In addition, there is a strong local commitment to maintain and expand the implementation of BMPs so that economic and environmental benefits can be realized and maintained. It is important to recognize, however, that continued education and outreach to encourage implementation of established practices, as well as continued development of new practices, will be necessary to maintain and build upon the successes realized to date.

4.0 THE CHALLENGE OF BMP IMPLEMENTATION

While agricultural BMPs have the potential to provide protection of groundwater from agrichemicals, their effectiveness is limited by both on-farm and institutional factors. These factors must be recognized and addressed if BMPs are to be an effective approach to addressing nonpoint source pollution (Logan, 1990). The relative importance of these limiting factors can vary in space (e.g., from farm to farm) and in time (e.g., from year to year). Many of these factors are economic-based, most are inter-related, and none are easy to overcome. However, there are potential avenues to pursue that could encourage BMP implementation and improve groundwater quality. These potential solutions are not easy to accomplish nor would they result in a quick fix. Both the limitations and potential solutions are discussed below.

4.1 Factors Complicating BMP Implementation and Water Quality Improvement

The factors complicating BMP implementation include, but are not necessarily limited to, the following:

- *Economic Considerations*
  - *Global Competition* – The rules and regulations that American growers must comply with to protect worker safety, food safety, and the environment are well intentioned and valuable, but have the unintended consequence of putting American growers at an economic disadvantage. American-grown products compete in an open market against products grown in countries with less stringent (and therefore less costly) rules and regulations. Environmental considerations are often recognized, and many growers want to incorporate them. However, growers are compelled by the market place to implement only the changes that make economic sense. Innovations or modified practices must pay for themselves to be widely adopted. Without cost sharing programs, many such innovations or practices are not widely adopted. The number of growers in Malheur County seeking cost share program money to implement environmentally sound practices far exceeds the number of growers that can actually be funded with the available money. For example, 198 Environmental Quality Incentives Program (EQIP) applications were received in 2003. The allotted $521,000 was sufficient to fund 13 projects. Similarly, 703 EQIP applications were received over the 7-year period of 1997 to 2003. Of these applications, funding levels were adequate to fund 82 contracts over the same period (<12%). Cost share program money is very limited and very competitive. More cost share program money would very likely result in more environmentally sound practices being adopted.
  - *Economic Stability* – When grower-operators have reasonable perspectives of economic security, it is more probable that environmental concerns can be incorporated into production plans. When economic pressures are severe and the scale of operations have to be rapidly increased to maintain some vestige of economic stability, environmental concerns are less apt to part of the conscious decision process.
  - *Lack of an Adequate Continuous Funding Source* – The amount of funds typically available for BMP education, implementation, and documentation is limited, with the possible exception of specific demonstration projects. The lack of continuity in funding BMP implementation projects causes a lack of continuity in the focus of natural resource agency staff tasked with promoting BMPs.
  - *Initial Capital Required* – Implementation of some BMPs requires a substantial investment of initial capital that many growers cannot afford without cost-share programs. Practices more likely to be adopted readily offer either relative ease of integration into existing farming practices or an economic or labor saving benefit (Logan, 1990).
  - *Economic Viability of a BMP* – If a BMP is to be implemented by a grower, it must be economically beneficial to the grower, or its absence must not be detrimental. Logan (1990) states that with some exceptions (e.g., conservation tillage), growers generally have not adopted BMPs except in special projects or where high levels of cost-sharing and technical assistance were available. Malheur County growers have adopted BMPs when cost-sharing levels were both high and low. Examples of BMPs that have been adopted largely at the expense of local growers include laser leveling, the use of gated pipe, the adoption of weed screens, adoption of tissue and soil sampling, and split application of fertilizer. Some growers have even started adopting nutrient applications using global positioning system (GPS)

and geographic information system (GIS) technology. Another aspect of the economic viability of a BMP is the life expectancy of the existing system. For example, the adoption of a new irrigation system or other major advance does not happen until the old system wears out. It does not make economic sense to replace a system before it is necessary. When the system is replaced, a more efficient technology can be adopted.

- *Rising Costs of Successive BMPs* – In some cases, the cost of each progressive improvement increases, making each step harder and harder to accomplish.

- *Incomplete Documentation* – Ongoing documentation of BMP implementation requires not only consistent grower cooperation, but consistent funding of the agency documenting the practices.

- *Shifting Environmental Priorities* – Both public agency and private citizen perceptions of the relative importance of various environmental issues associated with any particular region (northern Malheur County included) can change through time. Specific issues perceived as a priority are typically the issues that receive the most funding and attention. Groundwater quality was once a higher priority in northern Malheur County than it is currently. Currently TMDL development and implementation is placing a priority on the reduction of irrigation-induced erosion and the loss of phosphorus to surface waters.

- *Inherent Uncertainties in Budgeting Nitrogen* – Growers face a management dilemma because the effectiveness and efficiency of nitrogen management cannot be fully assessed, economically or environmentally, until the growing season is over (NRC, 1993). A crop that produces poor yields because of inclement weather will result in poor nitrogen use efficiency and uptake, potentially leaving large amounts of nitrogen to be lost to the environment, no matter how carefully a management plan was designed. Since producers must make nitrogen applications without being able to predict weather and crop yields, the potential for being wrong is always present and will always occur in some years. Furthermore, crop nitrogen needs are based on long-term averages of the many sources of variance in the nitrogen-yield response (NRC, 1993). However it should be noted that crop yields have greater stability in the irrigated fields of semi-arid Malheur County than in many other parts of the world.

- *The Allure of Optimum Yield*– Nitrogen fertilizer recovery rates decline rapidly as the crop approaches optimum and maximum yields, creating considerable potential for nitrogen losses into the environment (NRC, 1993). Because of the form of the nitrogen-yield response, the potential for nitrogen losses is very sensitive at high nitrogen application rates when plant uptake of nitrogen is limited. Attempts to achieve a small final yield increment can greatly contribute to nitrogen losses. The fate of this nitrogen can follow many paths in the nitrogen cycle; some is immobilized, but other portions may be leached into groundwater or otherwise lost (NRC, 1993).

- *Seasonal Nitrogen Cycling* – Nitrogen applied in the spring is immobilized by plants and microbes in the spring and summer. This immobilization period is followed by mineralization of the nitrogen from plant and microbial tissues in the fall (NRC, 1993). The seasonal dynamics are such that nitrate levels in the soil can be very low during the late summer and early fall. Following harvest, crop residues, root tissues, and microbial cells begin to mineralize and nitrify, often leading to high soil nitrate concentrations that are susceptible to leaching loss at the end of the irrigation season or with the onset of irrigation the following spring.

4.2 Potential Ways To Encourage BMP Implementation and Improve Groundwater Quality

Because contamination results from accepted farming techniques, improvements in groundwater quality will depend on widespread adoption of production practices that reduce environmentally mobile chemical inputs. Groundwater protection programs and policies that do not take into account the forces governing agricultural production (i.e., the market, new production techniques, and federal agricultural programs) may be adoptable and implementable, yet substantially ineffective (Roberts and Lighthall, 1991).

The potential ways to encourage BMP implementation that will improve groundwater quality include, but are not necessarily limited to, the following:

- *Change the Agricultural Infrastructure* – A shift in national agricultural economic priorities to incorporate long-term goals might encourage and enable large-scale changes in agriculture infrastructure (e.g., water delivery systems) that can allow high production rates, the economic viability of the grower, and address environmental concerns. Investment in such "social overhead capital" is currently a low national priority.

- *Consistent Adequate Funding* – More consistent and increased funding for BMP education, implementation and documentation would allow natural resource agency staff to identify and promote effective BMPs. Logan (1990) states that the most effective approach in protecting groundwater from nitrate contamination is restricting application rate to coincide with crop requirements. This is particularly true for crops with high nitrogen fertilizer requirements, for land application of livestock wastes, and for irrigation water management. The difficulty is in establishing nitrate rate limits that protect the farmer against both seasonal variations in a crop's nitrogen use efficiency and such non-leaching losses as denitrification.

- *Focused Education and Assistance* – Logan (1990) states that resources must be directed to problem areas where BMPs will have the greatest long-term impact recognizing the reality that sufficient resources likely will never be available to treat all sources of pollution. Farmers must be motivated through education, technical assistance, cost-sharing when necessary, and some regulatory sanctions to address agricultural pollution problems. The most effective BMPs are those that the farmer is likely to maintain after cost-sharing is terminated. Farmer's concerns for groundwater protection will be greater than for surface water because farm families are worried about contamination of their own wells. Education programs should focus on this critical factor.

- *Consistent Priorities* – More consistent priorities across public agency boundaries would provide local decision-makers with more consistent directions for developing and implementing policies (including groundwater protection BMPs).

- *Encourage The Determination of Realistic Yield Goals* – An unrealistically high yield goal will result in nitrogen application in excess of what is needed for the yield that is actually achieved, and will contribute to the mass of residual nitrogen in the soil-crop system. Following realistic yield goals, established on the basis of the historical yields achieved at each field, would reduce both the production costs and the amount of residual nitrogen (NRC, 1993).

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Based on the information presented in this report, the following conclusions have been made.

- Important progress has been made over the past decade on the "other indicators of progress" identified in the Action Plan.
- There is a strong local commitment to maintain and expand the implementation of BMPs so that economic and environmental benefits can be realized and maintained.
- The factors limiting widespread BMP implementation are very real and difficult to overcome.
- Continued education and research into new technologies and practices are necessary to maintain and build upon the successes realized to date.
- The fourth measure of Action Plan success (i.e., the one stating that "other indicators of progress" be implemented) has been met. to date and such efforts need to continue. However, documentation of BMP implementation from 1997 to the present is needed to confirm the continued implementation of BMPs.

5.2 Recommendations

Based on the conclusions presented above, the following recommendations are made. These recommendations are grouped according to the responsible parties.

Groundwater Management Committee, Malheur County SWCD, NRCS, FSA, Malheur and Owyhee Watershed Councils, and Oregon State University

- As available and appropriate, provide financial and technical support to assist in the implementation and documentation of established BMPs and continued research to identify additional appropriate BMPs in the GWMA.
- Seek to educate growers and other citizens about factors related to groundwater contamination.
- Encourage projects such as deep soil sampling to evaluate changes in the amount and movement of nitrate within the unsaturated zone.
- Develop and maintain documentation of the extent to which the other indicators of progress identified in the Action Plan have been implemented since 1997.
- Re-evaluate progress in developing and implementing BMPs in 2005 using data through December 2004.

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- As available and appropriate, provide financial and technical support to assist in the implementation and documentation of established BMPs and continued research to identify additional appropriate BMPs in the GWMA.
- Encourage projects such as deep soil sampling to evaluate changes in the amount and movement of nitrate within the unsaturated zone.

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Figure 1-1
Location of Northern Malheur County Groundwater Management Area
Northern Malheur County GWMA BMP Implementation Report

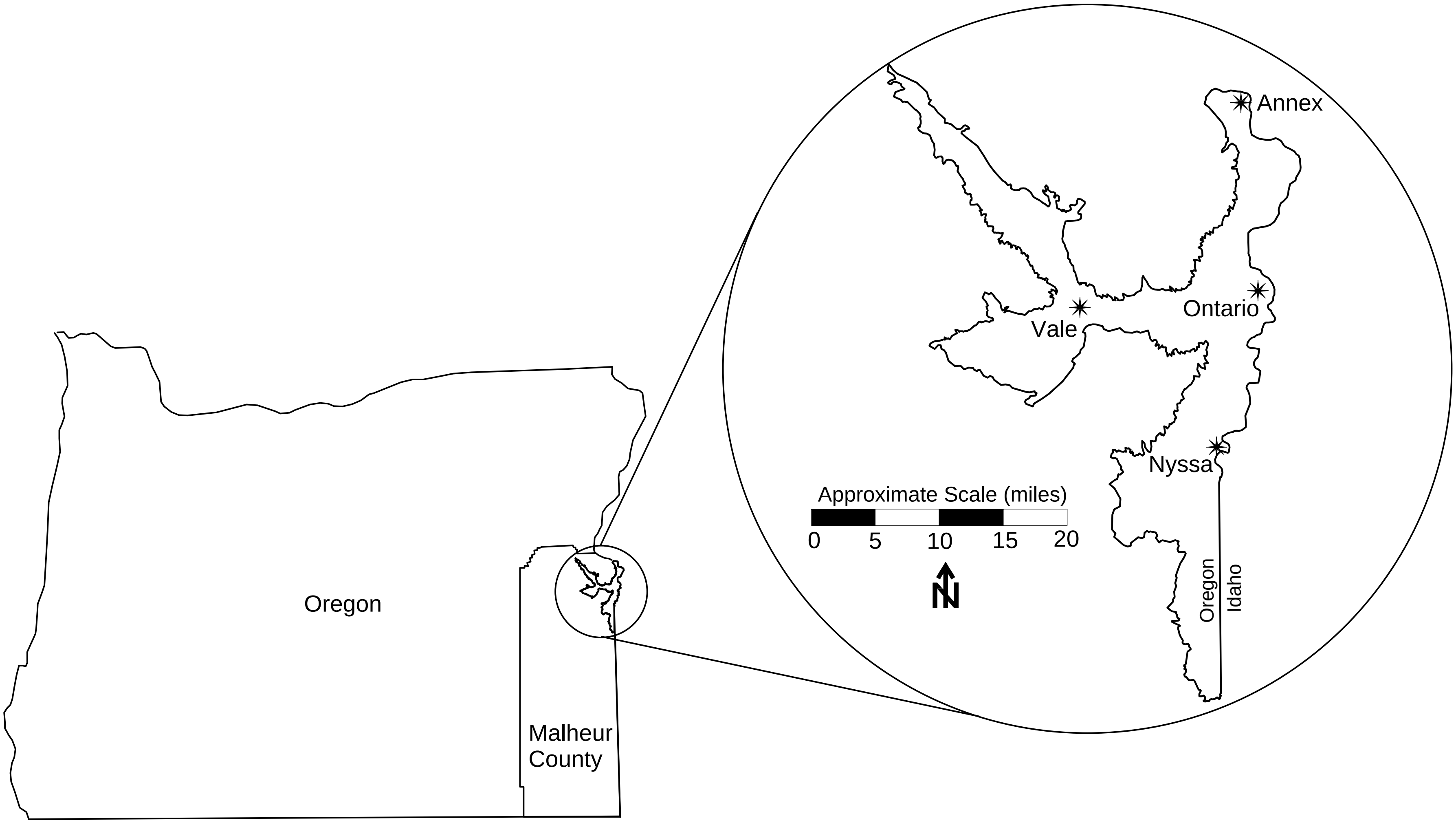
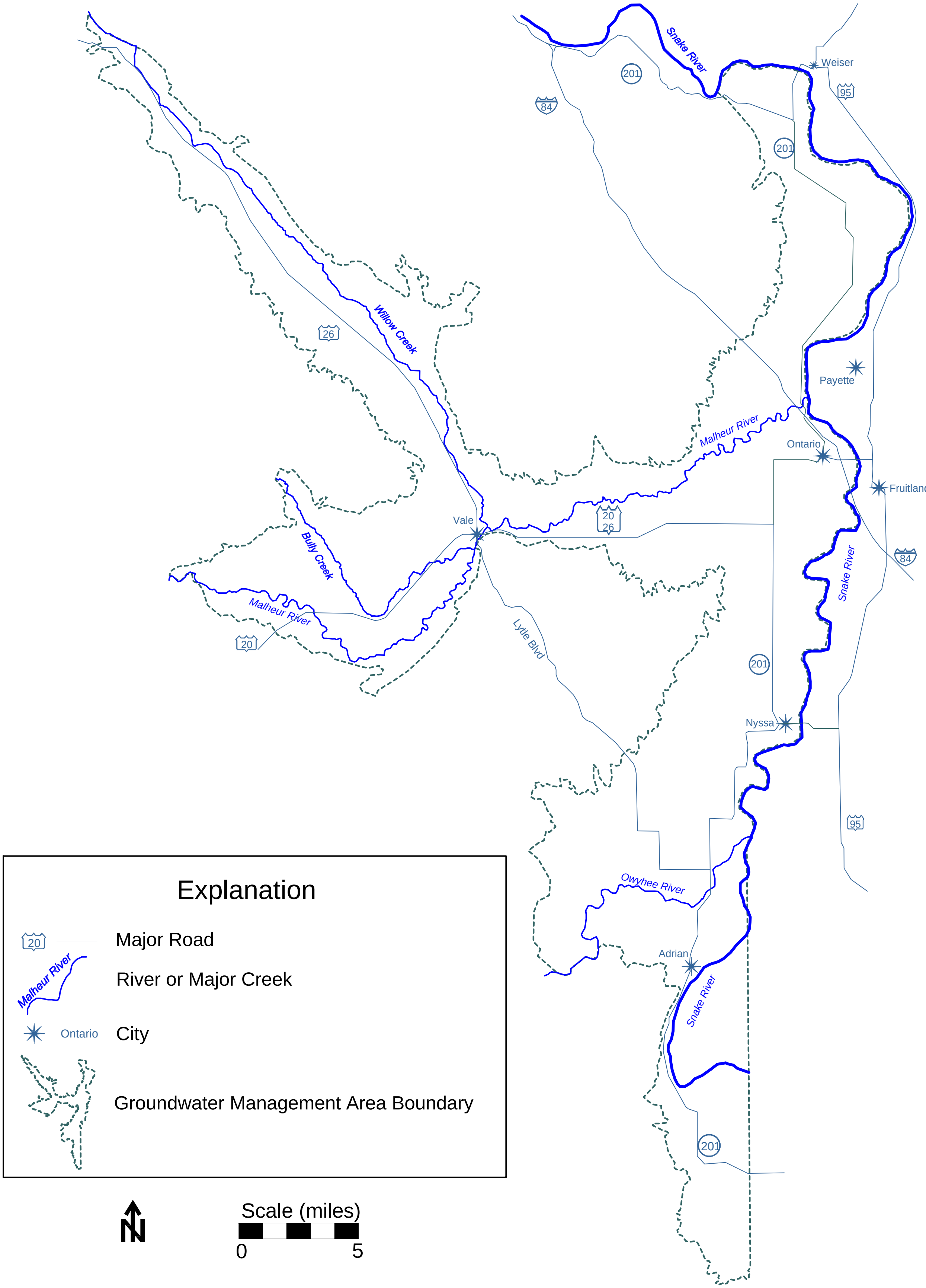
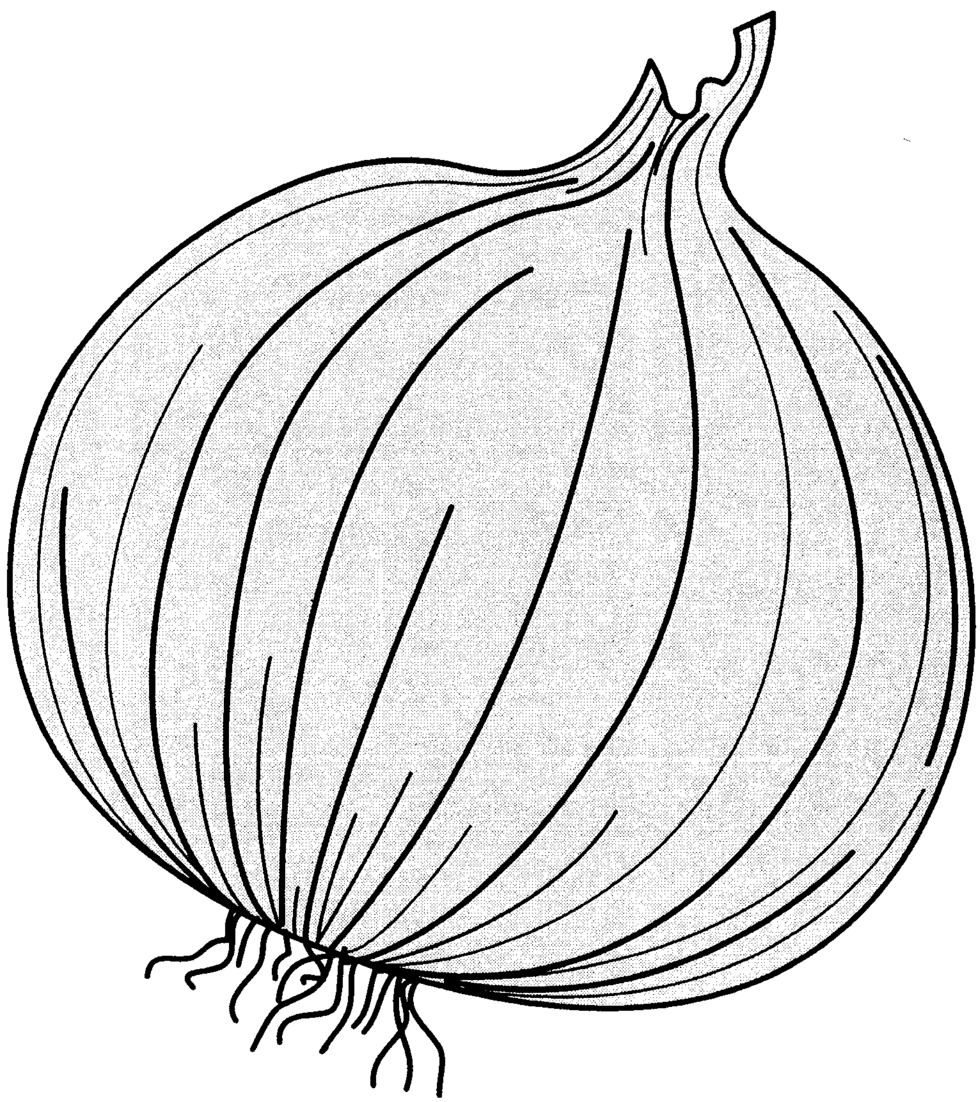


Figure 1-2
Site Layout Map
Northern Malheur County GWMA BMP Implementation Report



PNW 546
February 2001

Nutrient Management for Onions in the Pacific Northwest



A Pacific Northwest Extension Publication
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What's inside?

This nutrient management guide is designed to assist onion growers and crop advisors in producing a high-quality crop while protecting the environment from excess nutrients. Nutrient management strategies recommended here are based on data accumulated over many growing seasons with many different onion varieties in Idaho, Washington, and Oregon.

This publication provides current information on:

- How onions grow and how their growth pattern affects nutrient needs
- Timing and amount of crop nutrient uptake
- Keys to managing nitrogen efficiently
- Ways to monitor crop N status during the growing season
- How to assess the need for P, K, S, and micronutrient fertilization
- Fertilizer sources and application methods
- How to assess the need for lime on sandy soils in the Columbia Basin

Key points

Crop nutrient uptake

- The amount of nutrient uptake by an onion crop is very small from germination to bulb initiation.
- The period of rapid nutrient uptake starts at bulb initiation and continues through bulb growth.
- About 80 percent of the nutrients taken up by the crop are removed in the bulbs.

Nitrogen

Use these management strategies to efficiently utilize N:

- Credit N from nonfertilizer sources in determining N fertilizer application rates.
- Apply most or all of the N fertilizer as sidedress applications or through sprinkler or drip irrigation.
- When economically feasible, use improved irrigation practices to minimize deep percolation losses.
- Use plant tissue tests to assess the need for supplemental fertilization.
- Grow deeper rooted crops after onions to recover nitrate-N leached beyond the root zone.

Phosphorus

Take the following soil and crop management factors into consideration when determining P fertilizer application methods and rates:

- Soil test value (ppm)
- Soil free lime (calcium carbonate) concentration
- Fumigation. Soil fumigation prior to seeding onions might increase P fertilizer requirements. Fumigation kills the mycorrhizal fungi that help onion roots take up P from soil.

Acid soils in the Columbia Basin

- Soil acidity (pH less than 5.5) can reduce yield. On sandy soils, soil pH can fluctuate by 1 to 2 pH units during the year, depending on fertilizer and crop management practices.
- Soil acidity can be corrected by applying and incorporating lime before planting.
- Fertilization practices can have a dramatic effect on soil pH on sandy soils.
- Do not apply N and K fertilizers preplant on sandy soils subject to soil acidity problems.
- Reduce or eliminate application of acid-forming fertilizers such as mono-ammonium phosphate (e.g., 11-52-0), urea-sulfuric acid, and ammonium sulfate.

Contents

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Nutrient Management for Onions
in the Pacific Northwest

D.M. Sullivan, B.D. Brown, C.C. Shock, D.A. Horneck, R.G. Stevens, G.Q. Pelter, and E.B.G. Feibert

Onions are a high-value crop. Both high yield and quality are important economic considerations. Components of bulb quality include size, appearance, percentage of single-centered bulbs, and susceptibility to sprouting and decay in storage. Nutrient supply interacts with other management, pest, and climatic factors to affect quality and yield.

This nutrient management guide is designed to assist onion growers and crop advisors in producing a high-quality crop while protecting the environment from excess nutrients. Excess nitrate-nitrogen can leach below the root zone and contaminate groundwater, while excess phosphorus can be carried into lakes and streams by surface water runoff.

Nutrient management strategies recommended here are based on data accumulated over many growing seasons with many different onion varieties in Idaho, Washington, and Oregon. The field research database supporting this onion nutrient management guide probably is more extensive than for any other vegetable crop grown in the Northwest, with the exception of potatoes.

This guide focuses primarily on onion production in the Treasure Valley and the Columbia Basin. The Treasure Valley onion production area is within a 50-mile radius of Ontario, Oregon on the Snake River plain and along the tributaries of the Snake River. The Columbia Basin production area in central Washington and north central Oregon includes approximately 750,000 acres irrigated by water from the Columbia and Snake Rivers.

Growth and development

Understanding how the onion plant grows and develops is a key part of developing a strategy to supply nutrients for optimum bulb yield and quality.

An onion bulb is different from a root (such as a sugar beet) or a stem (such as a potato). Each onion "ring" is called a bulb scale in botanical terminology and is comprised of the base of a leaf. We describe onion growth and development during the following growth phases (Table 1):

- Germination
- Leaf growth
- Bulbing, or bulb initiation
- Bulb growth
- Maturation

Table 1.—Growth stages for seeded onions in the Pacific Northwest.

Growth phase	Numerical growth stage	Approximate days after planting	Approximate calendar date (April 1 planting)	Description
Germination	1	7 to 30	Apr 20	Radicle and flag leaf emergence
Leaf growth	2	30 to 50	May 10	1 to 2 true leaves
	3	50 to 70	May 30	3 to 4 true leaves
Bulbing or Bulb initiation	4	70 to 90	June 20	5 to 7 true leaves; bulb diameter is twice that of the neck
Bulb growth	5	90 to 110	July 10	8 to 12 true leaves; bulb diameter 1 to 1.5 inches
	6	110 to 130	July 30	Bulb diameter 1.5 to 3 inches
	7	130 to 150	Aug 20	Bulb diameter greater than 3 inches
Maturation	8	150+	Aug 30	Bulb enlargement near completion; more than 50 percent tops down
	9			Field curing period

Adapted from Schwartz and Mohan (1995).

Germination

Onion seeds can germinate at low soil temperatures. Soil temperatures above 34 to 37°F stimulate seed germination. Seed germination is most rapid and uniform at soil temperatures above 52°F.

Leaf growth

Onions have an unusually long period of slow growth to the 3-leaf stage. Their early vegetative growth rate is about half that of other cool-season crops such as lettuce and beets. The period of slow growth lasts about 50 to 70 days after planting under typical weather conditions. Onions planted in late March or early April typically reach the 3-leaf growth stage by late May or early June. During this early leaf growth phase, nutrient needs are very low.

Other cultural factors such as herbicide damage or soil acidity can further reduce early vegetative growth. Slow early growth caused by weather conditions sometimes is incorrectly attributed to nutrient deficiencies.

Rapid leaf growth begins when the onion plant has three leaves. Each emerging leaf is larger than the previous leaf. Leaf growth rate increases with temperature. Leaf growth requires an air temperature of at least 40°F and reaches a maximum at about 80°F.

Onion root growth occurs at a regular pace during leaf growth. New roots are produced from the bulb basal plate as leaves develop above ground. The shallow, sparsely branched root system of the onion plant has important implications for nutrient management. See "Root growth and development" (at left) for more details.

Root growth and development

Onions have a shallow, sparsely branched root system with most roots in the top foot of soil. Rooting density decreases with soil depth. The sparse, shallow rooting of onions has important implications for management of relatively immobile nutrients (P, K, and some micronutrients such as Zn). The unbranched root system of onions is less effective than most crop plants in extracting immobile nutrients. Therefore, onions are more susceptible than most crops to deficiencies of these nutrients.

The shallow root system of onions also is an important consideration for efficient management of mobile nutrients such as nitrate-N and sulfate-S. Mobile nutrients can be lost from the root zone by overirrigation. With furrow irrigation, mobile nutrients move to bed centers, where they typically become available later in the season when onion roots proliferate across the beds.

Onions are highly dependent on arbuscular mycorrhizal fungi for uptake of phosphorus from soils with low to medium soil test P concentrations. Mycorrhizal fungi produce a network of threadlike hyphae that extend from the onion roots into the soil, greatly increasing the absorptive surface area of the roots. Mycorrhizal fungi also can increase the uptake of zinc and other micronutrients in some high-pH calcareous soils.

Mycorrhizal fungi usually are abundant in agricultural soils, except when nonhost crops are grown, soil is fumigated, or high soil test P is present. Crops that do not host mycorrhizal fungi include sugar beets and mustards (e.g., canola).

Nematode feeding and root diseases can cause weak, poorly developed root systems.

Bulbing

The bulbing growth stage is considered to begin when bulb diameter reaches twice that of the neck. Most onion varieties initiate bulbs after six to eight leaves have been produced. Bulbing begins in response to increasing day length. Major onion types differ in the minimum day length needed to initiate bulbing. The minimum day length needed for bulbing is much shorter for early, overwintering onions, such as Walla Walla, than for spring-seeded onion varieties.

Temperature and light spectral quality also affect the onset of bulbing, but these effects are minor compared to day length. Once day length initiates bulbing, the higher the temperature, the earlier bulbing will occur. Densely planted onions have more shaded leaves and begin bulbing earlier because of altered light spectral quality. Shading initiates bulbing by providing more far red light and less red light to onion leaves.

Leaves continue to emerge during bulbing and bulb growth. Most onion varieties grown in the Pacific Northwest produce 12 to 14 true leaves.

Bulb growth

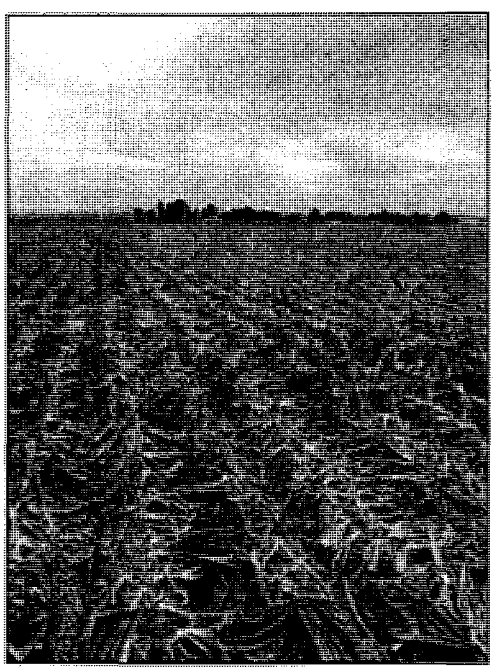
The onion plant has the highest demand for water and nutrients during bulb growth. Onion dry matter accumulation rates during bulb growth are comparable to those of a rapidly growing forage crop. Dry matter accumulates at a rate of 100 to 200 lb per acre per day (1,000 to 2,000 lb fresh weight per acre per day) during the peak growth period (Figure 1a).

Maturation

The timing of onion harvest depends on market opportunities, weather, and the planned storage period. As bulb growth slows, the onion neck becomes soft and the plant falls over. Maturation commonly is evaluated by the percentage of tops down and by the amount of dry leaves present.

Achieving a proper degree of maturation before harvest is a key factor in producing high-quality onions for storage. Growers sometimes suspect high levels of nutrients, particularly nitrogen, as the cause of poor maturation in the field and decay in storage. Usually, however, these problems result from a combination of environmental and crop management factors.

Environmental factors that can delay maturation and increase storage loss include hail damage to plants, a cooler than normal growing season, or wet weather for field curing of bulbs. Management factors such as sparse, uneven plant populations, a late planting date, water stress, or nutrient deficiencies also can slow development and maturation.



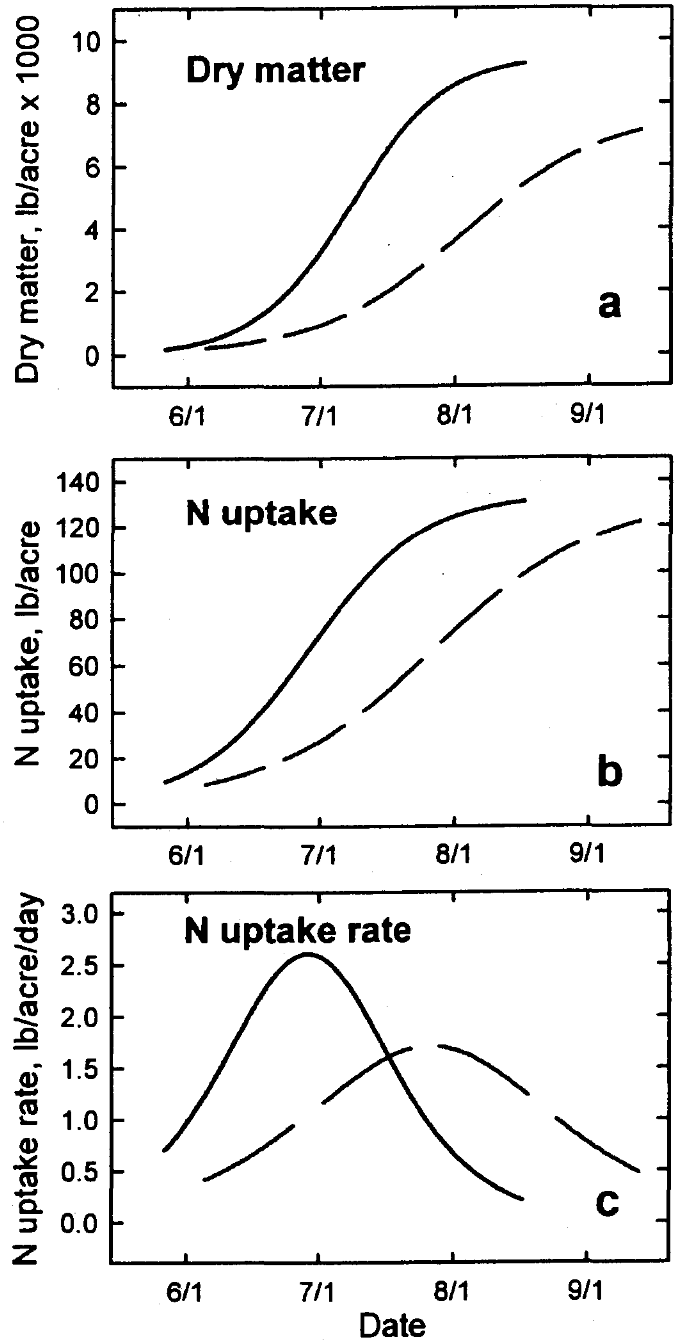


Figure 1.—Onion (bulb + leaves) dry matter (a), nitrogen uptake (b), and N uptake rate (c) for yellow onions at a field location in the Columbia Basin near Connell, WA (solid line) and at five field locations in the Treasure Valley near Parma, ID (dashed line). Columbia Basin data is for the 1998 season; it is averaged across two varieties, 'Prince' and 'Vision.' Average bulb yield (fresh wt. basis) for the two varieties was 840 cwt per acre (42 tons per acre) at the Columbia Basin site and 630 cwt per acre (32 tons per acre) at the Treasure Valley sites. Sources: Don Horneck, Oregon State University Extension Service, Umatilla County; Gary Pelter, Washington State University Cooperative Extension; Brad Brown, University of Idaho Parma Research and Extension Center.

Market classes for harvested onions

Premium prices are paid for large onions. After harvest, onions are sorted and marketed in the following size classes:

- Super colossal (Onion count must be 28 to 36 per 50-lb bag; diameter greater than 4¼ in)
- Colossal (> 4 in)
- Jumbo (3 to 4 in)
- Medium (2¼ to 3 in)

Markets for small onions (1 to 2¼ in) are limited.

Nitrogen

Crop N uptake

Nitrogen concentrations in bulbs of red, yellow, and white onion varieties are similar. Crop N removal (tops + bulbs) averaged about 140 lb N per acre in Columbia Basin trials (Figures 2 and 3). Crop N uptake typically ranges from 0.14 to 0.24 lb N per cwt fresh bulb yield. At harvest, about 15 to 40 lb N is present in tops, with the remainder present in bulbs (Figure 2). Crop N uptake rates during bulb growth range from 1 to 3 lb per acre per day (Figure 1c, page 5).

Strategy for N management

These management strategies help increase the efficiency of N utilization:

- Credit N from nonfertilizer sources (N in preplant soil test and irrigation water and N mineralized during the growing season) when determining N fertilizer application rates.
- Minimize preplant N fertilizer application.
- Apply most or all of the N fertilizer as side-dress applications or through sprinkler or drip irrigation.
- When economically feasible, use improved irrigation practices to minimize deep percolation losses.
- Use plant tissue tests to assess the need for supplemental fertilization.
- Grow deeper rooted crops after onions to recover N leached beyond the 2-foot depth.

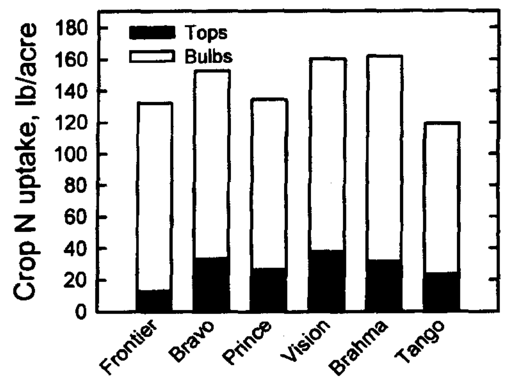


Figure 2.—Nitrogen uptake for six onion varieties grown at a field location in the Columbia Basin near Connell, WA. Variety descriptions: 'Frontier' is an early Japanese globe, 'Bravo' is a late U.S. Sweet Spanish, 'Prince' is a mid-late Dutch globe, 'Brahma' is a mid-late U.S. globe, and 'Tango' is a mid-late red globe onion variety. Fresh weight bulb yields ranged from 700 to 1,100 cwt per acre, with bulb dry matter of 10 to 12 percent. Sources: Don Horneck, Oregon State University Extension Service, Umatilla County; Gary Pelter, Washington State University Cooperative Extension. 1997 growing season.

Crop N uptake vs. available N supply

Nitrogen supplied to an onion crop comes from several sources. The available N supply is made up of:

- Preplant soil nitrate N and ammonium N
- N mineralized from crop residues and soil organic matter
- N supplied in irrigation water
- Fertilizer N

Fertilizer N should provide only a portion of the available N needed to grow the crop. We recommend a regular program of soil and irrigation water testing to determine how much available N is supplied by the soil and irrigation water. In some environments, high yields can be grown with small fertilizer N inputs because of the supply of available N in soil and irrigation water.

Estimates of crop N uptake can be used to estimate the available N supply needed for crop production. With good irrigation management, an onion crop can recover 40 to 60 percent of the available nitrogen from all sources.

The 700 to 1,100 cwt-per-acre bulb yields shown in Figure 2 were produced with an available N supply (including nitrate + ammonium-N in the soil before seeding, estimated soil N mineralization, and N added in irrigation water and fertilizer) of approximately 250 to 300 lb N per acre.

Crediting available N from nonfertilizer sources

Site-specific N management requires soil and water testing to estimate the amount of N from nonfertilizer sources.

Preplant soil nitrate-N

Preplant soil nitrate-N testing is a reliable tool for adjusting N fertilizer rates to site-specific needs. Spring sampling is more accurate than fall sampling because it accounts for nitrate

Crop nutrient uptake

One of the goals of nutrient management is to supply nutrients in a timely manner to maximize crop yield and quality. Crop nutrient uptake is calculated from measurements of crop biomass (dry matter) multiplied by crop nutrient concentration. You can use this number to estimate the total supply of available nutrient needed to grow the crop under good management.

Cumulative nutrient uptake by an onion crop follows a sigmoid or s-shaped curve during the growing season. The period of rapid nutrient uptake starts during bulbing (growth stage 4 in Table 1, page 3). Onions take up more than 100 lb per acre of nitrogen, potassium, and calcium, with substantially lower amounts of sulfur, phosphorus, and magnesium (Figure 3). About 80 percent of the nutrients present in the plant at harvest are present in the bulb; the remainder is present in tops.

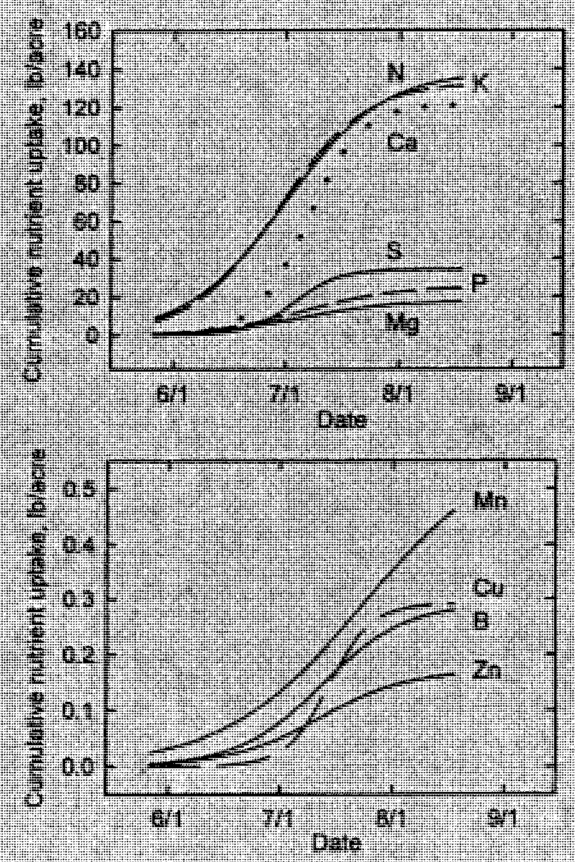


Figure 3.—Cumulative nutrient uptake by onions (bulb + leaves) for yellow onions grown near Connell, WA. Onion tissue was harvested at 13 dates during the growing season. Data is averaged across two varieties, 'Prince' and 'Vision.' Bulb yield (fresh wt. basis) was 840 cwt per acre (42 tons per acre) under furrow irrigation. Onions were seeded March 29 and harvested September 10. The final sample was collected about 7 days before undercutting. Sources: Don Horneck, Oregon State University Extension Service, Umatilla County; Gary Pelter, Washington State University Cooperative Extension. 1998 growing season.

Crop N uptake vs. N supplied by nonfertilizer sources

An example of how an onion crop can use nonfertilizer sources of N is shown in Table 2. In the example, available nitrogen supply was estimated for nonfertilizer sources; no fertilizer N was applied. Crop nitrogen uptake efficiency, calculated as a percentage of the available N supply, was 59 percent. This means that for each unit of available N supplied, crop N uptake increased by 0.59 units of N.

Table 2.—Example: Crop N uptake by high-yielding onions vs. available N supply from nonfertilizer sources.[a] Estimated crop N uptake efficiency = 59 percent.

Crop N uptake or available N supply	Line	Component of N budget	Nitrogen (lb/acre)
Crop N uptake	1	Tops plus bulbs[b]	160
Available N supply	2	Preplant soil nitrate + ammonium N (0 to 24 in)	76
	3	Irrigation water N (supplied via drip irrigation)	79
	4	Estimated soil N mineralization (mineralizable N soil test; 0 to 24 in)[c]	116
	5	Fertilizer N	0
	6	Total estimated available N supply (line 2 + line 3 + line 4 + line 5)	271
Crop N uptake efficiency	7	Estimated crop N uptake efficiency (line 1 ÷ line 6) x 100	59% of available N supply

[a]Yellow onions (cv. 'Vision') produced under drip irrigation at Oregon State University Malheur Experiment Station during 1995 growing season. Total bulb yield was 884 cwt per acre, with 71 percent of total yield in jumbo + colossal market grades (> 3 in diameter). In this trial, addition of N fertilizer (data not shown) did not increase bulb yield (as evaluated out of storage in December) or N uptake.

[b]Crop N uptake (tops + bulbs) determined from harvest of bulbs on September 2 prior to crop maturation.

[c]Mineralizable soil N estimated via anaerobic incubation for 7 days at 104°F (40°C).

Source: Feibert, E.B., C.C. Shock, and L.D. Saunders. 1997. Nitrogen management of precision irrigated onions. pp. 60–67. In: Proc. Western Nutrient Management Conference. Salt Lake City, UT.

movement over the winter and changes in nitrate-N that accompany decomposition of crop residues.

Collect samples from onion beds in the spring before the first irrigation. Sampling before the first irrigation is recommended because nitrate movement with irrigation water leads to more variable test results. Sample at two depths: 0 to 12 and 12 to 24 inches. Onion root systems typically reach below 12 inches during bulb growth.

The preplant soil nitrate test is strongly correlated with crop yield response to N fertilizer in the Treasure Valley (see below).

Using the preplant nitrate soil test in the Treasure Valley

Interpretation of the preplant nitrate-N test for onions in the Treasure Valley is based on extensive research. Eighteen field trials were conducted in grower fields from 1991 to 1996. Data from nine on-station trials at Parma (1978 to 1985) is also included in the database.

The objective of the research was to relate preplant soil nitrate-N values to crop yield response. Preplant soil nitrate in onion beds was measured prior to the first irrigation. N fertilizer rates ranging from 0 to 320 lb N per acre were side-dressed at bulb initiation in June or applied preplant. Growers used normal cultural and irrigation practices.

Onions were harvested and graded into market classes. The yield of large onions (jumbo plus colossal; onions > 3 in diameter) was compared among N rates at a field location. "Relative jumbo yield" was calculated for each N rate within a location as:

Relative jumbo yield (%) = A ÷ B x 100, where:

A = onion yield (> 3 in diameter) for a given N fertilizer rate

B = maximum onion yield (> 3 in diameter) for the field site in the year of the test

Relative jumbo yield did not increase in response to applied N fertilizer when preplant soil test N was above 80 lb N per acre for the 0- to 12-in depth or above 100 lb per acre for the 0- to 24-in depth (Figure 4a). Maximum onion yields occurred at much lower preplant soil test levels at many sites, particularly when large amounts of N were mineralized from crop residues and soil organic matter.

Onions required a total of 40 to 160 lb N per acre (preplant soil nitrate-N [0- to 24-in depth] plus side-dress fertilizer N) for maximum jumbo yields (Figure 4b). Onions did not require more than 160 lb N per acre for maximum yield at any site. Onion yield and size were reduced at some locations with more than 160 lb N per acre (preplant nitrate-N plus fertilizer N).

Preplant analyses for soil ammonium-N did not improve prediction of fertilizer N needs.

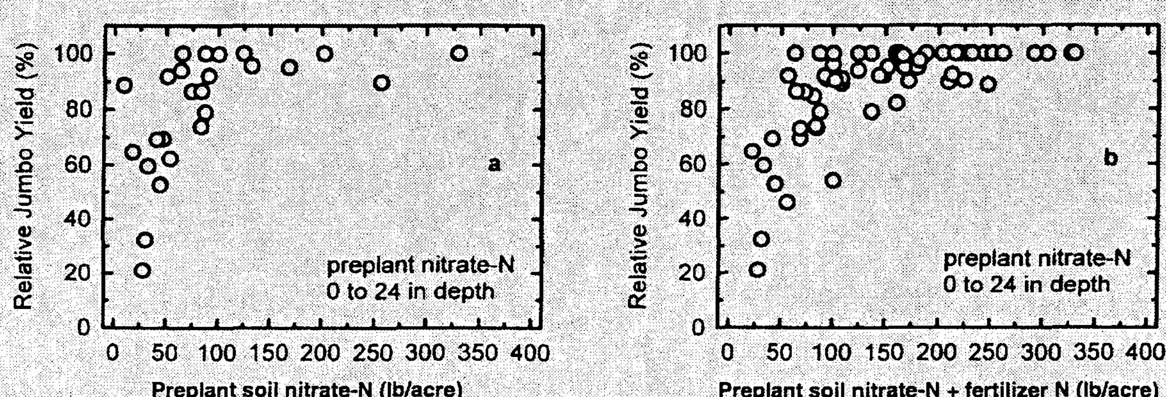


Figure 4.—Nitrogen supply from preplant soil nitrate-N (a) and preplant N + fertilizer N (b) vs. relative jumbo yield for Treasure Valley field locations near Parma, ID. A relative jumbo yield of 90 percent or above indicates that yields at that N rate were equal to maximum yield. Source: Brad Brown, University of Idaho Parma Research and Extension Center.

Estimating available N from mineralization

Mineralization process

Onions cannot utilize the organic nitrogen present in soil organic matter and crop residues until microbial activity releases available nitrogen (ammonium and nitrate forms). Onions take up both the ammonium and nitrate forms of nitrogen.

Crop residues decompose much more rapidly than soil organic matter. Crop residues decompose within weeks under favorable soil temperature and moisture conditions, while only a fraction (2 to 5 percent) of stable soil organic matter decomposes during a growing season. Most of the N mineralized accumulates as nitrate if it is not leached or taken up by the crop.

Estimating N mineralization

Estimates or credits for N mineralization that are used in estimating fertilizer N needs (line 8 in Table 3) include N mineralized from both soil organic matter and crop residues. N mineralization supplies a considerable amount of plant-available nitrogen during the key period for onion bulb growth (Figure 5).

The kind of crop residue affects the amount and timing of N mineralization. For example, sweet corn residue decomposes more rapidly and contains more N per acre than wheat residue (Figure 5). In Treasure Valley soils, the amount of N mineralized typically is lower with wheat as the previous crop (0 to 100 lb N/acre) than with a crop such as sweet corn (130 to 220 lb N/acre). Decomposition of wheat residue slows the rate of N mineralization early in the growing season. This effect is completed by about July 1 in the Treasure Valley. Soil N mineralization releases available N during the peak period for onion N uptake in July and August following either wheat or sweet corn.

Mineralizable N test

The mineralizable N test provides a rough prediction of N mineralization during the growing season. Mineralizable N is determined by anaerobic incubation of soil in water at 104°F (40°C) for 7 days. The high temperature used in the mineralizable N test speeds up the mineralization process and provides an estimate of season-long N mineralization in the field.

We recommend this test for trial use in the Treasure Valley. For Treasure Valley soils, there is a correlation between mineralizable N in the 0- to 12-inch and that in the 0- to 24-inch depth. Mineralizable N for the 0- to 24-inch depth is about 1.3 times the amount present in the 0- to 12-inch depth.

Collect soil samples for the mineralizable N test using the same procedure as for preplant nitrate-N. (Use the same samples for both tests.)

The mineralizable N test currently is not widely available at commercial laboratories. Check with your lab to see whether they can do this test.

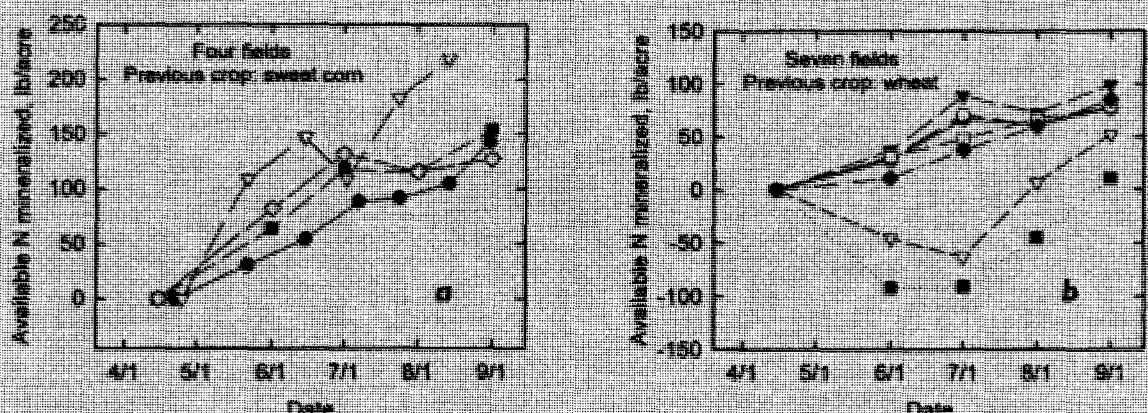


Figure 5.—Effect of sweet corn (a) or wheat (b) previous crop on N supplied by mineralization in Treasure Valley soils. Available N was determined by the buried bag method. Sources: Brad Brown, University of Idaho Parma Research and Extension Center, and Oregon State University Malheur Experiment Station (Steiber, et al. 1995).

Preplant soil ammonium-N

Growers sometimes include preplant ammonium-N as a credit when calculating N fertilizer requirements. Testing for ammonium-N in soil is important when N fertilizer has been applied recently, especially if the soil has been dry or cold since the application. Decomposition of crop residues that are high in N (e.g., alfalfa residue or sugar beet tops) in dry soil over the winter sometimes also results in high concentrations of ammonium-N the following spring.

Nitrogen mineralized from crop residues and soil organic matter

Soil microorganisms decompose crop residues and soil organic matter to produce the mineral forms of N (ammonium and nitrate) utilized by plants. This is an important source of plant-available N. The residue from the previous crop is an important factor determining the quantity of N mineralized. Soil temperature, moisture, and tillage also affect the rate of mineralization.

Current fertilizer guides take into account average soil N mineralization based on the previous crop, but do not require measurement of site-specific soil N mineralization potential. Recent research has focused on improving N mineralization estimates (see "Estimating available N from mineralization" at left). Research in the Treasure Valley has shown that N mineralization cannot be estimated accurately based on soil organic matter concentration.

Nitrogen supplied in irrigation water

You can determine the amount of nitrogen supplied by irrigation water by testing the water. "Effects of irrigation on N and S management" (at right) describes how to calculate an N credit for irrigation water. The efficiency of N supplied from irrigation water is similar to that of side-dress fertilizer N.

The timing of irrigation water N application coincides with crop N demand. Water is applied most frequently in July and August when onions are most active in extracting available N from the soil.

Effects of irrigation on N and S management

Plants take up most nitrogen and sulfur from the soil in the nitrate and sulfate forms. Nitrogen supplied as urea, ammonium-based fertilizers, or N mineralized from crop residues or soil organic matter is converted by microbial action to nitrate. Similarly, sulfur supplied as thiosulfate or S mineralized from soil organic matter or crop residues is converted to sulfate.

Irrigation water management is the most important tool in good management of nitrate-N and sulfate-S. These mobile nutrients move with water and are moved out of the root zone with excessive irrigation.

Irrigation water also can be a source of mobile nutrients. Water from wells or recycled irrigation water can supply significant amounts of nitrate-N or sulfate-S. Nitrate and sulfate can be present in the groundwater or might accumulate in irrigation reuse water. You can determine the amount of nitrate and sulfate in irrigation water by testing.

Only about half of the applied irrigation water is retained with furrow irrigation. Thus, you must estimate water retention when calculating the quantity of N and S applied with furrow irrigation. Calculate the amount of N or S supplied with irrigation as:

Nutrient applied (lb/acre) = A x B x C x 0.227

where:

A = irrigation water applied (inches per acre)

B = nitrate-N or sulfate-S concentration in water (mg/L)

C = decimal fraction of applied water retained in the field (for sprinkler or drip irrigation, C=1; for typical furrow irrigation systems, C = 0.5)

0.227 = conversion factor. The conversion factor is 0.227 for converting mg N/L or mg S/L to lb/acre.

Note: Units of mg per L are equivalent to ppm for water samples.

Example calculation

Your irrigation water contains 10 mg nitrate-N per L and 5 mg SO_4-S per L and you applied 48 inches of water via furrow irrigation during the growing season. Half of the applied water was retained on the field.

Nitrate-N applied = 48 x 10 x 0.5 x 0.227 = 54 lb/acre

Sulfate-S applied = 48 x 5 x 0.5 x 0.227 = 27 lb/acre

Table 3.—Worksheet for estimating fertilizer N application rate for onions.

Line	Estimate	Units	Data Source	How to Calculate	Example
1	Bulb yield	cwt per acre (fresh weight)	Production records	Choose a realistic yield goal based on production records	800
2	Unit crop N uptake	lb N per cwt of fresh bulb yield	University research	Average value is 0.19 lb N per cwt.[a]	0.19
3	Crop N uptake	lb N per acre	Calculation	Line 1 x Line 2	152
4	Crop N uptake efficiency	Percent of available N supply	University research	40 to 60%	50
5	Available N supply needed from all sources	lb N per acre	Calculation	Line 3 ÷ (Line 4 ÷ 100)	304
6	Available N supply from nonfertilizer sources	lb N per acre	Preplant soil test	Nitrate + ammonium N (0 to 24 inches)	60
7			Irrigation water test	Nitrate-N (use calculation from "Effects of irrigation on N and S management," page 11)	10
8			University research	Estimated soil N mineralization (use local values; consult your agronomist)	60
9			Calculation	Total available N supply from nonfertilizer sources (line 6 + line 7 + line 8)	130
10	Fertilizer N to apply[b]	lb N per acre	Calculation	Line 5 minus Line 9	174

[a]The usual range for bulb N uptake (fresh weight basis) is 0.14 to 0.24 lb N per cwt. The average value given here (0.19 lb N per cwt) is based on field trials with bulb yields of 400 to 1,030 cwt per acre.

[b] See "In-season fertilizer N application," page 13, for most efficient fertilizer N application methods.

Estimating the N fertilizer application rate

After estimating credits from nonfertilizer N sources, you can roughly estimate the amount of N fertilizer needed (Table 3). The lines in the worksheet with the greatest amount of uncertainty are crop N uptake efficiency (line 4) and estimated soil N mineralization (line 8). Most university fertilizer guides take into account average N uptake efficiency and soil N mineralization, but do not explicitly list these values. We show these factors in our worksheet to demonstrate how important they can be in accurately estimating N fertilizer rates. Consult your agronomist to determine local values for crop N uptake efficiency and soil N mineralization.

Use the worksheet only to roughly assess overall fertilizer N needs. The timing and method of N fertilization is more critical than the total amount of N fertilizer applied.

The worksheet can underestimate fertilizer N needs if soil mineralization is less than expected or the timing of soil N mineralization does not coincide with crop needs. If the worksheet calculates a zero N fertilizer rate, monitor root nitrate-N status to assure adequate N availability. (See "Monitoring crop N status during the growing season," page 14.)

If you apply organic fertilizer sources (e.g., compost) to supply available N, you will need to estimate the fraction of applied N that is available to the onion crop. *Fertilizing with Manure*, PNW publication 533, provides general estimates of first-year compost or manure N availability.

In-season N fertilizer application

Nitrogen fertilizer is utilized most efficiently when it is applied just prior to, or during, the period of rapid crop N uptake (Figure 1, page 5). The period of rapid crop N uptake begins at bulb initiation (growth stage 4; Table 1, page 3).

Application methods

Side-dressing

Side-dressing, the knifing of N into the shoulder of the onion beds, is one of the most efficient application methods for furrow-irrigated onions, especially when delayed until bulb initiation. Side-dress N can be applied only as long as fertilizer application equipment can get into the field without damaging onion plants.

Where leaching losses are high, split applications usually are more effective than a single side-dress application. Regardless of the number of applications, the amount of N applied at one time should not exceed 100 lb N per acre. Typical side-dress N application rates are 40 to 80 lb N per acre per application.

At high side-dress N rates (> 160 lb N per acre), onion yields sometimes were reduced in Treasure Valley trials. The yield reduction at high N rates probably was caused by root injury via ammonia toxicity or high soluble salt concentrations.

Sprinkler or drip irrigation

You can meet crop N needs efficiently by applying N fertilizer with sprinkler or drip irrigation. Consider crop N uptake rates (Figure 1c, page 5) in choosing the timing and amount of drip or sprinkler-applied N. Maximum crop N uptake rates for onions are 2 to 3 lb N per acre per day.

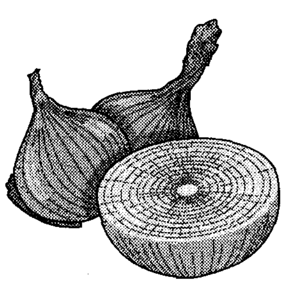
Furrow irrigation

Adding N to water used for furrow irrigation is a less precise method and generally is not recommended. Problems with water-run N applications include:

- Furrow irrigation does not distribute water evenly across the field. More N is applied to the top of the field than to the lower end of the field.
- Water leaving the field contains some of the fertilizer N.
- Adjacent furrows in the same field might be irrigated over a period of days (e.g., irrigation of every fifth furrow), making it difficult to synchronize water application and fertilizer application.

We recommend choosing another method of N application to replace water-run N applications. If water-run application is necessary, the following precautions can reduce or eliminate N loss from the field:

- Begin N application when water has advanced 30 percent of the way through the field. This practice avoids excessive application of N to the top part of the field.
- Shut off the fertilizer injection unit before water reaches the end of the field. This practice avoids N fertilizer loss in irrigation water runoff.
- Collect and reuse irrigation water.



Fertilizer N sources

The timing and method of fertilizer N application is more important than the N source. (See "In-season N fertilizer application," page 13.) In-season application of ammonium nitrate, ammonium sulfate, calcium nitrate, and urea-ammonium nitrate produced similar onion yield and quality in a 2-year Treasure Valley trial. N fertilizers differ in their effects on soil pH. (See "Acid soils in the Columbia Basin" at right.)

Controlled-release N fertilizer products offer promise for efficient utilization of N, particularly in soils prone to leaching. Polymer-coated urea (PCU) fertilizers are being evaluated for onion production in the Pacific Northwest and other western states. The polymer coating slows the release of available N. Coating urea with sulfur also reduces the rate of available N release from fertilizer granules. Sulfur-coated urea increased fertilizer N efficiency compared to uncoated urea in some Treasure Valley trials.

Monitoring crop N status during the growing season

There are two ways to monitor the success of nitrogen management practices during the growing season: soil testing and plant tissue testing. These tools can assist you in managing N to meet goals for crop yield, quality, and environmental protection. You can use them to determine the need for in-season N application when other data (see "Estimating the N fertilizer application rate," page 13) indicates that little or no fertilizer N is needed. They also can help you diagnose the cause of poor crop growth.

Both monitoring methods have limitations. Both are a "picture in time," reflecting current soil and plant N status. To get reliable information from these tools, collect samples periodically during the season.

Acid soils in the Columbia Basin

Soil acidity (pH less than 5.5) has been identified as a contributing factor in stand reduction and poor crop performance on loamy sand or sandy loam Columbia Basin soils. These soils were naturally neutral or slightly alkaline before cultivation; they have been acidified by N fertilization and other cropping practices.

Diagnosis

Soils with identified soil acidity problems are poorly buffered, with cation exchange capacities (CEC) of 5 to 10 meq/100 g. On these sandy soils, pH can fluctuate by 1 to 2 units during the year, depending on fertilizer and crop management practices. Soil pH usually is highest in winter or early spring. Fertilizer salts and soil biological activity reduce pH (increase soil acidity) during the growing season. Thus, preplant soil pH measurements might not reflect soil pH values during the growing season.

Soil acidity problems can occur even in fields that contain areas of calcareous (pH 8) soil. Therefore, pH might need to be adjusted on a site-specific basis within the field.

Soil acidity problems in Columbia Basin fields often look like a seeding or tillage problem. Often, plants in entire rows are missing, while plant stands in nearby rows are acceptable. This phenomenon likely is due to differences in depth of tillage. Deeper tillage often brings higher pH soil to the surface.

Plants affected by soil acidity exhibit slow, stunted growth. Root systems are poorly developed and might have some stubby roots similar to those injured by nematode feeding. Manganese in leaf tissue often is above 150 ppm, and soil pH in the onion row is below 5.

Soil and plant tissue tests for soil acidity

To anticipate and evaluate potential soil acidity problems, use the following soil tests:

- Lime requirement (one-quarter strength SMP buffer). This test measures reserve acidity present on cation exchange sites. It is used to evaluate the potential for pH decline during the growing season and the amount of lime needed to correct soil acidity. The standard lime requirement test (full-strength SMP buffer) cannot accurately determine lime requirements on very sandy soils.
- Exchangeable calcium. Exchangeable Ca below 3 meq/100 g indicates the potential for soil acidity problems.
- Soil pH. This test measures acidity in soil solution. Collect soil from the rooting depth (0 to 6 inches) in the onion row to monitor pH during the growing season.

High manganese (Mn) concentrations in onion leaf tissue can be an indicator of potential soil acidity problems. Further soil testing should be done when leaf Mn is greater than 100 ppm. Leaf tissue Mn concentrations can be misleading if foliar Mn has been applied.

Suggested management practices

Soil acidity can be corrected by applying and incorporating lime before planting. Correcting a soil acidity problem during the season is difficult because liming materials have low water solubility and remain near the soil surface.

Preplant application of 500 to 1,000 lb agricultural lime usually is sufficient to correct soil acidity problems for an onion crop on very sandy Columbia Basin soils. Use shallow tillage to incorporate lime into the top 6 inches of soil.

Fertilization practices can have a dramatic effect on soil pH. If possible, avoid preplant application of N and K fertilizers on sandy soils subject to soil acidity problems. The salt provided by these materials can reduce pH by 1 unit (e.g., from 6 to 5). Chloride from fertilizer sources such as potassium chloride also can increase plant injury by increasing uptake of Mn. Apply N and K in smaller increments during the growing season. Reduce or eliminate application of acid-forming fertilizers such as mono-ammonium phosphate (e.g.,11-52-0), urea-sulfuric acid, and ammonium sulfate.

Soil nitrate monitoring

You can monitor soil nitrate to assess available N in the root zone. It is most valuable early in the growing season when onion root systems are small and root samples are difficult to collect for nitrate analysis. Under furrow irrigation, nitrate concentrations are uneven across the bed, resulting in highly variable test results.

Sampling

To monitor early-season N availability, collect samples to a 6-inch depth within the row. If ammonium-based fertilizers or urea were applied recently, include ammonium-N analyses.

Early-season interpretation

Because of the variability typically observed in soil nitrate testing, we address only in-row nitrate concentrations in the high (above 20 ppm) and low (below 5 ppm) range. High nitrate-N concentrations (above 20 ppm in the root zone) indicate that N currently is not limiting crop growth, and N fertilizer applications should be delayed. Low nitrate concentrations (less than 5 ppm in the root zone) suggest that N might be limiting growth.

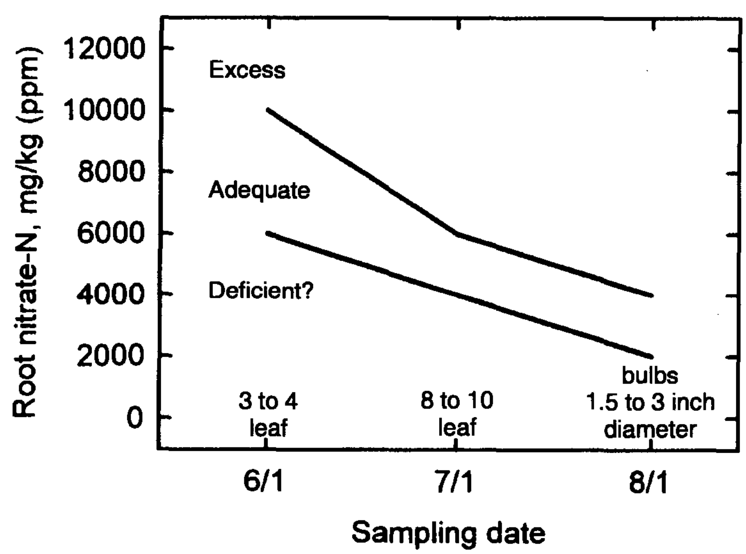


Figure 6.—Interpretation of onion root nitrate-N test. The adequate range includes root nitrate-N concentrations (dry wt. basis) associated with maximum bulb yield in Treasure Valley field trials. This interpretation is based on N fertilizer trials where side-dress N was applied during bulb initiation (5- to 7-leaf stage) with typical furrow irrigation water management. Maximum onion yield and size can be produced with lower root nitrate concentrations when low concentrations of nitrate are provided consistently by irrigation water, N mineralized from crop residues or soil organic matter, or slow-release N fertilizers. Source: Brad Brown, University of Idaho Parma Research and Extension Center.

Root nitrate monitoring

Onion roots display the greatest response to available N supply of any plant part. Root nitrate-N concentrations vary from more than 10,000 ppm (dry weight basis) after side-dress N fertilizer applications to less than 1,000 ppm for onions that are nitrogen deficient.

You can use leaf N as an indicator of plant N status at the 3- to 5-leaf stage, when root systems are small and root samples are difficult to collect. Leaf tissue concentrations above 3.5 to 4 percent N (dry wt. basis) in the most recently matured leaf are sufficient.

Root sampling

Collect root samples from 20 to 30 representative plants. Remove the plant from the field using a small spade or other lifting tool, being careful not to cut off or lose roots. Wash with water to remove soil and then cut off the roots at the base of the plant. After cutting off the onion roots, pack the washed roots loosely in a paper bag. For overnight shipment to the laboratory, pack the roots so that they start to dry in transit and do not become a slimy mess. Roots should reach the laboratory within 24 hours of sampling.

Interpretation

Root nitrate-N analyses are an indicator of plant N status at a particular time. This test does not reflect nitrate that might become available to the plant as the root system penetrates deeper or spreads laterally. Figure 6 shows adequate and excessive levels of root nitrate-N during a growing season.

Root nitrate concentrations can help you determine the need for N fertilizer application. If root nitrate concentrations are high, you can delay or omit side-dress N applications. High root nitrate-N concentrations late in the growing season usually reflect available N supply in excess of crop needs. However, root nitrate-N concentrations also can be high if another factor limits growth.

Most research trials have not demonstrated a link between high root nitrate late in the season and bulb shrinkage and rot in storage. Environmental conditions such as hail, poor conditions for field curing, or high humidity early in storage play a larger role than crop N status in determining storage loss.

Postharvest N management

Crop rotations that include a deep-rooted crop following onions (alfalfa, sugar beets, or cereals) can assist in recovering some of the nitrate-N from below the onion root zone. Consult your local Extension agent on cover cropping options for your area.

Phosphorus

Assessing P needs

Phosphorus deficiency reduces bulb size and can delay maturation. Crop P uptake for a bulb yield of 840 cwt/acre was 20 to 25 lb P per acre in Columbia Basin research (Figure 3, page 7). Maximum P uptake rates are 0.3 to 0.5 lb per acre per day during bulb growth.

Consider the following soil and crop management factors when determining P fertilizer application methods and rates:

- Soil test value (ppm)
- Soil free lime (calcium carbonate) concentration
- Fumigation

Collect soil samples from the 0- to 12-inch depth for P analysis. Different soil test methods are used in testing for P availability on alkaline and acid soils. The Bray P1 test is appropriate for acid to neutral soils (pH < 6.5). The Olsen (sodium bicarbonate) method is appropriate at all soil pH values. Check with your laboratory if you are unsure about which test method they use.

Fumigation prior to seeding onions might increase P fertilizer requirements. Fumigation kills the mycorrhizal fungi that help onion plants take up P. (See "Root growth and development," page 4.) In a 2-year Treasure Valley trial (Figure 7), fumigation caused P deficiency at soil test values below 30 ppm P. Without fumigation, adequate P for maximum yield was present at a soil test value of 10 ppm.

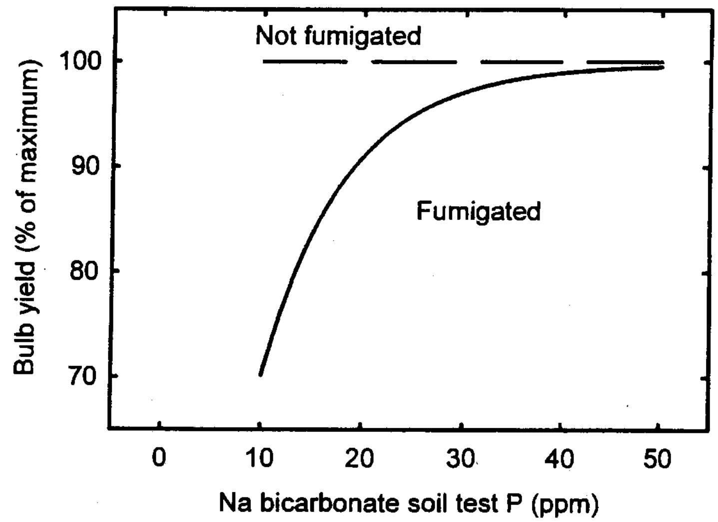


Figure 7.—Fumigation increases the need for fertilizer P. Without fumigation, maximum onion yields were produced at 10 ppm soil test P (Olsen sodium bicarbonate extractant). With fumigation, onion yields increased with increasing soil test P up to 30 ppm. Soil at the test site contained about 10 percent lime. Source: Mike Thornton, University of Idaho Parma Research and Extension Center.

Table 4 shows how soil and management factors affect P fertilizer requirements in the Treasure Valley. For other growing areas, research data for onions is more limited; consult a qualified agronomist for assistance.

Application methods

Incorporating P fertilizer in the planting bed is recommended. You can broadcast P prior to bedding or band it in conjunction with the bedding operation. Banded P fertilizer applications have been shown to be more effective than broadcast applications in western Oregon. Banding P below and to the side of the seed was no more effective than broadcast P in Treasure Valley trials. Do not place banded ammonium phosphates with onion seed because of the danger of ammonia toxicity.

Correcting P deficiency via foliar application is not recommended. Onion P requirements are very large compared to the amount of P that can be absorbed by leaf tissue.

Because of water quality concerns, minimizing P loss from the field is becoming an important consideration. Any practice that reduces furrow erosion will reduce total P loss from the field. You can reduce furrow erosion by a variety of methods, including laser

Table 4.—Phosphorus fertilizer rates based on soil test P, lime concentration, and fumigation for onions grown in the Treasure Valley.

Bicarbonate (Olsen) soil test P 0 to 12 inches	Soil lime concentration (%)[a]			
	0	5	10	15
(ppm)	P fertilizer application rate (lb P_2O_5 per acre)[b]			
	Not fumigated before planting			
0	160	200	240	280
5	100	140	180	220
10	40	80	120	160
15	0	20	60	100
20	0	0	0	40
above 25	0	0	0	0
	Fumigated before planting			
0	200	240	280	320
5	140	180	220	260
10	80	120	160	200
15	20	60	100	140
20	0	40	20	80
25	0	0	0	20
above 30	0	0	0	0

[a]Soil lime concentration as determined by calcium carbonate equivalent test.

[b]To convert from the oxide (P_2O_5) to the elemental form (P) multiply by 0.43.

Source: Brown, B. 2000. *Onions. Southern Idaho Fertilizer Guide.* CIS 1081. University of Idaho, Moscow, ID.

leveling, filter strips, sediment ponds, irrigation water management, straw mulching, and addition of PAM (polyacrylamide) to irrigation water.

Monitoring crop P status

Limited data exists to interpret crop P status via plant tissue testing. The range between deficient and adequate tissue P concentrations often is narrow because more plant biomass is produced when P deficiency is corrected. In a 2-year Treasure Valley trial, leaf phosphate-P (PO_4-P) was 3,000 ppm (dry wt. basis) in phosphorus-deficient onions, while in phosphorus-sufficient onions it was 3,300 ppm.

In the same trial, root PO_4-P concentrations necessary for maximum colossal production were 2,000 to 2,500 ppm at the 3- to 4-leaf stage and 1,600 to 2,000 ppm at the 8- to 9-leaf stage. Onions producing high yields at two Columbia Basin field locations had 1,500 to 3,500 ppm root PO_4-P during the growing season.

Potassium

Assessing K needs

Onions take up nearly equal amounts of N and K. A 700- to 1,100-cwt crop removed 110 to 160 lb K per acre in Columbia Basin trials (e.g., Figure 3, page 7), with peak uptake rates of 2 to 3 lb K per acre per day. Onions remove less K than potatoes and alfalfa.

Potassium is a positively charged ion that is held on exchange sites in soil. The potassium-supplying capacity of a soil usually is greater for soils with higher cation exchange capacity (CEC).

Potassium-deficient onions are relatively rare in the Treasure Valley. Potassium fertilization often is needed on the sandy soils that have a lower CEC in the Columbia Basin.

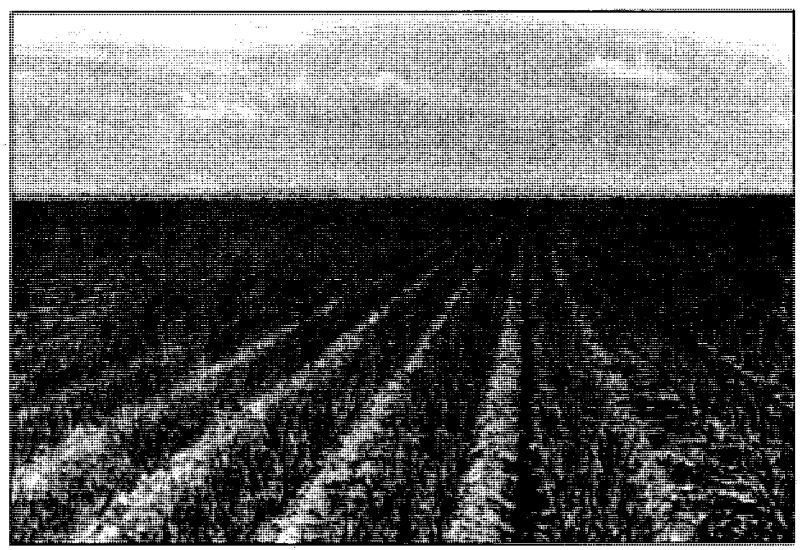
Laboratories determine available K status by extracting soils with sodium bicarbonate or ammonium acetate. Both extractants usually produce comparable soil test values and are considered equivalent. Soil test recommendations are based on a 0- to 12-inch sample. Table 5 shows the interpretation of soil test K from the *Southern Idaho Fertilizer Guide.*

Table 5.—Potassium fertilizer rates based on soil test K for onions grown in the Treasure Valley.

Potassium (K) soil test[a] 0 to 12 inches (ppm)	K fertilizer application rate	
	(lb K per acre)	(lb K_2O per acre)
0	200	240
50	100	120
above 100	0	0

[a]Soil test K as determined by sodium bicarbonate (Olsen) extraction.

Source: Brown, B. 2000. *Onions. Southern Idaho Fertilizer Guide.* CIS 1081. University of Idaho, Moscow, ID.



K fertilizer application

Potassium fertilizers are soluble salts. Apply K fertilizers only when needed, because excess salts can reduce seed germination and plant growth.

Potassium should be applied preplant on most soils. Incorporate it in the fall or during seedbed preparation. In-season application of K might be preferred on some very sandy soils in the Columbia Basin to avoid problems associated with excessive salts early in the growing season (see below).

Water stress and salinity

Onions are very sensitive to water stress. They respond to water stress with reduced rates of transpiration, photosynthesis, and growth. Water stress can be caused by soluble salts in the soil or by a soil water deficit.

During bulb growth, onions are more sensitive to water stress than most other crops. Water stress at this time reduces bulb yield and size. In Columbia Basin studies, water stress at the 3- to 5-leaf stage reduced the percentage of single-centered bulbs by 40 to 60 percent compared to nonstressed onions.

Drip irrigation systems can be managed to maintain consistent soil moisture during bulb development.

In Treasure Valley research with drip-irrigated onions, maximum bulb yield and size were achieved by maintaining soil moisture near field capacity at the 8-inch depth (a soil water potential of about –20 kPa, a reading of 0.2 bars or 20 centibars on a tensiometer). Maintaining soil water potential at –25 kPa requires 11 to 20 furrow irrigations during the growing season in the Treasure Valley, depending on seasonal precipitation and evapotranspiration.

Fertilizers incorporated into planting beds before seeding increase soluble salts. High levels of soluble salts can kill seedlings as they emerge. Onions can tolerate higher salt levels after plants are established. Screening tests for salinity tolerance show that yield reduction begins to occur at a conductivity of 1 to 2 mmhos/cm, and a 50 percent yield reduction occurs at 4 to 5 mmhos/cm.

Salinity problems also can include toxicity of specific elements such as boron or sodium. Boron and sodium toxicity usually are related to irrigation water quality. Extension vegetable crop specialists in California report that onions are more sensitive to salinity, sodium, and boron than are lettuce, cauliflower, broccoli, and cabbage.

Monitoring crop K status

Insufficient data exists to make fertilizer recommendations based on plant tissue K levels. At two adequately fertilized sites in the Columbia Basin, onion leaf tissue contained 2.5 to 3.5 percent K (dry wt. basis) at the 3- to 8-leaf growth stage, and root K concentrations ranged from 3 to 5 percent (dry wt. basis) during the growing season.

Calcium and magnesium

Research on the effects of calcium (Ca) or magnesium (Mg) application on onion bulb yield and quality is very limited.

Onion bulbs usually contain about 0.5 percent Ca (dry wt. basis), and crop uptake averages 50 lb per acre. One trial in the Treasure Valley with added Ca as calcium nitrate showed no response in bulb yield or quality. Higher plant Ca uptake sometimes occurs when calcium nitrate fertilizers are applied (e.g., uptake of 120 lb Ca per acre in Figure 3, page 7). Low Ca supply can be a concern on very sandy Columbia Basin soils with low pH values. (See "Acid soils in the Columbia Basin," page 15.)

Onion bulbs contain approximately 0.10 to 0.15 percent Mg (dry wt. basis). Crop Mg uptake ranged from 10 to 20 lb per acre in several Columbia Basin field trials (e.g., Figure 3, page 7).

Sulfur

Assessing S needs

Sulfur is an essential plant nutrient and it contributes to the distinctive flavor of onions. Volatile sulfur compounds are released by action of the enzyme allinase when onions are cut or bruised. Onion varieties differ in the amount and kinds of S compounds present in the bulb.

Some of the S compounds responsible for pungency can inhibit the growth of fungi and bacteria and have been shown to reduce storage losses of sweet, short-day onions grown in Georgia. Application of S fertilizer increased onion pungency in Treasure Valley trials, but did not affect bulb storage loss. Increased bulb pungency is a negative characteristic in marketing of most onions.

Onion bulbs contained 0.3 to 0.6 percent S (dry wt. basis) in Columbia Basin trials. The N to S ratio in bulbs ranged from 3 to 1 to about 5 to 1. An 840 cwt/acre crop removed about 35 lb S per acre (Figure 3, page 7). Maximum S uptake rates were 0.6 to 0.9 lb S per acre per day during bulb growth.

Sulfur fertilization is not needed in many locations because adequate S is supplied from other sources. Nonfertilizer sources of S include:

- Preplant soil sulfate-S
- Decomposition of crop residues and soil organic matter during the growing season
- Irrigation water

Soils containing lime can precipitate and store S as gypsum (calcium sulfate). Gypsum accumulated in the top 2 feet of soil serves as another source of plant-available S.

The preplant sulfate-S soil test is less reliable for prediction of plant responses to fertilizer S than soil tests for N, P, and Zn. Collect preplant soil samples for sulfate-S to a 24-in depth. Use the same soil samples collected for preplant nitrate-N analysis. (See "Preplant soil nitrate-N," page 7.)

Fertilizer application

Apply sulfur fertilizers if soil test values for sulfate-S are less than 5 ppm (mg/kg) and irrigation water sulfate-S is less than 5 ppm (mg/L). Apply 30 to 40 lb S per acre when soil and irrigation water tests indicate a need. Apply soluble S sources just prior to or during the period of rapid crop uptake (Figure 3, page 7) for maximum efficiency.

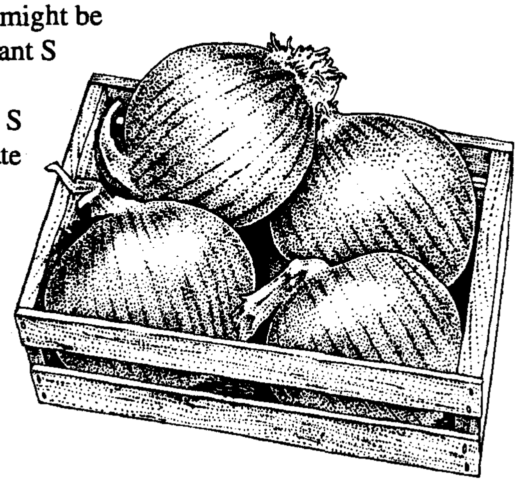
Sulfur salts such as potassium sulfate or ammonium sulfate can supply S. Do not apply ammonium thiosulfate near onion roots. Ammonium thiosulfate usually has a high pH (8) and contains some ammonia, which is toxic to roots. The thiosulfate ion itself also is toxic to roots. After a few days or weeks in soil, ammonia is converted to nontoxic ammonium-N, and thiosulfate is converted to nontoxic sulfate-S.

Urea-sulfuric acid supplies available S and N. It also increases soil acidity (lowers pH). The lower pH produced by urea-sulfuric acid application might temporarily increase availability of Zn on high-pH calcareous soils (those that contain carbonate or lime). It also might increase soil acidity problems on very sandy Columbia Basin soils. (See "Acid soils in the Columbia Basin," page 15.)

Monitoring crop S status

Limited data exists to interpret plant tissue tests for S. Total S in leaves and roots (3- to 8-leaf growth stage) ranged from 0.5 to 0.8 percent (dry wt. basis) for adequately fertilized onions in Columbia Basin trials. Onions supplied with low amounts of S in greenhouse trials had leaf S concentrations of less than 0.4 percent during bulb growth.

Root or bulb SO_4-S might be a useful indicator of plant S status. Bulb sulfate-S increased linearly with S fertilizer application rate in a recent greenhouse study with 'Southport White Globe' onions.



Total bulb S is a poor indicator of pungency. Onion varieties differ in the kinds and amounts of sulfur compounds present in bulbs.

Micronutrients

Onion uptake of micronutrients is most rapid during bulb growth (Figure 3, page 7). Applications of micronutrients are not recommended unless a reliable soil or plant tissue test indicates a need. Data to interpret soil and plant tissue tests for onion micronutrient status is limited. Most interpretations are based on response data from other crops. Research on onion response to Zn and B has been conducted in the Treasure Valley.

You can use soil tests to assess the potential for micronutrient deficiencies and toxicities. The DTPA soil test evaluates deficiencies of zinc (Zn), manganese (Mn), and copper (Cu). The hot-water and sorbitol extraction methods assess soil B availability. You can use leaf tissue tests to monitor total plant tissue concentrations of Zn, Mn, Cu, molybdenum (Mo), and boron (B).

Onions are sensitive to zinc deficiency. Deficiencies usually occur on white, high lime subsoils that have been exposed by land leveling or erosion. Soils are considered marginal at 0.8 to 1.0 ppm DTPA extractable Zn. Deficient Zn concentrations in leaf tissue probably are 10 to 20 ppm (dry wt. basis), based on data from other crops. Zinc deficiency can be corrected by soil or foliar Zn applications. There is insufficient data to support specific recommendations.

Application of manure or compost to other crops in rotation with onions might reduce or eliminate deficiencies of Zn and other micronutrients in onions. Manure or compost application prior to seeding onions generally is not recommended. Salts from manure or compost might reduce seed germination and increase water stress.

Onions did not respond to applied boron in Treasure Valley field tests even at low soil test levels of hot-water extractable boron (less than 0.5 ppm). Sufficient soil B levels on low organic matter, sandy soils in the Columbia Basin are about 0.3 ppm. If soil or plant tissue tests indicate a potential B deficiency, apply B fertilizer at low rates. Boron toxicity can occur if B is excessive. There is insufficient data to support specific recommendations.

Molybdenum (Mo) deficiency might occur on recently acidified, sandy soils in the Columbia Basin. Onions with leaf tissue Mo concentrations of less than 0.15 to 0.30 ppm (dry wt. basis) might respond to Mo application.

No research has been performed to assess manganese and copper response in onions grown in the Columbia Basin or the Treasure Valley.

Iron deficiency of onions has not been documented in the Pacific Northwest. DTPA soil tests and plant tissue tests for iron are not as reliable as those for other micronutrients. Trial applications of foliar iron might be warranted when soil pH is above 8.5. Soil applications of iron generally are ineffective in high pH soils.

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Strategies for Reducing Irrigation Water Use

Lynn Jensen and C.C. Shock

When water is plentiful, growers usually schedule irrigation practices around other farming activities. For example, most growers change furrow irrigation sets at 12- or 24-hour intervals because this timing is convenient and uses labor efficiently. When water is in short supply, you need to rethink some practices to obtain maximum benefit from available water. After all, next to the land itself, water is a grower's second most important resource. It makes sense to exchange management and labor for water.

Not everyone faces serious water shortages now, but problems might spread if Oregon has another dry winter. Also, power crises will lead to growing pressure to save water for power generation or endangered species such as salmon and bull trout. The issues affecting the Klamath Basin or similar ones such as Total Maximum Daily Load (TMDL) might be only a few years away from affecting many parts of Oregon.

The ideas below are only suggestions. One or more of them might work on your farm. They are not prioritized, but some will save more water than others. The first group of strategies can apply to any type of irrigation. The second group applies specifically to furrow irrigation.

Figure 1.—Using the AgriMet crop water use data.

(1) ESTIMATED CROP WATER USE - JULY 16, 2000 ONTO												
(2) CROP	(3) START	(4) DAILY CROP WATER USE-(IN) PENMAN ET - JULY				(5) Daily Forecast	(6) COVER DATE	(7) TERM DATE	(8) SUM ET	(9) 7 DAY USE	(10) 14 DAY USE
		12	13	14	15						
ONYN	401	0.32	0.3	0.29	0.31	0.32	710	820	20.6	2.16	4.3
POTS	501	0.33	0.32	0.3	0.32	0.34	610	820	19.7	2.3	4.28

(1) = Location of weather station: ONTO = Ontario, Malheur Experiment Station
(2) = Crop: ONYN = Onions; POTS = Shepody Potatoes
(3) = Start Date: Crop emergence date
(4) = Amount of water used by the crop each day for the past 4 days
(5) = Estimated water use for the date on the chart, i.e., July 16
(6) = Cover date: Date the crop reached full canopy
(7) = Term date: Date irrigation stops or crop is harvested
(8) = Sum ET: Total estimated water use from the beginning of the growing season to the current date
(9) = 7 day use: Prediction of water needed by crop for the next 7 days
(10) = 14 day use: Prediction of water needed by crop for the next 14 days

General strategies

- Leave some ground idle and apply the saved water to high-value crops. Because irrigation districts must keep their system charged with water, this strategy will have a greater impact if everyone in the district cuts back on irrigated acres.
- Do not over-irrigate. This sounds simple, but isn't. Most growers err on the side of excess. Too much water has less visual impact than too little, but it wastes soil and fertilizer as well as water.
- Use "ET" (evapotranspiration) charts from the Bureau of Reclamation AgriMet system. The charts show fairly accurate estimates of crop water use and can help you decide when and how much to irrigate. (See Figure 1 for information about how to use these charts.)
- Use soil-moisture monitoring equipment to measure how much moisture is in the soil. There are several types of sensors available. The most commonly used in Oregon are Watermark sensors, the Diviner, and tensiometers. These instruments, when used with ET charts, provide a fairly accurate estimate of irrigation needs. For more information on measuring soil moisture, see *Instrumentation for Soil Moisture Monitoring*.
- Graph soil moisture readings. The most important aspect of soil-moisture monitoring is graphing the readings in order to improve your irrigation accuracy. Even if you measure soil moisture with a shovel and your fingers, you can graph the readings. Figure 2 shows a portion of a graph used for Watermark sensors.
- Know each crop's tolerance of drought stress and irrigate accordingly. Some plants handle drought stress better than others. Barley uses less water than wheat. Sugar beets can extract moisture from a greater depth than most crops. Russet Burbank potatoes suffer greatly in quality when drought stressed—losing tuber grade and fry color. Shepody potatoes suffer less quality reduction than Russet Burbank, but still more than other crops. Total yield is reduced when Shepody and Umatilla Russet varieties are drought stressed. Potatoes can be stressed very early, but not after setting tubers. Water stress on onions affects yield and grade and reduces the percentage of single centers. Wheat and corn lose test weight and yield. For most crops, water

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stress at the flowering stage is most damaging.

- Know the water-holding capacity of your soils. A sandy loam soil will not hold as much water as a silt loam; thus it must be irrigated more frequently, but apply less water with each irrigation. Extra water is lost to leaching.
- Know the water-use requirements of the crops you intend to grow, and make sure you have enough water to get an economic yield.

Strategies for furrow irrigation

- Consider surge irrigation or at least use a modified surge program on the first irrigation. The wetting-drying cycle of surge irrigation reduces water loss to deep percolation, which is particularly important on the first irrigation when the soil is friable and takes a lot of water. For a modified surge irrigation program, alternate siphon tubes between rows every couple of hours on the first irrigation. This method can save water and reduce nitrogen loss through leaching.
- Use alternate-row irrigation; irrigate one side of a bed on one irrigation, the other row or side on the next. This practice works well with crops that are less sensitive to moisture stress.
- Irrigate only the wheel row. Since its infiltration rate usually is much lower than that of the soft row, water is less likely to move below the root zone.
- Compact the soft, non-traffic rows in furrow-irrigated fields so that their infiltration rate is similar to that of the wheel-traffic rows.
- Switch to sprinkler irrigation, which allows you to manage water more efficiently and apply it to the depth needed. Remember that some crops might have more disease problems under sprinklers because the foliage stays wet. Also, with increased power costs, this might not be a good option unless the water intake is high enough above the rest of your farm to allow you to set up a gravity flow system.
- Drip irrigation can save a lot of water, in many cases more than half of the amount used for furrow irrigation. It often increases yields as well. A drip system is costly to set up, but is practical for onions and promising for seed alfalfa. The Malheur Experiment Station is investigating ways to leave the tape in the ground through several cropping cycles. See *Drip Irrigation: An Introduction* for more information.
- Change irrigation sets when water reaches the end of the furrow rather than at a specified time of day.
- Use PAM (polyacrylamide) or straw mulch to improve water infiltration in tight soils (those with a low water infiltration rate).
- Eliminate deep watering of shallow-rooted crops such as onions and beans. Frequent, light irrigations help keep water in the root zone where plants can use it.
- Avoid over-watering the top of the field by cutting the water as soon as it reaches the end of the field. Most people over-water the top of the field, which stresses plants and causes nitrogen deficiency as nitrogen leaches below the root zone. Slightly drought stressing the bottom of the field should cause production losses similar to those caused by over-watering the top of the field. Straw the bottom of the field so that the water that gets there soaks in.
- Use catch basins to collect runoff and reuse it. Sometimes this involves pumping water to the top of the field or to the next field. Analyze the cost of pumping to see whether this strategy is cost-effective.

For more information

Web sites

AgriMet—daily crop evapotranspiration estimates (*mac1.pn.usbr.gov/agrimet/h2ouse.html*)

How to find irrigation information on the Internet (*www.microirrigationforum.com/new/onthenet*)

Irrigation Scheduling (*www.cropinfo.net/irrigschedule.htm*)

Instrumentation for Soil Moisture Monitoring (*www.cropinfo.net/AnnualReports/1997/instrumentation.wq.html*)

NRCS Irrigation Information Links (*www.wcc.nrcs.usda.gov/nrcsirrig/irrigate_bookmark.htm*)

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Irrigation Management Practices Checklist for Oregon, EM 8644 (1996). $2.25

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Soil Water Monitoring and Measurement, PNW 475 (1995). $1.00

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Figure 2.—Sample soil moisture graph.

Grower__________ Field ID______ Soil Type________ Year____

Critical Levels

Sand Soil - 30 centibars

Silt Loam - 50 centibars

Clays - 70 centibars

Days

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
0																
10																
20																
30																
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