Field Measurements of Nitrate Leaching Below Willamette Valley Row and Mint Crops

Jeff Feaga and John Selker

Western Oregon's Willamette Valley has fertile soils and a climate ideal for growing a wide variety of crops. Long, rainy winters make the Willamette Valley vulnerable to post-harvest nitrate (NO_3^-) leaching and shallow groundwater contamination.

According to the United States Geological Survey (1998), 9 percent of wells in the Willamette Valley exceed the EPA's 10 ppm drinking water standard for nitrogen (N) in the NO_3^- compound, or NO_3^--N. A study of 281 domestic drinking water wells in Lane County showed that 22 percent of the wells exceeded the same standard (Penhallegon, 1994). In a 2000–2001 study of 476 wells in the southern Willamette Valley, 35 wells exceeded the drinking water standard, with 21 percent of the total wells exceeding 7 ppm NO_3^--N (DEQ, 2002). Other studies have shown high concentrations of NO_3^--N within water draining from experimental fields planted in corn, broccoli, and snap beans (Sattell et al., 1999). Exposure to high concentrations of NO_3^- is known to cause breathing complications in infants (Weisenburger, 1993) and has been linked to cancerous tumors in laboratory animals (Pierzynski et al., 1994).

The objective of this field study was to measure NO_3^--N concentrations in water percolating below root depth on privately owned and operated vegetable and mint fields in Lane County. Two groundwater samplers were installed on each of six fields in conventional row vegetables, five fields in mint, and two fields in organic vegetables. All crop and nutrient management decisions on the fields were left entirely up to the individual growers. The goal of this research is to provide growers and Extension agents with accurate information about the occurrence of NO_3^- leaching to shallow groundwater from typical commercial farms in the Willamette Valley.

Contents

The NO_3^- Leaching Process

When fertilized at rates recommended for maximum yield, most cultivated crops are not very efficient at using applied N fertilizers. Vegetables are highly inefficient at using applied N because of their shallow rooting depths and relatively large distances between plants due to cultivation practices. Due to its relatively high economic value, low water-stress tolerance, and large N requirements, mint is a high-risk crop for NO_3^- leaching.

The quantity of N removed during harvest is generally 30 to 70 percent of the total quantity of N applied as fertilizer (Hermanson et al., 2000). Nitrogen not removed with the harvest either remains as NO_3^- in the soil, in the remaining plant residue, or is lost to the atmosphere as either ammonia (NH_3) or elemental

Jeff Feaga, former graduate research assistant in bioengineering, and John Selker, professor of bioengineering, Oregon State University.

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nitrogen (N_2) and nitrous oxide (N_2O) after denitrification. Excessive residual soil N after harvest may indicate that some of the following processes may be involved:

- Fertilizer is applied at **rates** exceeding recommended amounts to achieve maximum yield.
- Fertilizer was added at the wrong **time** of the growth cycle.
- Method of **application** is not efficiently supplying the growing plants with N.
- Excessive organic N is being **mineralized** into inorganic NO_3^-.
- A **poor yield** at harvest will ensure that significant quantities of NO_3^- remain in the soil to leach during the following winter.

Several other factors also contribute to the potential for NO_3^- leaching (Table 1).

Table 1. *Key issues to consider when assessing the potential for NO_3^--N leaching.*

Nitrate Leaching Potential
Amount of Residual Nitrogen Left after Harvest
• Amount: nitrogen application in excess of crop recommendations
• Timing: nitrogen applications after crop ceases to assimilate nitrogen for growth
• Uniformity: inefficient nitrogen application methods
Irrigation Practices
• Nonuniform irrigation due to incorrect operating pressures and/or worn or mismatched nozzles
• Over-irrigation in response to excessively dry or poor production areas
• High background nitrates in irrigation water
Mineralization of Organic Materials
• Untimely decay of nitrogen-rich dry matter or manure
Landscape and Climate
• Rainfall exceeding potential evapotranspiration for extended periods
• Rainfall while fields are not covered in standing crop
• Additional water saturating field from other areas (overland flow)

Nitrate (NO_3^-) and ammonium (NH_4^+) are the only plant-available forms of N. Because the top few feet of most agricultural soils are well-aerated during the growing season, the majority of NH_4^+ in applied fertilizers is quickly converted to NO_3^- by oxidation. Decaying organic N in plants undergoes a biological conversion called mineralization, which is the transformation of organic N to inorganic plant-available forms.

In most natural systems, N is limited and is cycled through its various chemical forms without significant loss to aquifers. In agricultural systems, the need to remove the N limitation on production results in accumulated free NO_3^-. Nitrate is easily leached with moving water because it has a negative charge and therefore does not bond to soil particles. The most critical time for NO_3^- leaching is the beginning of the winter rains, when soluble NO_3^- remaining after harvest is transported from the upper soil with percolating rainwater.

How Did We Make Field Measurements of NO_3^- Leaching?

The Oregon State University (OSU) Department of Bioresource Engineering conducted a cooperative study between 1993 and 1998 between several Lane County vegetable and mint growers and the OSU Extension Service. Two large groundwater sampling units and three suction-cup samplers were installed on each of six conventional vegetable, five mint, and two organic vegetable fields. The passive capillary samplers, or PCAPS, were installed at around 3.5 ft (1.1 m) below the field surface (Figure 1). The method of installation ensured that the soil column above the PCAPS was not disturbed, and that the overlying soil's original structure was retained. Soil water and dissolved NO_3^- percolating below the plant roots were collected, as this water is likely to move into groundwater aquifers with sufficient time.

PCAPS use fiberglass wicks that equilibrate to the surrounding soil's water pressure. As a result of this design, PCAPS can collect water moving through the soil over a range of conditions from saturated to draining and approaching field capacity. The PCAPS

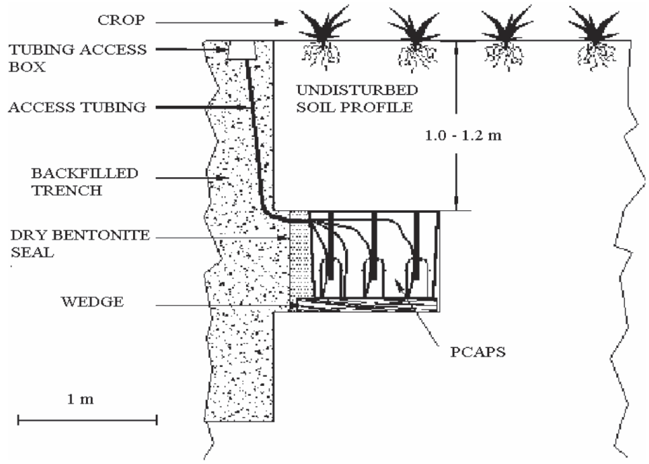

Figure 1.—PCAPS unit. Samplers were installed laterally from the trench to minimize soil disturbance above the lysimeters (picture modified from Brandi-Dohrn [1993]).

wicked surface collects water from an area of 3 ft^2 (0.28 m^2). The samplers were drained by pumping from the surface. The PCAPS had a 15.9-gallon (60 l) capacity and were large enough to require sampling only once a month. More details on the installation and operation of the PCAPS are given in Brandi-Dohrn et al. (1997) and Louie et al. (2000). In addition to PCAPS sampling, suction-cup samplers were used to make point measurements of NO_3^--N concentrations at the estimated winter water table depth ranging from 4.9 to 9.8 ft (1.5 to 3 meters).

How Were NO_3^--N Concentrations Measured and Averaged?

Water collected by the PCAPS was frozen until it could be analyzed for NO_3^--N concentration in the laboratory. Concentration data collected over the 5-year study were averaged with respect to flow. Flow-weighted averaging is an appropriate method to represent the average concentration over multiple sampling events, or when more than one sampler is measuring an event. To find a flow-weighted average for a 5-year period, for example, the total mass of NO_3^--N collected, divided by the total volume of water collected, would be the 5-year flow-weighted average. Flow-weighted averages are better than simply averaging monthly NO_3^--N concentrations because the method can prevent misleading data caused when sampling events that collect small volumes have very high concentrations.

What We Found

NO_3^--N Concentrations

Concentrations of NO_3^--N observed below the Lane County conventional vegetable and mint crops were flow-weighted and averaged for the entire study period and grouped according to field number (Figures 2 and 3). Average NO_3^--N concentrations below the root zone of five out of the six conventional vegetable fields exceeded the 10 ppm maximum NO_3^--N concentration allowed by the EPA for water *intended for drinking*. Three out of the five mint fields had average NO_3^--N concentrations exceeding the 10 ppm maximum. Although the water measured during these experiments was not intended for drinking and therefore not regulated, the data indicate NO_3^--N concentrations in underlying aquifers will likely rise in the future. In regions of the Willamette Valley where high N-input crops are being intensively grown over large contiguous areas, aquifers used for drinking water supply can be expected to approach or exceed the 10 ppm drinking water standard with time, unless nutrient management practices are modified.

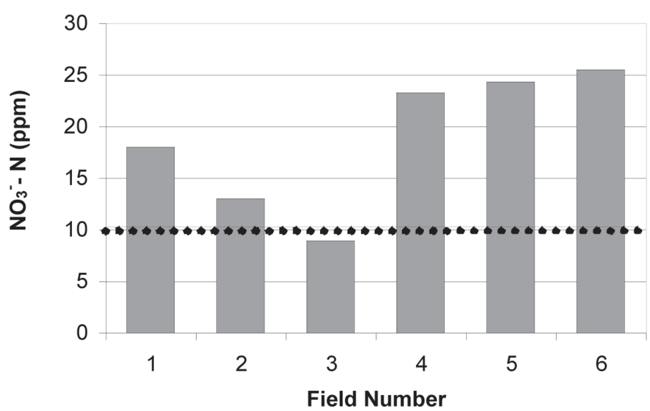

Figure 2.—Flow-weighted NO_3^--N concentrations for six fields planted to row crops during the entire study period. The dotted line indicates the EPA 10 ppm NO_3^--N drinking water standard.

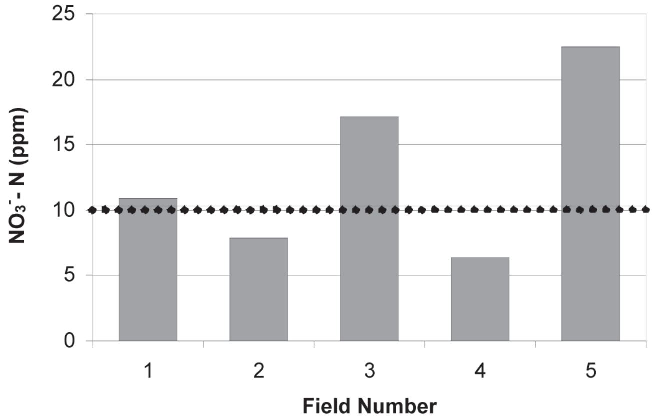

Figure 3.—*Flow-weighted NO_3^--N concentrations for five fields planted to mint during the entire study period. The dotted line indicates the EPA 10 ppm NO_3^--N drinking water standard.*

Organic growing operations represented in the study also showed considerable NO_3^--N concentration below the root zone (Figure 4). After the first two seasons, it was clear that NO_3^--N concentrations were very high. It was determined that poultry manure was applied in amounts well above recommended agronomic rates. Following an estimation of N content and mineralization rates of the manure, applications were reduced. The management changes enacted in February 1996 resulted in apparent reductions in NO_3^--N concentration during the latter half of the study. Mineralization rates, and thus N availability, from manure are hard to predict without a periodic analysis of the nutrient content in the manure. In addition, manure is often

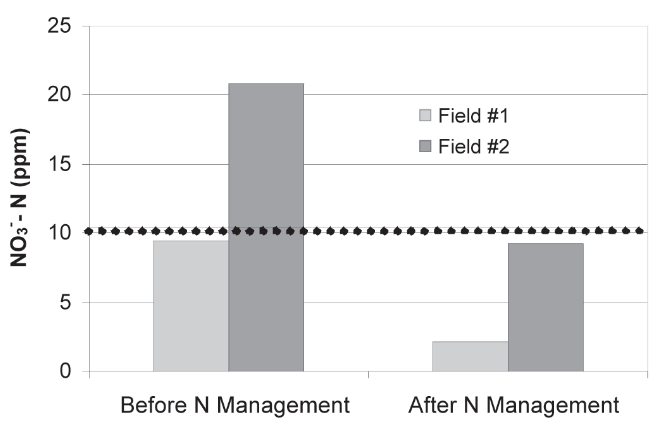

Figure 4.—*Flow-weighted NO_3^--N concentrations for two fields planted to organically grown vegetables during the entire study period. After revising manure application rates according to plant requirements, a considerable decrease in NO_3^--N concentration was observed. The dotted line indicates the EPA 10 ppm NO_3^--N drinking water standard.*

diluted with water to different degrees, making applications at recommended agronomic rates highly dependent on water content.

How Do NO_3^--N Concentrations Change Throughout the Season?

Concentrations from all samplers on all conventional vegetable fields were flow-weighted and grouped by month (Figure 5). Concentrations were the highest in the summer, when crops were fertilized and less water was available for dilution. At the onset of winter rains, the soil profile was flushed and most of the NO_3^- left after harvest is moved past sampler depth. Concentrations also decreased during this time, due to the high volumes of water diluting the NO_3^--N. Even during late winter, NO_3^--N concentrations on average were near to or higher than the EPA 10 ppm standard for drinking water.

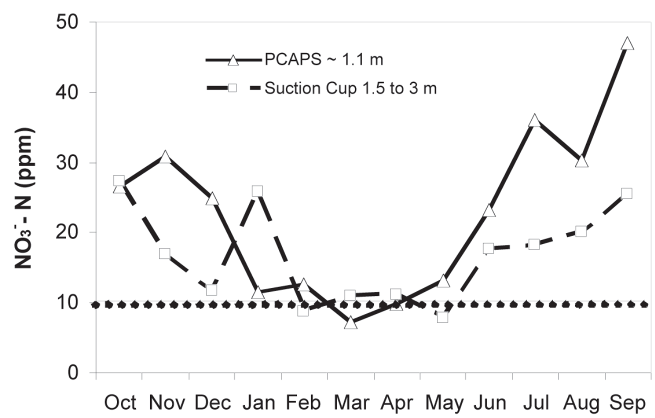

Figure 5.—*Measured monthly flow-weighted average NO_3^--N concentrations below six Lane County conventional vegetable fields throughout the 5-year study period. Shown are the concentrations measured by PCAPS as well as suction cup samplers. The dotted line indicates the EPA 10 ppm NO_3^--N drinking water standard.*

How Much Applied N Fertilizer Are We Losing Through Leaching?

The ability of Lane County PCAPS to make an accurate estimate of the real volume of water percolating to the groundwater was determined by Louie et al. (2000). The analysis was made by comparing collected water volumes from PCAPS to expected volumes calculated from a water balance. Results indicated that Lane County PCAPS overestimated the volume of water entering the ground by 25 percent. If we take this into account, we are able to make a good estimate of total mass of NO_3^--N lost to the groundwater. (Total mass NO_3^--N is the estimated water volume multiplied by the concentration NO_3^--N.)

Average N fertilizer application rates were 200 lb/acre for row crops and 250 lb/acre for mint. Average losses of NO_3^--N mass per acre were calculated for each of the study years and are shown in Figures 6 and 7. Average annual mass losses for each crop type were 93 and 82 lb/acre from conventional vegetable and mint fields, respectively. In monetary terms, such losses of N would equate to \$3,300–\$3,700 for each 100-acre field, if N is estimated to cost \$0.40/lb. It is important to note that a fraction of the NO_3^--N leached from this soil system may have originated as mineralization of organic matter. Soils are like a bank with respect to N fertilizers; sometimes N is applied and "saved" in the soil, while at other times N is "withdrawn" through mineralization. Whether or not the soil is gaining or losing N depends on many factors, including cultivation history, temperature, water content, and the carbon-to-N ratio in the soil.

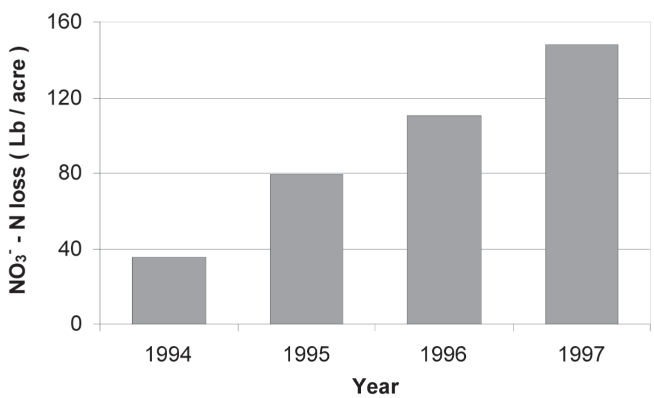

Figure 6.—*Average NO_3^--N mass leaching rate from vegetable fields during each of the study years. Water years are used (October of previous year to the September of posted year), as they correspond to breaks in the growing season and encompass an entire winter's precipitation. Note: October 1993 is not represented.*

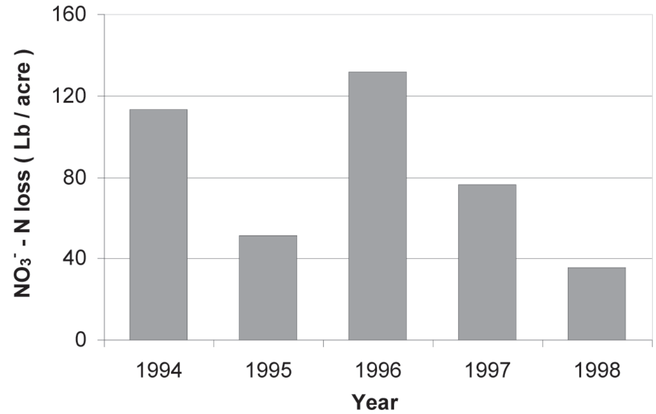

Figure 7.—*Average NO_3^--N mass leaching rate from mint fields during each of the study years. Water years are used (October of previous year to the September of posted year), as they correspond roughly to breaks in the growing season and encompass an entire winter's precipitation. Note: October 1993 and August and September 1998 are not represented.*

What Do Our Findings Mean for Management?

A 5-year field study of water collected from below the root zone of commercially grown vegetables and mint showed that NO_3^--N concentrations measured below a majority of the fields were higher than the EPA 10 ppm NO_3^--N standard set for drinking water.

The good news is that both excellent yields and environmental stewardship can be achieved by managing N and water inputs, as illustrated by sites with low NO_3^- losses under each cropping system. There are many options available to the grower to manage N. However, at this time it is still uncertain which of these best management practices (BMPs) are most effective in the Willamette Valley. Currently, growers and researchers are collaborating to find:

- Which BMPs are most effective for the various cropping systems and soil types in the Willamette Valley?
- What barriers do growers face in adopting alternative management practices and BMPs to reduce NO_3^- loss?
- Which are the most cost-effective management practices to reduce NO_3^- inputs to groundwater?

Though it is unclear at this time which of the BMPs will be found most effective and practical in the Willamette Valley, it is likely that future BMPs will concentrate on the following opportunities:

1) **Reduction of N Inputs**
   - *Determining rate and timing of fertilizer applications*—Fertilizer applications are specific for each type of crop and often vary depending on soil type. Applications that are coordinated to times of rapid plant uptake are most effective to achieve high yields and minimize leaching losses.
   - *Soil sampling*—Method focuses on periodic soil sampling to reduce N inputs. Chemical analysis of soils provides information on residual N content, as well as an estimate of organic matter content.
   - *Accounting for mineralization*—Mineralization of organic matter is a large source of plant-available N and can provide a substantial portion of N for the growing crop. If not accounted for, it may produce surplus plant-available NO_3^- that can be leached.
   - *Stem NO_3^- tests for peppermint*—The changing N requirements of peppermint throughout the growing season give an opportunity to design an application schedule according to crop N demand. To determine the current demand of N for the crop, a weekly stem tissue NO_3^- test is an option. The stem NO_3^- test uses a correlation between oil yields and NO_3^- content within the mint stem. Stem samples are taken throughout the period of fastest growth to ensure that NO_3^- content within the mint stem does not fall below critical values. More information can be found in Brown (1982) and Smesrud and Selker (1998).

2) **Use of cover crops to scavenge N**—Research in Oregon and around the country has shown promising results of winter cover crops to reduce the mass of NO_3^- leached below the root zone during the winter. Cereal crops are the most effective winter covers (Brandi-Dohrn, 1997; Sattell et al., 1999).

3) **Irrigation management**—To effectively minimize NO_3^- leaching from growing operations, it helps to make sure irrigation systems are properly maintained and that fields are not over-irrigated. Over-irrigation can easily leach plant-available N past the root zone, making it unavailable for plant growth. Irrigation systems applying nonuniform coverage will cause uneven NO_3^- leaching rates from the root zone. As a result, parts of the field will be N deficient, requiring additional applications or risking a poor harvest. Other areas of the field can accumulate N in excess of crop requirements.

   Soil properties can vary throughout fields. For example, areas of the field may consist of more coarsely textured soils. The infiltration of water into coarse soils is typically more rapid and can cause high leaching rates. Irrigation schemes should consider the variability of soils in the field.

   An effectively managed irrigation scheme can consider the following:
   - *Operating pressure*—Each system has an acceptable range of operating pressures. Deviation from this leads to poor uniformity of application.
   - *Nozzles*—Ensure that nozzles are of a consistent make and diameter and are not worn. Replacing all the nozzles at once at least every 4 years is recommended to maintain uniform application.
   - *Soil water monitoring*—With the aid of soil water monitoring, irrigation schedules can be adjusted to ensure that soil water content in the root zone is maintained within an appropriate range.
   - *Schedule irrigation based on expected ET*—Irrigation requirements vary throughout the year as potential evapotranspiration (ET) rates change with the weather. Irrigation set times can be adjusted to match the actual ET, rooting depth, and water-holding capacity of your soil.

Where to Find More Information

Several Extension publications discuss methods to streamline irrigation operations. The *Western Oregon Irrigation Guides*, EM 8713 (Smesrud et al., 2000), provide worksheets to aid in calculating irrigation set times based on potential evapotranspiration for 16 different commonly grown Willamette Valley crops. Sprinkler head maintenance and its relationship to application uniformity are discussed in Louie and Selker (2000). The post-harvest water requirements of mint are presented in Smesrud and Selker (1999).

Other Extension publications describing N requirements and application schedules for various vegetables, mint, and other crops include *Nitrogen Uptake and Utilization by Pacific Northwest Crops* (Sullivan et al., 1999) and *Peppermint Growth and Nutrient Uptake* (Christensen et al., 1998). A useful on-line source for papers and information concerning many aspects of agriculture and the environment is OSU Extension and Experiment Station Communications, located on the Web at http://eesc.oregonstate.edu/

The first step toward addressing the NO_3^- leaching problem is to become aware of the risk. With cooperation, groundwater and soil resources will be conserved for years to come. County offices of the OSU Extension Service are a helpful resource to keep up on current information that can assist growers in managing a sustainable, productive, and profitable business.

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