Nitrogen Scavenging:

Using Cover Crops to Reduce Nitrate Leaching in Western Oregon

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Willamette Valley field trials have shown that properly managed cover crops can reduce the amount of nitrate (NO_3^-) leached from the soil to the aquifer below. Nonpoint sources of nitrate include manured fields and grain and row-crop fields where economically optimal nitrogen (N) application rates are used. Grass, cereal, and brassica cover crops that grow rapidly in fall and early winter extract nitrate from the soil and incorporate it into plant biomass before winter rains leach it below the root zone (Figure 1). Nitrogen scavenging, then, is the capture of nitrate from the soil that otherwise would be lost by leaching. Cover crops that scavenge N not only reduce nitrate leaching but provide many other benefits, including organic matter additions, erosion control, improved tilth, and winter weed suppression.

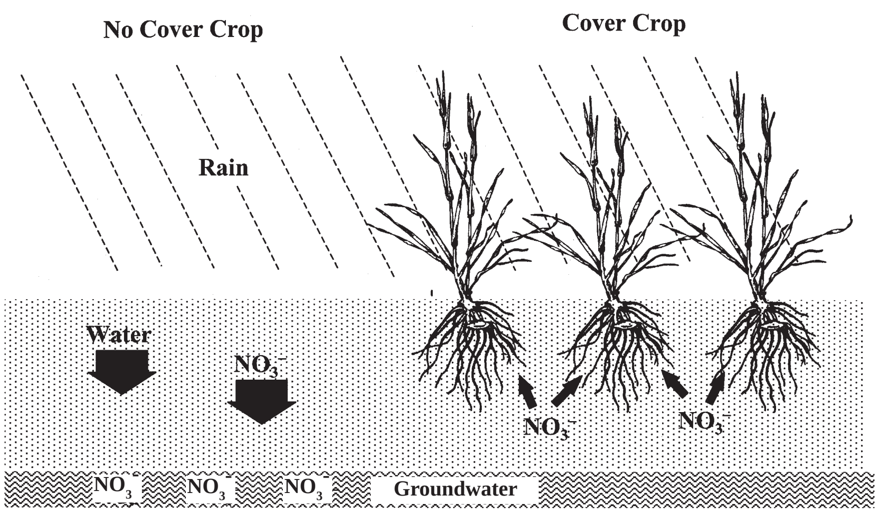

Figure 1.—Nitrogen scavenging decreases nitrogen losses from the soil and prevents potential groundwater contamination. Cover crops that grow rapidly in the fall are able to take up nitrate-nitrogen from the soil and incorporate it into their tissues before rains leach it into the groundwater.

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Potential health risks of nitrate leaching

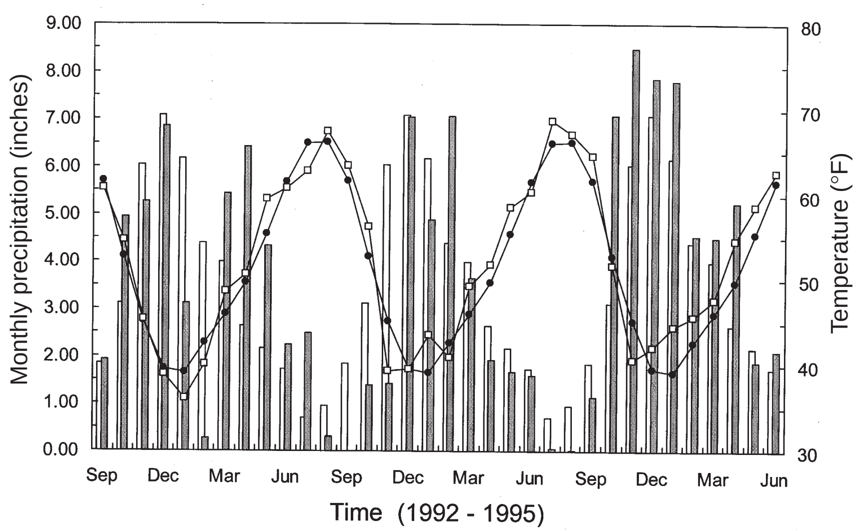

Figure 2.—Monthly amounts of precipitation (gray bars), 30-year (1960–1990) average monthly amounts of precipitation (white bars), monthly mean temperature (empty squares), and 30-year average monthly mean temperature (solid circles) for the 3-year observation period, recorded daily at the nearby (500 yd) Oregon Climate Weather station.

High groundwater nitrate levels constitute a potential health risk for nearly half of the U.S. population that depends on groundwater aquifers to supply drinking water. Nitrate is converted to nitrite in the digestive tracts of infants and ruminant animals. The nitrite combines with blood hemoglobin, reducing its ability to carry oxygen, and sometimes resulting in death (Weisenburger, 1993). Nitrite also may combine with amino groups to produce nitrosamines, which have been shown to produce cancerous tumors in laboratory animals, although no clear link to human cancers has been established (Pierzynski, et al., 1994).

A 1984 study found that more than 6 percent of the wells throughout the U.S. for which data were available exceeded the Environmental Protection Agency (EPA) drinking water quality criterion for nitrate (Madison and Brunett, 1984). A survey of 168 wells in the Willamette Valley found that 20 percent exceeded the EPA limit (CAST, 1985), and a 1988 study found that 28 of 82 tested wells in Marion County, Oregon exceeded the EPA limit (Petit, 1988).

Fall soil N

High inorganic N levels in fall increase nitrate leaching. Fall soil inorganic N (i.e., nitrate and ammonium) comes from residual fertilizer (that portion not utilized by the previous crop) and the decay of organic matter. Fall soil inorganic N levels can be high following use of recommended fertilizer N rates or high manure rates (often 100–200 lb N per acre but sometimes as high as 400–500 lb N per acre) to a depth of 120 cm.

Nitrate leaching

Western Oregon's Mediterranean climate of dry summers and wet winters (Figure 2) is especially conducive to nitrate leaching because nearly all aquifer recharge occurs during the cool, wet months of October through April, when fields often are fallow. Careful irrigation procedures during the summer minimize the loss of soil nitrate, which tends to be concentrated near the surface. However, fall and winter rains saturate the soil, which results in movement of soil nitrate-N down through the soil profile. Often this "bulge" of nitrate leaches below the root zone by January in western Oregon (Figure 3).

Nitrate moves with water because it has a weak negative charge and is not held in soils that are dominated by negatively charged clay and humus colloids. Although ammonium is not readily leached, it is rapidly converted to nitrate in aerated soils.

Nitrate scavenging

The amount of N scavenged depends in part on cover crop type, cover crop growth, soil type, amount of fall soil inorganic N, and weather. In typical western Oregon fertilized vegetable rotations, a cereal cover crop may scavenge 20–70 lb N per acre per year. However, much higher scavenging rates have been observed. Annual rye planted into 16-inch-tall silage corn (i.e., relay planted) on a heavily manured field scavenged more than 260 lb N per acre by the following spring (personal communication, Mike Gangwer, OSU Extension Service). And irrigated Micah barley planted in fall of 1993 took up 92 lb N per acre after just 6 weeks of growth (personal communication, T. Buford).

Nitrogen is “stored” in the cover crop until it is killed. As cover crop residues decompose, residue-N is converted to plant-available N forms, temporarily “tied up” in microbial cells, or stabilized in soil organic matter.

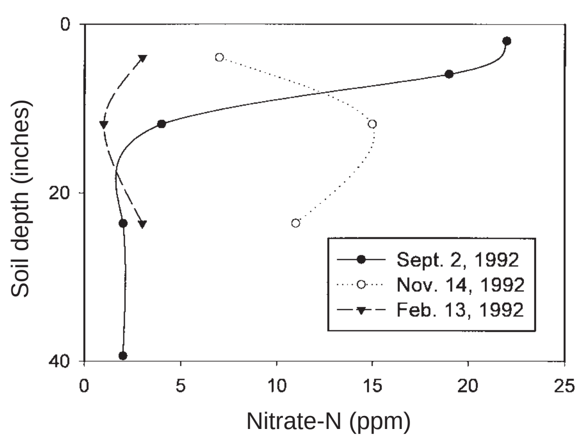

Figure 3.—Soil nitrate levels at different depths and dates under a rye cover crop in the winter of 1992–93. Summer crops in this plot received recommended (i.e., N2) rates of nitrogen fertilizer. Note how nitrate moves down through the profile with early winter rains.

Biological N transformations

Microbial bacteria, fungi, and soil fauna make up a complex and diverse biological web in the soil. They drive nutrient cycling among residues, secondary decomposition products, the soil solution, microbial biomass, soil organic matter, the atmosphere, and growing plants.

N *mineralization* refers to the process in which organic forms of N are converted to plant-available forms. The decomposition of soil organic matter and other organic inputs, such as manures, crop residues, and cover crops, results in the release of ammonium (NH_4^+), an inorganic, plant-available form of N. Microbial activity and the quality of decomposing organic matter control the rate of N mineralization.

Microbial activity depends on moisture and temperature; warm, moist soils are conducive to N mineralization. Also, wetting/drying cycles cause “flushes” of N to be released. This process is of particular concern in Oregon because soils usually are dry and warm when fall rains begin. With the onset of fall precipitation, “mineralization flushes” of ammonium occur, and then the ammonium is converted to nitrate by nitrifying bacteria. Thus, mobile nitrate is released just as Oregon enters the rainy season when leaching potential is greatest.

The C:N (carbon to nitrogen) ratio and lignin content of organic inputs such as cover crop residue also affect N mineralization. If there is a large amount of C relative to N (high C:N ratio), bacteria remove inorganic N from the soil solution and temporarily “store” it in their biomass. However, if the amount of carbon relative to nitrogen is low, then the decomposition of residues increases soil nitrate levels. Residues high in lignin (e.g., mature cereals and some manures) have lower rates of N mineralization.

Leachate collection trial—methods

A replicated field trial at the Northwest Research and Extension Center (NWREC) in Aurora, OR (north Willamette Valley) was designed to measure whether cereal cover crops affect the amount of N leached to groundwater in western Oregon annual vegetable rotations.

Cereal rye cover crop and fallow plots (four replications) were the main plots, with three subplots receiving different fertilizer-N application rates. Leachate was collected and measured with lysimeters installed below the root zone of each subplot, and then analyzed for nitrate content. Summer crop and cereal rye cover crop N and dry matter accumulation were measured, as well as soil inorganic N.

The field trial site is slightly sloped, and the soil is classified as a Willamette loam. The USDA soil classification is loam/silt loam at the 5-inch depth, loam/clay loam at 25 inches, and loam at 57 inches. Average total precipitation is 41 inches/year, the majority falling from November through April. Potential evapotranspiration is greater than precipitation from May through October.

Summer crop production and sampling

Summer crop production was rotated between sweet corn and broccoli. All plots were moldboard plowed, followed by two to three passes with a disk-harrow combination. Final seedbed preparation was with a spike-tooth harrow followed by packing rollers.

Subplots within the cover cropped and fallow plots received a zero (N0), medium (N1), or recommended (N2) rate of urea fertilizer. N0, N1, and N2 rates were 0, 50, and 200 lb N per acre per year for corn, and 0, 125, and 250 lb N per acre per year for broccoli. Half the N was applied soon after planting, and the other half was applied approximately 1 month later.

Summer crops were sampled at harvest for agronomic yield and N and dry matter accumulation.

Table 1.—Average cereal rye dry matter and N accumulation by mid-April for subplots receiving the recommended N rate (i.e., N2).

	1992–93	1993–94	1994–95
Dry matter (ton/acre)	1.3	1.2	0.4
N (lb/acre)	40	44	12

Cover crop production and sampling

Cover crop seedbed preparation was similar to that of summer crops. Cereal rye was drilled (65 lb/acre) when soil conditions permitted; otherwise it was broadcast and followed by a light disking. Cover crops were sampled in mid-April for dry matter and N accumulation.

Cover crop stands were good in the winters of 1992–93 and 1993–94, but were poor in 1994–95 due to extremely wet field conditions (Table 1).

Leachate collection

Leachate was collected using Passive Capillary Wick Sampler lysimeters (PCAPS), which consist of a collection pan of known area covered with fiberglass wicks. The wicks apply a small suction on the leachate, which is collected in bottles that are emptied from the surface.

To avoid disturbing the soil above the sampler, installation of the PCAPS involved digging a trench outside the plot area, then digging sideways into the plot at a depth of 47 inches. The collection pan was wedged tightly to the top of the horizontal excavation, and excavations were backfilled. Bottles were emptied on a weekly basis during times of heavy precipitation, or following each inch of cumulative precipitation. Leachate samples were analyzed for nitrate.

The volume of leachate per unit area percolating past the 47-inch depth was calculated by dividing the volume of leachate collected by the area of the collection pan. The amount of nitrate per unit area (e.g., lb nitrate/acre) leaching past the 47-inch depth was calculated by multiplying the total volume of leachate per area times the nitrate concentration in the leachate. Average daily nitrate leaching losses per unit area were calculated by dividing the total amount of nitrate leached per unit area by the number of days in the sample period.

Sampling soil N

Soil inorganic N was measured in the fall after harvest. Composite samples from four different depths (0–8, 8–16, 16–32, and 32–64 inches) were taken from each subplot and analyzed for nitrate and ammonium.

Leachate collection trial—results

Soil inorganic N content in fall

Soil inorganic N levels in early fall were higher in fertilized subplots as expected, but varied widely from year to year due to summer crop N uptake efficiency, irrigation practices, and climatic differences. For example, in early fall during the years 1992–1994, N0 plots ranged from 40 to 97 lb N per acre in the 0–120 cm depth, and N2 plots ranged from 90 to 495 lb N per acre.

Any effects that incorporating the cereal rye in spring might have had on soil inorganic N were gone by the following fall. There was no detectable difference between inorganic N levels in fallow and cereal rye cover-cropped plots at that time. This suggests that it is the growing cover crop that affects nitrate levels in leachate, rather than previous years' residue.

Percolation volume

Cover crops potentially decrease percolation by increasing evapotranspiration. But they also generally increase infiltration by protecting the soil surface from raindrop impact and providing channels for the water to move through. In this trial, there were no significant differences in percolation of fallow and cover-cropped plots as indicated by the volume of collected leachate. Therefore, N uptake, rather than changes in water relations, affected nitrate levels in leachate.

The amount of leachate percolating through the soil at the 47-inch depth did vary from year to year. Winter of 1994–95 was a very wet year (Figure 2) and resulted in percolation volumes that were 151 percent and 220 percent of the 1992–93 and 1993–94 winters respectively (when averaged across all treatments).

Nitrate leaching losses

Leaching rate

Nearly all leaching occurred during the winter, although over-irrigation in the summer of 1994 did result in some losses. Figure 4 shows the average amount of nitrate (lb) leached per day for fallow and cover-cropped plots receiving the recommended N rate (N2). Heavy rains caused sharp peaks in nitrate leaching. For example, nearly 5 inches of rain fell on October 27, 1994 (the highest 24-hour rain recorded to date), resulting in the peak observed on October 28.

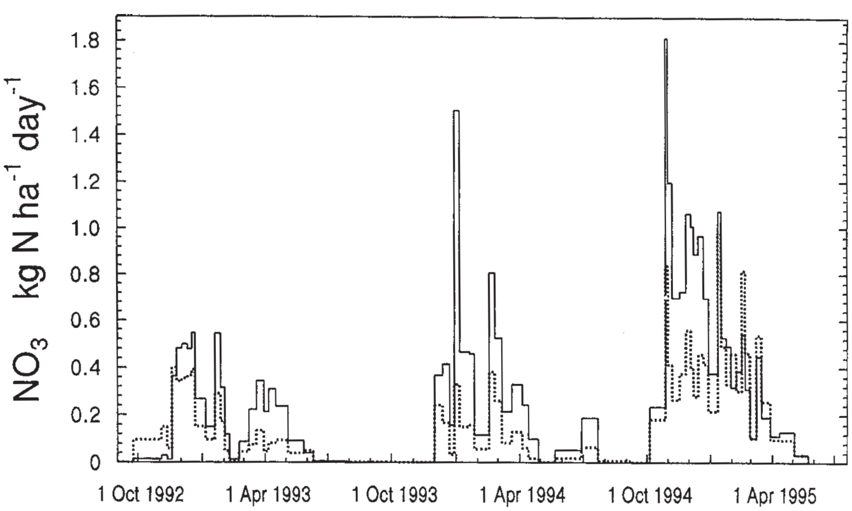

Figure 4.—Average daily nitrate-N flux between sampling dates under plots receiving recommended N rate (i.e., N2). The dashed line is for plots with a rye cover crop, and the solid line is for plots without a cover crop.

Nitrate leaching in cover-cropped plots was consistently lower than in fallow plots with two exceptions. During the fall of 1992, infiltration rates were higher in cover-cropped plots receiving the N2 fertilization rates than in other plots, which increased the nitrate leaching rate. The negligible difference between nitrate leaching in fallow and cover-cropped plots during spring of 1995 probably was due to the poor cover crop stand.

Cumulative leaching losses

The cereal rye cover crop reduced seasonal cumulative nitrate leaching losses when compared to fallow plots (Table 2). Reductions at the recommended N rate (N2) were 14, 31, and 30 lb per acre for the 1992–93, 1993–94, and 1994–95 winters respectively. Again, the poor seasonal reduction during winter of 1994–95 N0 treatments may be attributed to the poor cereal rye stand. For the entire 3-year period, N leaching losses were reduced by 32 to 42 percent due to the cereal rye cover crop.

Fertilizer leaching losses

The amount of fertilizer-N (urea) lost by leaching was estimated as:

> [N leached in fertilized plots (N1 or N2)] – [N leached in control (N0)]

Generally, a larger percentage of fertilizer-N was leached from N2 plots than from N1 plots. During the winter of 1992–93 following sweet corn, 6 percent of the N1 fertilizer-N and 13 percent of the N2 fertilizer-N was lost. In the winter of 1993–94 following broccoli, losses were 10 percent of the N1 and 15 percent of the N2 fertilizer-N. However, during the winter of 1994–95 following sweet corn, the trend was reversed; 54 percent of the N1 and 35 percent of the N2 fertilizer-N was leached.

At the recommended N rate (N2), the winter cereal rye cover crop reduced the amount of fertilizer-N lost to leaching from 15 to 5 percent in 1993–94 and from 35 to 19 percent in 1994–95.

Table 2.—The nitrate-N cumulative leaching losses during each winter season of the observation period and for the entire period. *Leaching reduction due to the cover crop is the amount leached under fallow less the amount leached under the cover crop.*

Fertilizer N-Rate	Average nitrate leached (lb/acre)						Leaching reduction due to cover crop					
	Winter-fallow			Winter cereal rye			lb/acre			%		
	Winter of			Winter of			Winter of			Winter of		
	92–93	93–94	94–95	92–93	93–94	94–95	92–93	93–94	94–95	92–93	93–94	94–95
NO	22	13	22	8	7	23	14	6	-1	62	48	-3
N1	26	25	49	14	12	43	12	13	6	46	54	12
N2	43	49	92	29	19	62	14	31	30	34	63	33
	Entire period (Sept. 1992–June 1995)						Entire period (Sept. 1992–June 1995)					
N0	60			40			20			33		
N1	103			70			33			32		
N2	190			111			79			42		

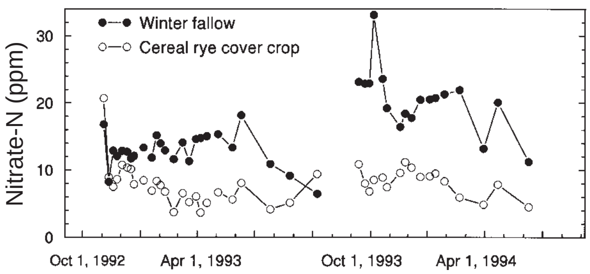

Figure 5.—Nitrate concentration in soil solution at a depth of 48 inches in bare versus cover-cropped soils following fertilized summer crops that received the recommended N rate (i.e., N2).

Nitrate concentration of leachate and EPA standards

The nitrate concentration of leachate is important because an aquifer eventually equilibrates to the same nitrate concentration as its recharge. Cereal rye reduced the average (flow-weighted) leachate nitrate concentration during all 3 years in plots receiving the recommended N rate (N2) (Figure 5).

Leachate nitrate concentrations under N2 fallow plots exceeded the EPA drinking water standard (10 ppm N as NO_3) by 34 percent, 119 percent, and 78 percent during the winters of 1992–93, 1993–94, and 1994–95 respectively. However, the average (flow-weighted) nitrate concentrations in N2 plots with cover crops were 39 percent, 58 percent, and 22 percent lower than in fallow plots for the winters of 1992–93, 1993–94, and 1994–95 respectively. Those reductions were sufficient to lower leachate nitrate concentrations below the EPA limit in the winters of 1992–93 and 1993–94.

As expected, leachate nitrate concentration increased with increasing N rates. Differences in leachate nitrate concentration between N0 and N2 plots were highly significant over the 3-year period. Similarly, differences between N1 plots and N0 or N2 plots were significant.

Leachate nitrate concentration temporal trends

The leachate nitrate concentration collected under cover-cropped plots generally decreased as winter progressed. However, under fallow plots it increased as the high nitrate concentrations near the surface moved down through the soil profile. During the winter of 1994–95, there was so much rain that concentrations in all plots decreased as the winter progressed.

Conclusions and recommendations

This study showed that a cereal cover crop can reduce nitrate leaching significantly. This reduction appears to be due largely to N uptake by the cover crop and not to a change in the amount of water percolating to groundwater. The effectiveness of a cover crop in reducing nitrate leaching is determined by the amount of fall growth by the cover crop. Thus, it is important to plant as early as possible (September) to maximize fall growth before heavy rains and cold weather reduce cover crop growth.

For more information

OSU Extension publications

Columbia Root-Knot Nematode Control in Potato Using Crop Rotations and Cover Crops, EM 8740 (1999). $1.50

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