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CLEAN WATER FOR WASHINGTON

How Fertilizers and Plant Nutrients Affect Groundwater Quality

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Essential plant nutrients occur naturally in soil. To increase crop yield, growers supplement soil nutrients by adding chemical fertilizers and organic fertilizers such as animal manures and crop residues. Because excess nutrients can move below the root zone, managing plant nutrients is an important part of protecting groundwater quality.

The soil supplies 13 essential plant nutrients (Table 1). The first three are the primary nutrients. Plants need the largest quantities of these nutrients, which are most often included in fertilizers. The second three are called secondary nutrients. Plants need smaller amounts of secondary nutrients, which are often added as soil amendments. Plants require small quantities of the remaining nutrients, or micronutrients, in the relative order listed.

Table 1. Essential plant nutrients. Plants obtain these elements from soil, fertilizer, crop residues, and other organic additions. Plants also require carbon, hydrogen, and oxygen, which they derive from water and air. Nutrients are listed in relative order of plant uptake.

Name	**Chemical symbol**	**Plant-available ions in soil water**	**Solubility**
Primary Nutrients			
Nitrogen	N	NH_4^+,NO_3^-,NO_2^-	high
Phosphorus	P	$HPO_4^=$,$H_2PO_4^-$	very low
Potassium	K	K^+	low
Secondary Nutrients			
Sulfur	S	$SO_4^=$	high
Calcium	Ca	Ca^{++}	low
Magnesium	Mg	Mg^{++}	low
Micronutrients			
Zinc	Zn	Zn^{++}	very low

Iron	Fe	Fe++,Fe+++	very low
Copper	Cu	Cu++,Cu+	very low
Manganese	Mn	Mn++,Mn++++	very low
Boron	B	H_3BO_3	medium
Molybdenum	Mo	MoO_4=	low
Chlorine	Cl	Cl-	high

Plants can take up only those nutrients that are in solution (dissolved in soil water). Chemically, nutrients in solution are ions. For example, sodium chloride (NaCl) is common table salt. When dissolved in water, salt breaks down into sodium ions, Na+, and chlorine ions, Cl-. Nutrient ions have a positive or negative charge as listed in Table 1. Many soil particles are negatively charged; they attract and bind positively charged nutrients, making them less likely to leach.

Leaching is the movement of materials dissolved in water. It is a natural process in soil. If leaching did not occur, soil would gradually accumulate enough nutrients and other ions to prevent plant growth (high salt levels). Groundwater contamination occurs when excess amounts of nutrients leach below the root zone and into groundwater (Fig. 1). Soluble nutrients that are available to plants are also subject to leaching. Nutrients that leach below the root zone can contaminate groundwater. The root zone can vary from 1 to 6 feet, depending on the crop and its stage of development.

Nitrate is of particular concern because it leaches easily and contaminates groundwater at low concentrations. Other easily leached nutrients are seldom present in fertilized soils at levels that currently are considered to degrade groundwater.

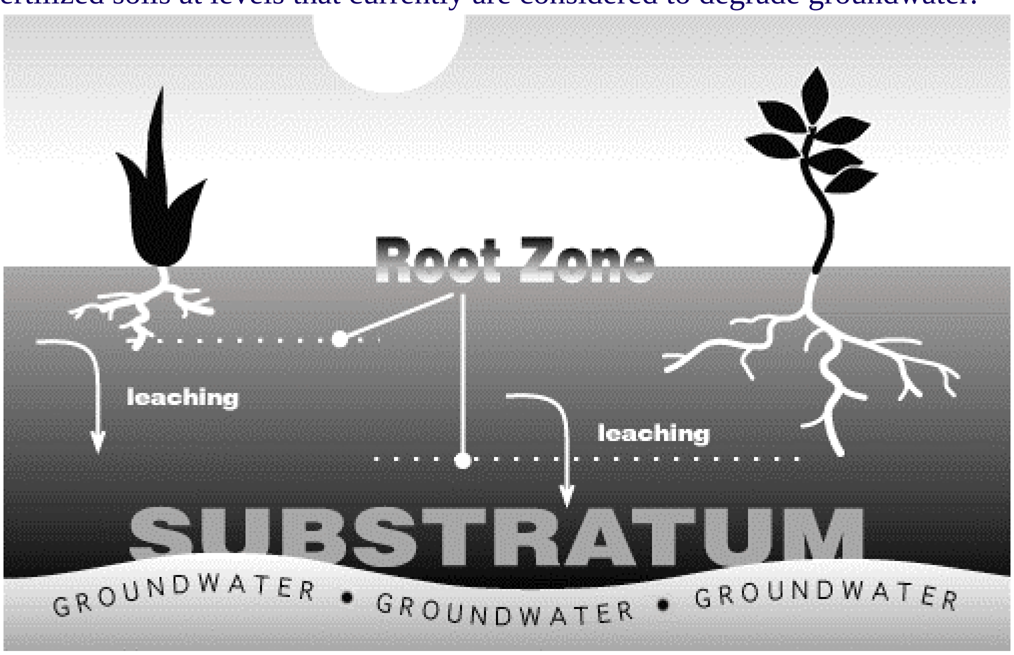

Fig. 1. Nutrients leached below the root zone can contaminate groundwater. Because the root zone can vary from 1 to 6 feet, the area of critical management will vary with

the crop and stage of development.

Nitrogen in the Plant Environment

Growers add more nitrogen (N) to the soil to increase crop production than any other nutrient. In soil, organic N and inorganic N are converted to highly leachable nitrate. The risk of nitrate leaching and contaminating groundwater is highest when the following are true:

- Nitrogen applications exceed crop needs.
- Timing of N applications does not coincide with crop needs.
- Soils are well drained.
- Excess rainfall or irrigation increases leaching.

Even though N movement in soil is not completely predictable, and soil type and rainfall cannot be altered, sound management is critical. Nitrogen application rate and timing, irrigation amount and timing, and crop management can be modified to increase crop nitrogen uptake and reduce nitrate leaching.

Nitrogen Forms

Understanding N forms and changes in the soil environment is essential for sound N management. Poor management decisions can increase N contamination of groundwater.

Table 2. Common chemical forms of nitrogen in soil and fertilizers.

Compound Group	**Name**	**Symbol**	**Remarks**
Organic	Proteins, Amino Acids	$R\text{-}NH_2$	Contained in manures, biosolids, composts, plant residues, and soil organic matter. Immobile. Not plant-available.
	Urea	$(H_2N)_2CO$	Commercial fertilizer. Also in fresh animal manure. Rapidly converted to NH_4+ in soil.
Inorganic	Ammonia	NH_3	Applied to soil as anhydrous ammonia fertilizer. A component of fresh animal manure. Can be lost to the atmosphere as a gas. Rapidly converted to NH_4+ in soil.
	Ammonium	NH_4+	Can be absorbed by clay and organic matter, preventing large amounts from moving with water. Plant-available. Converted to NO_3- by soil microorganisms (nitrification).
			Short-lived intermediate in

			nitrification. Concentration in soil is usually insignificant.
	Nitrate	NO_3-	Typically present in relatively large amounts and highly mobile with water. Plant-available.
Atmospheric	Nitrogen	N_2	Comprises about 80% of soil atmosphere. Source of N for legumes. Not utilized by other crops.

Nitrogen in the soil takes many forms (Table 2):

Organic N occurs as proteins and amino acids. It is part of soil organic matter, animal manure, crop residue, biosolids (municipal wastewater sludge), and other organic materials added to the soil. Organic N is available to plants only after microorganisms convert it to inorganic forms.

Inorganic N. Plant-available inorganic forms of nitrogen are ammonium (NH_4+) and nitrate (NO_3-). Ammonia (NH_3) occurs in anhydrous ammonia fertilizer and in fresh animal manure. However, ammonia is short-lived in most soils and is rapidly converted to ammonium (NH_4+), to nitrite (NO_2-), and then to nitrate (NO_3-). Nitrate, which is highly water soluble, moves easily with water, and therefore leaches readily.

Atmospheric N occurs mostly as nitrogen gas (N_2), which is about 80% of the atmosphere. Plants do not utilize atmospheric N. but N-fixing bacteria living on the roots of legumes such as alfalfa, beans and clovers convert atmospheric N to organic N. This N fixation can add significant amounts of N to the soil.

Nitrogen Cycle

The N cycle (Fig. 2) illustrates changes of nitrogen forms in soil. The N cycle includes fixation of atmospheric N, microbial mineralization and nitrification, N uptake by plants and soil organisms, leaching, and gaseous N losses. Chemical, biological, and physical processes all affect nitrogen in the soil.

Mineralization is the release of inorganic N, as ammonium, by microbial breakdown of plant residues, added organic materials, and soil organic matter. The rate of inorganic N release depends on the material being digested, and on soil temperature and moisture content. Mineralization may take weeks, months, or years. Nitrogen is released slowly from soil organic matter, but more rapidly from some crop residues, animal manure, biosolids, agricultural processing byproducts, and compost. Urea mineralizes very rapidly.

Many commercial fertilizers contain ammonium N, which plants can use directly. Microorganisms also use ammonium or nitrate when they digest plant residues with little N, such as straw or sawdust. Inorganic ammonium is held on soil particles and is leached slowly until converted to nitrate.

Nitrification is the conversion of ammonium into nitrate by soil bacteria. Nitrate is available to plants and microorganisms, and many plants select it over ammonium. In well-drained, warm soils, ammonium converts rapidly to nitrite and then to nitrate. Under normal soil conditions nitrite is very shortlived and does not represent a significant portion of the N pool.

In saturated soils, which contain an energy source for microorganisms, microbial denitrification may convert nitrate to gaseous N. The gaseous N (N_2 or N_20) is then lost to the atmosphere.

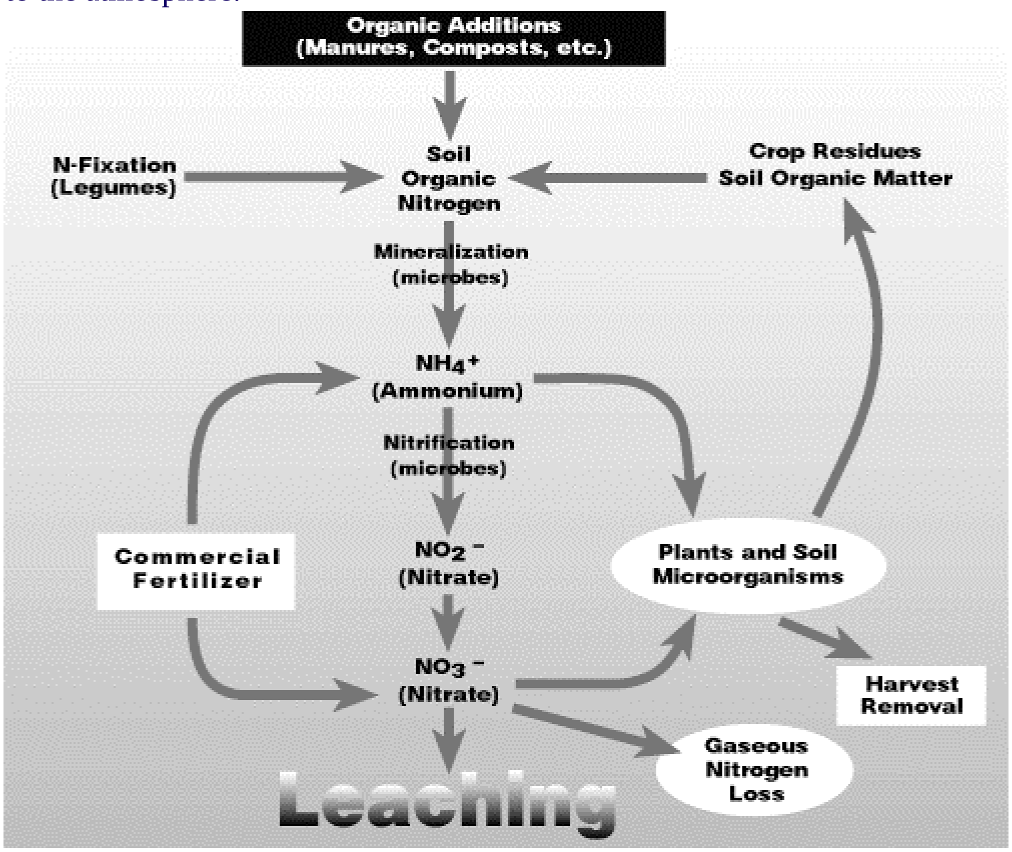

Fig. 2. Nitrogen Cycle. Legumes, soil organic matter, crop residues, and organic additions (manures, composts, etc.) are sources of organic N. Organic N is mineralized into ammonium (NH_4+). Commercial fertilizer supplies N as ammonium or nitrate (NO_3-). Microbes nitrify ammonium to nitrate. Plants, microorganisms, leaching below the root zone, and release of gaseous N to the atmosphere remove N from the root zone soil solution. Crop harvest removes N stored in plants. Nitrogen present in both crop residues and soil microorganisms becomes a part of the soil organic N content.

Phosphorus and Other Nutrients

Phosphorus (P) is second to nitrogen in chemical quantities applied to cropland. Plants take up phosphorus as phosphate ions (H_2PO_4- or HPO_4=) from soil water.

These ions occur at very low levels in soil water: less than 1 part per million (ppm). Most soil P is in organic forms or in soil minerals that are relatively insoluble. Although negatively charged, so it does not bond with soil particles, phosphorus combines with calcium, iron, and aluminum into almost insoluble compounds. Because of its low solubility, very little P leaches to groundwater. Phosphorus carried off-site in eroding soil can contaminate surface water.

Soil water leaching out of the root zone has an electrical balance between positively and negatively charged ions. The positive ions are largely sodium, potassium, calcium, and magnesium. The negative ions are largely nitrate, sulfate, chloride, and carbonates ($HC0_3$- or H_2CO_3). All of these ions occur in groundwater naturally and in large quantities; only nitrate is a contaminant.

Positively charged metal ions (manganese, copper, iron, and zinc) are sometimes applied in small quantities in fertilizer or organic material like manure or biosolids. Metals are sparingly soluble and do not leach in soil water. Molybdenum (MoO_4=) and boron (H_3BO_3), needed in small quantities by plants, are negative or neutral ions in soil water. The total soil content of molybdenum is very low (1-4 ppm) and tends to be immobile. Growers add fertilizer boron only in small amounts, because the range between adequacy and toxicity is very small for some plants.

High Risk Environments

To reduce fertilizer impacts on groundwater quality, identify high risk environments and manage nutrients carefully. High risk environments include:

- Sandy soils
- Shallow-rooted crops
- High rainfall areas or excess irrigation
- Shallow unprotected groundwater
- Wellheads and homesteads

As more information becomes available on nutrients leaching to groundwater, other high risk areas may be identified.

Even properly constructed wells directly link the ground surface and groundwater. Protect the well area from nutrients and other contaminants that may flow to, around, or down the outside of the well to groundwater.

Prevent contaminated water from feeding back to a well from water lines. Install anti-backsiphoning valves (special check valves) ***between*** the well and:

- Residential hose bibs
- Spray tank filling lines
- Pumps to inject nutrients into irrigation water
- Pumps to inject medications or nutrients into livestock water

Nitrogen Management

Sound management can decrease, but not eliminate, N leaching to groundwater. The following section discusses some Best Management Practices (BMPs).

Estimate Yield. The first step in managing N for crop production is to estimate realistically the yields under current management practices and available inputs. Use the yield history of each specific field rather than the highest possible yield or the average yield of larger areas.

Nitrogen Requirement. Calculate the crop N needed based on the field's yield history and planned inputs (WSU Cooperative Extension Bulletins are helpful in this process).

Estimate Available N. Before fertilizing or spreading manure, estimate the amount of plant-available N in the soil. In central and eastern Washington, take soil samples to determine residual ammonium and nitrate available in the soil profile. Western Washington soils have low inorganic N levels in the spring due to leaching and gaseous N losses during winter months. Therefore, soil scientists do not recommend predicting N needs by using ammonium and nitrate sampling.

Estimate the amount of N to be released through mineralization of organic N from manures, legumes, plant residues, and soil organic matter during the coming growing season. Subtract these nonfertilizer N contributions from the total N required. Determine the amount of fertilizer required to provide the N needed to produce the crop.

Fertilizer Placement and Timing. Place fertilizer to increase crop N uptake. Placing concentrated N applications near the root zone is generally more efficient than spreading fertilizer uniformly over a field. Schedule N applications so adequate N is available during peak plant demand. In some cropping systems, two or more "split" applications can significantly increase plant use of fertilizer N.

Crop Rotations can increase N utilization. Relatively deep rooted crops (alfalfa, corn, wheat) in rotations with shallow rooted ones (potatoes, onions) can extract N from deeper in the soil. Catch-crops that grow during the winter, such as winter rye, use inorganic N that could otherwise leach. Incorporate the catch-crop to release N during growth of the next crop.

Crop Management. An adequate supply of all plant nutrients and adequate control of plant pests increases crop N uptake. Good soil tilth promotes root growth and the utilization of N from the soil profile.

Proper amounts and timing of irrigation can improve crop production and N uptake. Excessive or poorly timed irrigation can be a major cause of N leaching below the root zone. If nutrients are applied with irrigation (fertigation), water application must be as uniform as possible for uniform nutrient application.

Summary of BMPs to reduce potential nitrogen groundwater contamination:

Nitrogen Management

- Estimate crop yields accurately.
- Determine N requirement for crop.
- Estimate currently available N.
  - Residual soil ammonium and nitrate from soil test.
  - Estimate N contribution from:
  Manures
  Legumes and plant residues
  Organic matter
  Irrigation water
- Determine need for additional N.
- Place N where roots can take it up.
- Time N applications so that it is available during peak plant demand (split application where appropriate).
- Use tissue testing (nutrient analysis of plant samples) to monitor in-season N availability.
- Use catch-crops to recover leachable N.

Crop Management

- Supply adequate amounts of all plant nutrients.
- Practice proper pest management.
- Apply adequate but not excessive irrigation.

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