AE1218

Working to Avoid Nitrogen contamination

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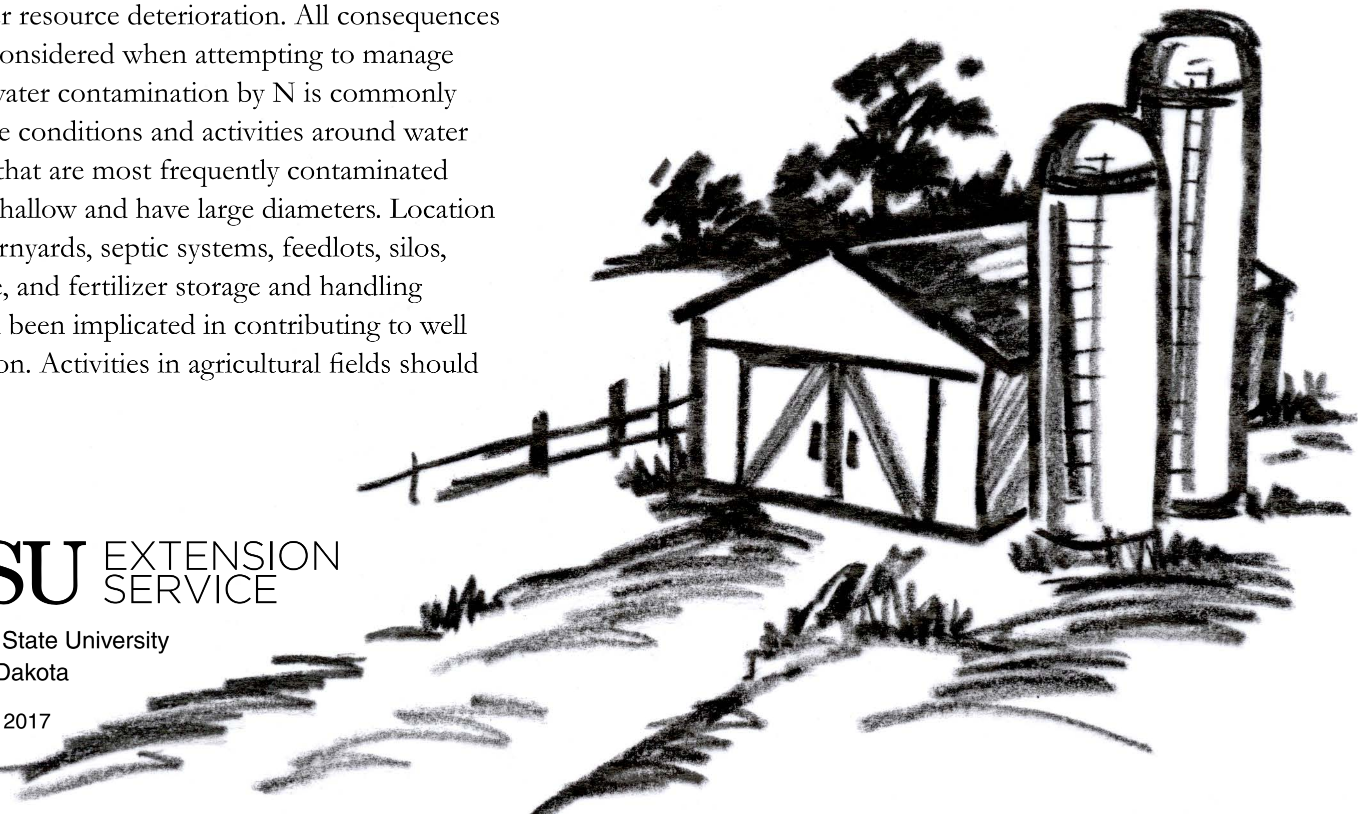
Our Effect on Nitrogen in the Environment

Activities of human beings have changed the balance of nitrogen (N) on the planet. Burning fossil fuels for energy, intensive use of land to grow food, and disposal of organic wastes have an effect on the N cycle. Studying the influence of our activities on the N cycle helps us understand the consequences of changing the balance of N in the environment. Positive consequences include improved crop yields, while negative consequences include water resource deterioration. All consequences need to be considered when attempting to manage N. Groundwater contamination by N is commonly related to the conditions and activities around water wells. Wells that are most frequently contaminated with N are shallow and have large diameters. Location of barns, barnyards, septic systems, feedlots, silos, buried waste, and fertilizer storage and handling sites have all been implicated in contributing to well contamination. Activities in agricultural fields should also be considered as sources of N in contaminated wells. In most cropped fields regular applications of N fertilizer are used to meet plant requirements for optimum yield. Surface water contamination by N has been shown to be more prevalent in agricultural areas compared to other landuses. However, contamination of streams with ammonia (NH_3) from municipal sewage treatment is commonly seen downstream from urban areas.



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Cropping Systems

Groundwater

There is less N available to be leached to groundwater under permanent vegetation compared to cultivated areas. Evidence from groundwater investigations often shows higher concentrations of nitrate (NO_3) in groundwater under cropped areas compared to less intensive land uses such as rangeland. Corn, potatoes, and shallow rooted vegetables have greater potential to allow NO_3 movement beyond the rooting zone compared to other crops. This is due to a combination of nutrient use patterns, growth characteristics, and relatively high nutrient requirements. The combination of crops grown in a rotation also affects the potential for groundwater contamination by N. For example, less N moves beyond the rooting zone with a corn-soybean rotation compared to continuous corn. Rotations of deep-rooted crops such as sunflower, safflower, alfalfa and sweet clover will utilize some of the N leached from crops with shallow root zones.

Management recommendations

- **Leaching losses from fields planted to corn may be reduced by rotating with other crops that use N more efficiently, such as small grains or legumes. In areas of high groundwater vulnerability continuous corn should never be considered as an option.**
- **Leached N lost from fields with corn, potato, or shallow rooted vegetable crops may be utilized by rotating with crops that have deeper rooting systems. The options are more limited for corn, because it is a relatively deep rooted crop. However, alfalfa has a deeper rooting system than corn and can be economically grown in many areas.**

Surface Water

There is a strong connection between runoff, erosion, and nutrient losses. Because the type of crop grown influences runoff, nutrient losses vary with different crops. In general, soils under corn, beans, potatoes, and sunflower that maintain an obvious linear pattern (row) with a distinct furrow in between the rows have greater erosion compared to soils under solid seeded crops such as small grains. The use of solid seeded planting methods with crops that have been traditionally planted in rows would be an exception.

Crop effects on nutrient losses can be complicated when combined with other factors that influence runoff, such as annual precipitation, land slope and drainage type. For example, in one watershed study more runoff and erosion occurred in fields planted to row crops compared to small grains in years of average precipitation. However, during periods of above-average precipitation, more runoff and erosion occurred in areas where small grains predominated. The relative changes in erosion were explained by the general topography of the areas where these crops were grown. Small grains were grown in areas of steeper slopes compared to row crops, so as precipitation increased runoff and erosion from the small grain fields with steeper slopes increased at a greater rate compared to the row crops fields on more level slopes.

Crop nutrient requirements and crop use efficiency influence the amount of nutrient losses from fields. Higher losses of NO_3 can be expected from corn and potatoes compared to small grains and hay crops due to higher nutrient requirements and lower water and nutrient use efficiency.

Management recommendations

- **If row crops are grown, they should be rotated with solid seeded, high residue crops that help protect the soil surface and reduce nutrient losses in runoff.**
- **Planting cover crops after harvest of low residue crops such as beans and potatoes will help protect the soil surface from erosion during the period between harvest and planting the following year.**

Tillage

Groundwater

Tillage tends to increase the amount of NO_3 in soil because it enhances mineralization. Most cropland has some degree of tillage. Comparative studies of different land uses show that groundwater underlying cultivated soils generally contains higher levels of NO_3 compared to natural uncultivated soils.

The type of tillage also influences N movement through the soil profile. Tillage causes disruption of macropores. In recent years innovations in equipment and chemicals have led to reduced levels of tillage in many areas. This trend seems to be a benefit for groundwater protection in some areas because of reduced mineralization and increased immobilization. However, in many areas improvement of soil structure in no-tilled soils has created a network of macropores that conduct water and nutrients through the soil profile. The end result is increased flow of water and its dissolved load to groundwater. It is apparent that tillage has both advantages and disadvantages with respect to groundwater that vary with local conditions.

Management recommendations

- **Conservation tillage may cause greater immobilization of N thus reducing availability for leaching.** However, it may also lead to greater N leaching by increasing water infiltration and percolation. Information from studies on local soils should be used to determine if conservation tillage will have positive or negative impacts on groundwater.

Surface Water

Tillage practices that leave the soil surface unprotected greatly increase the potential for runoff, erosion, and nutrient losses from fields. The major input of N to surface water is generally associated with sediment eroded from land surrounding streams or lakes. Fields with reduced tillage or no tillage contribute much less total N to surface water than conventionally tilled fields. However, NO_3 loading has often been observed to be greater from fields with reduced tillage compared to conventionally tilled fields.

Minimum tillage tends to increase percolation and reduce runoff. Unless tile drainage is installed in a field, this reduction in runoff decreases the potential for surface water contamination from N. Studies also indicate that reduced tillage promotes smaller quantities of residual soil N after harvest, decreasing the potential for N losses from erosion.

The effects of tillage systems on N losses from fields depends on plant residue, surface texture, bulk density, aggregate stability and surface soil chemistry. For example, little difference has been demonstrated in runoff and soil loss between conservation and conventional tillage in fine-textured soils.

Soil conservation practices used to protect tilled fields from erosion will not effectively protect surface water unless they are applied to critical areas and are designed to reduce soluble loads of nutrients.

Management recommendations

- **Conservation tillage will help protect surface water from N, but not to the same degree on all soils.** The advantages of increased stored soil moisture under conservation tillage are greatest for drier soil types.
- **When possible tillage should follow the contour or align transverse to the direction of the slope.** This will reduce the erosive power of water flowing down the hillslope. Combining tillage on the contour with alternating strips of grass or hay crops provides even further soil protection.
- **In areas of uniform slopes, tillage along the contour may be combined with field terraces as an additional method to reduce the erosive power of hillslope runoff.**
- **Grassed waterways may be installed to protect areas of concentrated runoff (drainageways) from gully erosion.**
- **Low lying areas of wet soils along drainageways and adjacent to streams and wetlands should be protected from tillage to the greatest extent possible.** In their natural state, these areas function as environmental filters and help to protect surface water from activities further upslope.

Summer Fallow

Groundwater

Summer fallow tends to reduce crop-water-use efficiency due to deep percolation of water below the rooting zone. The fallowed soil not only loses a portion of the precipitation that infiltrates the surface, but also a portion of the solutes present in the soil, such as NO_3 released by mineralization. Summer fallow generally increases the potential for groundwater contamination by N. Although NO_3 leaching from summer fallowed fields with coarse textured soils is more likely to occur, significant leaching may also occur in finer textured soils.

Management recommendations

- **In areas overlying shallow aquifers, summer fallow should be either eliminated from the crop rotation or reduced to a small percentage of the total farmed acres.**

Surface Water

The effect of summer fallow in the northern plains on surface water is related to soil erosion. The higher content of available N in summer fallowed soils coupled with greater potential for water and wind erosion increases the potential for N losses from these fields. With respect to surface water protection, chemical fallow has much less negative impact compared to “black” fallow. This is because crop residue protects the surface and erosion losses are similar to fields with conservation tillage.

Management recommendations

- **Black summer fallow (tilled for weed control) should be either eliminated from the crop rotation or reduced to a small percentage of the total farmed acres.**
- **Use herbicides to control weeds and maintain crop residue during the fallow period.** This alternative provides similar protection from erosion compared to conservation tillage.

Fertilizer Applications

Groundwater

The N use efficiency (NUE) of fertilizer applications of most cropping systems rarely averages greater than 50 percent and generally decreases with increased amounts of N applied. Improving the NUE is a critical factor in reducing environmental impacts of N. N fertilizer inputs that match plant nutrient requirement during the growing season will generally improve NUE. Despite the low efficiency of use for N fertilizer, groundwater contamination is rarely a direct result of fertilizer application.

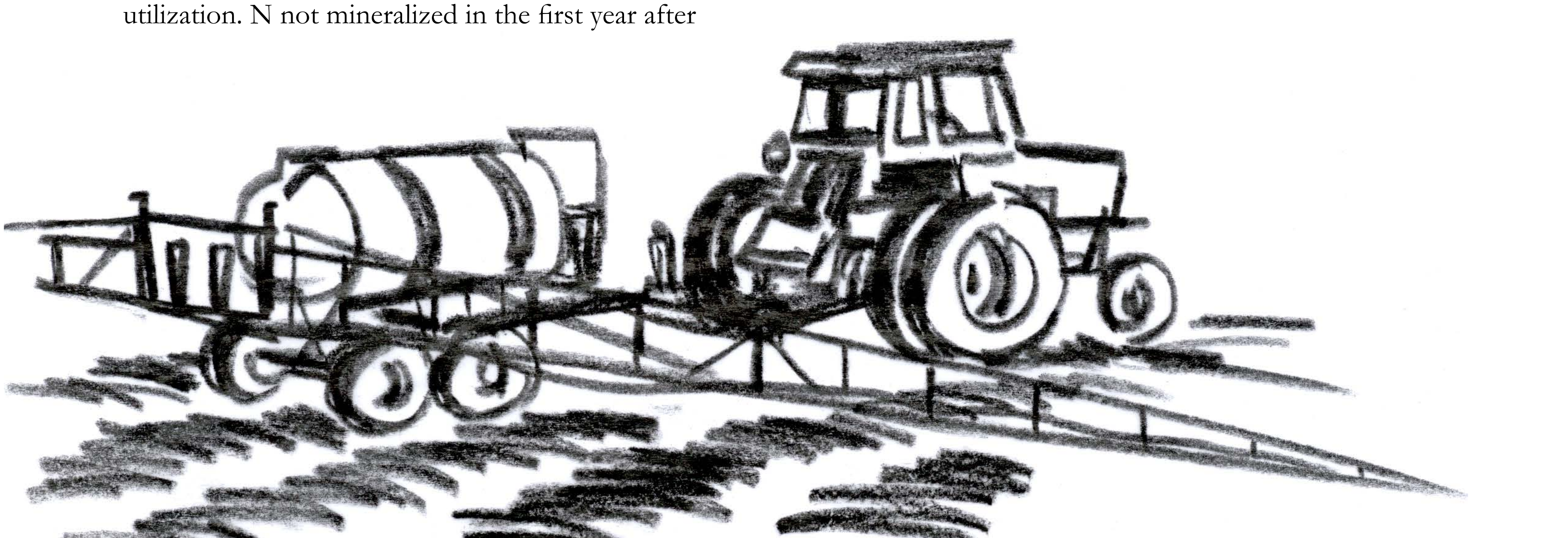
Application of N fertilizer does not necessarily increase the potential for groundwater contamination. Improved plant growth due to application of recommended rates of N fertilizer can actually result in lower NO_3 leaching losses. Expanded root growth of healthy fertilized plants extracts more N from the soil compared to less vigorous unfertilized plants.

In the northern plains lack of rainfall has the greatest influence on N leaching to groundwater. In most soils of this area, other than sandy or gravelly textures, NO_3 leaching beyond the root zone only occurs in years of above average precipitation. Regular soil testing is useful to account for residual NO_3 left in the soil after the growing season, because it will usually be available for the crop in the following year. This is important to both economic and environmental management. If the residual N is not taken into account, fertilizer applications will be in excess of crop needs.

Several factors need to be considered when using organic wastes for fertilizer to insure efficient utilization. N not mineralized in the first year after application of manure generally becomes part of the soil organic matter and releases N relatively slowly. Because manures from various sources decompose at different rates, it is necessary to determine the decomposition rates for proper fertilization. Constant annual manure applications that supply N to meet the entire crop demand will ultimately cause excessive fertilization; decreasing amounts need to be applied each year to lower the potential for NO_3 leaching.

The method of application or form of organic waste may make a measurable difference with respect to leaching losses. Liquid manure application generally results in more leaching than solid manure. Enhancing volatilization of NH_3 from sewage sludge by aging, dewatering, and applying to the soil surface will minimize conversion to NO_3 and reduce the potential for leaching to groundwater. Excessive production of NO_3 from nitrification of land-applied sludge may be managed by addition of organic carbon.

Fertilizer recommendations for groundwater protection have been demonstrated to be effective in lowering the potential for N contamination under many circumstances. Often these recommendations have little or no impact on yield or a profitable return. However, this is not always true. Economic efficiency may require above-optimum fertilizer applications. Under these circumstances, if fertilizer rates are reduced for environmental protection, crop yields will also be reduced. Agronomic recommendations should always be tested for local conditions to determine the balance between economic returns and water resource protection.



Management recommendations

- **The level of residual soil NO_3 should be determined by analysis of soil samples taken from each cropped field.** Fertilizer applications should be based on soil analyses results and selection of a reasonable yield goal.
- **N applications should be managed very carefully on sandy or gravelly soils due to the high potential for leaching losses.** Fall applications are not recommended on these types of soils. Split applications of N should be considered to ensure that adequate N is available during critical stages of crop growth. Slow-release fertilizer or nitrification inhibitors are recommended to reduce the potential for build-up of NO_3 and sudden loss due to rapid leaching from intense rainfall.
- **Fall applications of anhydrous NH_3 or urea on finer textured soils should be delayed until soil temperatures reach 45° F or less.** At these temperatures conversion to NO_3 is slow, so the potential for NO_3 leaching losses is reduced.
- **N fertilizer should be stored in an area protected from excessive surface runoff or water infiltration.** A fertilizer storage area should have an impermeable surface from which runoff is diverted. Commercial fertilizers should be stored in areas where the integrity of packaging can be maintained and where spills or leaks can be easily detected and managed.
- **Animal manure used as a fertilizer source should be tested to determine nutrient value.** Manure application must account for decay rates or mineralization so the proper amount of N is available for crop requirements. NO_3 release from manure occurs over a period of many years, so previous applications must be accounted for each growing season.
- **Injection of liquid manure into sandy or gravelly soils that overlay shallow groundwater is not recommended.** N and other contaminants have been shown to have greater mobility in a liquid slurry compared to dry manure.

Surface Water

There is a positive correlation between amount of agricultural land in a watershed and the concentration of N in watershed streams. In some areas excessive applications of N are strongly linked to high concentrations of N in streams. However, under most circumstances N levels in streams cannot be directly linked to a single source such as fertilizer applications. In fact, it has been shown that proper fertilizer application according to plant growth needs results in decreased N losses from fields. Fertilizer applications improve plant growth and increase crop residues that reduce runoff and erosion.

Applying animal manure to land has potential to result in N contamination of surface water if not managed correctly. The potential for N transport from land-applied manure is quite variable. However, greater losses of N generally occur from fields fertilized with animal manure as compared to inorganic fertilizer. Applications of manure to more erodible soils will result in greater potential for contamination of surface water resources due to the particulate nature of the material compared to the more soluble forms of N in inorganic fertilizers. Compensating for low NUE of animal manure by applying higher rates to meet annual crop requirements also adds to the potential for surface water contamination. Incorporation of animal wastes into the soil soon after application significantly reduces the potential for N movement from the field.

It is important to base animal manure applications on a balance between N and phosphorus (P). Animal manure applications based solely on N recommendations can result in high P levels that contribute to surface water problems.

Management recommendations

- **The first five fertilizer management recommendations for groundwater protection also apply to surface water protection, because they are designed to reduce excess NO_3 in the soil that can be lost to water resources.**
- **Manure applied to the soil surface should be immediately incorporated or injected on soils with slopes greater than 6 percent.**
- **Manure applications should be avoided on frozen ground or during excessively wet periods of time.** Manure should never be applied any closer than 25 to 30 feet from a stream or lake or within 200 feet if the soil is frozen.
- **Manure applications must balance plant requirements for both N and phosphorus.** Applications based only on N requirements of plants will eventually result in excessive levels of soil P.

Organic Wastes

Groundwater

Drainage from septic systems is identified as one of the sources for elevated NO_3 in groundwater. The main form of N that exits a septic drainage system is ammonium (NH_4), but it is quickly changed to NO_3 and subsequently leached. Leaching occurs within a few feet of the drainage field, so there is little opportunity for dilution or plant uptake. The amount of N added to a septic drainage field from a family of four is approximately 200 X the amount mineralized from soil organic matter plus the amount deposited from the atmosphere. This means that under normal circumstances high concentrations of NO_3 leach from most septic drainage fields. NO_3 contamination of groundwater from septic drainage fields is most likely to be a problem in areas of low rainfall and high development density, due to the lack of dilution of a large quantity of N.

N contamination of wells has been associated with the proximity of livestock yards and animal waste. However, reliable relationships that predict the levels of N contamination using the distance between wells and livestock yards do not exist. Significant leaching of NO_3 from livestock feedlots is most likely to occur on sandy or gravelly soils, or when compacted conditions are not maintained due to low stocking rates, frequent disturbance of compacted layers, or lot abandonment.

Management recommendations

- **Water wells should be constructed according to modern standards as outlined in Article 33-18 of the North Dakota Century Code to prevent surface water infiltration through seams, cracks or holes in the casing.** Wells should not be located in depressional areas or low landscape positions that receive surface water runoff. Wells should be located at least 50 feet from privy pits, cesspools, septic tanks, and sewage filtration fields; 100 feet from barnyards or feedlots; and 250 feet from livestock manure storage areas. If these precautions are used, the potential for well contamination with N from organic wastes will be reduced.
- **Abandoned wells in the vicinity of livestock yards or manure storage should be sealed according to appropriate methods as outlined in NDSU Extension publication AE-996, A Guide to Plugging Abandoned Wells.**
- **The surface of an animal yard or feedlot should be maintained by allowing the compacted layer of manure immediately above the soil surface to remain undisturbed.** This 3 to 4-inch layer serves as a seal to NO_3 leaching. Only when the area is no longer used for animal production should the compacted layer of manure be removed.
- **Recommendations for organic waste applications that protect groundwater are listed in the Fertilizer Applications section.**

Surface Water

The management of organic wastes and runoff from areas in close proximity to surface water has a significant effect on the amount of N that is mobilized and transported to surface water resources. Proper design of storage facilities, regular maintenance of animal yards, and diversion of runoff water will reduce the potential for contamination of surface water from livestock facilities. Proper septic system installation and maintenance are needed to ensure that human waste does not run directly into surface water resources.

Management recommendations

- **Septic system installation should conform to standard design, siting, and construction requirements as outlined in NDSU Extension Service publication AE-892, Individual Home Sewage Treatment Systems.** This will ensure that waste receives proper treatment.
- **Septic systems should be maintained through regular inspections and avoiding excessive amounts of grease, oil, or caustic chemicals that will plug or damage the system.** Plugged septic drainage fields allow waste to flow to the surface and contaminate water resources.
- **Manure (liquid or dry) should be stored in properly designed facilities that are protected from excessive runoff, flooding, or overflow conditions that would allow contamination of surface water.** Proper design and location of animal waste facilities may be determined from the MidWest Planning Service Bulletin 18, Livestock Waste Facilities Handbook.
- **Recommendations for organic waste applications that protect surface water are listed in the Fertilizer Applications section.**

Irrigation

Groundwater

Irrigation should not be linked to NO_3 contamination of groundwater without considering other factors that influence N fate in soils and the geologic materials below. Irrigation often occurs where groundwater is shallow and soils have high sand content. These two factors alone increase the potential for groundwater contamination. Many irrigated crops, such as potatoes, are quite intolerant of low soil water contents. Maintance of higher soil water contents through increased irrigation water results in greater potential for leaching. When conditions that maximize vertical water movement through the soil profile are coupled with the presence of a mobile chemical such as NO_3, the potential for groundwater contamination increases. Crops with large nutrient requirements and shallow rooting depths such as potatoes and vegetables, further increase the potential for groundwater contamination.

Irrigation water management appears to be the most important factor in reducing potential for N leaching. The method of irrigation water application influences the leaching process. Generally the potential for leaching is smallest for drip irrigation and highest for furrow irrigation. Deficit water scheduling that depletes the soil of water in the fall substantially reduces NO_3 leaching from irrigated fields.

Management recommendations

- **Schedule irrigation appropriately by monitoring soil water and crop water use.** Regular measurement of soil water is an accurate way of determining when to irrigate. An indirect method used to estimate soil-water balance, commonly called the "checkbook method," is based on knowledge of the soil water holding capacity, daily crop water use, and daily precipitation measurements. Soil water content determined using the checkbook method should be verified occasionally with field measurements. It is critical that the water budget is determined systematically and accurately so that applications of water meet the needs of the crop but do not result in over-application.
- **Time water applications to avoid water movement beyond the rooting zone.** Weather patterns should be assessed prior to each irrigation. Deficit irrigation techniques that leave room in the rooting zone for additional water from rainfall have been demonstrated to conserve water without yield reductions. Irrigation should not fill the soil to field capacity and the soil profile should never be used to store irrigation water through the winter. To the contrary, irrigation water should be managed so that stored soil water is at a minimum in the fall.
- **Adjust water application amounts to meet varying crop demands at different growth stages.** Irrigation has the potential to meet these variable demands more readily than dryland agriculture, thus maintaining a stable environment for plant growth. Large amounts of unused available N are not likely to be left in the soil if management results in maintenance of vigorous plant growth throughout the year. The potential for NO_3 leaching and groundwater contamination is diminished if this practice is followed.
- **Irrigation water must be applied uniformly and accurately.** A functional flow meter and accurate pressure gauge, either at the pump or on the pipeline near the point of discharge,

(continued)

are essential for accurate irrigation water and N fertilizer application. Uniform application rates can only be accomplished if irrigation equipment functions properly; therefore, sprinklers, nozzles, pipes, etc. must be checked regularly. Placing catch cans under the system to measure actual amounts of water delivered to the soil surface can check uniformity of application.

- **Chemigation equipment that protects the water supply must be used to inject N into an irrigation system.** State regulations regarding proper chemigation equipment required to protect the water source from back-siphoning must be followed. Chemigation provides an opportunity to ensure that adequate N is supplied to the crop during critical growth stages. Application of N through the irrigation system can be accomplished at later growth stages when other methods of delivery are not possible. In addition, applying N through the irrigation system helps to split applications and avoids applying all the N in a single application, which has both economic and environmental benefits.
- **The chemigation unit must be calibrated with each use to ensure accurate application of N.** An accurate way of measuring the amount of chemical being injected into the irrigation system is essential to good irrigation management. Accurate measurement of the amount of applied N not only optimizes chemical usage but also ensures a uniform application over the entire irrigated field if the system is designed and operating correctly.
- **Secondary containment should be provided where N fertilizer is stored near the irrigation well when chemigation is practiced.** Secondary containment, made of impermeable material, reduces the risk of contamination in the case of a leak or spill.
- **Recommendations related to groundwater protection under the Cropping System, Tillage, Fertilizer Applications, and Organic Waste sections are also appropriate to irrigated fields.**

Surface Water

The processes that affect N availability, mobility, and translocation to surface water under irrigated agricultural systems are the same as those for non-irrigated agriculture. Soils consistently maintained at field capacity are more likely to generate runoff during rain events compared to similar soils allowed to dry down to lower water contents. Application of irrigation water that causes surface runoff or subsurface drainage that outlets to surface drains creates potential for N contamination.

Many irrigated soils are susceptible to wind erosion. Topsoil removed from irrigated fields and deposited in ditches, streams, and lakes is a source of water pollution. Conservation practices that reduce wind erosion are particularly important in irrigated fields with low residue crops such as potatoes or beans.

Management recommendations

- **The first four recommendations for groundwater protection under irrigated fields are also appropriate for surface water protection.** These practices promote efficient water input, which helps reduce over-application of water and saturated conditions that may lead to runoff. In addition, good irrigation scheduling should help avoid excessively dry conditions that may lead to wind erosion.
- **Recommendations related to surface water protection under the Cropping System, Tillage, Fertilizer Applications, and Organic Waste sections are also appropriate to irrigated fields.**

Further Information and References

For information related to nitrogen and water quality refer to:

AE1216 Water quality and nitrogen

AE1217 How to assess for nitrogen problems in water resources

EB-64 Managing nitrogen fertilizer to prevent groundwater contamination

For an in-depth discussion on how our activities affect nitrogen in the environment refer to:

ER-62 Diffuse sources of nitrogen related to water quality protection in the Northern Great Plains

For more information on this and other topics, see www.ag.ndsu.edu

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