Best Management Practices For Nitrogen Fertilization

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Best Management Practices for Nitrogen Fertilization

Nitrogen (N) is the essential plant element that most frequently limits irrigated crop production in Colorado. Commercial N fertilizers are a cost-effective means of supplementing soil supplied N for plant growth and are necessary for sustaining high crop yields. However, it has been documented that improper or excessive use of N fertilizer can lead to nitrate pollution of ground or surface water. Both urban and rural fertilizer applicators can minimize this problem by implementing Best Management Practices (BMPs) for fertilizer use.

Nitrate in Drinking Water

Nitrate (NO_3) is a naturally occurring form of N that is highly soluble in water and may cause health problems if ingested in large amounts. A number of sources of NO_3 exist, including manure, septic and municipal effluent, decomposing organic matter, soil organic matter, and N fertilizer. High NO_3 levels in drinking water can cause methemoglobinemia, or "blue baby syndrome," a condition primarily seen in very young infants and farm animals. Although reports of methemoglobinemia are extremely rare, the U.S. EPA has established a safe drinking water standard of 10 ppm NO_3-N for community drinking water supplies.

Managing the amount, form, placement, and timing of N application is the most practical and acceptable approach to minimizing ground and surface water contamination resulting from fertilizer use. Some states have already imposed controls on the use of fertilizer. In Colorado, the use of fertilizers by both urban and rural applicators may be regulated under the Agricultural Chemicals and Groundwater Protection Act (Senate Bill 90-126) if the Colorado Department of Agriculture finds voluntary measures insufficient to protect groundwater. Therefore, applicators need to evaluate the nitrate leaching potential of fields where fertilizer is used and voluntarily adopt BMPs to protect water quality.

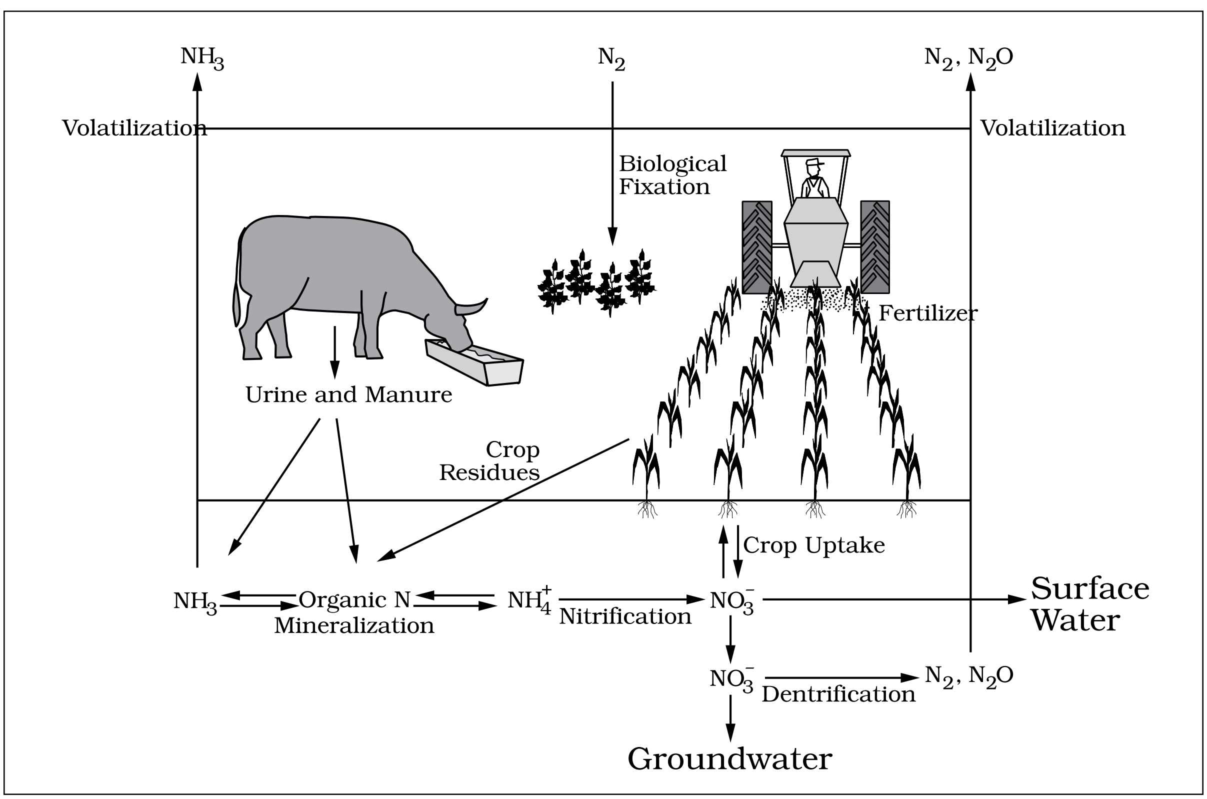


Figure 1. The nitrogen cycle

The BMP Approach

Rather than legislate overly restrictive measures on farmers and related industries, the Colorado Legislature passed the Agricultural Chemicals and Groundwater Protection Act (SB 90-126) to promote the voluntary adoption of Best Management Practices. The act calls for education and training of all producers and agricultural chemical applicators in the proper use of pesticides and fertilizers. Voluntary adoption of BMPs by agricultural chemical users will help prevent contamination of water resources, improve public perception of the industry, and perhaps eliminate the need for further regulation and mandatory controls.

BMPs are recommended methods, structures, or practices designed to prevent or reduce water pollution. Implicit within the BMPs concept is a voluntary, site-specific approach to water quality problems. Development of BMPs in Colorado is being accomplished largely at the local level, with significant input from chemical applicators and other local experts. Many of these methods are already standard practices, known to be both environmentally and economically beneficial.

The Nitrogen Cycle

Fertilizer use efficiency is at, or near, an all-time high in U.S. agriculture. Total fertilizer use has remained relatively level since the mid 1980s, while crop yields continue to increase. In spite of this, it is estimated that about 25% of all preplant N applied to corn is lost through leaching or denitrification. This loss is estimated to be even higher during wet years. Leaching is the major problem on coarse-textured soils, while denitrification is the primary pathway on poorly drained clay soils. While a certain amount of loss is unavoidable, producers can gain economic and environmental benefits by minimizing losses and maximizing crop uptake.

To fully understand the transformation and movement of N in the environment, some knowledge of the N cycle is needed. Nitrogen in the soil is commonly found in the form of organic N in the soil humus, ammonium (NH_4), nitrate (NO_3), or in a gaseous form (NH_3, N_2, N_2). Nitrogen in soil organic matter may be converted to the NH_4 form by a biological process called mineralization. The NH_4 form is converted to NO_3 by another biological process called nitrification (Figure 1). Fertilizer N, whether organic or inorganic, is biologically transformed to NO_3, which is highly leachable. The speed of this transformation is determined by soil temperature and moisture, but will eventually occur in any well-drained agricultural soil. Plants will absorb and utilize both NH_4 and NO_3. Therefore, producers need to match N applications to crop uptake patterns to minimize NO_3 leaching and maximize efficiency.

Determining Leaching Hazard

Leaching potential of a given site depends upon soil properties, management, irrigation, and climatic factors. Depth to groundwater and the overlying geologic material determine the contamination potential of an aquifer. Due to the site-specific nature of these properties, applicators must determine the relative leaching hazard of each application site in order to select the appropriate BMPs (Table 1).

Leaching hazard can be ranked as severe, moderate, or slight by simultaneously considering soil characteristics, irrigation method, and aquifer vulnerability. Those operators with sites that have a *severe* leaching potential and a shallow water table (<25 feet deep) must select appropriate BMPs to decrease leaching hazard. Operators working under *moderate* leaching conditions should assess what particular practices may cause future groundwater contamination and make the necessary changes to prevent any groundwater quality problems. Operators with uncontaminated groundwater and *slight* leaching hazard should continue observing good management practices. Table 1 can help operators evaluate the potential leaching hazard of their particular sites.

Information on the depth to the water table and water quality can be obtained through several sources, if not currently known. All rural well owners are strongly encouraged to periodically have a water sample analyzed by a qualified laboratory. The Colorado Department of Health or your local county health office frequently have information on the quality and vulnerability of groundwater in your area. Experienced local well drillers also have knowledge of local groundwater conditions. Agencies such as the Soil Conservation Service, Cooperative Extension, and others can frequently provide information to help you evaluate groundwater vulnerability at your site.

In some cases, soil type and a shallow water table combine to create a very high leaching potential. For example, if the soil at a given site is course textured, and depth to the water table is less than 10 feet, it is strongly recommended that shallow-rooted crops not be grown under conventional furrow irrigation. Deeper rooted crops and higher efficiency irrigation methods are necessary for these conditions.

Nitrogen Management Practices to Protect Water Quality

While soil, climatic, and geologic characteristics of the site strongly influence leaching potential, management practices finally determine the amount and extent of N leaching. Proper nutrient management includes:

- accounting for crop N needs
- applying appropriate inputs as determined by N budget (See N worksheet.)
- applying N when and where it can be used most efficiently by the crop.

This will assure residual soil NO_3 is minimized. The following management practices will help producers and fertilizer applicators maximize economic returns from fertilizer dollars while protecting water quality.

Soil Testing

Soil testing is a very important BMP for determining plant nutrient needs. Yearly sampling of each field is necessary to make accurate N fertilizer recommendations. The key to good soil test results is proper sampling protocol. Each sample should contain 12 to 20 cores of soil from a reasonably uniform area of approximately 40 acres. Large fields should be broken into sampling units based upon crop, yield, and fertilizer histories. Deep soil sampling for residual NO_3 is requisite to precise fertilizer recommendations and provides producers season-end information regarding crop N use and N remaining for next year's crop. Sampling to a minimum depth of 2 to 3 feet is recommended for all soil types.

Realistic Yield Goals

Setting realistic yield goals is also a very important BMP. Fertilizer N recommendations are based upon a yield goal submitted by producers with their soil samples. While farmers tend to be optimistic, overestimating yield goals results in excess N applications, leading to loss of farm income and potential groundwater contamination.

Applying enough fertilizer for a 200 bu/A corn crop, when other conditions such as limited irrigation water will only allow a 150 bu/A yield, can result in 60-70 lb/A of excess N being applied. Rather than project a **yield goal,** it is recommended that producers establish a **yield expectation** based upon historical yield averages.

Yield expectations must be established on a field-by-field basis. The five most recent yield averages for each field should represent an obtainable yield. If a recent crop has been lost to hail or other disaster, that year's yield should be omitted from the average. Colorado State University suggests that a producer add 5% to the five-year yield average and use this value as the yield expectation. If the crop season and growing conditions appear to be above average, producers can adjust N rates upward at sidedressing or by applying N through irrigation water. In-season soil or plant tissue analysis may be used to determine if additional N is required. The key to setting realistic yield expectations is to base them on actual field averages plus a modest increase for improved management and good growing conditions.

Table 1. Potential leaching hazard as predicted by soil type[1], aquifer depth[2], and irrigation method *

	Aquifer Depth and Condition		
Irrigation method	Shallow or contaminated	Deep or uncontaminated	Aquifer properties unknown
Flood or Conventional furrow with efficiency < 60%	Coarse soil: *Severe* Fine soil: *Moderate*	Coarse soil: *Moderate* Fine soil: *Slight*	Coarse soil: *Severe* Fine soil: *Moderate*
Sprinkler or surge furrow with efficiency > 60%	Coarse soil: *Moderate* Fine soil: *Slight*	Coarse soil: *Moderate* Fine soil: *Slight*	Coarse soil: *Moderate* Fine soil: *Slight*
Dryland or drip irrigation	Coarse soil: *Moderate* Fine soil: *Slight*	Coarse soil: *Slight* Fine soil: *Slight*	Coarse soil: *Moderate* Fine soil: *Slight*

[1] Soil texture breakdown: Coarse soil is soil with >35% sand and <30% clay including sand, loamy sand, sandy loam, sandy clay loam, or loam soil. If greater than a third of the field contains these coarse-textured soils, the entire field should be considered coarse in this rating scale. Fine-textured soil includes all soils not listed above.

[2] Shallow groundwater is defined here as <25 feet below the soil surface. Contaminated refers to aquifers yielding water with > 10 ppm NO_3-N or any detection of pesticide.

Severe leaching hazard: Operators should implement all appropriate BMPs.
Moderate leaching hazard: Operators should evaluate fertilizer use and apply appropriate BMPs.
Slight leaching hazard: Operators should continue to use fertilizers according to recommendations and good management procedures.

* For more detailed information about your site and soils, contact your local Soil Conservation Service office.

Nitrogen Credits From Sources Other Than Commercial Fertilizer

Soil organic matter, irrigation water, manure, and previous legume crops all contribute N to the growing crop. The N contribution from these sources must be credited in order to make accurate fertilizer recommendations. Table 2 suggests average credits from various sources of N.

Legume crops can be a very significant source of plant available N due to bacterial N_2 fixation in root nodules. Plowing down a full stand of alfalfa will release as much as 100 pounds of N per acre in the first year after plowdown. The amount of N credit given for legumes depends upon the crop, stand, and degree of nodulation. A minimum of 30 lb N/acre should be credited in the first year after any legume crop.

Irrigation water containing nitrate can supply N to the crop since it is applied and taken up as the crop is actively growing. Water tests for NO_3-N should be taken annually to accurately calculate this credit. Multiply ppm NO_3-N by 2.7 lb/AF times the amount of effective water applied (in feet) to the crop to determine pounds of N per acre applied in the irrigation water. Inexpensive quick tests are available for on-farm water testing. If a water sample is taken for laboratory analysis, it should be kept cool, but not frozen, until it gets to the lab.

Calculation 1. Irrigation water N credit

Example:
30 inches of water applied containing 7 ppm NO_3-N

$$7 \text{ ppm } NO_3\text{-N} \times 2.7 \text{ lb N/AF} \times \frac{\textit{30 inches applied/A}}{\text{12 inches/AF}} = 47.25 \text{ lb N/A}$$

Table 2. Nitrogen credits for crop requirements

N Source	N Credit
Soil organic matter	30.0 lb N/%OM
Residual soil nitrate	3.6 lb N/ppm NO_3-N
Manure	10.0 lb N/ton dry manure
Irrigation water	2.7 lb N/AF x ppm NO_3-N
Previous alfalfa/sweet clover	50.0 lb N/A
Other previous legume crop	30.0 lb N/A

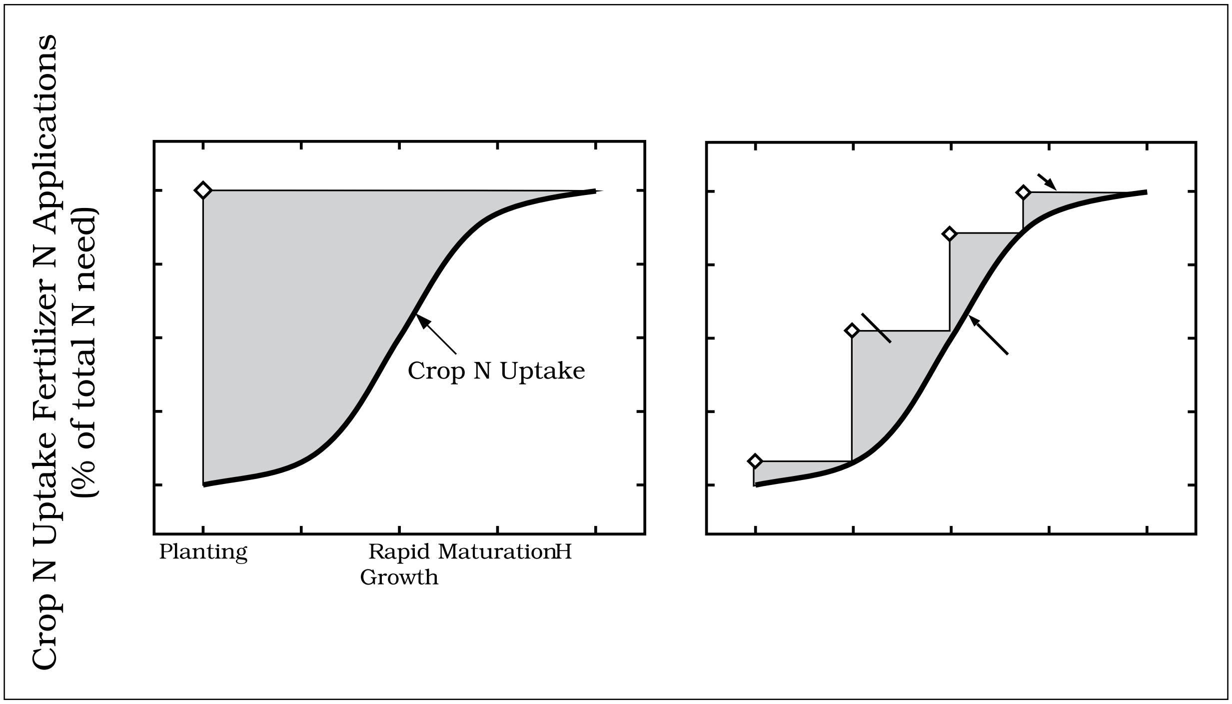
Manure is an excellent plant nutrient source, but excessive manure applications can result in water pollution from soil buildup of N and P. For best results, manure should be analyzed prior to application to determine nutrient content. Subsequent manure application rates should be determined by factoring the previous application to avoid excess loading. In general, about 50% of total N in manure is available the first year after application, 25% in the second year, and 12.5% in the third year. In the absence of an accurate manure analysis, operators should credit 10 lb N/ton of dry manure applied the first year after application.

Sewage sludge is another valuable source of plant nutrients that must be properly used to avoid environmental problems. One ton of dry sludge may contain up to 100 pounds of total N, 120 pounds P_2O_5, and 10 pounds K_2O at a fertilizer value of $30 to $60 per ton. In Colorado, the land application of municipal sludges is regulated by the Colorado Department of Health (5CCR 1003-7) and restrictions are in place to prevent ground or surface water contamination. While application rates may be limited by heavy metal content of the sludge or P content of the soil, crop N requirements typically set the appropriate sludge rate. However, sludge application rates can exceed actual crop N uptake when crop yields are significantly lower than anticipated. Sludge acts as a slow release N source and can cause a buildup of soil NO_3 levels over time if N uptake is lower than estimated. For this reason, producers using sludge should use deep soil testing and sludge analysis to adjust application rates over time. Crop N uptake should be calculated using conservative yield estimates, crediting all available N sources, and assuming a 30% annual N mineralization rate for anaerobically digested sludge and a 50% annual N mineralization rate for aerobically digested sludge.

Fertilizer Placement and Timing

Proper timing and optimal fertilizer placement can greatly enhance plant uptake of N. Subsurface applied or incorporated fertilizer is much less subject to surface losses than surface broadcast fertilizer. Band applied fertilizer can be placed in closer proximity to plant roots. All surface applied fertilizers should be incorporated to reduce runoff and volatilization. In furrow irrigated cropland, alternate furrow irrigation used with ridge banded fertilizer can significantly reduce downward movement of N. Application of N through high efficiency irrigation systems such as center pivot or surge systems at periods of maximum crop uptake may increase N efficiency. It is not recommended that N be applied through low efficiency furrow or flood systems due to runoff and deep percolation losses. In higher efficiency surface systems such as surge irrigation, tailwater recovery should be employed to capture and recycle nutrients. Surface application of fertilizer or manure on frozen or snow-covered sloping fields should also be avoided.

Fertilizer applications should be timed to coincide as closely as possible to the period of maximum crop uptake. Fall applied N fertilizer has been shown to cause groundwater degradation in areas of high fall and winter precipitation. It should be avoided on spring planted crops in situations with severe potential leaching hazard (Table 1). There may be economic and management benefits to applying N in the fall, but the environmental risks make this a poor choice on coarse-textured soils or in situations where preplant irrigation is necessary. Partial application of N in the spring, followed by sidedress application, improves crop N uptake efficiency and reduces N available for leaching (Figure 2). Waiting until the crop is well established before applying large amounts of N reduces early season losses and allows producers to more accurately determine the crop yield potential. Poor stands, poor weed control, and below average precipitation are good reasons to adjust N rates downward at sidedress time. Conversely, exceptional conditions warrant increased N at sidedress. This type of managerial flexibility offers producers economic benefits and helps maintain water quality.



Nitrogen Fertilizer Forms

Nitrate forms of N fertilizer are readily available to crops, but are subject to leaching losses. Nitrate forms should not be applied in large amounts when the leaching hazard is moderate to high. Ammonium N forms, such as urea or anhydrous ammonia, are preferred in these situations because they are not subject to immediate leaching. However, under warm, moist soil conditions, transformation of NH_4 to NO_3 occurs rapidly. Other more slowly available N sources are commercially available and should be used where they are economically feasible.

Nitrification inhibitors can be used to delay the conversion of NH_4 to NO_3 under certain conditions. Farmers should consider using nitrification inhibitors when it is not feasible to use split applications or other management techniques on leachable soils. Nitrification inhibitors seldom produce a direct economic return to farmers and should not be used as a substitute for following other BMPs, but they can reduce leaching under certain situations.

Plant Analysis

Plant analysis during the growing season is another practice to help assess nutrient sufficiency in the growing plant. While nutrient deficiencies are many times visibly apparent, excess nutrient levels can only be determined by plant tissue analysis. This technology offers producers the ability to apply lower rates of N preplant, and to monitor and adjust plant nutrient status throughout the growing season. Plant analysis, when properly used, offers producers insurance that careful N management will not negatively affect the bottom line.

Irrigation Management

Colorado's semi-arid climate normally results in little off-season leaching of soil nitrates. Under dryland agriculture, the most significant water quality impacts are usually from soil erosion and subsequent nutrient enrichment of surface water. Irrigated crop production has the greatest potential to cause groundwater contamination due to the large volume of water applied. Nutrients leached below the crop root zone are lost to the system and may become pollutants. Crop root zone depth will vary by soil type, irrigation method, and management (Table 3). Therefore, conscientious management of irrigation water is critical to proper N management.

Increasing irrigation efficiency and uniformity reduces the amount of water drained through the soil, and decreases the amount of NO_3 and other contaminants leached. A number of technologies allow producers to apply water uniformly without excessive waste, and help to determine the optimum timing and amount of water to be applied. Among these are irrigation systems such as sprinkler, low-energy precision application, surge, and drip. Delivery systems such as lined ditches and gated pipe, as well as reuse systems such as tailwater recovery ponds, can greatly enhance overall efficiency. Shortening irrigation run lengths on coarse-textured soils can decrease deep percolation and leaching. Laser leveling of fields, irrigation scheduling according to soil water depletion and plant needs, and conservation tillage methods can also significantly decrease irrigation requirements. Proper irrigation scheduling, coupled with efficient irrigation systems, are among the most important BMPs to reduce nitrate leaching.

Other N Management Tools

Although proper N rates and good irrigation management are the most critical components of N management, there are other tools that should also be considered. Proper calibration and maintenance of fertilizer equipment is essential to get uniform distribution of fertilizer at the correct rate. Crop rotation can be beneficial by minimizing total fertilizer and pesticide needs. Often, yield improvement and economic benefits are achieved through a good rotation plan that takes advantage of better pest control, soil tilth, and N fixation by legumes. Deep-rooted crops can be used to scavenge N left in the subsoil by shallow-rooted crops. Cover crops are beneficial in preventing wind and water erosion, and they can use residual N in the soil profile. Finally, computer-assisted decision aides such as the Nitrate Leaching and Economic Analysis Package model can help producers make wise choices and avoid unnecessary water quality degradation.

Table 3. Approximate rooting depths for selected crops under furrow irrigation

Crop	Root Depth at Maturity (ft)
Corn	3-6
Small grains	3-5
Onions	1-2
Sugarbeet	5-8
Alfalfa	8-15
Dry beans	2-3

Best Management Practices for Nitrogen Fertilization

Guidance Principle: Manage nitrogen applications to maximize crop growth and economic return while protecting water quality.

To select the nitrogen BMPs that achieve water quality goals for your operation, consider:
- potential leaching hazard of the application site
- overall costs and benefits
- short-term and long-term effects on water quality
- most suitable practices to your site and your farm management plan.

General BMPs

1.1 Base nitrogen fertilizer rates on results from soil analysis, as well as irrigation water and plant analysis when appropriate, using environmentally and economically sound guidelines.

1.2 Analyze soil samples for each field. As a guideline, sample depth should be at least 2 to 3 feet, preferably to the depth of the effective root zone.

1.3 Establish realistic crop yield expectations for each crop and field based upon soil properties, available moisture, yield history, and management level. Yield expectations should be based upon established crop yields for each field, plus a reasonable increase (5% suggested) for good management and growing conditions.

1.4 Manage irrigation water to maximize efficiency and minimize leaching by meeting the Irrigation BMPs or the SCS-approved Irrigation Water Management practice standard and specification.

1.5 Identify fields with severe leaching potential or severe surface loss potential. Employ all appropriate BMPs on these fields to reduce nutrient movement to water.

1.6 Develop a yearly N management plan for each field and crop. The plan should include, as a minimum:

a. the previous crop, variety, and yield

b. the current crop, variety, and expected yield

c. current soil test analysis data showing the amount of available N in the soil

d. an estimate of the amount of N available from soil organic matter, manures, and previous legume crops to become available during the crop growth period

e. the amount of supplemental N to be applied to meet expected crop yield. This includes N from chemical fertilizers, manures, organic wastes, irrigation water, and other sources

f. special management practices needed to reduce N leaching. These include timing of application, multiple applications, sidedressing, banding, foliar feeding, fertigation, stable forms of N, nitrification inhibitors, or needed changes in crops or crop sequence.

Maintain these records for at least three years. (See Nitrogen Management Record Sheet for suggested format.)

Nitrogen Application BMPs

1.7 Time application of N fertilizer to coincide as closely as possible to the period of maximum crop uptake.

1.8 Use sidedress or in-season fertilizer application for at least 40% of the total N applied to irrigated spring planted crops or fields with severe leaching hazard (Table 1).

1.9 Avoid fall application of nitrogen fertilizer for spring planted crops on fields with severe potential leaching hazard.

1.10 Apply N fertilizers where they can be most efficiently taken up by the crop.

a. Ridge banded fertilizer used in conjunction with alternate row furrow irrigation can reduce downward movement of N.

b. Multiple, small applications of N through sprinkler irrigation systems can increase fertilizer efficiency and reduce total N fertilizer application.

c. Fertilizers applied on irrigated fields with high surface loss potential should be subsurface banded or incorporated immediately after application.

d. Nitrogen applied in irrigation water should be metered with an appropriate device that is properly calibrated. Due to the increased possibility of leaching or runoff, N fertilization through conventional flood or furrow irrigation systems is strongly discouraged.

1.11 The following recommendations apply to cropland fields where the leaching potential is moderate to severe:

a. Follow alfalfa or other legumes with high N use crops (such as small grains, sugar beets, or corn) that efficiently use N fixed by the legume.

b. Follow shallow-rooted crops with low N use efficiency in the rotation by a deep-rooted, high N use crop which scavenges excess N (such as corn, sugarbeets, or alfalfa). Analyze subsoil samples for residual NO_3 to determine carryover credit to the subsequent crop.

c. Use fall planted cover crops such as rye or triticale to scavenge excess N in areas where fall growth is sufficient for establishment.

Nitrogen Fertilizer Handling and Storage BMPs

1.12 Mix and store N fertilizers at least 100 feet away from wellheads or surface water bodies, except at fertigation sites. Protect permanent fertilizer storage and mixing/loading sites from hazards sue to spills, leaks, or stormwater.

For more information about nitrogen fertilizer management or specific inquiries about BMPs, contact Colorado State University Cooperative Extension. They have publications, programs, and specialists available to help you answer questions about water quality.

Related source material from Colorado State University Cooperative Extension:

SIA	**.500**	**Soil sampling – the key to a quality fertilizer recommendation**
	.501	**Soil test for fertilizer recommendation**
	.502	**Soil test explanation**
	.508	**Fertigation through surge values**
	.512	**Fertigation: applying fertilizers through irrigation water**
	.514	**Nitrogen and irrigation management – keys to profitable yields and water quality**
	.517	**Nitrates in drinking water**
	.547	**Land application of municipal sludge**
	.550	**Nitrogen sources and transformations**
XCM-37		**Guide to Fertilizer Recommendations in Colorado**

1.13 Do not store fertilizer in underground containers or pits.

1.14 Lock or secure valves on fertilizer storage containers when the container is not in use.

1.15 Protect fertigation application sites from spills or leaks of N fertilizer. Fertigation systems must comply with the Colorado Chemigation Act.

1.16 Inspect and calibrate fertilizer application equipment at least once annually.

1.17 When cleaning fertilizer equipment, recover excess fertilizer and wash water for reuse. Use rinse water in the subsequent fertilizer batch when possible, or apply at agronomic rates on cropland, avoiding high runoff areas.

NITROGEN MANAGEMENT RECORD SHEET

Field Description: ______________________________

Soil type: ______________ SCS leaching potential ranking: ______________

Previous crop: ______________ SCS runoff potential ranking: ______________

Yield: ______________ Soil tested: ______________

Manure tested: ______________ Water tested: ______________

Crop year: ______________ Crop and variety: ______________

1. Expected yield: ______________
2. Total N needed to achieve expected yield: ______________ lb N/A
   (expected crop uptake/efficiency factor)
3. Residual soil NO_3: ______________ lb N/A
4. Irrigation water NO_3-N credit: ______________ lb N/A
   (ppm NO_3-N x AF of effective irrigation water x 2.7 = lb N/A)
5. Soil organic matter credit (credit 30 lb N per % OM): ______________ lb N/A
6. Manure credit: ______________ lb N/A
   (credit minimum of 10 lb N/ton applied manure if analysis not performed)
7. Nitrogen available from previous manure applications: ______________ lb N/A
8. Nitrogen available from previous legume crop: ______________ lb N/A
9. Total N available to crops (sum of lines 3, 4, 5, 6, 7, and 8): ______________ lb N/A
10. Nitrogen fertilizer requirement: ______________ lb N/A

Fertilizer N applied: ______________lb/A Manure N applied: ______________lb/A

Application dates and amounts: ______________

Form of N used: ______________

Actual crop yield: ______________bu/A Total irrigation water applied: ______________

Notes: