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BEST MANAGEMENT PRACTICES FOR IRRIGATED AGRICULTURE

A guide for Colorado Producers

Colorado State University

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PREFACE

This document represents the efforts of several groups to identify best management practices (BMPs) to help reduce agricultural contamination of Colorado water resources. The Colorado Water Resources Research Institute funded a joint project by the CSU Agronomy Department and Northern Colorado Water Conservancy District to document irrigation management practices to minimize nonpoint source pollution. Concurrently, the Colorado Department of Agriculture's Groundwater Advisory Committee requested that CSU develop a set BMPs for ag chemical use with significant input from individuals who use and recommend pesticides and fertilizers in the field.

A work group was formed in the fall of 1993 to prepare a set of BMPs containing nutrient and irrigation guidelines and recommendations. In structuring the work group, emphasis was placed on utilizing local agricultural expertise from producers, agrichemical fieldmen, and crop advisors directly involved in production agriculture.

This bulletin is a synthesis of university and practitioner knowledge of managing our soil and water resources. These guidelines are not a exhaustive list of management strategies, but are some options and resources that producers can evaluate for their own specific operations. Voluntary adoption of BMPs by agricultural producers should help to reduce adverse environmental impacts from irrigated agriculture and perhaps minimize further regulation.

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Rear cover photo credit: William Cotton, Colorado State University

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regarding drinking water quality and the environment has put the use of agricultural chemicals in irrigated agriculture in the national spotlight. Reports of pesticides and nitrates found in ground and surface water increase the need for farmers, ranchers, and other chemical applicators to modify some production practices.

Preventing groundwater contamination is particularly important because, once polluted, groundwater is very difficult and expensive to clean up. The Colorado legislature addressed this concern in 1990 by passing the Agricultural Chemicals and Groundwater Protection Act (SB 90-126). This Act declares that the public policy of Colorado is to protect groundwater and the environment from impairment or degradation due to the improper use of agricultural chemicals, while allowing for their proper and correct use.

Rather than legislate overly restrictive measures on farmers and related industries, Colorado has elected to encourage the voluntary adoption of Best Management Practices (BMPs). This allows the agricultural chemical user's to select BMPs appropriate to their specific managerial constraints, while still meeting environmental quality goals. Voluntary adoption of these measures by agricultural chemical users will help prevent contamination of water resources, improve public perception of the industry, and perhaps reduce the need for further regulation and mandatory controls.

While some runoff and leaching is unavoidable, nonpoint source pollution can be reduced by managing irrigation systems so that the timing and amount of applied irrigation water matches crop water needs as close as possible. Nitrate (NO_3) from fertilizer is extremely soluble and moves readily with irrigation water. Phosphorus is relatively insoluble, but may degrade surface water if irrigation causes erosion of soil sediments. Therefore, producers should carefully manage fertilizer and irrigation water to keep water resources clean. Pesticide movement through soil is usually much slower than NO_3. As a result, management practices which minimize NO_3 movement also should reduce nonpoint source pollution from pesticides.

Best Management Practices for the use of irrigation water can help increase efficiency and uniformity, and reduce contamination of water resources. Due to the fact that each farm is unique, producers must evaluate their system to determine which BMPs are suitable for their operation. Irrigation management BMPs include: irrigation scheduling, equipment modification, land leveling, tailwater recovery, proper tillage and residue management, and chemigation safety.

Best Management Practices

Best Management Practices are recommended methods, structures, and practices designed to prevent or reduce water pollution while maintaining economic returns. Many of these methods are already standard practices, known to be both environmentally and economically sustainable.

The goal of BMPs is to protect Colorado water resources from degradation, while maintaining the economic viability of Colorado agriculture and related industries. The BMP approach encourages voluntary adoption of improved practices by all Colorado citizens using pesticides and fertilizers. Success with voluntary BMPs will depend upon how many chemical applicators actually use them.

BMPs can be classified as either source, structural, cultural, or managerial controls.

• **Source controls** are considered the easiest to regulate and implement. They include restriction or removal of a particular pesticide or nutrient source. Such controls are generally accomplished by the EPA for pesticides, or at the state or local level for fertilizers.

• **Structural controls** usually require some capital outlay and maintenance, but are very effective in controlling water and sediment movement. Cost sharing of these types of controls is often available through the USDA.

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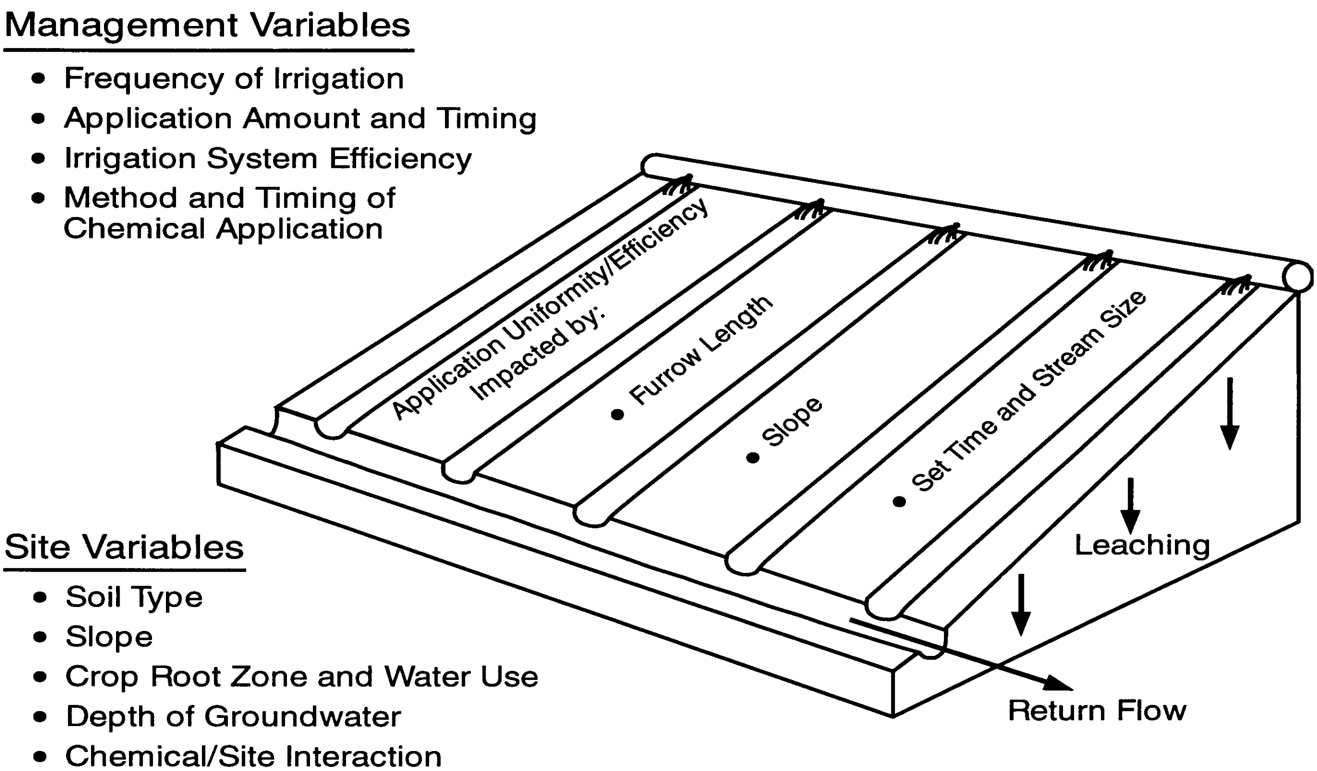


Figure 1. Management variables influencing pollutant losses from irrigated fields.

• **Cultural controls** include cropping and tillage practices which either minimize pest problems and reduce the need for chemical controls or maximize nutrient use efficiency by conservation and crop rotations.

• **Managerial controls** are management strategies and tools that minimize pollutant losses in surface or ground water. These methods are much more site specific than source or structural controls. A higher level of management enables producers to consider both environmental and economic impacts when choosing production methods.

Examples of BMPs by category

Source Controls

• Voluntary restriction of a labeled pesticide by manufacturer
• Mandatory label restrictions by EPA
• Local restriction of nitrogen fertilizer application

Structural Controls

• Sprinkler, drip, and surge irrigation
• Chemigation backsiphon devices
• Irrigation tailwater recovery systems
• Grass waterways and filter strips

Cultural Controls

• Conservation tillage
• Cover cropping
• Crop rotation
• Application techniques, such as split N application

Management Controls

• Irrigation scheduling
• Integrated pest management (IPM)
• Soil and water analysis
• Recordkeeping of pesticide and fertilizer use

What Can City Dwellers Do?

Over application of nitrogen fertilizer and pesticides to lawns has been shown to cause groundwater contamination in some cases. If these chemicals are properly applied to turf at labelled rates, and no heavy rainfall or irrigation occurs shortly after application, research has shown that they cause little environmental hazard.

Homeowners and urban chemical applicators can help protect our environment and minimize groundwater problems by adopting BMPs. Information is available at your local Cooperative Extension office outlining proper lawn and garden management techniques. The local Master Gardeners program also can help you determine how to properly fertilize and control pests.

Best Management Practices for Lawn and Garden Care

- Apply all pesticides at the lowest effective labelled rate.
- Time chemical application for optimum effectiveness. Do not apply pesticide immediately prior to irrigation unless specified by the label.
- Apply only enough irrigation water to satisfy plant needs. Do not leach soils after pesticide or fertilizer application.
- Store all pesticides and fertilizers in a safe, dry place with the labels intact.
- Check with your county Department of Natural Resources prior to disposing of any lawn care chemical.

Pumping groundwater for surface irrigation. *Photo by William Cotton, Colorado State University*

BMPs for Irrigation Management

BMP 1.1 Schedule irrigation according to crop ET, soil water depletion, and water availability; accounting for precipitation and chemigation.

Proper irrigation scheduling, based on timely measurements or estimations of soil moisture content and crop water needs, is one of the most important BMPs for irrigation management. A number of devices, techniques, and computer aides are available to assist producers in determining when water is needed and how much is required (Table 1).

Irrigation scheduling uses a selected water management strategy to prevent the over-application of water while maximizing net return. In a sense, all irrigations are scheduled; whether by sophisticated computer controlled systems, ditch water availability, or just the irrigator's hunch as to when water is needed. Experienced producers know how long it takes them to get water across their field and are proficient in avoiding crop stress during years of average rainfall. The difficulty lies in applying only enough water to fill the effective root zone without unnecessary deep percolation or runoff. Proper accounting for crop water use provides producers with the knowledge of how much water should be applied at any one irrigation event.

Effective scheduling requires knowledge of:

- Soil water holding capacity
- Current available soil moisture content
- Crop water use or ET
- Crop sensitivity to moisture stress at current growth stage
- Irrigation and effective rainfall received
- Availability of water supply
- Length of time it takes to irrigate a particular field

The decision to irrigate should be based upon an estimate of crop and soil water status, coupled with some indicator of economic return. Proper scheduling may allow producers to reduce the traditional number of irrigations, thereby conserving water, labor, and plant nutrients. In some cases, the final irrigation of the season can be avoided through proper scheduling. This is especially advantageous from a water quality standpoint, because it is desirable to go into the off-season with a depleted soil profile. This leaves space for storage of precipitation in the crop root zone without unnecessary leaching or runoff.

Scheduling irrigation applications is often accomplished by using root zone-water balance approaches. These methods use a "check-book" or budgeting approach to account for all inputs and withdrawals of water from the soil. A simple mathematical expression can be written to illustrate this concept:

$$I + P = ET + D_r + R_o + (\theta_E - \theta_B)$$

where:

I	= irrigation water applied
P	= precipitation
ET	= evapotranspiration (soil evaporation + plant use)
D_r	= drainage or percolation of water below the rootzone
R_o	= runoff
θ_E	= the water content expressed as a depth of water at the end of a time interval
θ_B	= the soil water content (depth) at the beginning of the time interval.

The beginning soil water content (θ_B) is generally estimated as field capacity if the rootzone was fully wetted previously. Drainage (D_r) is estimated as the excess water applied above the field capacity depth. Precipitation is easily measured. The main unknown in the balance is ET. This information may be available for crops in a specific area through local water conservancy districts, SCS, or Extension offices.

Producers should choose the scheduling method which best suits their needs and management capabilities. Regardless of the method used, some on-site calibration is required. For more information on irrigation scheduling, see Colorado State University Cooperative Extension Service-In-Action sheets SIA 4.707 and 4.708.

Table 1. Irrigation scheduling methods and tools

Method	Tools or parameters used	Advantages/disadvantages
Soil moisture monitoring (Indicates when and how much to irrigate)		
Hand feel and appearance	Hand probe	Variable accuracy, requires experience
Soil moisture tension	Tensiometers	Good accuracy, easy to read, but narrow range
Electrical resistance tester	Gypsum block	Works over large range, limited accuracy
Indirect moisture content	Neutron probe/TDR	Expensive, many regulations
Gravimetric analysis	Oven and scale	Labor intensive
Crop canopy index (Indicates when to irrigate but not how much to apply)		
Visual appearance	Field observations	Variable accuracy
Water stress index	Infrared thermometer	Expensive
Water budget approach (No field work required, but needs periodic calibration since only estimates water use)		
Checkbook method	Computer/calculator	Indicates when and how much water to apply
Reference ET	Weather station data	Requires appropriate crop coefficient
Atmometer	Weather station data	Requires appropriate crop coefficient

BMP 1.2 ***Contact a qualified professional to help schedule irrigation and improve the management of your irrigation system if you need assistance.***

Many producers find that irrigation services offered by crop consultants are the most cost effective method of scheduling and managing their water. Irrigation scheduling information is also available from your local Cooperative Extension, Soil Conservation Service, or water conservancy district office.

Soil and Crop Properties

Soil characteristics which affect irrigation management include the water intake rate, available water holding capacity, and soil erosivity. Soil texture, organic matter content, soil structure and permeability influence these characteristics and may limit producers' management and system options. For this reason, no one type of irrigation system is universally more efficient than another.

BMP 1.3 ***Determine soil type in each field and monitor soil moisture by the feel method, tensiometers, resistance blocks, or other acceptable methods.***

Producers should know the predominant soil type in each field receiving irrigation water. The available

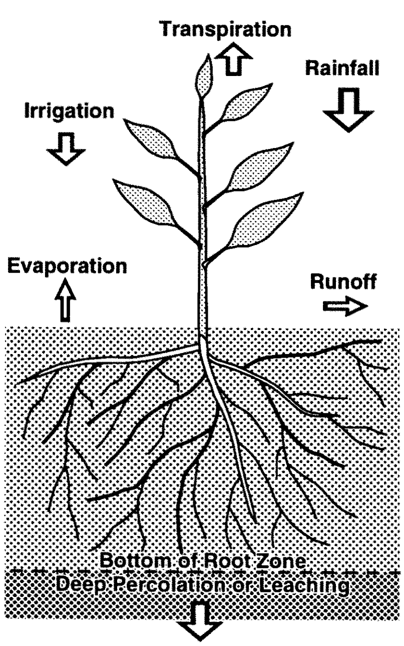


Figure 2. Source and fate of water in the crop system.

water holding capacity should be used with the current depletion status to schedule irrigations (Table 2). This soil information can usually be obtained from your local SCS office or county soils maps.

Table 2. Typical available water holding capacity of soils of different texture

Soil Textural Class	Inches of Available Water/Foot of Soil Depth
Coarse sands	0.60 - 0.80
Fine sands	0.80 - 1.00
Loamy sands	1.10 - 1.20
Sandy loams	1.25 - 1.40
Fine sandy loams	1.50 - 2.00
Loam	2.20 - 2.50
Silty loams	2.00 - 2.50
Silty clay loams	1.80 - 2.00
Silty clay	1.50 - 1.70
Clay	1.30 - 1.50

BMP 1.4 ***Time irrigations to individual crop needs to eliminate unnecessary applications.***

Proper timing of irrigation to crop needs greatly improves overall seasonal efficiency. In some cases, producers have limited flexibility in timing irrigation and must irrigate according to ditch water availability. It is especially important in these cases to apply the correct amount of water.

Crop characteristics influencing irrigation management options include crop water demand and effective root zone depth (Figure 2). Plants remove water from the soil by a process known as transpiration. Consumptive use refers to the amount of water transpired by the plant plus what is evaporated from the soil. It is known as ET and is usually the total amount of water transferable with a water right (Table 3). Local ET figures may be available from weather services, County Extension offices, water conservancy districts, agricultural consultants, or satellite information services (DTN, FarmDayta II). Accounting for crop ET between irrigations allows producers to determine when and how much water must be replaced in the soil profile.

Table 3. Estimated seasonal consumptive water use for selected crops and sites

Crop	Burlington	Delta	Greeley	MonteVista	Rocky Ford
	inches of water				
Alfalfa	35.6	35.3	31.6	23.6	37.7
Pasture Grass	31.1	30.8	26.6	19.8	32.9
Dry Beans	19.2	-	18.4	-	-
Corn	26.0	25.8	21.7	-	27.7
Vegetables	-	21.6	17.7	11.5	22.2
Grain Sorghum	21.5	-	19.5	-	-
Potatoes	-	-	28.1	16.5	-
Sugarbeets	30.0	31.0	29.3	-	32.7
Winter wheat	18.0	-	16.4	-	-
Spring wheat	-	18.1	-	12.7	14.1

Source: SCS Colorado Irrigation Guide, 1988.

Crop root depth is primarily influenced by plant genetics, restrictions within the soil profile, and the maturity stage of the crop (Table 4). Irrigation water that penetrates below crop roots constitutes deep percolation and should be minimized. Shallow rooted and young crops with undeveloped root systems present a difficult challenge under furrow or flood irrigation systems. If shallow rooted crops are part of your production system, rotate with deeper rooted crops and manage agricultural chemicals carefully to decrease transport by deep percolation.

If the soil at a given site is sandy and depth to the water table is less than 10 feet, it is recommended that shallow rooted crops not be grown under conventional furrow irrigation. Deeper rooted crops and higher efficiency irrigation methods will help minimize groundwater impacts under these conditions.

Table 4. Approximate maximum rooting depths for selected crops under furrow irrigation

Crop	Maximum Root Depth at Maturity (ft)
Corn	3-5
Small Grains	3-5
Onions	1-2
Sugarbeet	5-8
Alfalfa	5-15
Dry Beans	2-3

Source: Crops and Soils Magazine, 1984

Determining Leaching Hazard

BMP 1.5 ***Determine the relative leaching potential of your particular soil and site. Producers should employ all appropriate BMPs on fields with severe 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 at each application site in order to select the appropriate BMPs and chemical inputs.

The Soil Conservation Service ranks leaching hazard as severe, moderate, or slight by simultaneously considering soil type, irrigation method, and aquifer vulnerability. Operators with uncontaminated groundwater and slight leaching hazard should continue using good management practices. Operators working under moderate leaching conditions should assess what practices may cause future groundwater contamination and make the necessary changes to prevent groundwater quality impairment. Those operators with sites that have a severe leaching potential should select appropriate BMPs to decrease leaching hazard.

Information on the depth to the water table and water quality can be obtained from several sources. Agencies such as the Soil Conservation Service, Cooperative Extension, and others should be able to provide information to help you evaluate groundwater vulnerability at your site. A routine water analysis for bacteria and NO_3 can also help determine if your well water is a source of concern.

Improved Irrigation Technologies

BMP 1.6 ***Install improved irrigation systems where feasible to increase application efficiency and uniformity.***

Concern about irrigation efficiency is not new in Colorado, where irrigation utilizes about 80% of the 1.8 trillion gallons of water diverted annually in the state. Irrigation efficiency can be calculated as the ratio of water needed for crop production to the volume of water diverted for irrigation. Field level irrigation efficiency for a single application can be defined as:

$$E_a = \frac{\text{Volume of crop evapotranspiration}}{\text{Volume of water applied to field}}$$

Application efficiencies can vary widely depending upon irrigation method, soil, crop, topography, climate, and management.

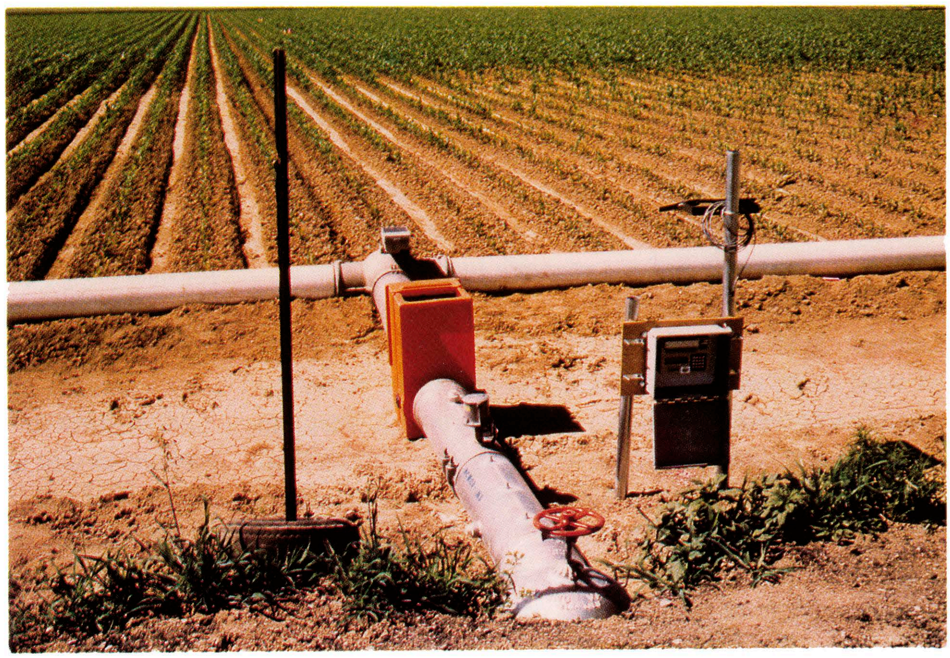
A number of technologies have been developed to apply water more uniformly without excessive waste. Among these are systems such as low pressure center pivot, LEPA (Low-Energy Precision Application), surge, and micro-irrigation. These improvements may require capital, energy, or increased management costs; whereas the conventional surface systems often require relatively minimal maintenance of delivery systems.

Table 5. Approximate efficiency of various irrigation application methods

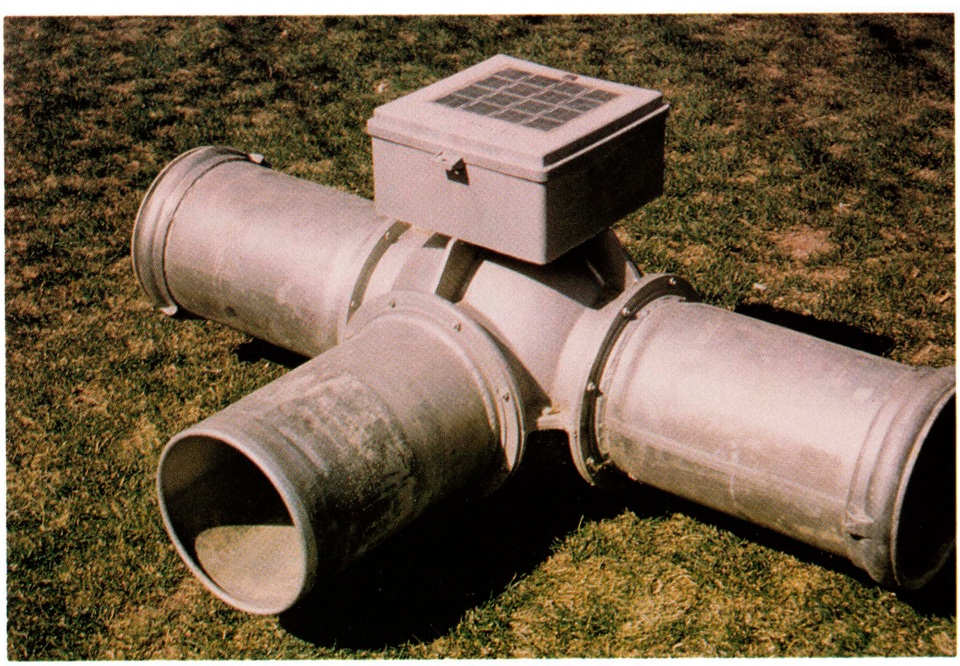
	range	mean
	----------% efficiency----------	
Conventional furrow	25-60	40
Surge	30-80	60
Sprinkler	60-95	75
Drip	80-95	90

Adapted from: CSU Cooperative Extension SIA .514

Changing from a high pressure center pivot to a low pressure system (<35 psi) can reduce pumping costs and increase efficiency if properly designed. LEPA systems operate at even lower pivot pressures and have different modes of operation, including chemigation nozzles. Significant trade-offs exist within these systems, such as runoff potential versus evaporation and drift losses. These considerations and pump requirements must be evaluated before upgrading the system.



Surge irrigation system. ***Photo by Grant Cardon, Colorado State University***



Surge valve. Photo by Grant Cardon, Colorado State University

Micro-irrigation systems such as drip or micro-sprinklers offer the advantage of precise N and irrigation water management if operated correctly. Fertilizers and some pest control chemicals can be injected near the end of the irrigation set with excellent uniformity and little leaching. These systems are being used profitably in orchards, vineyards, and high value row crops. The high initial cost of installation and potential for clogging with poor quality water present obstacles for some producers. However, the high uniformity, efficiency, and low labor requirements offer significant advantages to irrigators short on water.

BMP 1.7 Minimize deep percolation on surface irrigated fields by installing surge flow systems where feasible.

Surge flow irrigation uses a valve to send a series of water pulses down alternating sets of furrows. This technique requires less total water, reducing runoff while increasing uniformity. When properly used, surge can save labor and increase efficiency. Irrigators currently using conventional furrow irrigation on coarse textured soils, fine soils with cracking problems, or on slopes in excess of 1% should consider installing surge valves as a best management practice. For more information on surge irrigation, see the CSU Cooperative Extension Bulletin 543A, "Surge Irrigation Guide".

BMP 1.8 Line irrigation water delivery ditches and install pipelines to convey irrigation water to reduce seepage losses.

Delivery systems such as lined ditches and gated pipe, as well as reuse systems such as tailwater recovery ponds can greatly enhance overall efficiency. Seepage from unlined ditches often results in losses of more than 25% of diverted water. When ditch water contains added N fertilizer or municipal effluent, NO_3 leaching from the ditch can be a significant problem. Lining ditches with concrete, plastic, or other materials may increase total efficiency and decrease contaminant loading. Similarly, the installation of pipeline to convey irrigation water can decrease evaporation losses and seepage. However, reduced aquifer recharge and impairment of irrigation created wetlands may result from reducing seepage. If ditches cannot be lined for practical reasons, metering N fertilizer into irrigation ditches should be avoided.

BMP 1.9 Divert and capture irrigation runoff into reuse systems where feasible.

Tailwater recovery systems can increase efficiency and reduce nutrient losses from furrow irrigated fields with appreciable slopes. Reusing tailwater may require a properly engineered system that involves some costs, maintenance, and land requirements. Where tailwater reuse is feasible and permissible, it provides an excellent means of saving water, energy, and nutrients. Be sure to consult your water conservancy district prior to implementing BMPs 1.8 or 1.9.

Managing Surface Irrigated Fields

Most surface irrigation systems have inherent inefficiencies due to deep percolation on the upper end and runoff at the lower end of the field. Equipment innovations can reduce these inefficiencies, but management decisions are most important. Efficient systems result when design and management enable producers to uniformly apply enough water to fill the effective

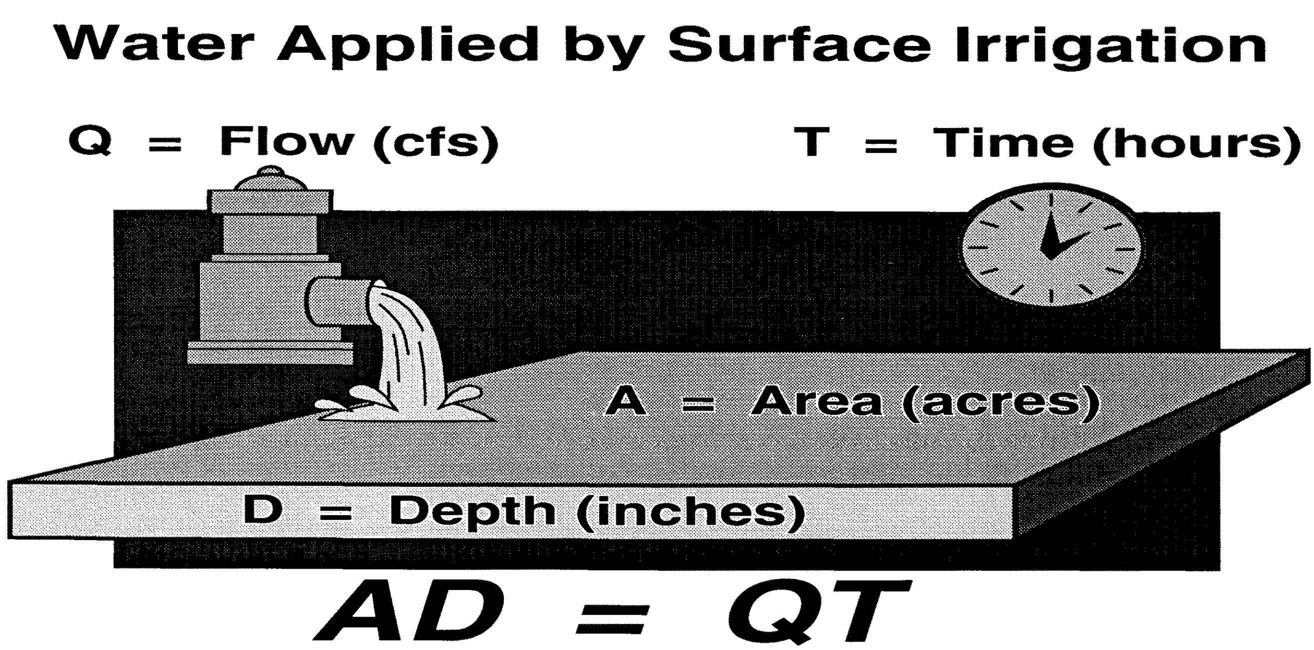


Figure 3. Method for estimating amount of water applied by surface irrigation.

Concrete lined ditches reduce seepage losses.

crop root zone with minimal runoff. The correct amount of water to apply at each irrigation varies due to changes in root depth, soil moisture status, and the soil intake rate. The irrigation set size, stream size, set time, and length of run can all be managed by irrigators to improve efficiency (Figure 1). A well designed and properly managed surface system can attain efficiencies of 60% or better.

Irrigators should not be content merely to get the water to the end of the furrows, but should also consider how much water is applied and how it is distributed. Producers should think about surface irrigation in terms of depth of water applied to the field. A simple relationship to estimate the amount of water applied by surface irrigation systems can be written as:

AD = QT

where:

A = Area (acres)
D = Depth (inches)
Q = Flow (cfs)
T = Time (hours)(Figure 3).

For example, 1 cubic foot per second (cfs) applied for 2 hours will result in 2 inches of water applied to 1 acre. (Figure 3).

BMP 1.10 Install sprinkler systems on surface irrigated fields with severe leaching potential where feasible.

In some cases, the most effective method of conserving water and managing inputs on sandy soils is to install sprinkler systems. The cost of this BMP may restrict its feasibility on many fields. Consult with an irrigation engineer to determine the benefit of upgrading to sprinkler irrigation on highly leachable soils.

BMP 1.11 Monitor the amount and uniformity of irrigation water applied.

Irrigators need a method to measure or accurately estimate the amount of water applied to the field to determine efficiency. Weirs or flumes can be used to measure water flow in open ditches. Flow meters can be installed in gated pipe systems, or irrigators can simply use a bucket and stop watch to estimate application via siphon tubes*. Once application rate is known, producers can determine how much water is actually applied to the field.

Improving water distribution uniformity is critical to optimize irrigation management. This cannot be done simply. Determining uniformity requires the producer's knowledge of the field, crop, and irrigation system. Producers should probe fields within 72 hours after irrigation to determine depth of application down the field. Checking for visual signs of plant stress can also indicate areas of poor water penetration. Most commonly the upper end of the field is overwatered and the lower end underwatered (Figure 4). Several management techniques can be used to increase uniformity of application, including: changing row length or stream size, land leveling, and installing borders or blocked end furrows. Unequal water infiltration due to compaction caused by equipment traffic may be reduced by in-row ripping at cultivation or sidedressing. Excessive water intake on coarse soils early in the crop season can be reduced by driving all rows prior to the first irrigation. In some cases, the best method of improving uniformity is to install an improved irrigation system. Consult your water conservancy district or local SCS office for more information on increasing irrigation uniformity.

* 1 cubic foot/second (cfs) ≅ 450 gallons/minute ≅ 1 acre inch/hr

Siphon tube irrigation. Photo by William Cotton, Colorado State University

BMP 1.12 Maintain sufficient surface residue to reduce overland water flow and increase water intake rate.

Surface residues from crop stubble can either increase or decrease irrigation uniformity depending upon irrigation system type and characteristics. Where practical, follow soil conservation practices such as minimum tillage to reduce erosion of soil sediments containing nutrients or pesticides. Sloping lands with low intake rate will benefit from increased surface residue. However, furrow irrigated fields with slow advance times may be difficult to manage under no-till or reduced tillage options. Compliance with USDA mandated conservation programs may require producers to shorten row lengths and increase stream size to achieve efficient irrigation under high residue farming systems.

BMP 1.13 Adjust irrigation run distance to maximize irrigation efficiency.

Irrigation runs which are too long result in overwatering at the top of the furrow by the time the lower end is adequately watered (Figure 4). Furrow length should be based on actual water infiltration rates. The rate water penetrates into the soil is a function of soil texture, structure, compaction, and furrow spacing. Infiltration rate will vary between irrigations and even dur ing a single irrigation. However, after the water has been on the field for 1 to 2 hours, intake rate tends to remain constant and can be used to evaluate irrigation run distance.

As a guideline, irrigation runs on leveled fields usually should not exceed 660 feet on coarse textured soils or 1300 feet on fine soils. Sloping fields and compacted soils with lower intake rates may allow longer runs. Better application uniformity, as well as reduced runoff and deep percolation result from optimizing irrigation run lengths. For more information on optimizing your irrigation system, consult the USDA SCS "Colorado Irrigation Guide" or your local SCS office.

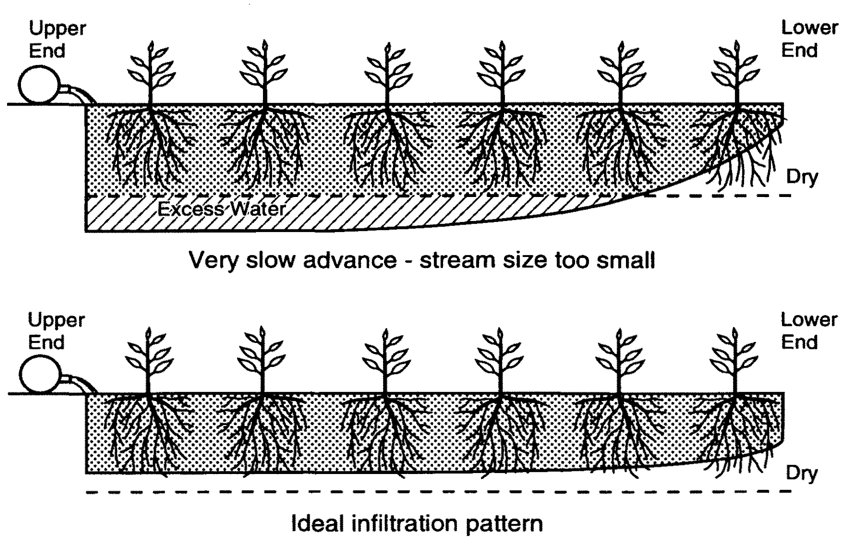


Figure 4. Infiltration patterns with furrow irrigation. Source: Eisenhauer et al., 1991

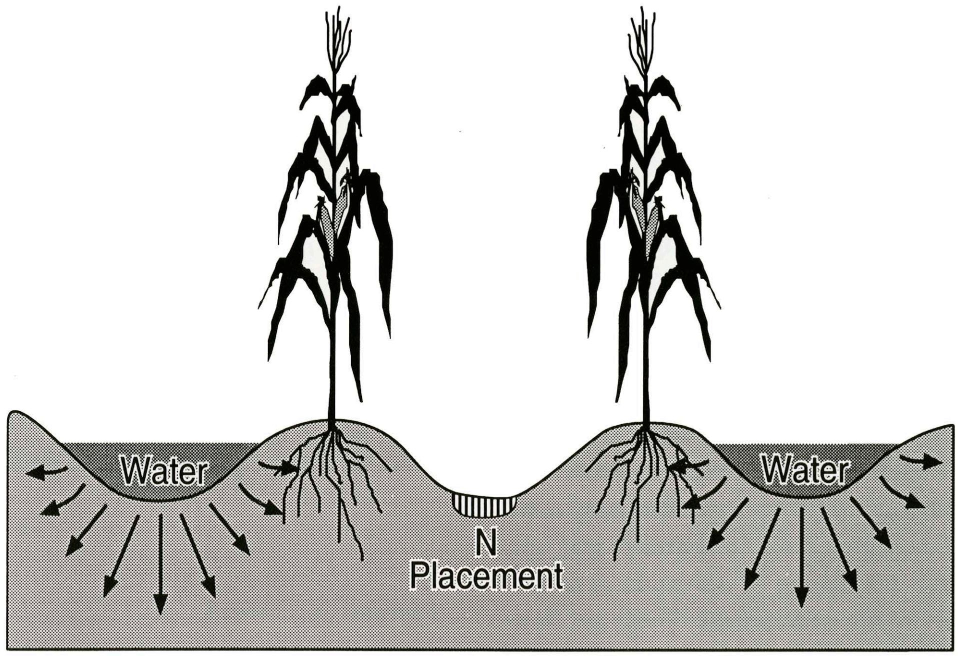


Figure 5. Typical irrigation water movement under alternate furrow N and water application.

BMP 1.14 Minimize irrigation runoff through the use of land leveling, blocked end furrows, and border systems.

Land leveling can improve irrigation uniformity whenever non-uniform slopes contribute to excess runoff or deep percolation. Factors such as soil depth, subsoil characteristics, topography, and the economics of land leveling must be considered prior to any leveling, but especially when deep cuts are necessary.

Gated pipe with socks. Photo by William Cotton, Colorado State University

Border systems, blocked end furrows, and level basins permit water to be applied rapidly and evenly over the set. These systems are best suited to crops that are not damaged by flooding for short periods of time and on soils where infiltration rates are neither extremely low nor high. Level basins can be used effectively on soils with low infiltration rates. Be sure to time chemical applications on blocked end furrow systems to reduce the possibility of leaching.

BMP 1.15 Alternate irrigated furrows and N fertilizer placement on soils with severe leaching potential to reduce nitrate leaching to groundwater.

Coupling alternate row irrigation with N fertilizer placement in the dry furrow may significantly reduce downward movement of NO_3 (Figure 5). Irrigating every other furrow supplies water to one side of each row, resulting in a larger area being covered during each irrigation set. This can be especially useful during the first irrigation, when it may take considerably longer for water to get through the field. Longer set times often required for this BMP may result in increased deep percolation. During dry years, irrigators may need to switch furrows at each irrigation to improve nutrient availability. Another advantage of alternate row irrigation is that the soil profile of a recently irrigated field can store more rainfall within the root zone of the unirrigated rows, resulting in less leaching due to unexpected rainfall. Research has shown that crop yields compare favorably to fields with every row irrigation. Alternate row irrigation generally does not work well on steep slopes or on soils with poor intake rates. For more information on alternate row irrigation, refer to the University of Nebraska NebGuide 91-1021, "Managing Furrow Irrigation Systems".

BMP 1.16 Adjust irrigation application rate and set time for soil conditions to achieve greater uniformity.

Irrigation application rate and set time must be adjusted according to the soil intake rate and slope. Soils vary significantly in water infiltration rate; ranging from 2.0 to 0.2 inches per hour. Surface irrigators should experiment with different combinations of stream size and set times to achieve the greatest uniformity of water infiltration coupled with the least runoff. When selecting the optimum stream size, begin with the maximum stream size that does not cause serious erosion. In general, the maximum non-erosive stream size will decrease as slope increases (Table 6). Often, the optimum combination of stream size to set time is the one which advances water to the end of the furrow about half way through the total set time. However, this may vary with soil conditions. Producers can reduce total runoff and optimize uniformity by using cutback techniques.

Table 6. Maximum furrow stream size for various slopes*

Slope (%)	Stream size (gpm)
0.20	50.0
0.40	30.0
0.75	17.0
1.25	10.0

Source: SCS "Colorado Irrigation Guide"
*Note: Optimum stream size will vary with soil type and conditions.

Limited Irrigation

Limited irrigation may be practiced by water-short producers to stretch their water resources and maximize returns. The water quality benefits of limited irrigation systems result from the reduced leaching and runoff that this approach dictates. Producers limit their use of water in this method to only a few well-timed and well-managed applications. Selection of crops capable of withstanding some drought stress is critical to tolerating drier than average years under limited irrigation. Long term use of limited irrigation may also require salinity management.

Salinity Management

BMP 1.17 Time leaching of soluble salts to coicide with periods of low residual soil nitrate.

Leaching excess salts which are carried by irrigation water is necessary in some Colorado soils to avoid salt accumulation in the root zone. Typically, additional water (known as the leaching requirement) in the amount of about 5-15% of total consumptive use must be applied annually to leach soluble salts from the crop root zone. The leaching requirement can be calculated fairly precisely as a function of soil and water salinity. However, most irrigation systems in Colorado do not achieve efficiencies which warrant the addition of a leaching fraction.

Where leaching for excess salts is necessary because of poor quality water, it is essential that the leaching be done when soil NO_3 levels are low and crop N needs have been satisfied. Soils should never be intentionally leached within 72 hours after the application of any pesticide.

Managing Sprinkler Systems

BMP 1.18 Minimize leaching and surface runoff on sprinkler irrigated fields by decreasing application depth, increasing surface residue, utilizing basin tillage, or changing nozzle and pressure configuration, height or droplet size as appropriate.

Sprinkler system operators should match application depth with infiltration properties of the soil. Proper pivot design is essential to achieve high efficiencies with minimal runoff or deep percolation. Irrigators should adjust application depth (speed of travel) to soil moisture depletion status to achieve the proper depth of application. Soil moisture monitoring and irrigation scheduling are essential BMPs for managing water application on sprinkler irrigated fields.

Basin tillage with a dammer-diker or similar implement can be used to increase intake and reduce runoff on sloping fields with low infiltration rates under sprinkler irrigation. Basin size and distance between basins should be adjusted according to slope and soil intake rate.

BMP 1.19 Test sprinkler systems periodically for depth of application, pressure, and uniformity.

Operators should test each sprinkler regularly to ensure the system maintains proper function and maximum efficiency. If necessary, contract a professional consultant or irrigation specialist for help in optimizing your system.

Chemigation Safety

BMP 1.20 Reduce water application rate to ensure no runoff or deep percolation occurs during chemigation.

Chemigation, the process of applying fertilizers and pesticides through irrigation water, can be economical and effective if conducted properly. However, the major disadvantage of this method is the potential hazard to groundwater resulting from backflow of pesticides into wells or pesticide spills in close proximity to the well bore. Additionally, chemicals injected into irrigation water can move off the intended target by wind drift, runoff, or deep percolation.

Avoid chemigation when additional water is not needed by the crop, if possible. Be sure to adjust irrigation schedule to account for water applied during chemigation.

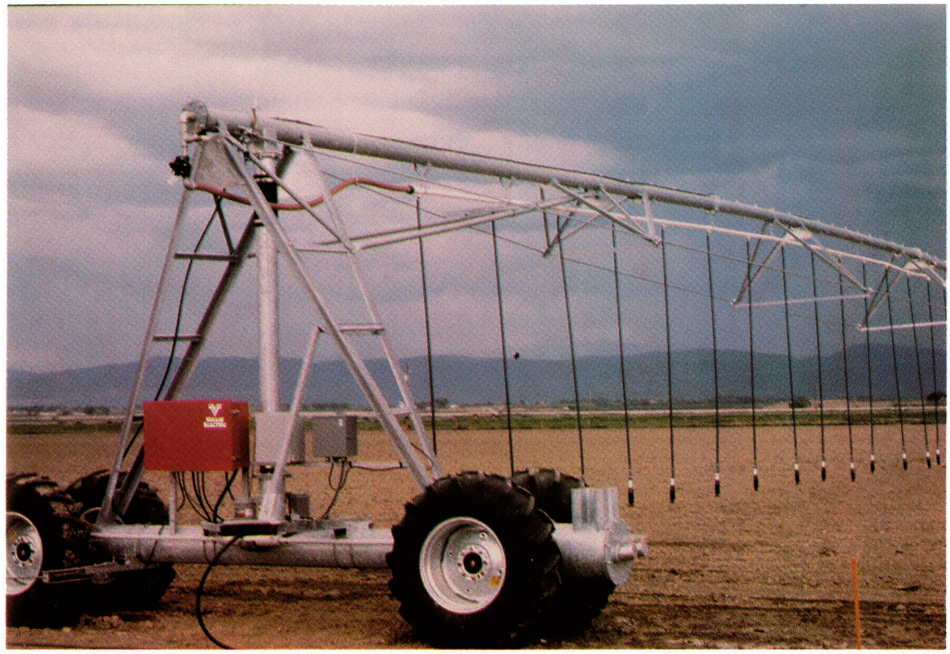
BMP 1.21 Meter N fertilizer applied in irrigation water with an appropriate device which is properly calibrated.

On sandy textured soils, splitting N fertilizer application by fertigation through sprinkler systems has been shown to increase crop yields and reduce NO_3 leaching hazard when irrigation water is applied at appropriate rates. On fine textured soils, crop yields have not been shown to improve significantly by this method, but split application of N is still a best management practice for environmental reasons.

Fertilizer application through surge flow irrigation systems can be used effectively in conjunction with tail water recovery. Liquid forms of fertilizer can be added through the system during late cutback cycles. Knowledge of the correct amount of fertilizer needed per acre, water application rate, and the acreage under the surge valve are critical to proper calibration of the fertilizer injector and length of cycle. A high level of management is needed to ensure proper cutback cycle settings to avoid runoff and loss of N to surface waters.

Conventional furrow irrigation systems are much more difficult to manage to ensure uniformity of application without runoff or leaching. For this reason, application of fertilizer via conventional surface irrigation is discouraged, especially in areas with coarse soils and shallow groundwater. Tailwater recovery and reuse should be employed on any chemigated field which produces significant amounts of runoff.

BMP 1.22 ***Read the chemical label prior to chemigation. Follow all label instructions and take careful note of the specific chemigation instructions on the label. Chemigation must be done in accordance with the rules of the Colorado Chemigation Act.***



Linear move sprinkler system. Photo by Grant Cardon, Colorado State University

Pesticide application through irrigation water is restricted by the EPA under current labeling regulations. The EPA requires each chemical label to either specifically prohibit chemigation or to detail instructions for chemigation on the label. Chemigators should read all label precautions; paying close attention to the chemigation instructions.

Low pressure drop nozzels reduce drift loss and increase application precision. Photo by Grant Cardon, Colorado State University

In Colorado, all chemigators operating closed irrigation systems must have a permit from the Colorado Department of Agriculture and install backflow prevention valves, inspection ports, and check valves as appropriate. Producers chemigating through open systems where backflow is not possible are not required to obtain permits to comply with the Colorado Chemigation Act, but still should observe the appropriate precautions.

BMP 1.23 ***Upgrade well condition to reduce the possibility of point source contamination at the wellhead.***

Agricultural chemical handling and storage at the chemigation site are a potential source of groundwater contamination. Producers who store chemicals near the wellhead should install secondary containment to capture leaks or spills. Poorly designed or maintained wells can act as direct conduits for chemicals into the groundwater. Therefore, it is extremely important to handle chemicals carefully around the wellhead and at the chemigation site. Be sure to clean up any spills or leaks immediately to avoid well contamination.

BMP 1.24 ***Monitor and inspect chemigation equipment and safety devices regularly to determine proper function. Replace all worn or non-functional components immediately.***

All chemigation safety equipment should be inspected regularly and maintained in good operating condition. During chemigation, monitor equipment and chemical level frequently. Never leave chemigation equipment unattended for any prolonged duration. Wells where chemicals are handled nearby should be routinely inspected for evidence of damage. Annual water quality monitoring at operational chemigation wells can provide valuable information on the vulnerability of a well and a historic database to document water quality trends. Visual or audio well inspections by a pump or well maintenance company can usually help identify any needed improvements at the wellhead. For more information on chemigation management, see CSU Cooperative Extension SIA 4.713 and 0.512.

Pesticide and Fertilizer Handling and Storage

BMP 1.25 ***Mix and store pesticide and fertilizers at least 100 feet away from wellheads or surface water bodies, except at chemigation sites. Permanent storage and mixing sites should be protected from hazards due to spills, leaks, or stormwater.***

Storage and handling of pesticides and fertilizers in their concentrated forms poses a high potential risk to surface or ground water. For this reason, it is essential that facilities for the storage and handling of these products be properly sited and constructed. Colorado law now requires operations handling large volumes of agricultural chemicals to comply with containment regulations.

Chemicals should not be stored in underground containers or pits. Storage facilities should be locked or otherwise secured when the container is not is use. Application equipment should be inspected and calibrated frequently. When cleaning equipment after application, excess chemical and all wash water should be recovered for reuse. Rinse water should be used in the subsequent batch when possible, or be applied at proper rates on cropland, avoiding high runoff areas.

Chemical/Site Interaction

Agricultural chemicals vary significantly in their persistence, water solubility, and soil adsorption. A number of biological, chemical, and physical processes determine pesticide fate and persistence at a given site. Highly mobile chemicals may move rapidly to groundwater, even under situations where the leaching potential is not considered significant. A pesticide such as glyphosate is normally highly immobile, even when leaching hazard is severe (Table 7).

Persistence, measured as the half-life, is an indicator of the period of time during which the pesticide is exposed to the forces of leaching. Persistence ranges, from a few days to years, depending upon chemical properties and degradation pathways. Adsorption and solubility of a chemical determine the rate of movement through the soil profile. Applicators need to be aware of these chemical properties to select pest management appropriate for a given site.

Avoid the use of mobile pesticides on fields with severe leaching potential. If possible, apply these chemicals after, rather than prior to irrigation. In situations where surface loss or leaching is highly probable, select non-chemical pest control alternatives such as tillage, rotation, or biological pest control.

Table 7. Characteristics and predicted mobility of selected pesticides

Pesticide	1/2 Life (days)	Sorption Coefficient (K_{oc})	Predicted Mobility
Dicamba	14	2	very mobile
2,4-D	21	20	moderately mobile
Atrazine	60	163	slightly mobile
Alachlor	10	190	slightly mobile
Metolachor	20	201	nearly immobile
Malathion	1	1800	nearly immobile
Glyphosate	30	10000	immobile
Paraquat	3600	100000	immobile

*Higher sorption coefficient indicates a chemical is more likely to be held by the soil.

Nitrogen Fertilizer Management

Nitrogen (N) is the essential plant element which 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 surface or ground water. Both urban and rural fertilizer applicators can minimize this problem by implementing BMPs for fertilizer use.

Nitrate 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.

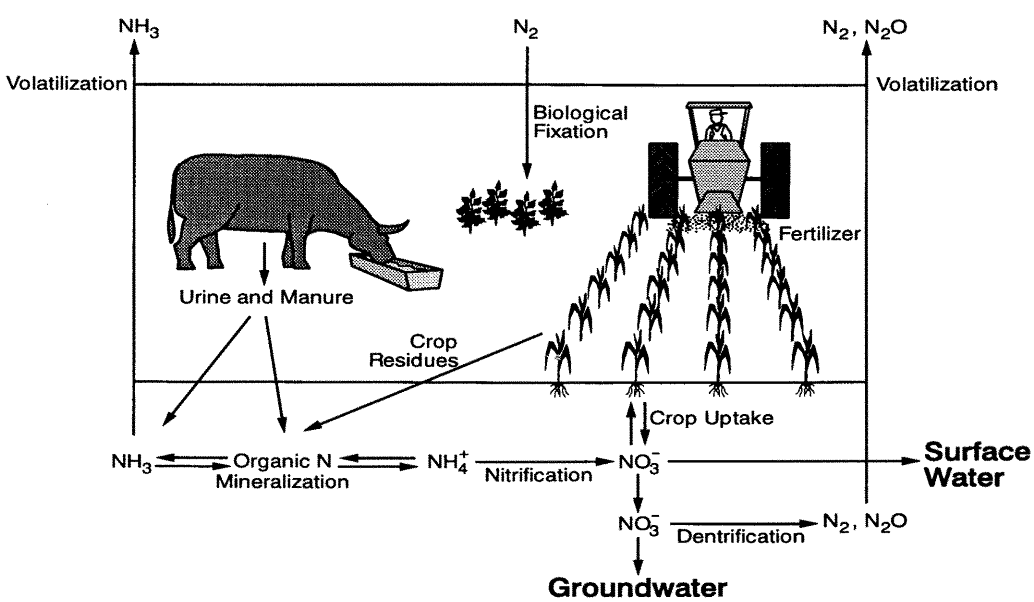


Figure 6. The Nitrogen Cycle

The Nitrogen Cycle

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_2O, 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 (see Figure 6). 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.

Nitrogen Fertilizer Management Practices to Protect Water Quality

BMP 2.1 Base N fertilizer rates on results from soil analysis, as well as irrigation water and plant analysis when appropriate, using environmentally and economically sound guidelines.

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.
- Applying N when and where it can be used most efficiently by the crop.

This will assure that the residual soil NO_3 available for leaching is minimized. The following management practices also will help producers and fertilizer applicators maximize economic returns from fertilizer dollars while protecting water quality. For more information on crop N requirements, refer to CSU Cooperative Extension bulletin XCM-34, "Guide to Fertilizer Recommendations in Colorado".

BMP 2.2 Develop a nutrient management plan for each field and crop.

The plan should include:

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 from previous legume crops expected to become available during the crop growth period.
e. The amount of supplemental N necessary 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 including: timing of application, multiple applications, sidedressing, banding, foliar feeding, fertigation, stable forms of N, nitrification inhibitors or needed changes in crops or crop sequence. These records should be maintained for several years to help producers refine their management. (See "N Management Record Sheet" in Appendix for suggested format)

Soil Testing

BMP 2.3 Sample soil from each field for analysis of plant available nutrients. As a guideline, sample depth should be at least 2 to 3 feet, preferably to the depth of the effective root zone.

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 15-20 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. Keep the surface soil sample separate from subsoil so that it can be analyzed for P, K, and micronutrients. Sampling to a minimum depth of 2 to 3 feet is recommended for all soil types. For more detailed information on soil sampling, see CSU Cooperative Extension SIA .500, "Soil Sampling".

Realistic Yield Goals

BMP 2.4 ***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.***

Setting realistic yield goals is a very important BMP. Fertilizer N recommendations should be 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/acre corn crop when other conditions such as limited irrigation water will only allow a 150 bu/acre yield, can result in 60-70 lbs/acre 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 their five year yield average and use this value as their yield expectation. If the crop season and growing conditions appear to be above average, producers can adjust N rates upwards at sidedressing or by applying N through irrigation water. In-season soil or plant tissue analysis may be utilized to determine whether 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.

Nitrogen Credits From Sources Other Than Commercial Fertilizer

BMP 2.5 ***Credit all sources of plant available N to crop fertilizer requirements.***

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 8 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 may release as much as 100 lbs 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 lbs N/acre should be credited in the first year after any legume crop.

Sewage sludge is another valuable source of plant nutrients that must be properly used to avoid environmental problems. Each ton of dry sludge contains approximately 50-100 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 surface or ground 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 utilize 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.

Table 8. Nitrogen Credits for Crop Requirements

N Source	N Credit
Soil organic matter	30 lbs N/% OM
Residual soil nitrate	3.6 lbs N/ppm NO_3-N
Manure	10.0 lbs N/ton manure
Irrigation water	2.7 lbs N/AF x ppm NO_3-N
Previous alfalfa/sweet clover	50 - 100 lbs N/acre
Other previous legume crop	30 lbs N/acre

BMP 2.6 Analyze irrigation water quality periodically, and credit NO_3-N in water to crop requirements.

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 periodically during the irrigation season to accurately calculate this credit. Multiply ppm NO_3-N by 2.7 lbs/acre ft. times the amount of water applied to the crop (in AF) to determine lbs N/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 refrigerated, but not frozen, until it gets to the lab.

Example Calculation: Irrigation water N credit

20 inches of effective irrigation containing 7 ppm NO_3-N = ? lb N/A

$$\frac{\text{20 inches applied/A}}{\text{12 inches/AF}} \times (2.7 \text{ lbs N/AF}) \times (7 \text{ ppm } NO_3\text{-N}) = 31.5 \text{ lb N/A}$$

Table 9. N credit from irrigation water

NO_3-N conc. in water (ppm or mg/L)	Effective Irrigation					
	------------ Acre inches ------------					
	6	12	18	24	30	36
	------------ lb N/A ------------					
2	3	5	8	11	14	16
4	5	11	16	22	27	33
6	8	16	24	32	41	49
8	11	22	32	43	54	65
10	13	27	40	54	67	81
12	15	32	48	65	81	97
14	18	37	56	76	95	113
16	21	42	64	87	109	129
18	24	47	72	98	123	145

Fertilizer Placement and Timing

BMP 2.7 Apply N fertilizers where they can be most efficiently taken up by the crop.

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.

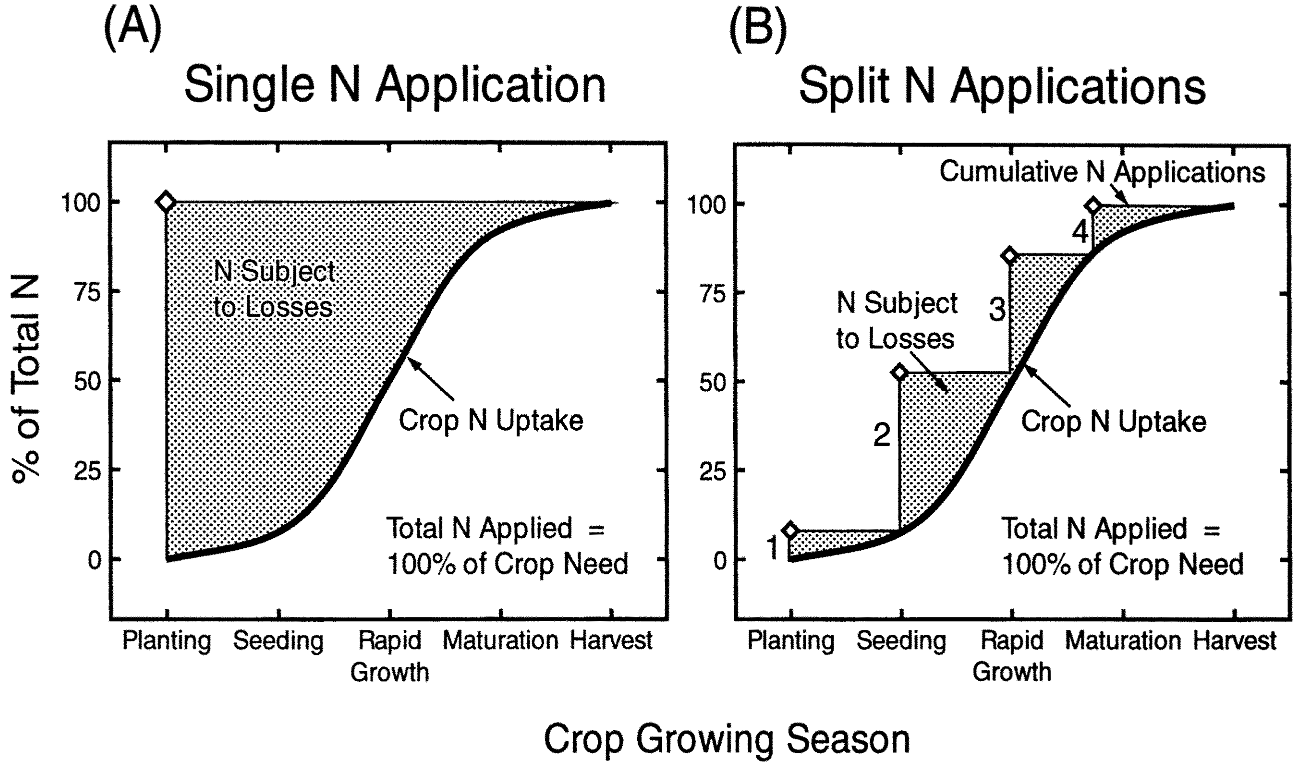


Figure 7. General estimations of potential soil nitrogen losses occurring when nitrogen fertilizer is applied in a single (A) or in split applications (B). Source: Nitrogen Fertilizer Management in Arizona

BMP 2.8 Time application of N fertilizer to coincide as closely as possible to the period of maximum crop uptake.

Fertilizer applications should be timed to coincide as closely as possible to the period of maximum crop uptake. Partial application of N in the spring, followed by sidedress application improves crop N uptake efficiency and reduces N available for leaching (Figure 7). Waiting until the crop is well established before applying large amounts of N reduces the chance of early season losses and allows producers to more accurately determine the crop yield potential. Poor stands 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.

BMP 2.9 Avoid fall application of nitrogen fertilizer for spring planted crops.

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 moderate to severe leaching potential. 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.

Nitrogen Fertilizer Forms and Nitrification Inhibitors

BMP 2.10 Use nitrification inhibitors in combination with ammoniacal fertilizers, where feasible.

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 severe. 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 such as IBDU or the coated ureas are commercially available and should be utilized 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

BMP 2.11 ***Use plant tissue analysis where appropriate to guide in-season nitrogen fertilizer application.***

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.

Other N Management Tools

Although proper N rates and good irrigation management are the most critical components of N management, there are other tools which 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 due to 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 can utilize residual N in the soil profile. Finally, computer assisted decision aides such as the Nitrate Leaching and Economic Analysis Package (NLEAP) model can help producers make wise choices and avoid unnecessary water quality degradation.

Best Management Practices for Manure Utilization

Livestock manure is rich in plant available nutrients which can be valuable assets to crop producers. However, it also can be a source of both ground and surface water contamination if improperly handled.

Possible Sources of Water Contamination

Improper storage and land application of manure presents multiple opportunities for water contamination. The primary constituents of manure or products released during manure decomposition that may cause water quality problems include pathogenic organisms, nitrate, ammonia, phosphorous, salts, and organic solids. Nitrate is the most common groundwater pollutant from fields which receive manure.

Contamination of surface water may occur if there is excessive runoff or erosion from sloping fields. Groundwater contamination occurs when nitrate from the manure leaches through the soil profile to the water table. To determine the pollution potential at your site, the following questions need to be considered:

- Is the soil texture coarse (sandy with low amounts of clay) and the depth to groundwater less than 50 feet?
- Does the field have greater than a 1% slope and little surface residue?
- Does excess water from irrigation or precipitation runoff or leach?
- Is manure applied at rates greater than crop nutrient requirements?
- Are there surface waters or wells immediately downhill from the field?
- Have recent well water analyses indicated that local groundwater has elevated NO_3-N levels (> 10 ppm)?
- Does the field have a long history of manure application?

If the answer to any one of these questions is yes, manure application at your site may have potential water quality impacts. Manure rates may need to be adjusted downward and all appropriate BMPs employed. Additionally, it may be helpful to periodically test wells near livestock operations and manured fields for NO_3 and bacterial contamination to determine whether management practices are sufficiently protecting water quality.

Managing Land Application of Manure

Manure should be applied to land at rates that match annual expected crop nutrient uptake to ensure that excess loading does not lead to contamination. Manure applied in excess of crop needs will not increase crop yields, but will increase soil N and P to levels that can lead to nutrient leaching or runoff. Furthermore, excessive manure rates can lead to potentially high levels of plant damaging soluble salts.

Proper manure application rates depend upon actual manure analysis, soil texture, soil fertility, crop, yield goal, field slope and drainage, irrigation method, and groundwater vulnerability. The application rate should be based upon a nutrient management plan which accounts for crop N needs and plant-available N in the manure. If commercial N fertilizer is used in addition to manure, the total available N should not exceed the N requirements of the crop.

Soil and Manure Testing

BMP 3.1 Analyze manure for nutrient content to determine application rate.

Proper soil and manure testing are the foundation of a sound nutrient management program. There are a number of qualified labs in Colorado that can provide these services. Without a manure analysis, you may be buying unnecessary commercial fertilizer or applying too much manure to your fields. Neither practice is economically or environmentally sound. Manure can also be a source of salts and weed seeds, and these components should also be assessed prior to application.

Obtaining a representative sample is the key to good soil or manure analysis. Techniques for proper soil sampling are available from your local Cooperative Extension office. For proper manure sampling, you need a clean bucket and sample jar. If you are spreading manure daily, take many small samples over a representative period. For periodic spreading from a manure pack or pile, collect samples from a variety of locations in the pack or pile using a clean shovel or fork. Be sure that you collect both manure and bedding if they will be applied together. Agitate liquid manure handling systems before sampling and collect several separate samples. Combine the individual spot samples from a particular lot or lagoon in the bucket and mix thoroughly before filling the sample jar. Keep the sample refrigerated and deliver it to the laboratory within 24 hours. Collect the samples well in advance of your spreading date so that you will have time to obtain test results and calculate the correct application rate. An accurate manure test is an excellent investment of time and money, as it may help you realize significant savings on fertilizer bills while simultaneously avoiding water contamination problems.

Table 10. Approximate nutrient composition of various types of animal manure at time applied t the land (wet weight basis)

Type of manure		Dry matter	Total[a] N	NH_4	P_2O_5	K_2O
Solid handling Systems		-%-	- - - - - - - - -	**lb/ton**	- - - - - - - - -	
Swine	Without bedding	18	10	6	9	8
	With bedding	18	8	5	7	7
Beef	Without bedding	52	21	7	14	23
	With bedding	50	21	8	18	26
Dairy cattle	Without bedding	18	9	4	4	10
	With bedding	21	9	5	4	10
Sheep	Without bedding	28	18	5	11	26
	With bedding	28	14	5	9	25
Poultry	Without litter	45	33	26	48	34
	With litter	75	56	36	45	34
	Deep pit (compost)	76	68	44	64	45
Turkeys	Without litter	22	27	17	20	17
	With litter	29	20	13	16	13
Horses	With bedding	46	14	4	4	14
Liquid handling Systems[b]			- - - - -	**lb/1000 gal**	- - - - - -	
Swine	Liquid pit	4	36	26	27	22
	Lagoon[c]	1	4	3	2	7
Beef cattle	Liquid pit	11	40	24	27	23
	Lagoon[c]	1	4	2	9	5
Dairy cattle	Liquid pit	8	24	12	18	29
	Lagoon[c]	1	4	2.5	4	10
Poultry	Liquid pit	13	80	64	36	96

[a]Ammonium N plus organic N, which is slow releasing.
[b]Application conversion factors: 1,000 gal = about 4 tons; 27,154 gal = 1 acre inch.
[c]includes feedlot runoff water
Source: Colorado State University Cooperative Extension Bulletin 552A, "Utilization of Animal Manure as Fertilizer", 1992.

Organic N Mineralization

BMP 3.2 Base long term, repeated manure applications upon soil test data and manure N mineralization rates.

The total amount of N in manure is not plant available in the first year after application due to the slow release of N tied up in organic forms. Organic N becomes available to plants when soil microorganisms decompose organic compounds such as proteins, and the N released is converted to NH_4. This process, known as mineralization, occurs over a period of several years after manure application. The amount mineralized in the first year depends upon manure source, soil temperature, moisture, and handling. In general, about 30% - 50% of the organic N becomes available in the first year (Table 11). Thereafter, the amount of N mineralized from the manure gradually decreases. In the absence of better estimates, producers should assume that 50% of the total N in applied manure is available the first year, 25% in the second year, and 12.5% in the third year. Producers should give three years of N credit from any application of manure, in addition to the NO_3 credit identified by soil testing (see Appendix Table 2).

Table 11. Approximate fraction of organic N mineralized in the first year after application

Manure source	Fraction of organic N mineralized in first year
Beef & Dairy cattle	
solid (without bedding)	.35
liquid (anaerobic)	.30
Swine	
solid	.50
liquid (anaerobic)	.35
Sheep	
solid	.25
Horse	
solid (with bedding)	.20
Poultry	
solid (without litter)	.35

Source: CSU Cooperative Extension Bulletin 552A, "Utilization of Animal Manure as Fertilizer".

All of the NO_3 and NH_4 contained in the manure is available to plants. However, some available N may be lost to volatilization, denitrification, leaching, or immobilization by soil microorganisms. Deep soil NO_3 testing should be used in subsequent years to keep application rates in line with crop needs. Fresh manure will usually mineralize at a faster rate than old or dry manure because it has not lost as much NH_3 to volatilization, and is therefore a better media for soil microbes.

Manures with high moisture and low N content require high tonnages to meet crop N requirements. This may result in application of excessive salts and P. Therefore, for land receiving frequent manure applications, it is recommended that approximately half of the crop N requirement should be met from manure and the other half from commercial N fertilizer. This will minimize the potential for salt problems or excessive P buildup. For more information on determining proper manure application rates, see CSU Cooperative Extension Bulletin 552A, "Utilization of Animal Manure as Fertilizer".

Determining Manure Application Rates

BMP 3.3 ***Determine manure application rates after all available N from the soil, previous crop residues, irrigation, and carry-over from previous manure applications is credited to crop N requirements.***

Once you have an accurate analysis of soil fertility and manure nutrient content, you can determine application rates based upon crop needs. Plant nutrient uptake depends upon crop, growing conditions, and actual yield. It can be estimated by multiplying average nutrient uptake of the plant by the expected yield.

If manure is applied at the maximum rate, additional fertilizer N should not be applied. Maximum rate is based upon a one-time application. If yearly application of manure is made, credit should be given to the N mineralized from manure applied during the three previous years.

Evaluating Sufficiency of Land Base for Application

BMP 3.4 ***Evaluate the sufficiency of the land base used for manure application to safely accommodate the amount of manure generated by the animal feeding operation.***

Livestock producers should determine whether they have sufficient land for application of manure produced. If the land base is determined to be inadequate, arrangements should be made to apply manure to other crop lands. To calculate a conservative estimate of the minimum land base required, you need to know the total manure production of your facility and have a manure sample analyzed for N, P, and K (see Table 12). Estimate the annual crop nutrient removal and divide by total lbs N per ton of manure (see Appendix table 1). This will give you an estimate of the acceptable application rate in tons of manure/acre. Total manure production divided by acceptable tons per acre will give the minimum land area for annual manure application rates.

Table 12. Typical manure and nutrient production by livestock*

Animal	Raw Manure/ 1000 lb animal			Total N	P_2O_5	K_2O
	(lb/day)	(Ton/yr)	(gal/yr)	- - - -(lbs/day/1000 lb animal) - - -		
Beef	60	11.5	2,880	0.34	0.27	0.31
Dairy	82	15.0	3,610	0.36	0.10	0.27
Poultry	80	14.5	3,500	1.10	0.78	0.55
Horse	50	9.0	2,160	0.28	0.12	0.23
Lamb	40	7.0	1,680	0.45	0.16	0.36
Swine	63	11.5	2,800	0.42	0.37	0.26
Turkey	43	8.0	1,880	0.74	0.64	0.64

*Calculated on an "as excreted" basis per 1000 lbs of animal. Actual amount and content may vary significantly with age, feed ration, breed, and handling.
Source: USDA-SCS. Agricultural Waste Management Field Handbook. 1992.

Total N can be used to calculate a conservative estimate of safe continuous manure application, as all N will eventually become available. However, the most precise method of calculating long term application rates requires a calculation of decay rate over a period of three to four years. Computer software is available from several midwest states to help make this calculation. Phosphorus loading should also be considered in determining an acceptable long term loading rate. In general, P loading is not a primary concern in Colorado, because of the large capacity for P fixation of most Colorado soils. It is recommended that manure be applied on a rotational basis to fields to be planted to a high N use crop such as irrigated corn or forage. In situations where a field is loaded with very high amounts of residual NO_3, alfalfa is a good scavenger crop to remove deep NO_3.

Side-roll irrigation system for hay production *Photo by William Cotton, Colorado State University*

Example calculation: Determining land requirements for long term manure disposal

ex. Beef feedlot with 150 steers at 1,000 lbs each.

Total manure produced (from Table 12)	= 11.5 ton/yr/1,000 lb animal
11.5 ton x 150 animals	= 1,725 tons/yr

150 bu corn/acre crop x 1.35 lb N/bu = 200 lb N/acre

Total N in manure	= 20 lb/ton (1.0% N)
$\frac{200 \text{ lb N/acre}}{20 \text{ lb N/ton}}$	= 10 Ton manure/acre
$\frac{1{,}725 \text{ Ton/yr}}{10 \text{ tons/acre}}$	= 172.5 acre minimum*

* To avoid salt and P buildup, it is suggested that long term manure application rates be based upon no more than 50% of crop N needs being satisfied from manure.

Manure Application

BMP 3.5 Incorporate manure after application to prevent surface runoff.

Surface applied manure should be incorporated as soon as possible to reduce odor and nutrient loss by volatilization or runoff. The risk of surface loss is reduced by injection application under the soil surface, but still may cause surface water quality problems where fields are sloping or erosive.

BMP 3.6 Limit application of manure on frozen or saturated ground to lands not subject to excessive surface runoff.

In general, manure application should be avoided on frozen or saturated fields, unless very level (less than 1% slope), to avoid surface runoff. Delayed incorporation may be acceptable on level fields if sunlight decomposition of pathogens or NH_3 volatilization is desired. If fresh manure is not incorporated within 72 hours after application, over 30% of the NH_4-N may be lost to volatilization. The rate of volatilization increases in warm, dry, windy conditions.

Manure is most valuable as a nutrient source if it is applied as close to planting as possible. However, manure with a high salt content may affect germination and seedling growth of sensitive crops, such as beans. If fall application is necessary in order to clean out manure storage areas, try to wait until after soil temperature is less than 50°F to reduce organic and NH_4 conversion to NO_3. If irrigation equipment is available to apply liquid manure, the best practice is to apply manure in frequent, light applications to match crop uptake patterns and nutrient needs.

Spreader Calibration

BMP 3.7 Apply manure uniformly with properly calibrated equipment.

The value of carefully calculating manure application rates is seriously diminished if manure spreaders are poorly calibrated. Proper calibration is essential in order to apply manure correctly. Manure spreaders discharge at widely varying rates, depending on travel speed, PTO speed, gear box settings, discharge openings, manure moisture and consistency.

Spreader calibration requires measuring the amount of manure applied to a given area. The simplest technique for solid manure is to lay out a 10 x 10 foot plastic sheet in the field and drive over it at the speed and settings you assume are correct for the chosen application rate. The manure collected is transferred to a bucket or washtub and weighed. Subtract the weight of the bucket, and multiply manure weight (in pounds) by 0.22 to determine tons applied per acre. Best results are obtained by repeating the procedure several times and using the average value.

Another calibration method is to weigh each truckload of manure applied to a given land area. This can be used to calculate manure loading on a wet weight basis. Change the spreader or ground speed as necessary to achieve the desired rate. Remember to re-check the calibration whenever a different manure source with a different moisture content or density is applied. Using good equipment and the proper overlap distance will ensure better nutrient distribution and help avoid "hot spots" or areas with nutrient deficiency.

Example calculation: Manure Spreader Calibration

Ex. Manure collected 3 times on a 10' x 10' plastic sheet

(40 lbs + 45 lbs + 35 lbs)/3 = 40 lbs manure average

40 lbs x 0.22 = 8.8 tons manure applied per acre

Accurate recordkeeping is an important component of any crop management program. Keeping accurate records allows managers to make good decisions regarding manure and nutrient applications. Additionally, these records provide documentation that you are complying with state and local regulations to protect Colorado's water resources. All operators should maintain records of manure applications, laboratory analyses, and crop yields for several years to help evaluate and improve management practices.

Summary

To maximize irrigation water efficiency and uniformity, and to protect water quality, producers should determine:

- When irrigation water should be applied
- How much water is needed to satisfy crop requirements
- Application rate, set time, stream size or set size required to apply the correct amount of water
- Potential for fertilizers and pesticides to move from the target site due to irrigation or application practices.

This information should be used to select irrigation methods and BMPs to conserve water and reduce unwanted water quality impacts from leaching or runoff. Proper irrigation management is essential to keeping NO_3 and pesticide out of our groundwater. Obviously, all BMPS are not appropriate for every field and irrigation system. Producers must evaluate agronomic and economic factors to determine the feasibility of installing upgraded systems or management practices. In many cases, it is advisable to obtain professional help in evaluating options for improving irrigation systems.

Drip irrigation system for grapes. *Photo by William Cotton, Colorado State University*

For more information about irrigation and nutrient management, contact Colorado State University Cooperative Extension, your local Soil Conservation Service office, or your water conservancy district. They have publications, programs, and specialists available to help you answer questions about water quality.

Irrigation canal conveys water to downstream users. Photo by William Cotton, Colorado State University

Related source material from Colorado State University Cooperative Extension:

Service in Action sheets

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
	4.700	Estimating soil moisture for irrigation
	4.703	Drip irrigation for orchard crops
	4.704	Center-pivot irrigation systems
	4.707	Irrigation scheduling: the water balance approach
	4.708	Irrigation scheduling
	4.709	Tailwater recovery for surface irrigation
	4.711	Low pressure center-pivot sprinkler system
	4.712	Improving irrigation pumping plant efficiencies
	4.713	Applying pesticides through center-pivot irrigation systems
	4.715	Crop water use and critical growth stages

Bulletin XCM-37 Guide to Fertilizer Recommendations in Colorado
Bulletin 543A Surge Irrigation Guide
Bulletin 552A Utilization of Animal Manure as Fertilizer

Additional resources:

Scheduling irrigation: A guide for improved irrigation water management through proper timing and amount of water application. USDA, 1987.

Colorado Irrigation Guide. USDA Soil Conservation Service.

Colorado Chemigation Act. Title 35, Article 11 CRS.

Big gun sprinkler system irrigating sorghum. Photo Credit: Colorado State University Photographic Archives

INDEX

BMPS for IRRIGATED AGRICULTURE

GLOSSARY of TERMS

Agricultural Chemicals:	Pesticides such as herbicides, fungicides, insecticides, rodenticides, and nematicides, as well as commercial fertilizers and plant growth regulators are all considered agricultural chemicals whether they are used in a rural or urban setting.
Aquifer:	A water bearing layer of rock, sand, or gravel that will yield usable supplies of water.
Background Water Quality:	Pre-existing condition of a particular aquifer that has not been altered by human activities. Almost all groundwater contains some levels of natural contaminants such as sodium, nitrate, chloride, and others.
Best Management Practices (BMPs):	Recommended methods for preventing or reducing non-point source water pollution.
Contaminant:	Any physical, chemical, biological, or radio- logical substance which degrades water quality.
Eutrophication:	Process by which water resources become enriched with dissolved nutrients such as nitrogen and phosphorous, which may limit oxygen levels in the water.
Groundwater:	Water which saturates subsurface formations or aquifers.
Groundwater Monitoring:	Sampling and analyzing groundwater for various quality constituents.
Hydrologic Cycle:	The dynamic movement of water through the environment in its various forms as driven by solar energy.
Integrated Pest Management (IPM):	A strategy for pest control which employs chemical, biological, and cultural control methods into a single program.
Leaching:	The downward movement of dissolved or suspended minerals, fertilizers, agricultural chemicals, or other substances through the soil profile.
Maximum Contaminant Level (MCL):	The highest amount of a specific contaminant allowed by the EPA in public drinking water supplies. These are health based standards which by law must be set as close to the "no-risk" level as feasible.
Nitrate (NO_3):	A form of nitrogen which is very soluble in water and which could cause health problems if consumed in large amounts.

Non-point Source Pollution:	Water contamination from diffuse sources such as agricultural fields, urban runoff, or large construction sites.
Parts per million (ppm):	A unit of proportion used to describe the concentration of a chemical in water, equivalent to mg/L.
Risk Assessment:	Determining the probability of injury, disease, or death from a specific source and weighing that probability against societal benefits.
Vadose Zone:	The unsaturated soil or parent material below the crop root zone and above the water table.

Appendix 1: Calculating nitrogen fertilizer requirement.

Several methods can be used for calculating fertilizer N requirement for various crops. Colorado State University's Guide to Fertilizer Recommendations (XCM-37) lists values for N needs according to soil NO_3 test and % OM. Another method is to multiply expected yield goal by a given crop factor to arrive at lbs N/A needed for crop growth. The following table can be used to estimate N needs of various crops. Typical yields are given only as default values and should be adjusted to expected yields at your location.

Example:

Corn for grain, expected yield 180 bu/A

180 bu/A x 56 lb/bu = 10,080 lb grain/A
1.6 % N x 10,080 lb grain = 161 lb N removed/A
(From Appendix Table 1)

N uptake efficiency varies widely as a result of management and environmental factors. Producers should endeavor to increase N efficiency by implementing appropriate BMPs such as split fertilizer application, banding fertilizer, and careful irrigation management.

Typical N fertilizer uptake efficiencies under irrigated conditions range from 50 to 75% for many deep-rooted agronomic crops. For example, corn contains about 0.9 lbs of N/bu of grain. Highly efficient management systems can achieve maximum economic grain yields with as little 1.1 lbs N/bu. Moderately efficient management may require 1.35 lbs N/bu, while producers on highly leachable soils with inefficient irrigation systems may need more than 1.5 lbs N/bu. Excellent management is needed on these leachable soils to attain high N uptake efficiencies. Grain producers should normally assume efficiencies in the 60 to 70% range for calculating N needs and adjust upward or downward as indicated by soil and crop N status.

Shallow rooted and vegetable crops frequently have a lower N fertilizer use efficiency under irrigated conditions. Efficiencies of 50-60% are common and may be used as a starting place to calculate N fertilizer needs for these crops until nutrient management is significantly upgraded.

Example:

161 lb N/.70 efficiency factor= 230 lb N required/A

Be sure to credit soil NO_3, organic matter %, previous crop residue, manure, and irrigation water NO_3 to calculated N requirement.

Appendix Table 1. Nitrogen removed in the harvested part of the crop

Crop	Weight lb/bu	Typical Annual yield/acre	% N in Dry Harvested Material
Grain crops			
Barley	48	80 bu.	1.8
		2 T. straw	0.7
Corn	56	150 bu.	1.6
		3.5 T. stover	1.1
Oats	32	60 bu.	1.9
		1.5 T. straw	0.6
Rye	56	30 bu.	2.0
		1.5 T. straw	0.5
Sorghum	56	60 bu.	1.6
		3 T. stover	1.0
Wheat	60	40 bu.	2.0
		1.5 T. straw	0.6
Oil crops			
Canola	50	35 bu.	3.6
		3 T. straw	4.4
Sunflower	25	1,100 lb.	3.5
		2 T. stover	1.5
Forage crops			
Alfalfa		4 tons	2.2
Big bluestem		3 tons	0.9
Birdsfoot trefoil		3 tons	2.4
Bluegrass-pastd.		2 tons	2.9
Bromegrass		3 tons	1.8
Alfalfa-grass		4 tons	1.5
Little bluestem		3 tons	1.1
Orchardgrass		4 tons	1.4
Red clover		2.5 tons	2.0
Reed canarygrass		4.5 tons	1.3
Ryegrass		4 tons	1.6
Switchgrass		3 tons	1.1
Tall fescue		3.5 tons	1.9
Timothy		2.5 tons	1.2
Wheatgrass		1 ton	1.4

Source: USDA Agricultural Waste Management Field Handbook, 1992

Table 1. Nitrogen removed in the harvested part of the crop (cont.)

Crop	Dry Matter %	Typical Annual yield/acre	% N in Dry Harvested Material
Silage crops			
Alfalfa haylage	(50%)	10 wet/5 dry	2.7
Corn silage	(35%)	20 wet/7 dry	1.1
Forage sorghum	(30%)	20 wet/6 dry	1.4
Oat haylage	(40%)	10 wet/4 dry	1.6
Sorghum-sudan	(50%)	10 wet/5 dry	1.3
Sugar crops			
Sugar beets		20 tons	0.2
Turf grass			
Bluegrass		2 tons	2.9
Bentgrass		2.5 tons	3.1
Vegetable crops			
Bell peppers		9 tons	0.4
Beans, dry		0.5 tons	3.1
Cabbage		20 tons	0.3
Carrots		13 tons	0.1
Celery		27 tons	0.1
Cucumbers		10 tons	0.2
Lettuce (heads)		14 tons	0.2
Onions		18 tons	0.3
Peas		1.5 tons	3.6
Potatoes		14.5 tons	0.3
Snap beans		3 tons	0.8
Sweet corn		5.5 tons	0.8
Sweet potatoes		7 tons	0.3

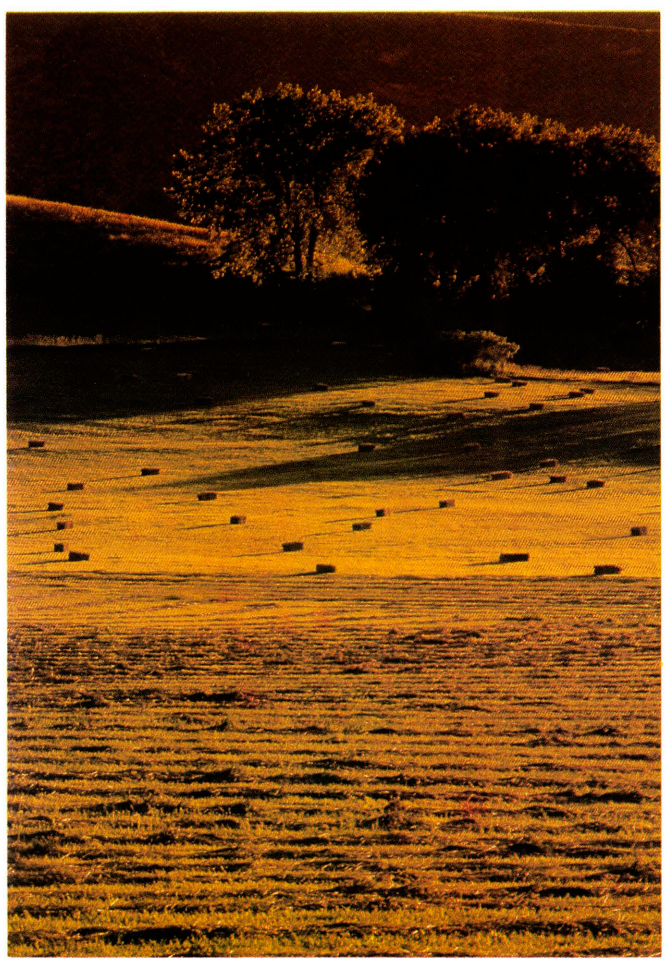
Source: USDA Agricultural Waste Management Field Handbook, 1992

Appendix 2. Calculating loading rates of manure.

1. Example Manure Analysis (Beef feedlot manure, wet weight basis)

[Data from sample analysis]

Dry Matter	20.0%
Total N	1.0%
NH_4-N	3000.0 mg/kg (ppm)
NO_3-N	10.0 mg/kg (ppm)
P_2O_5	0.2%
K_2O	0.5%



Irrigated hay production. Photo by William Cotton, Colorado State University

2. Available N in manure

Total N	= 1.0%
NO_3-N	= 10 mg/kg/10,000
	= .001% N
.001% N x 20 (lb/ton)/%	= .02 lbs NO_3-N/ton
NH_4-N	= 3000 mg/kg/10,000
	= 0.3% N
0.3% N x 20 (lb/ton)/%	= 6.0 lbs N/ton manure
Organic N	= Total N - (NO_3-N + NH_4-N)
	= 1.0% - (.001% + .3%)
	= 0.70%
0.70% N x 20(lb/ton)/%	= 14.0 lbs organic N/ton manure
.35 N mineralized/yr x 14.0 lbs N/ton (from Table 11)	= 4.9 lbs organic N/ton available in first year
Available N	= 4.9 + .02 + 6.0
	≅11 lb N/ton manure (wet weight basis)

3. Available P in manure

P_2O_5 $= 0.2\% \times 20$ (lb/ton)/%
$= 4$ lb P_SO_5/ton manure

4. Crop N Requirement - Refer to "Guide to Fertilizer Recommendations in Colorado" (Follett et al., 1991), or a current soil test report.

ex. N required for 180 bu Corn crop = 230 lbs N/acre
Subtract N credits from other sources such as soil NO_3, legume crop, irrigation water NO_3.
If 230 lbs additional N required for expected yield,

Maximum manure loading rate = (230 lbs N/acre)/(11 lbs available N/ton manure)

$\cong$ 20 tons manure/acre

5. Phosphorous Supplied by Manure

20 tons manure/acre x 4 lb P_2O_5/ton manure = 80 lb P_2O_5/acre

Conversion Factors:

ppm = mg/kg
ppm ÷ 10,000 = %
% nutrient x 20 = lb nutrient/ton

$P \times 2.3 = P_2O_5$
$K \times 1.2 = K_2O$

Appendix Table 2. Approximate nutrient credits[1] from various manure sources at the time applied to the land (calculated on a wet weight or as is basis)

Manure type	% Moisture	Available Nutrients[2] First year N	First year P_2O_5	Second year N	Third Year N
		lb/ton			
Beef					
Feedlot	48	10	8	3	2
with bedding	50	10	10	3	2
lagoon sludge (lb/1,000 gal)	89	36	15	10	5
Dairy					
without bedding	82	6	2	1	1
with bedding	79	6	2	1	1
lagoon sludge (lb/1,000 gal)	92	16	10	3	2
Swine					
without bedding	82	8	5	1	1
with bedding	82	6	4	1	1
lagoon sludge (lb/1,000 gal)	96	38	15	9	4
Sheep					
without bedding	72	8	6	3	2
with bedding	72	7	5	2	2
Horses					
with bedding	54	6	2	2	1
Poultry					
without litter	55	28	26	2	1
with litter	25	43	25	5	2
deep pit (compost)	24	52	35	6	3
Turkeys					
without litter	78	20	11	2	1
with litter	71	15	9	2	1

[1]Values given are approximations only. Analysis of manure and soil is the only accurate way to determine nutrient loading rates due to the wide range of variability in nutrient content caused by source, moisture, age, and handling.

[2]N credit assumes all NH_4-N and NO_3-N is available during the first crop season. Organic N becomes available slowly over a longer period of time. Unincorporated manure will lose NH_4 due to volatilization, resulting in a decrease of available N during the first crop year.
P credit assumes most of the P is available in the first year. P credit thereafter should be determined by soil testing.

Values derived from "Utilization of Animal Manure as Fertilizer", 1993. Colorado State University Cooperative Extension Bulletin 552A.

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 & Variety: ______________

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

Fertilizer N applied: ______________ lbs/A. Manure N applied: ______________ Tons/A

Application dates and amounts: ______________________________

Form of N used: ______________________________

Actual crop yield: ______________ Total irrigation water applied: ______________

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