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Best Management Practices for Corn Production in South Dakota: Irrigation and Salt Management

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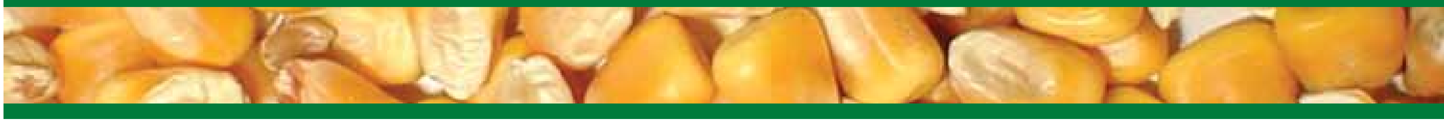
CHAPTER 6
Irrigation and Salt Management

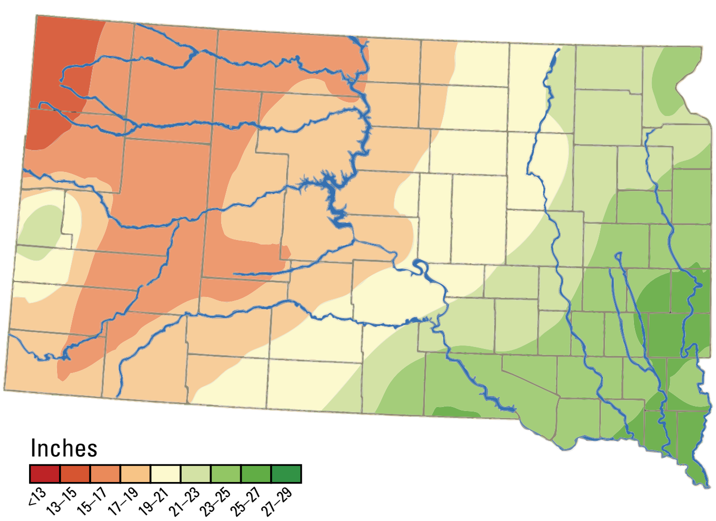


In South Dakota, average annual precipitation ranges from less than 13 inches to nearly 30 inches, generally increasing from west to east (fig. 6.1). However, all regions of South Dakota can experience drought. Irrigation can reduce a crop's dependence on natural rainfall and improve yields. To best capitalize on investment in irrigation equipment, it has been suggested that one should increase plant populations on irrigated land by 2,000 to 3,000 plants per acre (Aldrich et al. 1975). This chapter discusses how much irrigation water to apply and how to manage the salts contained in the water. If you are planning a new system or expanding an existing system, equipment and management options should be discussed with your local irrigation equipment dealer or Extension educator. A permit may be required to irrigate in South Dakota. For permit requirements, contact the South Dakota Department of Environment and Natural Resources (DENR).

Soil-Water-Plant Relations

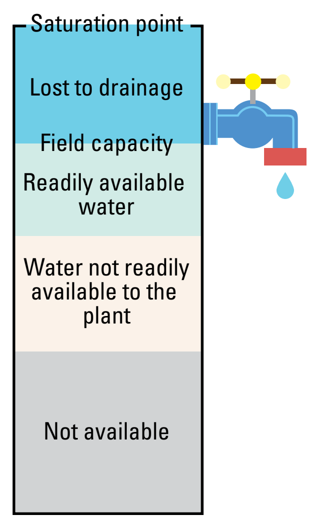
The amount of water retained and available for plant growth from the soil is dependent on the soil texture and organic matter content. Soil serves as a water storage reservoir for the plant, though not all soil water is available to the plant (fig. 6.2).

Figure 6.1. Average annual precipitation (in inches) in South Dakota, 1977–2006



(Courtesy of Kurtis D. Reitsma, South Dakota State University)

Figure 6.2. Soil water availability as related to saturation, field capacity, and permanent wilting point



(Courtesy of Todd Trooien, South Dakota State University)

Soil's water-holding properties are similar to a sponge: when a sponge is placed in a bucket of water, all the pores in the sponge are filled to the saturation point with water; when the saturated sponge is removed from the bucket, some of the water freely drains out of the sponge. When at its maximum water-holding capacity, soil is referred to as "saturated." After water has drained freely from the soil, the soil water content reaches "field capacity" (fig. 6.2). Water content can continue to decrease through plant uptake and evaporation until "permanent wilting point" is reached. Water held by the soil between field capacity and permanent wilting point is called "plant-available water" and varies by soil texture (Table 6.1).

Table 6.1. Ranges of plant-available water for different soil textures

Soil texture	Plant-available water (inch/ft. soil)
Fine sands	0.7–1.0
Loamy sands	0.9–1.5
Sandy loams	1.3–1.8
Loam	1.8–2.5
Silt loams	1.8–2.6
Clay loam	1.8–2.5
Clay	1.8–2.4

As soil dries and approaches permanent wilting point, the remaining water becomes more difficult for the plant roots to absorb. Corn is most susceptible to water stress when plant-available soil water is 50% or less. To maximize productivity, irrigation water should be applied to maintain water content between 50 to 100% of field capacity through the R3 growth stage. Usually, irrigation can cease by Aug. 15, but this date can vary depending on the growing season and region.

To be most effective, water must be applied to the zone containing a majority of the corn roots. Early in the growing season, the roots may be concentrated in the surface 12 inches. As the season progresses, roots can extend down to 5 feet. Most of the roots, however, are found in the surface 3 feet. Therefore, unless local knowledge or experience suggests otherwise, schedule irrigation according to the soil water content in the surface 3 feet.

The relative amount of water lost to transpiration (water lost from leaves to air) and evaporation (water lost from soil to air) changes during the year. At planting, evaporation is the most important water-loss mechanism; however, at corn tasseling, the major water-loss mechanism is transpiration.

Irrigation Scheduling

"Irrigation scheduling" is the process of predicting the amount and timing of the next irrigation. The amount of water applied at the next irrigation may be determined by irrigator preference, by timing, by amount of water contained in the soil, by soil characteristics, and by equipment capacity. When scheduling irrigation, it is important to realize that heavy irrigations (saturating at least the top 2 feet of soil) are typically more effective and take less time than several light irrigations. Wetting the soil to deeper depths also promotes deeper root development; light irrigations promote shallow rooting, which may lead to nutrient deficiency or lodging problems later in the season. The most widely used approach for irrigation scheduling is called the "Checkbook Approach" (Werner 1993). Whether using the Checkbook Approach or another method, soil water content should occasionally be measured.

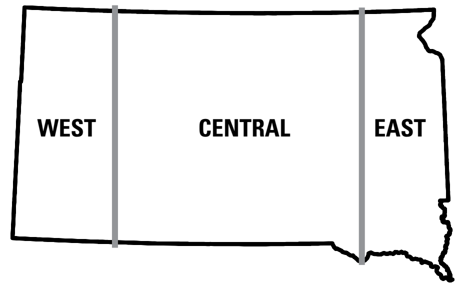
The Checkbook Approach for Estimating Soil Water

The Checkbook Approach is often called the "Water Balance Method." This method adds water received from rainfall and irrigation to the water balance and subtracts evapotranspiration (ET). To maximize productivity, the field should be irrigated before readily available water has been depleted. Detailed information for this approach is available at http://agbiopubs.sdstate.edu/articles/EC897.pdf. The Checkbook Approach utilizes the following tools:

- a rain gauge to measure rainfall and irrigation
- estimated ET figures
- soil moisture balance worksheets
- soil water content measurements (to validate checkbook balances)

Evapotranspiration, which is the loss of water from both evaporation and transpiration, is calculated using weather data (i.e., temperature, wind, and relative humidity) and crop information. Values of ET vary by climate across South Dakota (fig. 6.3 and Table 6.2). Daily values of corn ET are published on the South Dakota State Climatologist's website (http://climate.sdstate.edu/awdn/et/et.asp); if you are located close to a weather station, these are the most accurate estimates of ET. If a weather station is not located near your farm, ET can be estimated by measuring evaporation with an instrument known as an "atmometer" (Broner 1993).

Figure 6.3. Evapotranspiration (ET) regions of South Dakota



(Courtesy of Todd Trooien, South Dakota State University)

For irrigation planning, South Dakota can be split into regions: West, Central, and East (fig. 6.3). Daily water-use estimates are used to calculate water use over the season (Table 6.3). For example, to estimate irrigation requirements, daily water-use values are summed and compared with your field's expected rainfall estimates (Table 6.2). The difference between daily water use and expected rainfall is the "irrigation potential" (examples of this calculation are presented in Table 6.3).

Table 6.2. Estimated corn water use per day in South Dakota

Weeks after emergence	Western region				Central region				Eastern region		
	---------Maximum temperature °F---------										
	50–59	70–79	90–99		50–59	70–79	90–99		50–59	70–79	90–99
	----------Inches of water used/day----------										
1	0.02	0.04	0.07		0.02	0.04	0.07		0.02	0.04	0.06
3	0.03	0.06	0.09		0.03	0.05	0.09		0.02	0.05	0.08
5	0.05	0.1	0.17		0.05	0.1	0.17		0.04	0.09	0.15
7	0.08	0.16	0.27		0.08	0.16	0.27		0.07	0.15	0.23
9	0.1	0.2	0.33		0.1	0.19	0.34		0.09	0.18	0.29
11	0.1	0.22	0.35		0.1	0.21	0.36		0.09	0.2	0.31
13	0.1	0.2	0.32		0.1	0.19	0.33		0.09	0.18	0.29
15	0.07	0.15	0.25		0.07	0.15	0.26		0.07	0.14	0.22
17	0.05	0.11	0.17		0.05	0.1	0.18		0.05	0.1	0.15

(Modified from Werner 1993)

Table 6.3. Examples of estimating seasonal and future water use

A. Seasonal water use

In eastern South Dakota, when temperatures reach 90 to 99°F, seasonal crop water use is about 24.1 inches. At Brookings, the 30-year average precipitation during the growing season (May through Aug.) is 16 inches. Available water for the surface 3 feet of a silt loam soil is 6 inches. Readily available water is one-half of the available water, or 3 inches. Thus, 19 inches of water (16 inches + 3 inches) is available to the crop in an average year. The irrigation or precipitation needed to maximize yield is the difference between these values (crop water use minus available water): 24.1 – 19 = 5.1 inches.

B. Future water use

What is the potential water use next week (11 weeks after emergence) in the central region of state if the temperature is 85°F?

7 days x 0.21 inch/day = 1.47 inch

For the Checkbook Approach, rainfall should be measured at your location. The total (gross) rainfall should not be entered into the checkbook irrigation schedule; instead, use "effective rainfall," which is the amount of rain that actually soaked into the soil and is available to the crop. The effective rainfall is usually less than the measured rainfall.

Soil Water Measurement

Checkbook balances should be periodically checked against measured soil water content. Soil water status can be 1) estimated by the "hand-feel" method, 2) measured from soil samples by calculating the gravimetric water content, or 3) monitored with sensors.

1. The hand-feel method is fast and inexpensive. It involves "feeling" a soil of known water content and comparing that to a soil with unknown water content; available water is estimated by how the soil "feels" in your hand. Note that a "same" amount of available water for different soil textures will "feel" different, so you need to "calibrate" your feel to the different soil textures that are found in your fields. Obviously, hand-feeling is the least accurate method, but it can be effective with some practice.

2. Gravimetric water content is measured by collecting samples and calculating the weight difference between wet and oven-dried samples. Samples can be dried in a microwave oven using procedures detailed in Schneekloth et al. (2007). Drying with a microwave oven is much quicker than drying with a conventional oven and can provide moisture percentage estimates within an hour of collecting the sample. The percent moisture is calculated with the following equation:

$$\%\text{moisture} = \frac{(\text{wet weight soil} - \text{dry weight soil})}{\text{dry weight of soil.}} \times 100\%$$

3. Soil water content or status can also be measured with sensors placed in the soil. Two commonly used sensors are gypsum and granular matrix blocks (e.g., WaterMark®). For irrigation scheduling, sensors should be placed at multiple depths (6", 18", and 30") at both the start and endpoint of the irrigation system. When placing a soil moisture sensor, push a soil probe into the soil to the desired depth. With soil from that depth, make a thin slurry with soil and water, insert the sensor into the hole, and pour the slurry into the hole. The slurry will help ensure good contact between the soil and the sensor.

Another way to look at soil water is to consider "soil water depletion." Soil water depletion is the amount of water required to bring the root zone back to field capacity. When the soil is at field capacity, depletion is zero. Optimal irrigation efficiency is realized when irrigation water is applied in the amount equal to depletion. Runoff and deep drainage can result when water is applied in excess of depletion. Excess irrigation water application not only diminishes irrigation efficiency but also can result in nutrient and pesticide losses from runoff and leaching.

Critical Plant Growth Stages

Adequate soil moisture is needed for germination; therefore, if the soil is dry, irrigation may be needed to improve germination and seedling vigor. As the crop develops, moist soil is needed for root development. Check your fields by probing to ensure that there are layers of dry soil in the profile. Irrigation may be needed earlier than expected to wet deeper soil layers. Most irrigation systems cannot keep up with crop water demands during the later critical growth periods (VT to R3) (Werner 1993); therefore, planning is needed (Table 6.2). The first priority for irrigation should be a 3-week period starting just before tassel (VT) and ending just after silking.

Corn is less susceptible to water stress during later grain-development stages (R3). Soil water levels should be maintained to allow the crop to reach maturity (R6) but can be allowed to approach 70% depletion at this time. Terminating irrigation early does not promote early maturing and dry-down of the grain (Werner 1993).

Many soils contain 2 to 4 inches of water when they reach 60 to 70% depletion. Monitoring soil water content is a good indicator for deciding when to end irrigation. Depleting soil water at the end of the season minimizes the risk of nutrient leaching, allows you to take advantage of any off-season precipitation, and allows for surface-soil drying prior to harvest. Rather than terminating irrigation at a given date, monitor weather forecasts, crop development, and soil moisture.

Irrigation Systems

Commonly used irrigation systems are classified as surface, sprinkler, and micro-irrigation. Surface irrigation systems have been used for millennia. Surface irrigation is inherently non-uniform because the soil surface is used both for water conveyance and for water storage. Water is available to infiltrate into the soil longer at the top of the field, so more water is stored in the soil profile in that area. The uniformity of water distribution can be improved by minimizing the length of run. Short runs reduce the difference of infiltration time between the top and bottom of the field, improving water-distribution uniformity.

An alternative is to optimize the uniformity by increasing the water inflow rate to a maximum, without causing excessive soil erosion at the top of the field. This advances the water as quickly as possible across the field by reducing the difference in infiltration time. Other methods for increasing uniformity include surge irrigation, cutback irrigation, furrow packing (usually for the first irrigation), and the use of polyacrylamide (PAM) soil amendments.

Center pivot is the most popular irrigation method in South Dakota. Center-pivot systems can reduce labor requirements (compared to surface irrigation), increase distribution uniformity and irrigation efficiency (potentially, for the latter), and allow the effective application of fertilizer or pesticides with the irrigation water. With center-pivot systems, nozzles can be placed either on the pipe or at the top of or within the corn canopy.

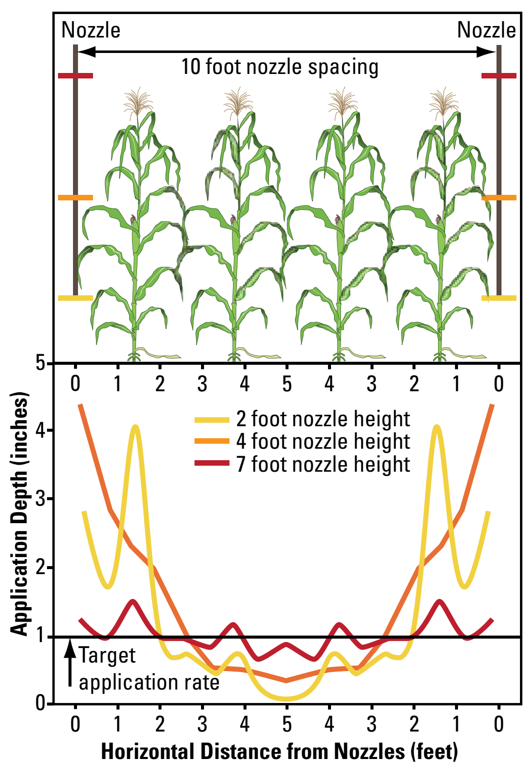
Historically, high-pressure systems had impact sprinklers widely spaced and mounted on the pipe. These systems were effective, but to generate the required operating pressure they required high energy inputs. As pressure inputs have been reduced, nozzle installation elevations have been moved closer to the ground. Drop hoses or pipes can be used to lower the nozzles to just above or even into the crop canopy. Where water supplies are greatly diminished and irrigation systems have limited capacity, nozzles have been installed as low as 2 feet above the soil surface. In some cases the pipe has been covered with a sock that drags on the ground (so that water is applied directly to the soil surface).

High-pressure systems reduce the amount of water that might be lost to wind drift or evaporation; however, losses due to wind drift and evaporation are small (as a percentage of the total amount of water applied). The danger of using low nozzle elevations is that runoff can occur. If you are considering installing nozzles near the soil surface, be sure that your soils have high infiltration rates (>0.25"/hr). In addition, nozzles must be spaced more closely together (approximately 5-feet apart).

Installing nozzles near the top of the mature corn canopy (approximately 7 feet) is a good compromise in many situations. This allows for a wider spread of water from the nozzles while still reducing wind drift and droplet evaporation (fig. 6.4).

Subsurface drip irrigation (SDI) is a type of micro-irrigation system. SDI systems have high water-use efficiency and have been used to irrigate

Figure 6.4. Nozzle placement in the canopy



(Courtesy of Colorado State University)

corn in the central and southern high plains of the United States. A disadvantage with these systems is that they are expensive to install. They are not commonly used in South Dakota but may be an option for areas poorly suited to center-pivot irrigation (e.g., some field shapes, small field sizes, and so on).

Managing Saline (salts) and Sodium Problems

Salts most often interfere with crop water uptake and can reduce yields and crop quality. To prevent salt accumulation in irrigated systems, monitor the salinity (i.e., total salt content—measured as electrical conductivity) and sodium content of water and soil. In addition, salt buildup can be hastened when several low irrigation applications are applied (compared with heavier applications). Yield impacts from salts (salinity) vary greatly with management, soil type, and weather conditions. If salinity problems are suspected, consult with an Extension educator or crop consultant.

Soil and water samples can be collected and analyzed for salts (electrical conductivity) and sodium (Na) content. The interpretation of the laboratory results depends on the laboratory method. Saline (salts) recommendations are based on laboratory tests that measure the electrical conductivity (EC) of the soil. As EC increases, so does the concentration of soluble salts. There are generally two laboratory methods for measuring EC: "saturated paste" and "1:1 soil to solution." The two approaches will not result in the same values. The South Dakota State University Soil Testing Laboratory uses the 1:1 soil to solution ratio approach to assess salt accumulation in soil.

Crops have different salt tolerances (Table 6.4), and salts affect plants differently based on growth stage. During germination, many plants are much more sensitive to salts than at later growth stages. To minimize salt-related germination problems, high-quality irrigation water can be used to leach soluble salts from the surface soil. High temperature, low humidity, and high winds increase evaporation and make the plant more susceptible to salinity problems, with symptoms appearing similar to water stress. High humidity benefits salt-sensitive crops more than salt-tolerant plants. High temperatures decrease any plant's ability to tolerate salt.

In dryland situations, salt problems most often occur in the low areas of fields. The most important management consideration for these areas is maximizing transpiration and minimizing evaporation (Franzen 2007). Salts can be managed in these fields in the following manners:

- Testing the salinity level and planting salt-tolerant crops.
- Using shallow tillage to minimize the mixing of surface and subsurface soils with high salt contents.
- Scheduling seeding when salt levels are low (spring).
- Minimizing salt accumulation by including deep-rooted long-season plants in the rotation. Late-maturing plants are beneficial because they mulch the soil, thus reducing the potential for surface evaporation. In addition, late-maturing plants reduce the potential for the capillary movement of salts to the surface.

Salt problems often occur in soils with poor internal drainage. Layers of low permeability restrict the flow of water "out the bottom" more slowly than evapotranspiration removes water from the upper profile. To avoid the accumulation of salts in irrigated situations, the soil must have adequate drainage capacity, even if your water quality is relatively good. Water must move freely through the soil, leave the root zone, and carry with it some salts. Without adequate drainage capacity, salts will build up over time and cause problems. In poorly drained situations, select salt-tolerant crops and/or install artificial drainage to remove excess water and salts from permeable soils. County, district, federal, or state drainage laws may apply to artificial drainage systems.

Salt accumulation in the soil profile can also be managed by applying extra water to leach the salts

Table 6.4. Comparison of different approaches for assessing soil salinity problems

Crop	Threshold salinity 1:1 ratio	Threshold salinity Saturated paste	Saturated paste at 70% yield loss
	------------dS/m-----------		
Corn	1.3	1.7	4.2
Alfalfa	1.4	2.0	6.1
Soybean	2.4	5.0	6.5
Wheat	2.8	6.0	10.2

(Courtesy of Franzen 2007)

from the soil profile. The amount of water needed is referred to as the “leaching requirement” (LR).

$$LR= \frac{\text{Irrigation Water EC (dS/m)}}{\text{Acceptable Deep Drainage EC (dS/m)}}$$

LR is determined by measuring both irrigation water and acceptable deep drainage water and then placing those figures into the equation above. For example, if the irrigation water EC is 2 dS*/m and the acceptable deep drainage EC value is 6 dS/m (50% yield reduction), the LR is 0.33. A leaching requirement of 0.33 means that 33% more water (over the plant’s requirements) is needed. For example, if 3 inches of water are required by the plant, then the amount of water needed to meet the needs of the plant and to wash excess salts out of the profile is 4 inches (4 = 3 + [3 • 0.33]). More information for managing saline soils is provided in Bischoff and Werner (1999).

Irrigation water can contain ions that are toxic to corn. In South Dakota, two ions of concern are sodium (Na) and boron (B). Na and B can reduce yields when their concentrations exceed 230 and 1 mg/L, respectively. In South Dakota, aquifers with high concentrations of Na may also have high concentrations of B. To determine the Na and B concentrations of your irrigation water, collect a representative pint of water and send it to an appropriate laboratory for analysis. The Olsen Biochemistry Laboratory on the campus of SDSU can perform an irrigation compatibility analysis of your irrigation water.

Managing Sodic Problems

Extreme care must be used in soils with high Na contents. Na destroys soils by dispersing soil colloids and destroying soil structure. In addition, high Na reduces water infiltration and permeability. Irrigating with water that had high Na concentrations has rendered some land in South Dakota useless. Na-affected soils often have very poor drainage, and Na-sensitive plants experience reduced growth. Nutrient-deficiency symptoms (resulting from high pH) and poor soil physical conditions are often observed in high-Na situations.

If an Na problem is suspected, contact your local Extension educator or crop consultant for advice. Suspected Na problems can be confirmed by testing soil and irrigation water for Na, calcium (Ca), and magnesium (Mg) content. Sodium-adsorption ratios (SAR) are calculated using these values and provide an indication of current or impending Na problems. The SAR ratio is the amount of cationic (positive) charge contributed to a soil by sodium (Na^+) compared to that contributed by calcium (Ca^{2+}) and magnesium (Mg^{2+}). The SAR is determined from a water extract of a saturated soil paste. An SAR value below 13 is desirable, but values above 8 can indicate the onset of a problem (if steps are not taken to reduce Na in the soil profile). If the SAR is above 13, Na can cause the deterioration of soil structure and water infiltration problems. Some labs report high Na levels as ESP (exchangeable sodium percentage). An ESP of more than 15 is considered the threshold value for a soil classified as sodic. This means that Na occupies more than 15% of the soil’s cation exchange capacity (CEC).

If Na is a problem, the long-term goal should be to prevent further degradation and reduce further addition of Na. Some options for managing sodic soils include planting Na-tolerant plants, improving drainage, and adding low-Na manure or gypsum or other sources of calcium. Elemental sulfur (S) is sometimes recommended to lower soil pH values. However, because soils in South Dakota typically resist pH change because of high buffering capacity, applications of elemental S may not provide any benefit to the soil. If gypsum ($CaSO_4 \cdot 2H_2O$) is present at deeper soil depths, deep tillage may help bring the gypsum to the soil surface. If drainage and soil amendments are not possible, consider an alternative land use, such as pastureland planted with salt- and Na-tolerant grasses.

* DeciSiemen per meter (dS/m) is a unit of conductivity equal to 1/10th mho. Conductivity of soil is often reported as millimhos per cm (mmho/cm) where 1 dS/m = 1mmho/cm.

Chemigation

One advantage of irrigating is the ability to apply fertilizers or pesticides with the irrigation system. This practice is commonly referred to as "chemigation." Fertilizer applied through an irrigation system must remain soluble in the irrigation water because precipitates form and nozzles, emitters, and fittings can become clogged. After fertilizer application, a short irrigation may be used to wash the fertilizer off the plant and lessen the possibility of fertilizer burn. If applying pesticides, the pesticide must be labeled both for corn and for application with the irrigation system.

When chemigating you must also protect the water supply. Backflow into a well or other water supply can have serious consequences for other users and make the water unusable for their applications. State law requires the use of an anti-backflow device when chemigating; examples of anti-backflow devices include such things as check valves and low-pressure relief valves (SDCL §34A-2A-3). Always read and follow the instructions on the product label and take precautions to protect yourself and others from exposure to chemicals.

When using chemigation to apply liquid nitrogen or other chemicals, you may not need water at the time you want to apply the chemicals. Apply the chemicals in a timely fashion, but use the least amount of water possible. High-capacity injection equipment, along with an irrigation system that can cover the field in the shortest period of time, is desirable for chemigation.

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