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BEST MANAGEMENT PRACTICES

CHAPTER 33

Irrigating Corn in South Dakota

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In South Dakota, average annual precipitation decreases from east to west across the state (Fig. 33.1). However, plants in all regions can experience water stress, and irrigation can reduce yield losses. This chapter discusses when and how much irrigation water to apply.

Soil-Water-Plant Relationships

If you are planning a new or expanding an existing irrigation system, equipment and management options should be discussed with your local advisor and you will need to obtain a permit from the South Dakota Department of Environment and Natural Resources (DENR). Once you obtain a receipt of the application, you will receive a report and recommendation along with a public notice to be submitted to your local newspaper. If your application is not contested, it takes at least two months to process the permit. If the application is contested, then it will be considered by the state Water Management Board. For additional permit requirements, contact the DENR. Information about South Dakota aquifers is available in Iles (2008).

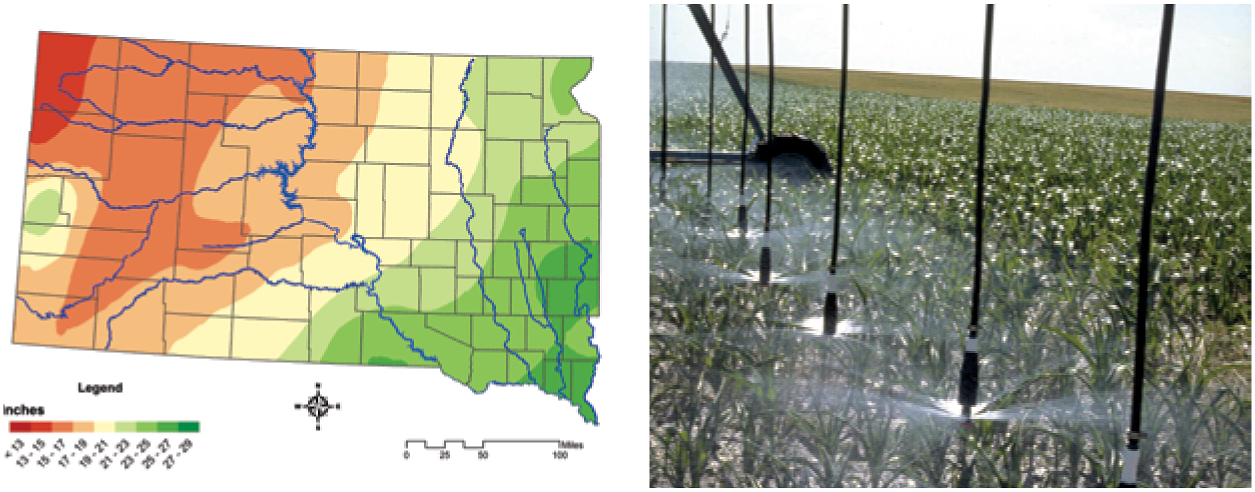

Figure 33.1 Average annual precipitation (in inches) in South Dakota from 1981 to 2010 and irrigating a corn field (Courtesy K. Reitsma and G.W. Buchleiter, Bugwood.org)

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. 33.2). Soil 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. When the saturated sponge is removed from the bucket, some of the water freely drains out of the sponge. When this free-water drainage stops, the soil is at field capacity (FC). In field soil, this drainage occurs over several days after a precipitation event that saturates the soil. Water content can continue to decrease through plant uptake and evaporation until the permanent wilting point (PWP) is reached. The permanent wilting point is the point where plants will no longer recover when water is added. Water held by the soil between FC and PWP is called plant available water (PAW) and varies by soil texture (Example 33.1). Plant available water ranges from 0.9 inches of water/foot of soil in fine sands to 2.3 inches/foot in silt loams. Because soils vary by depth, the total amount of PAW needs to be calculated by soil texture for each depth and summed to estimate the PAW throughout the whole root zone.

As soil dries, the remaining water becomes increasingly more difficult for the plant roots to absorb (Fig. 33.2). When 30% to 70% of the plant available water has been depleted, the plant starts to experience water stress. The percentage of plant available water that the soil is allowed to reach before triggering irrigation is the management allowable depletion (MAD). The water held in the soil above the MAD is called the readily available water (RAW). The RAW can be calculated as the PAW multiplied by the MAD. The MAD value is dependent on the drought tolerance of the plant. A common MAD value used in corn production is 50%.

To be most effective, water must be applied to and stored in 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. A general guideline is to schedule irrigations based on the amount of PAW in the surface 2 feet prior to R1 (silk) and 3 feet thereafter.

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. Applying more water than the amount needed to bring the soil to field capacity can result in runoff, erosion, and deep

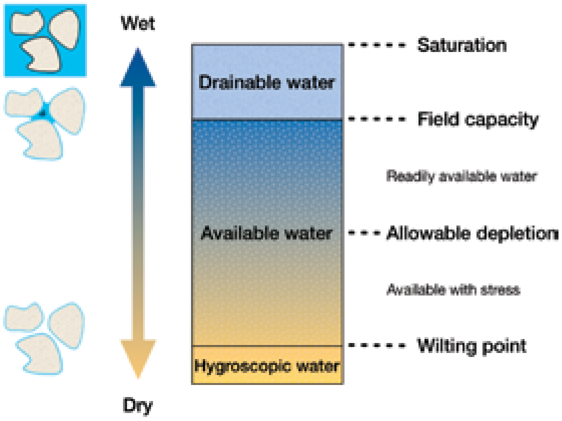

Figure 33.2 Soil water availability as related to saturation, field capacity, and permanent wilting point. The management allowable depletion (MAD) is the point where irrigation should be applied. (Adapted from Gary Sands, University of Minnesota Extension)

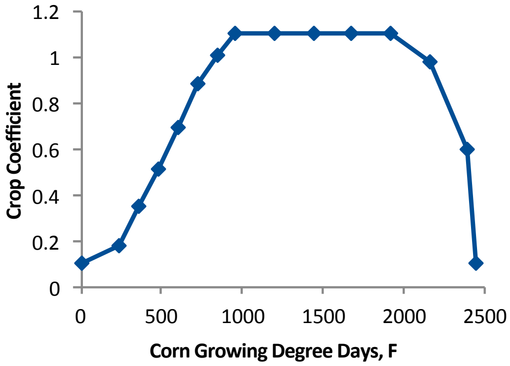

Figure 33.3 Crop coefficient (Kc) for various corn growth stages. Values from the High Plains Regional Climate Center (www.hprcc.unl.edu) based on an alfalfa reference.

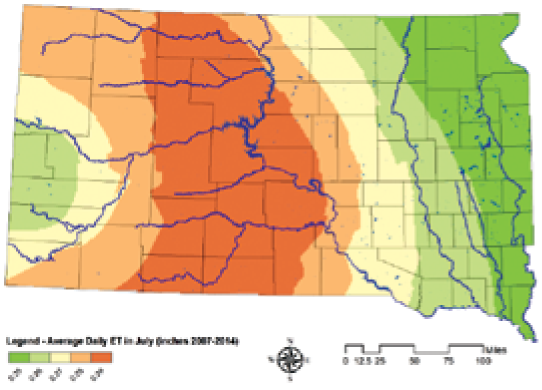

Figure 33.4 Average daily ET (inches/day) in July in South Dakota, 2007-2014.

Example 33.1 Determine the amount of PAW in the surface 36 inches of soil. The soil textures at the site by depth are silt loam (0-6 inches), clay (6-18 inches), and sandy loam (18 to 36 inches). Use the following table to determine plant available water.

Step 1. Calculate the PAW for each soil layer and total plant available water in the root zone (to a depth of 36 inches).

Ranges of PAW for different soil textures (Werner, 1993).

Soil Texture	Plant Available Water (inch/ft of 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 loam	1.8-2.6
Clay loam	1.8-2.5
Clay	1.8-2.4

Calculate the PAW by soil texture. The upper and lower values for the range of PAW are added and the divided by 2 (to get the average amount).

$$\text{silt loam} = \frac{\text{Upper+lower values}}{2} = \frac{1.8+2.6}{2} = \frac{2.2\text{ inches}}{\text{ft soil}}$$

$$\text{Plant available water: clay} = \frac{1.8+2.4}{2} = \frac{2.1\text{ inches}}{\text{ft soil}}$$

$$\text{Plant available water: sandy loam} = \frac{1.3+1.8}{2} = \frac{1.55\text{ inches}}{\text{ft soil}}$$

Step 2. Calculate the amount of water in the surface 36 inches. Note that each texture has a different depth, which can vary from less than 1 ft to more than a foot. Therefore, the amount of water held has to be corrected for the depth of the soil texture.

$$\text{Depth 1: } \frac{2.2\text{ inches}}{\text{ft soil}} \times \frac{1\text{ foot soil}}{12\text{ inches}} \times 6\text{inches} = 1.1\text{ inch water}$$

$$\text{Depth 2: } \frac{2.1\text{ inches}}{\text{ft soil}} \times \frac{1\text{ foot soil}}{12\text{ inches}} \times 12\text{inches} = 2.1\text{ inch water}$$

$$\text{Depth 3: } \frac{1.55\text{ inches}}{\text{ft soil}} \times \frac{1\text{ foot soil}}{12\text{ inches}} \times 18\text{inches} = 2.32\text{ inch water}$$

Step 3. Calculate the total PAW

Total is 1.1 + 2.1 + 2.32 = 5.52 inches of water

drainage. Runoff and deep drainage can contribute to increased energy costs, and nutrient and pesticide losses.

The amount of water lost to transpiration (water lost from plants to air) and evaporation (water lost from soil to air) is called evapotranspiration (ET). Early in the growing season (after planting), evaporation is the most important water-loss mechanism, but as the corn develops and reaches full canopy, transpiration becomes more important. Weather data (temperature, solar radiation, wind, and relative humidity) are used to calculate a reference ET (ETref) value, using either alfalfa (ETr) or grass (ETo) as the reference surface. Crop-specific information is used to adjust the ETref value by a coefficient specific to the crop (Kc) that changes depending on the plant growth stage (Fig. 33.3). For example, between 0 and about 720 growing-degree days, the Kc for corn ranges from 0.1 (early in the season) to 0.9 of the ETref. When corn is going from vegetative to reproductive phases, the Kc is > 1, indicating that corn is using more water than the reference crop during that time. The amount of water used by corn decreases as the plant matures in the fall. A map of SD showing average daily ET in July can be seen in Figure 33.4. Daily values of corn ET are published on the South Dakota State Ag Weather Tool on the South Dakota Climate website (http://climate.sdstate.edu/awdn/et/et.asp).

Irrigation Scheduling

The amount and timing of each irrigation are a function of irrigator preference, the amount of water contained in the soil, soil and plant characteristics, and equipment capacity. When scheduling irrigation, it is important to realize that heavy irrigations (refilling the profile to at least the top 2 feet of soil) are typically more effective than light, more frequent irrigations. Wetting the soil to deeper depths promotes deeper root development, which can reduce lodging and enhance nutrient efficiency. Soils with lower water infiltration rates, however, may require shallow and more frequent irrigations to prevent runoff. To minimize yield losses due to water stress in sandy soils, frequent irrigations maybe required during grain filling and critical crop stages.

The Checkbook Approach for Estimating Soil Water

A commonly used irrigation scheduling method is called the Checkbook Approach (Werner, 1993) (Table 33.1). Whether using the Checkbook Approach or another method, soil water content should be measured occasionally to make sure the calculated value is accurate.

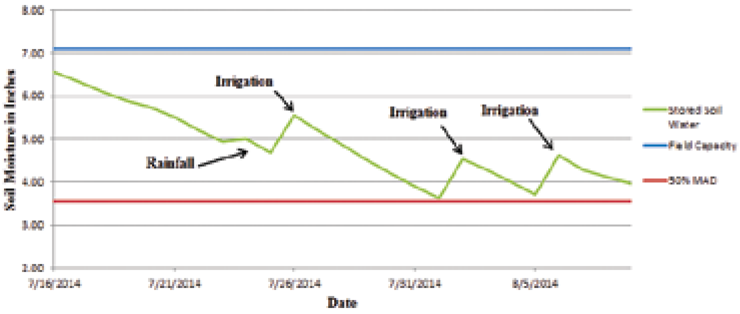

Figure 33.5 Daily values of stored soil water in relation to maximum plant available water (PAW) (field capacity) and a constant management allowable depletion (MAD) = 50% of FC (i.e., 7.1/2 = 3.5 in).

The Checkbook Approach often is called the Water Balance Method. This method adds water received from rainfall and irrigation to the water balance and subtracts ET. To maximize productivity, the field should be irrigated before readily available water has been depleted. This can be seen graphically in Figure 33.5. As the crop consumptive water use reduces the plant available water, irrigations can be timed to stay above the management allowable depletion (MAD) for corn. Greater irrigation amounts will allow for additional time between irrigations, but be careful not to raise the stored water content higher than the field capacity or runoff, leaching, flood stress of the roots, or increased disease incidence may occur. The Checkbook Approach utilizes the following tools:

- A rain gauge to measure rainfall and irrigation.
- Estimated ET values.
- Soil moisture balance worksheets (Table 33.1).
- Soil water content measurements (to validate checkbook balances).

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

Table 33.1 Checkbook Approach example, water amounts shown in inches (Werner, 1993).

Date	Corn Stage	Notes	Max Temp	ET (-)	Irrigation (Net) (+)	Rain (+)	PAW = 7.1"* Stored Water	% of PAW Remaining
7/22/2014	R1	Partly Cloudy, 10-15 mph Wind	86	0.37		0	5.21	73%
7/23/2014	R1	Sunny, 5 mph Wind	82	0.25			4.93	69%
7/24/2014	R1	Cloudy, 10 mph Wind	76	0.21		0.27	4.99	70%
7/25/2014	R2	Sunny, Calm	85	0.31			4.68	66%
7/26/2014	R2	Sunny Calm	89	0.33	1.2		5.5	78%
7/27/2014	R2	Sunny Calm	90	0.35			5.20	73%

*See Example 33.1 for calculation of total PAW (total plant available water) in the profile.

Example 33.2 Determine the effective rainfall for a 3-inch rain. The corn crop is full canopy cover and runoff is not detected.

$$\text{Effecive rainfall}=0.2+[0.8\times(3-0.2)]-0.05=2.39 \text{ inches}$$

In this calculation all rainfall < 0.2 inches counts, 80% of the rainfall > 0.2 inches, and 0.05 inches is subtracted for plant interception.

amount of rain that actually soaked into the soil and is available to the crop. Effective precipitation can be estimated by measuring the gross rainfall and subtracting an estimate of how much of the rain ran on or off the field. Due to runoff, effective rainfall is usually less than the measured rainfall. One approach to estimate effective precipitation is to include all rainfall up to 0.2 inch, and then 80% of any rainfall greater than 0.2 inch. If the crop is at full canopy cover, a small amount (up to 0.05 inch for corn) may be subtracted for water intercepted and retained by the leaves (Example 33.2). Additional details for estimating effective precipitation can be found in Cahoon et al. (1992).

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.

The Hand-feel Method

This is a fast and inexpensive method and it involves estimating the soil water content using your thumb and forefinger. In this method, the hand should be calibrated for different soil textures and moisture contents. Hand-feeling is the least accurate method and should be used only to get a rough idea of water status.

Gravimetric Water Content

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. For the microwave method:

1. Collect 5 to 10 soil cores from a given soil depth and management zone with a soil probe. Note the location of samples and store and seal in a plastic bag.

2. Mix the sample.

3. Weigh a plate and place around 25 g gram (approximately 1 ounce) on the plate and re-weigh. The wet weight of the sample is Ws_{wet}.

4. Place in a microwave for 10 minutes. Weigh, and put in the microwave for an additional 5 minutes. Repeat the process until the weight is constant. The weight of this dry sample is Ws_{dry}.

5. Calculate the gravimetric water content using the equation:
   $\%\ \text{moisture}=\left(\frac{Ws_{wet}-Ws_{dry}}{Ws_{dry}}\right)\times 100\%$ An example of this calculation is shown in Example 33.3.

Soil Water Sensors

The soil water content or status can also be measured with sensors placed in the soil. For irrigation scheduling, sensors should be placed at multiple depths (such as 6", 18", and 30" to represent the top 3 feet of soil) near both the start and endpoint of the irrigation system. When installing a soil water sensor such as a gypsum block or granular matrix block, insert the sensor into a PVC pipe sleeve. This can help you be more accurate with your depth and helps to protect the wire from rodents. Make the hole as

Example 33.3 Calculate the amount of plant available water remaining in the surface 12 inches for a silt loam soil when Ws_{wet} is 25 g and Ws_{dry} is 20 g. In this problem, the bulk density for the soil is 1.3 g cm^{-3} and the percentage of soil water at the permanent wilting point (PWP) is 9%.

Step 1. Determine the gravimetric water content:

$$\% \text{ moisture}=\frac{(25\text{-}20)}{20\times100\%}=25\%$$

This value represents the gravimetric water content. To convert this value to inches of plant available water remaining in the soil, the value needs to be converted to a volumetric basis (Step 2).

Step 2. Determine the amount of plant available water (PAW) remaining in the soil:

$$\text{PAW}=(\text{sample depth})\times(\text{bulk density})\times\left(\frac{\%\text{ moisture - }\%\text{ moisture at PWP}}{100}\right)$$

$$\text{PAW}=12\text{ inches}\times\left(\frac{1.3\text{g}}{\text{cm}^3}\right)\times[(25\text{-}9)/100]=2.5\text{ inches}$$

Note: These calculations convert gravimetric values to volumetric values. Weight-based (gravimetric) values are reported as g/g whereas volumetric values are reported as g/volume. Some instruments measure volumetric values and some measure volumetric values. Only convert gravimetric values to volumetric values.

tight as possible to the diameter of the sensor to assure that the measurements are as representative as possible.

Soils are variable so multiple stations of sensors can be useful to understand the variation of water availability within the field. A balance must be struck between cost and labor requirements for installation of multiple stations and the increased knowledge and understanding of the field that will be gained from the added stations.

To install, use a soil probe as close in diameter as possible to the soil sensor to create the hole, and insert the sensor. There should be a tight fit between the sensor and the soil (Air between the soil and the sensor will affect the readings). If a tight fit isn't achieved, it may be necessary to make a soil-water slurry, pour the slurry into the hole, and place the sensor into the slurry. The slurry will have properties that differ from the surrounding soil so the sensor readings may be affected but to a lesser extent than air pockets. The sensor may not read accurately right after installation. With wetting and drying cycles, the measurements should become more accurate.

The greatest value from soil water sensors can be gained by monitoring them for long periods of time. The accuracy of any single water content measurement may be suspect but changes over time reveal trends that can be useful for managing irrigation water. It is important to monitor and maintain the sensors, so they operate accurately. Practice and skill are required to obtain accurate measurements and information.

Soil water tension can be measured with sensors such as gypsum blocks (Werner, 2002), granular matrix blocks (e.g., Watermark®,

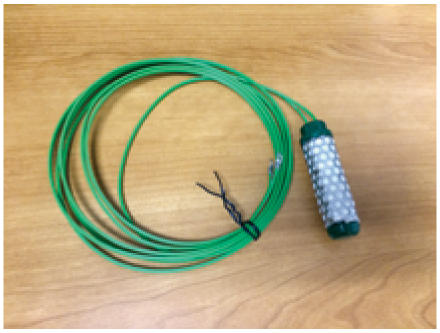

Figure 33.6 Watermark® Granular Matrix sensor. (Irrometer, Co., Riverside, CA). (Courtesy of Todd Trooien, South Dakota State University)

Figure 33.7. ECH$_2$O EC-5 soil water content sensor (Decagon Devices, Pullman, WA, Decagon.com). Note the RD-45 connector at the end of the cable for easy connection to a data logger. (Courtesy of Todd Trooien, South Dakota State University)

Fig. 33.6, Irmak et al., 2014) or tensiometers (Kranz et al., 1989). These sensors measure the soil water tension, the energy with which the water is held in the soil, rather than soil water content. All of these sensors have been used for irrigation management for many years and are readily available at relatively low cost.

Soil water content is often measured with sensors that fall into one of two measurement categories: capacitive sensors or time domain reflectometry (also called transmissivity). Various capacitive soil water content sensors are available, including the ECH_2O (Fig. 33.7, Decagon.com), and the Enviroscan probes (Sentek.com). The ECH_2O sensors are placed at a single depth in a single location. The Enviroscan probe contains a series of sensors located on a single instrument so multiple depths (an entire profile) can be measured at the same time. Research results with capacitive probes have been mixed. Profile capacitive methods such as the Enviroscan have been shown to be unreliable for irrigation management purposes (Evett et al., 2012). But other research has shown that capacitive sensors provide useful information if they are calibrated for local conditions (Rudnick et al., 2015).

Time domain transmissivity (TDT) methods have been shown to be more accurate for use in irrigation management (Evett et al., 2012). Some readily available TDT sensors include: Acclima (Acclima.com) and Gro Point (Esica.com, Evett et al., 2015).

Soil water measurements can improve irrigation management by providing data for making current and future decisions. Storing the data can be done on personal computers, hard drives, or in the cloud. Cloud-based storage will most likely be managed by commercial irrigation management services. If you purchase these services, data is uploaded to the internet and stored on commercial servers. This is beneficial because the information can be accessed by multiple devices. These cloud services typically include decision support software that provides irrigation guidance. There are many systems or packages available.

Critical Plant Growth Stages

The two most critical periods for irrigation of corn are seed germination and from V8 (3 weeks prior to tasseling) to a week after silking (R3). Adequate soil moisture near the soil surface is needed for germination. If the surface soil layer is dry, irrigation may be needed to improve germination and seedling vigor. Adequate water in the root zone is needed for root development.

Between V8 and R3, meeting the high water demand will require planning (Werner, 1993). After R3 corn is less susceptible to water stress than between V8 and R3. From R3 to R6 soil water levels should be allowed to approach 70% maximum allowable depletion. Terminating irrigation before R6 does not promote early maturing and dry-down of the grain (Werner, 1993). Many soils contain 2 to 4 inches of water in the root zone when they reach 60% to 70% maximum allowable depletion. Depleting soil water at the end of the season minimizes nutrient leaching and provides an opportunity for the surface soil to dry prior to harvest.

Irrigation Systems

Surface Irrigation

Surface irrigation has been used for millennia. Surface irrigation is inherently nonuniform because the soil surface is used for water conveyance and 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, thus reducing the difference in infiltration time. Other methods for increasing uniformity include surge irrigation, cutback irrigation, and furrow packing (usually for the first irrigation). Polyacrylamide (PAM) soil amendments are often used to reduce soil erosion when the irrigated soils are particularly erodible.

Center Pivot

Center pivot irrigation is the most popular irrigation method in South Dakota. Center pivot systems can reduce labor requirements (compared with surface irrigation), increase distribution uniformity and irrigation efficiency, and allow the effective application of fertilizer or pesticides with the irrigation water. With center-pivot systems, nozzles can be placed above, at the top of the canopy, or within the corn canopy. Historically, high-pressure systems used high impact, widely spaced sprinklers that were mounted on the pipe. These systems were effective but had high energy requirements. To reduce energy requirements, operating pressures have decreased. Drop hoses or pipes can be used to lower the nozzles to just above or even into the crop canopy. This is known as mid-elevation spray application (MESA). 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. This is known as low-elevation spray application (LESA). The LESA system requires many additional nozzles compared with MESA because the lower pressure creates a smaller wetted diameter from the nozzle. This raises the initial cost of the system but will save money in energy over the long term. In some cases, the sprinkler is covered with a sock that drags on the ground so that water is applied directly to the soil surface. This is called low-energy precision application (LEPA). The greatest 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 inch/hr).

The most-used system is MESA because wind drift and evaporation are reduced compared with the high-pressure system, nozzles are kept out of the crop canopy most of the time, and wetted diameters can be larger than low-pressure systems, which reduces risk of runoff and requires fewer nozzles.

Pressure regulators are an important consideration for sprinkler irrigation systems. When the elevation of a sprinkler changes, the pressure changes. This change of pressure results in a change of water flow rate through the sprinkler. If the irrigation system must go up and down hills, pressure regulators should be used. A pressure regulator will reduce the pressure when the sprinkler is at a low elevation. This keeps the pressure and the flow rate constant when the sprinkler changes elevations. This is important to keep water application uniform across the field. In general, pressure regulators should be installed when the sprinkler flow rate variation exceeds 10%. NRCS recommends the use of pressure regulators when the variation of pressure exceeds 20% (which corresponds to a flow rate variation of 10%). Increasing the pumping pressure will have little to no effect on the nozzle flow rate with pressure regulators. The pressure increase will affect only the flow rate and distance of the spray at the end gun, if installed.

Subsurface Drip Irrigation

Subsurface drip irrigation (SDI, Fig. 33.8) is a microirrigation system. SDI systems have high water-use efficiencies and they have been used to irrigate corn in the central and southern Great Plains. A disadvantage with this system is the high installation cost. Drip lines are normally buried in the soil across the field every 5 feet (60”) for 30-inch rows. This allows every row to be within 15” of a drip line. Even though SDI is expensive, it does offer some additional benefits. Low amounts of nitrogen can be added to the water through the system at any crop growth stage (spoon-fed). SDI systems have the highest potential application efficiency with little to no evaporation. SDI allows for lower pump capacities than a pivot, it will fit into oddly shaped fields, and it covers the whole area. Pressure-compensating emitters can handle some field topography but may still be limited. Maintenance of these systems includes periodic flushing of the lines and chemical injection into the water to provide pH or biological control to help keep the emitters from plugging. Rodents can also pose a threat to these systems, as the plastic tape can be easily punctured. Leaks are often determined by troubleshooting system pressures and by finding excess water at the ground surface.

Figure 33.8 Subsurface drip irrigation (SDI). Water is added to the field near the plant roots with no exposure to the soil surface. (Courtesy of Dr. F.R. Lamm, Kansas State University)

Managing Saline (salts) and Sodium Problems

This section concentrates on salt problems associated with irrigation systems. Additional information on saline and sodic soil management is available in Chapter 32. Salt problems often occur when the irrigation water contains high salt concentration and when the soil has 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 an 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 accumulate 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 (see Chapter 32 as tiling is not suitable for some 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 from the soil profile. The amount of water needed to leach salts is referred to as the "leaching requirement" (LR).

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

LR is determined by measuring the electrical conductivity (EC) of irrigation water and acceptable deep drainage water and then placing those values into the equation above. EC of irrigation water is commonly reported in units of decisiemens per meter (dS/m). A sample calculation is provided in Example 33.4.

Example 33.4 Determine the leaching requirement if the irrigation water EC is 2 dS/m and the acceptable deep drainage EC value is 6 dS/m.

$$LR=\frac{2}{6}=0.33$$

A leaching requirement of 0.33 means that 33% more water (over the plant's requirements) is needed to leach salts from the upper profile. For example, if the plant requires 3 inches of water, 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 ($4 = 3 + [3 \bullet 0.33]$). More information for managing saline soils is provided in Bischoff and Werner (1999).

Toxic Ions (Na and B) Contained in Irrigation Water

Irrigation water can contain ions that are toxic to corn. In South Dakota, two ions of concern are boron (B) and sodium (Na). B can reduce yields when its concentration exceeds 1 mg/L. Many South Dakota aquifers with high concentrations of B also have high concentrations of Na. To determine the B and Na concentrations of your irrigation water, collect a representative pint of water and send it to an appropriate laboratory for analysis. Contact your regional extension center for help in locating a water quality testing lab.

Extreme care must be used in soils with high Na contents or when using water with high Na concentration. Na destroys soils by dispersing soil colloids and destroying soil structure. In addition, high Na reduces water infiltration and permeability. Irrigating with water that has 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 a 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. Additional information about saline and sodic soil problems is provided in Chapter 32.

Table 33.2 Backflow prevention options for site-specific risks. (NRCS MT NEM)

	Reduced Pressure Principal Assembly	Double Check Valve Assembly	Pressure Vacuum Breaker Assembly	Air Gap
Continuous Pressure	X	X	X	
Possible Back Pressure	X	X		X
Possible Back Siphonage	X	X	X	X
Nontoxic	X	X	X	X
Toxic (Chemicals and Pathogens)	X		X	X

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. Recent South Dakota research is showing that application of S is an effective amendment to reclaim sodic soils. If gypsum ($CaSO_4 \bullet 2H_2O$) 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.

Chemigation

An irrigation system with the proper additional equipment can apply fertilizers or pesticides with the water. This practice is commonly referred to as chemigation. Chemigation is well-suited for center pivot systems. However, chemigation is not well-suited for large-volume irrigation guns because of drift and uniformity problems. Advantages of chemigation include: 1) reduced soil compaction, 2) less labor and reduced costs, 3) rapidly applied treatments; and 4) less mixing. The disadvantages include: 1) high initial equipment costs, 2) need for specialized equipment, and 3) some products are not approved for chemigation.

Fertilizer applied through an irrigation system must remain soluble in the irrigation water. If it is not water-soluble, precipitates will form and nozzles, emitters, and fittings can become clogged. If you are unsure of solubility of a fertilizer:

- Fill a clear jar with irrigation water.
- Add the fertilizer at the concentration you will apply to the field.
- Look for precipitates at the bottom of the jar.
- If precipitates form, you should not use that material for chemigation.

After fertilizer application, a small irrigation may be applied to wash the fertilizer off the plant and reduce the possibility of fertilizer burn. When using chemigation to apply liquid nitrogen or other chemicals, you may not need water at the time you want to apply the chemicals. If that is the case, apply the chemicals in a timely fashion but use the least amount of water possible. High-capacity injection equipment and an irrigation system that can cover the field in the shortest period of time are desirable for chemigation.

When chemigating you must also protect the water supply and environment. Backflow of the chemical into a well or other water supply or leakage of the chemical can have serious consequences. State law requires the use of an anti-backflow device when chemigating (SDCL §34A-2A-3). In South Dakota, requirements include an irrigation pipeline check valve, a vacuum relief valve, an automatic low pressure drain, a chemical injection line check valve, interconnect of the injection pump and irrigation pump, and an inspection port. Table 33.2 shows various backflow prevention options. Additionally, standard professional practices for chemigation and water supply protection have been developed (ASAE, 1989).

If applying a pesticide with the irrigation system, the pesticide must be labeled both for corn and for application with the irrigation system. Chemigation is not recommended for use with volume guns (big guns) because of poor application uniformity and wind drift problems. Always read and follow the instructions on the product label and take precautions to protect yourself and others from chemical exposure.

In summary, properly managed irrigation can pay dividends by reducing stress caused by lack of water and thereby increasing crop yields. Irrigated lands should be managed for high yields and high returns to maximize the return on the irrigation investment. Such management might include increasing plant population to best capitalize on investment in irrigation equipment. Irrigation research in Nebraska has shown economic optimum seeding rates for corn might be increased from 26,000 up to 34,000 seeds/acre on irrigated croplands (Barr et al., 2013).

Table 33.3 Water terms used in Chapter 33.

Saturation point	All pores are filled with water.	0 bars
Field capacity	Water in the soil after free drainage.	-1/3 bars
Plant available water	The total amount of water in the soil that the plant can use.	Between -1/3 and -15 bars
Maximum allowable depletion	Point where the irrigation should be turned on.	
Readily available water	Between 30% to 70% of the plant available water.	
Permanent wilting point	Plant will not recover from the water stress.	-15 bars
Evapotranspiration (ET)	Water lost through evaporation and transpiration.	

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Acknowledgements

Support for this document was provided by South Dakota State University, SDSU Extension, and the South Dakota Corn Utilization Council.

Supported in part by:
SOUTH DAKOTA
CORN UTILIZATION COUNCIL
A GROWING INVESTMENT

Ostrem, D., T. Trooien, and Chris Hay. 2016. Chapter 33: Irrigating Corn in South Dakota. In Clay, D.E., C.G. Carlson, S.A. Clay, and E. Byamukama (eds). iGrow Corn: Best Management Practices. South Dakota State University

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