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IRRIGATION HANDBOOK
FOR THE GREAT PLAINS

MONSANTO

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Our mission is to apply innovation and technology to help you – America's farmers and stakeholders grow yield sustainably. Our goal is for you to be successful by producing more abundant, healthier quality food, feed, and fiber while reducing the impact on the environment.

We have multiple cropping system demonstrations focused on the challenges farmers face. In order for growers in this region to increase yield sustainably; water is at the forefront of many of our demonstrations and research. We showcase water utilization methods as well as new technologies in our product pipeline specifically focused on the cropping systems of the High Plains.

IRRIGATION HANDBOOK FOR THE GREAT PLAINS

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INTRODUCTION

Declining groundwater levels in the Great Plains are forcing changes to crop production and irrigation strategies. In order to maximize the productivity of arable ground, farmers need to enhance water use efficiency (WUE) in irrigated agriculture. In the simplest terms, WUE is a measure of the crop yield produced per unit of water used (irrigation plus precipitation).

The Ogallala Aquifer, the world's largest underground water system and the primary source of irrigation water for much of the region, is threatened by overuse.[1] Now, more than ever, farmers are being asked to grow their crops with limited water, mainly due to restrictions on water allocations and reductions in well capacities and application rates. In order to remain profitable, farmers will need to develop strategies to more effectively utilize limited irrigation water. This will require changes in residue management, careful soil moisture and plant monitoring to determine irrigation timing and amount, replacement of inefficient irrigation equipment, and adjustments to cropping practices. With the aid of advanced technologies in plant breeding and agronomic practices, farmers in the Great Plains have the potential to maintain economic returns sufficient for sustainability while reducing costly inputs of water and other natural resources.

Best management practices for conserving water will vary from location to location due to dramatic climatic differences across the Great Plains region. For example, annual rainfall in eastern Kansas averages 40 inches while western Nebraska receives only about 10 to 15 inches annually.[2]

[1]Evett, S.R., Colaizzi, P.D., O'Shaughnessy, S.A., Lamm, F.R., Trout, T.J., and Kranz, W.L. 2014. The future of irrigation on the U.S. Great Plains. Proceedings of the 2014 CPIC, Burlington, Colorado, Feb 25-26.

[2]Average annual precipitation map. The National Atlas. http://www.nationalatlas.gov.

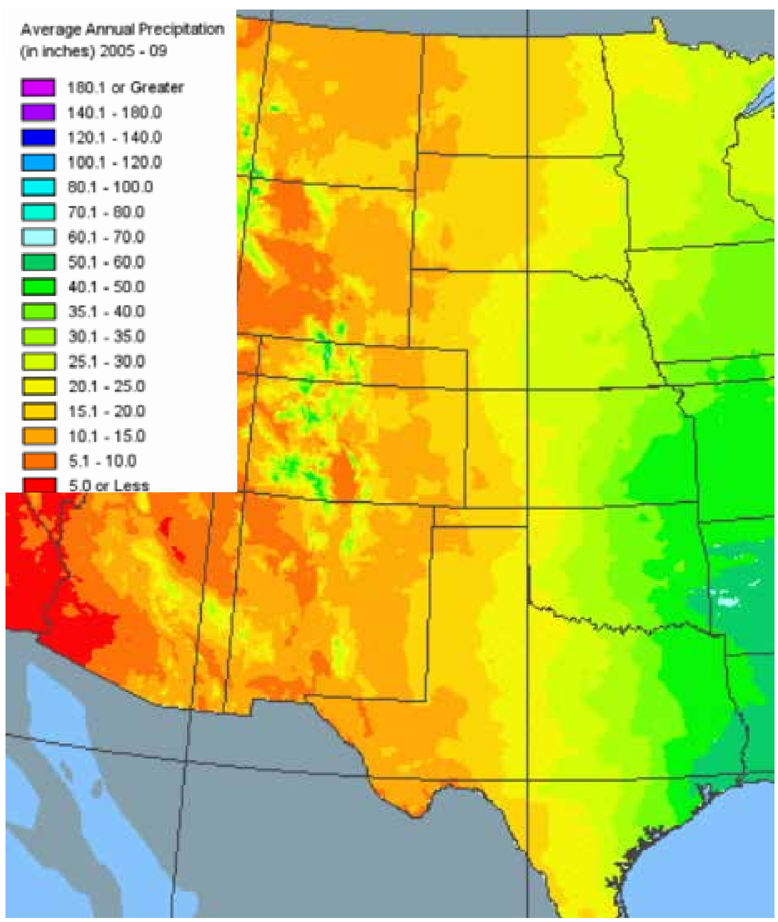


Figure 0.1 Average annual precipitation in the Great Plains, 2005-2009

Source: Average annual precipitation map. The National Atlas. http://www.nationalatlas.gov.

CHAPTER 1
RESIDUE MANAGEMENT

Conventional tillage has negative consequences, especially in the semi-arid regions of the Great Plains. Conventional tillage is full width, deep (greater than 6 inches) tillage that disturbs 100 percent of the soil surface and leaves less than 15 percent residue remaining after planting. This form of tillage, in combination with limited natural precipitation and high winds typical of the region, is a major contributor to soil erosion and loss of soil moisture. According to the USDA, conservation tillage and maintenance of crop residue cover on the soil surface substantially reduces erosion and soil water loss compared to conventional tillage.[1,2] The National Crop Residue Management Survey specifies that 30 percent or more of crop residue must be left after planting to qualify as a conservation tillage system. The benefits of conservation tillage and crop residue management include, but are not limited to:

Figure 1.1 Dust storm, Colby, Kansas, May 2004

- **Greater soil moisture retention.** Crop residues reduce soil moisture evaporation by providing a layer of insulation which reduces solar radiation, wind velocity, and temperatures near the soil surface. In addition, surface residue creates barriers to water movement, which allows more time for infiltration and reduces runoff.
- **Reduced soil erosion.** Stubble and residue anchor the soil, which reduces erosion from wind and runoff.
- **Increased organic matter.** Decomposition of crop residues left after harvest provides additional organic matter, and thereby a greater pool of organic nitrogen.
- **Reduced soil compaction**. Conservation tillage may result in less compaction due to limited passes of equipment through the field. Soil compaction can negatively affect water infiltration rates and reduce soil pore size, which can lead to water runoff and potentially inhibit root growth.[3] On some soil types, soil compaction can occur with long-term conservation tillage. Fields under long-term conservation tillage should be checked periodically for compaction layers.
- **Decreased fuel consumption.** Fewer tillage operations can result in reduced fuel costs. However, without tillage to disturb weeds and certain insects and diseases that overwinter in the soil and crop residues, there is often an increased need for pesticides with conservation tillage.

[1]Kohl, K.D. 1991. Conservation tillage: Effects on soil erosion. Publication AE 3050. Iowa State University Extension.

[2]USDA National Agricultural Library. Sustainable agriculture: Definitions and terms. 2007. www.nal.usda.gov/afsic/pubs/terms/srb9902terms.shtml#term11

[3]Tichota, J. and M. Petersen. 2011. Corn production and strip tillage in the western plains. Monsanto National Research Summary.

Figure 1.2 Water infiltration with strip tillage versus conventional tillage. Soil managed with strip-tillage (left) has better water infiltration compared to a soil managed with conventional tillage (right). Photo courtesy of Orthman Manufacturing, Inc.

Source: Tichota, J. and M. Petersen. 2011. Corn production and strip tillage in the western plains. Monsanto National Research Summary.

CONSERVATION TILLAGE SYSTEMS

Tillage can affect soil physical properties in both beneficial and detrimental ways. The nature of these effects is influenced by the crop and cropping system, soil type, and climate.[1] It may be necessary for farmers to verify and perhaps modify the observations about the effects of tillage systems in the following paragraphs based on local expert knowledge of soil types, crops, cropping systems, and climate.

TILLAGE PRACTICES

No-Till

No-till is the preferred soil management option for dryland production because it preserves more soil moisture over other systems. With no-till, the soil is left undisturbed by tillage and crop residue is left on the surface following harvest. Soil structure, organic matter, and water holding capacity often improve under continuous no-till conditions, generally over a period of five years or greater. Continuous no-till farming can almost eliminate soil erosion.[2] Soil quality may improve because beneficial soil microorganisms and earthworms are left undisturbed, which aid in the buildup of soil organic matter.

In some combinations of soil and climate, no-till farming results in increased soil compaction and increased runoff compared with other conservation tillage systems. This is most likely to occur with finer textured soils and drier climates under which residue amounts may be smaller and soil microbes that promote infiltration are relatively absent compared to more humid regions. Periodic deep tillage may be needed if a compacted layer develops.

Strip Tillage

Strip-till acres in the Great Plains region have greatly increased over the past decade. This system is minimum-till farming where the soil is left undisturbed except for narrow strips where tillage and residue removal are performed to facilitate planting. Strip tillage offers the moisture retention benefits of minimum tillage while facilitating the planting of corn into heavy residues, with the added ability to place fertilizer directly into the tilled plant root zone. The strip tilling operation can be placed several inches away from the old row to improve compacted soil conditions and infiltration in poorly drained soils.[3] Strip tillage can be performed in the fall or spring ahead of planting. Spring strip-till is preferred when cattle graze crop residue during the winter months to minimize any surface compaction issues resulting from cattle foot traffic on non-frozen soils.

Strip tillage is preferred in fully irrigated continuous corn acres due to the added benefit of residue management. Abundant residue can overwhelm planting equipment, decrease planting accuracy, and cause problems with fertilizer placement. Rotations that include low residue producing crops such as soybeans and sunflowers may minimize residue accumulation and may not necessitate strip-till to achieve favorable planting conditions.

Vertical Tillage

Vertical tillage is a form of conservation tillage, referred to as reduced-till, that aids in sizing of residue while limiting the disturbance of the soil. This system involves full-width, shallow tillage that disrupts the top 2 to 3 inches of soil while retaining 30 percent or more surface residue. Vertical tillage tools are used to cut the residue into smaller pieces and mix them with the soil for even distribution and better contact with soil for decomposition. As with any practice that disturbs the soil, this form of tillage will result in greater soil moisture loss than a no-till approach.

CONSERVATION TILLAGE RESEARCH STUDIES

No-till farming can result in water savings and higher yield potential.

In a long-term tillage comparison study conducted near Lincoln, Nebraska from 2000 to 2007, higher yields were consistently achieved with no-till versus conventional tillage across all crops in nearly all years of the study. This study demonstrated that the water conservation benefits of no-till in dryland cropping systems (improved water infiltration, reduced runoff and evaporative losses) can account for a savings of approximately 5 to 12 inches of water per year.[4]

Strip tillage can result in reduced soil compaction and improved soil quality and water infiltration.

A seven-year Monsanto research trial conducted in Yuma, Colorado compared strip tillage to conventional tillage. The study found that soil quality and water infiltration rates were improved in the strip-tilled plots over the conventionally tilled soils. Surface residue and reduced compaction resulting from the practice of strip tillage helped to reduce runoff and allowed the soil to capture more moisture during intense precipitation events. Study results showed that the average time for water to infiltrate on a dry sandy clay loam soil was 1.1 minutes in strip tillage compared to 3.5 minutes for the same soil type under conventional tillage. Similar results were reported for water infiltration into soils at field capacity (Figure 1.3).[3]

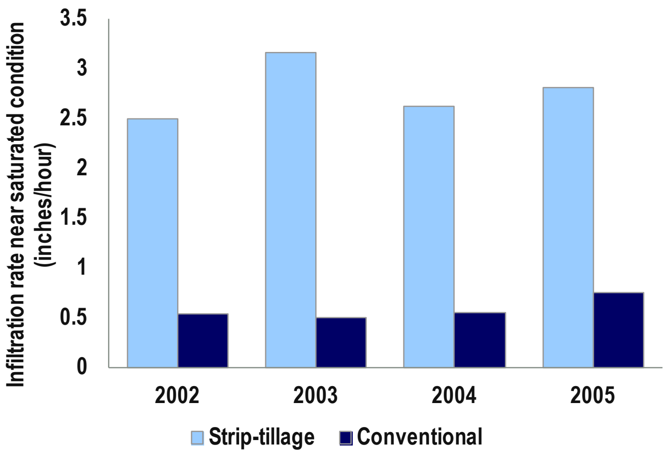


Figure 1.3 Water infiltration in inches per hour into a wet soil managed under strip tillage or conventional tillage systems, Yuma, Colorado.

Source: Tichota, J. and M. Petersen. 2011. Corn production and strip tillage in the western plains. Monsanto National Research Summary.

The degree of soil compaction relative to tillage is dependent on soil type.

Research conducted in Bushland, Texas showed that some soils, like the Pullman soil in the Texas Panhandle, consolidate progressively under no-till and in the long-term have lower infiltration rates and greater runoff than the same soil under conventional tillage.[5] Despite greater runoff under no-till, the Pullman soil in this study had more plant available water for spring planting under no-till due to the decreased evaporative loss that results with higher crop residue levels. This decreased evaporative loss is minimal during drought and for some crops, such as cotton, due to lack of residue.

[1]Pikul Jr., J.L., Schwartz, R.C., Benjamin, J.G., Baumhardt, R.L., and Merrill, S. 2006. Cropping system influences on soil physical properties in the Great Plains. Renewable Agriculture and Food Systems. vol 21(1): 15-25.

[2]Herbek, J., Murdock, L., Grove, J., Grabau, L., Van Sanford, D., Martin, J., James, J., Call, D., Hershman, D., and Johnson, D. 2009. Comparing no-till and tilled wheat in Kentucky. Publication ID-177. University of Kentucky Extension.

[3]Tichota, J. and M. Petersen. 2011. Corn production and strip tillage in the western plains. Monsanto National Research Summary.

[4]Yields from a long-term tillage comparison study. CropWatch. University of Nebraska-Lincoln Extension. http://cropwatch.unl.edu/tillage/rmfyields.

[5]Baumhardt, R.L., Schwartz, R.C., MacDonald, J.C., and Tolk, J.A. 2011. Tillage and cattle grazing effects on soil properties and grain yields in a dryland wheat-sorghum-fallow rotation. Agronomy Journal. vol 103(3): 914-922.

THE IMPORTANCE OF RESIDUE COVER

Decades of studies have demonstrated the benefits to soil structure, soil moisture retention, and the resulting effect on crop yields that year-round residue cover can provide.

Crop residue cover can decrease soil water evaporation, providing an opportunity to boost yield potential.

An experiment conducted near Garden City, Kansas from 2004 to 2006 investigated soil water evaporation during the summer months under a corn canopy. Evaporation was measured from three different types of soil cover: bare soil (no residue), soils covered by corn stover, and soils covered by wheat stover. In this study, crop residue cover decreased soil water evaporation by 3 inches (approximately 50 percent) compared to evaporation from bare soil.

Another study conducted in North Platte, Nebraska from 2007 to 2010 evaluated the effect that residue cover had on corn and soybean yields and soil moisture. In all years of the study, the crop was purposely water-stressed so that any water conservation in the residue-covered plots might translate into higher yields. Higher corn and soybean yields were attained in each year of the study in the plots with residue cover. Two years of corn yields were 25 and 17 bushels per acre greater in the fields with residue cover and resulted in water savings of 3.0 and 3.5 inches, respectively. Two years of soybean yields were 10 and 8 bushels per acre greater in the fields with residue cover and resulted in water savings of 5.0 and 2.5 inches, respectively (Table 1.1).[1]

Table 1.1 Crop yield and water savings for crops grown on residue covered soil and on bare soil at North Platte, Nebraska

		YIELD (BU/ACRE)			WATER SAVINGS (INCHES)		
Year	Crop	Residue	Bare soil	Difference	Yield*	Soil**	Total
2007	Corn	197	172	25	3.0	0.0	3.0
2008	Corn	186	169	17	2.0	1.5	3.5
2009	Soybean	68	58	10	3.0	2.0	5.0
2010	Soybean	61	53	8	2.5	0.0	2.5

*Additional irrigation water needed to produce the same yield on the bare soil plots as was obtained on the residue covered plots. **Additional soil water (in the top 4 ft of soil at the end of the growing season) in the residue covered plots compared to the bare soil plots.

Source: Van Donk, S.J. and N.L. Klocke. 2012. Tillage and crop residue removal effects on evaporation, irrigation requirements, and yield. Proceedings of the 2012 CPIC. Colby, Kansas, Feb 21-22.

Residue cover is important when crops are not growing. In a study conducted in Bushland, Texas, soils with 7,000 to over 10,000 pounds of wheat residue per acre during the fallow period averaged 3.2 to 3.6 inches more soil water stored compared to a bare soil surface prior to planting.[2] To attain 7,000 pounds of residue, a corn or sorghum crop would have to produce 140 bushels, wheat 70 bushels, and soybean 105 bushels.[3] Another Bushland, Texas study demonstrated that wheat residue cover during a fallow period greatly increased infiltration and stored soil moisture prior to planting. However, with sorghum residue on the soil surface, the limited residue cover may have led to surface soil particle consolidation from rainfall, which led to increased runoff amounts for the no-till system compared to the tilled system.[4] In areas where residue cover is limited, a periodic tillage operation may be needed to alleviate surface crusting that can impede infiltration in no-till systems.

The impact of residue cover can vary by amount and geography.
Table 1.2 demonstrates the impact of various levels of residue cover on stored soil water between a winter wheat crop and corn the following spring. Stored soil moisture improved with increasing amounts of residue cover in all locations. Additional stored moisture from the highest residue treatment compared to the bare soil surface ranged from 1.4 inches at Bushland, Texas to 2.7 inches at North Platte, Nebraska.[5]

Table 1.2 Impact of various levels of residue cover (corn following winter wheat) on stored soil water in different geographies

LOCATION	YEARS	INCHES OF STORED SOIL WATER			
		0 lb/acre	1,963 lb/acre	3,925 lb/acre	5,888 lb/acre
Bushland, TX	3	2.8	3.9	3.9	4.2
Akron, CO	6	5.3	5.9	6.5	7.3
North Platte, NE	7	6.5	7.6	8.5	9.2
Sidney, MT	4	2.1	2.7	3.7	4.0

Source: Greb, B.W. 1983. Water conservation: Central Great Plains. In H.E. Dregne and W.O. Willis (editors) Dryland Agriculture. Agronomy Monograph No. 23. ASA. Madison, Wisconsin.

[1]Van Donk, S.J. and N.L. Klocke. 2012. Tillage and crop residue removal effects on evaporation, irrigation requirements, and yield. Proceedings of the 2012 CPIC. Colby, Kansas, Feb 21-22.

[2]Unger, P.W. 1978. Straw-mulch rate effect on soil water storage and sorghum yield. Soil Science Society of America Journal. vol 42(3): 486-491.

[3]Wortmann, C.S., Klein, R.N., and Shapiro, C.A. 2012. Harvesting crop residues. NebGuide G1846. University of Nebraska-Lincoln Extension.

[4]Baumhardt, R.L. 2001. Residue management effects on infiltration into semi-arid drylands. Proceedings of the 2001 Southern Conservation Tillage Conference for Sustainable Agriculture. Oklahoma City, Oklahoma.

[5]Greb, B.W. 1983. Water conservation: Central Great Plains. In H.E. Dregne and W.O. Willis (editors) Dryland Agriculture. Agronomy Monograph No. 23. ASA. Madison, WI.

RESIDUE DISTRIBUTION

Uniform distribution of crop residues from grain harvest is important for year-round soil moisture retention. Proper spreading of residue aids in uniform seed placement and soil warming, and improved crop emergence in the spring. More residue cover results in less soil moisture loss to evaporation, though very high amounts of residue can have negative impacts as well. Too much residue cover can impede planting operations by causing soils to remain too cool and wet in the spring and can create a physical barrier to planting equipment and seedling emergence, resulting in poor seed placement and uneven plant growth.

For proper residue distribution:

- Combines or similar machines used for harvesting should be equipped with spreaders and adjusted to spread residue over the working width of the header.
- Chaff spreaders attached to the rear axle are most effective for spreading wheat and soybean residues because a larger percentage of the harvested residue is handled by the combine's cleaning shoe.[1]
- According to the Natural Resources Conservation Service (NRCS) Conservation Practice Standards, planters or drills should plant directly through untilled residue (for no-till) or in a tilled seedbed prepared in a narrow strip along each row (for strip-till) by planter attachments such as rotary tillers, sweeps, multiple coulters, or row cleaning devices. In reduced tillage operations (vertical-till), residue can be removed from the row area prior to or as part of the planting operation.

Estimating Percent Residue Cover

Knowing the approximate percentage of crop residue cover in the field is not only useful for planning field operations but is sometimes needed to determine if a field qualifies for certain federal, state, or local conservation programs. The USDA recommends using the line-transect method for estimating and reporting percent residue cover. This method involves simple field observations and measurements using a 50- to 100-foot long measuring tape, line or rope that can be marked at 100 equal intervals. Percent cover is determined by counting the number of marks that lie directly over a piece of residue.[2]

For complete details on the line-transect method and worksheets for reporting percent residue cover, please refer to the USDA National Agronomy Manual, pages: 503-126 to 503-128, found at www.nrcs.usda.gov/wps/portal/nrcs/detail/national/technical/references/?cid=nrcs143_026834.

For a general estimate of crop residue cover, when reporting is not necessary, the photo-comparison method can be used. This involves comparing sections of the field that are representative of typical residue cover throughout the field to photographs of known percentage cover.[3]

Example photographs and a detailed explanation on this method can be found in Purdue University's Agronomy Guide, section AY-269-W at www.extension.purdue.edu.

[1]Eck, K.J., Brown, D.E., and Brown, A.B. 2001. Managing crop residue with farm machinery. Agronomy Guide AY280. Purdue University Extension.

[2]Subpart 503E Crop residue. 2011. USDA-NRCS National Agronomy Manual. 4th edition. 503-126 to 503-128.

[3]Eck, K.J. and D.E. Brown. 2004. Estimating corn and soybean residue cover. Agronomy Guide AY269W. Purdue University Extension.

STUBBLE HEIGHT

Standing crop residue such as wheat stubble slows the wind velocity above the soil surface, which reduces the evaporative demand on soil water. Standing residue is more effective than flattened residue at trapping snowfall and retaining moisture in the field for plant use as opposed to the snow blowing to field edges and fence lines.

To reduce evaporative losses and provide adequate snow retention in no-till and strip-till operations, the USDA National Conservation Practice Standards specify that:

- Crop stubble height should be a minimum of 10 inches for crops with a row spacing of less than 15 inches.
- For crops with a row spacing of 15 inches or greater, crop stubble height should be a minimum of 15 inches.
- Following harvest, at least 50 percent of the crop stubble should be left standing for snow catch. Leaving stubble taller than the 10-inch minimum will trap more snow and provide better insulation to plant roots.

Harvesting wheat at taller stubble heights may improve the yield potential of the following crop.

A six-year study initiated in 2006 in Tribune, Kansas demonstrated that dryland corn yielded higher when planted into tall wheat stubble. Corn or grain sorghum grown in a three-year rotation (wheat-summer crop-fallow) at three different stubble heights was evaluated: low-cut (half the optimal cutter bar height averaging 9 inches), optimal (high cutter bar height averaging 18 inches), and strip-cut (stubble remaining after stripper header harvest averaging 27 inches). Corn grain yields averaged from 2007 to 2012 were 11 bushels per acre greater when planted into either optimal or strip-cut stubble than into low-cut stubble. However, no significant effect was seen on grain sorghum yield with respect to stubble height. This study suggests harvesting the wheat crop at shorter stubble heights can result in a yield penalty for the subsequent dryland corn crop.[1]

[1]Schlegel, A. 2013. Effect of wheat stubble height on subsequent corn and grain sorghum crops. Southwest Research-Extension Center 2013 Field Day Report. Kansas State University Extension.

CROP ROTATION

Increasing restrictions on water use in the Great Plains region is challenging the production of continuous corn. Crop rotation can be used for better water conservation (discussed in Chapter 2) and residue management. Over time, crop rotation can result in improved soil physical, chemical, and biological properties. This improved soil structure can lead to an increase in the water holding capacity of the soil, particularly in no-till systems.

Alternating between high and low residue crops allows more time for the heavy residues to break down, potentially reducing residue management costs. Corn and wheat are considered high residue crops which decompose slowly. These residues can become burdensome, especially in the practice of irrigated continuous corn, and will often require some removal or tillage. Soybeans are considered low residue crops and are more easily decomposed. Winter wheat can be planted directly following a soybean crop because the wheat provides better winter cover than the fragile soybean residue alone. This is practical because soybeans are usually harvested early enough to allow time for winter wheat to establish.

The "best" crop rotation strategy will differ by region depending on many factors including precipitation and evapotranspiration rates. Consult local University and USDA Agricultural Research Service (ARS) studies for the crop rotations that work best in your area.

COVER CROPS

In some regions, additional water savings may be realized with the incorporation of a winter annual such as wheat due to added snow catch and reduced soil water evaporation. Planting corn or soybean following winter wheat can be a good strategy because wheat stubble can retain high amounts of soil moisture in early spring. While in some cases cover crops (winter annuals) have been shown to improve soil quality, farmers in drier regions should consider the water consumed by the cover crop. In areas where rainfall is the limiting factor in crop production, water consumed by cover crops may reduce the water available for the subsequent crop. The benefits and drawbacks of cover crops will vary by each field's soil type and local climate.

In the semi-arid regions of the Great Plains, cover crops may have an adverse effect on stored soil moisture.

Research at Akron, Colorado and Sidney, Nebraska has shown that cover crops grown during the fallow period reduced the available soil water at wheat planting (Figure 1.4). Subsequent wheat yield was reduced by almost 6 bushels per acre for every inch of water used by the cover crop that was not replenished prior to wheat planting.[1]

A study conducted near Bushland, Texas, found that terminated wheat grown before cotton production had an adverse effect on stored soil moisture. The main disadvantage of the terminated wheat-cotton system is the amount of water used to establish the wheat residue, water that could potentially be used by the cotton crop.[2]

[1]Nielsen, D.C., Lyon, D.J., and Hergert, G.W. 2013. Cover crop water use and impacts on wheat yields in the Central Great Plains. Proceedings of the 2014 High Plains Ag. Lab. Advisory Committee Annual Meeting. Sidney, Nebraska, Feb 13.

[2]Lascano, R.J. and R.L. Baumhardt. 1996. Effects of crop residue on soil and plant water evaporation in a dryland cotton system. Theoretical and Applied Climatology. vol 54: 69-84.

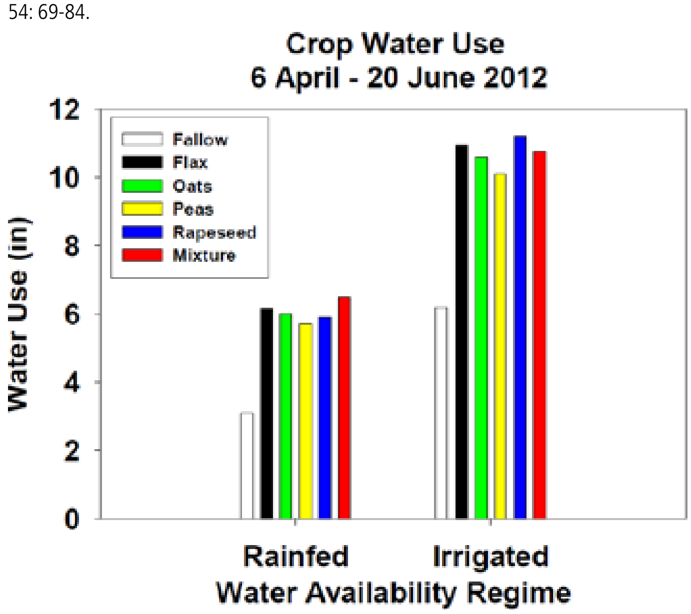


Figure 1.4 Water use by spring planted cover crops versus fallow at Akron, CO

Source: Nielsen, D.C., Lyon, D.J., and Hergert, G.W. 2013. Cover crop water use and impacts on wheat yields in the Central Great Plains. Proceedings of the 2014 High Plains Ag. Lab. Advisory Committee Annual Meeting. Sidney, Nebraska, Feb 13.

RESIDUE REMOVAL

Grazing

Late fall and winter grazing of cattle on crop residues, a common practice in the Great Plains region, can benefit both the cattle industry and crop producers. Grazing reduces the amount of winter feed needed for the cattle and the related costs of feed storage. For the crop producer, grazing cattle removes some of the excess crop residue that can cause problems with soil warming and emergence in the spring. Grazing can also reduce fuel and labor costs associated with residue management practices, like shredding stalks. Crop producers also benefit from the rent paid by the cattle owner for use of the land and for the nutrients in the manure left behind. Corn and grain sorghum residues are the most common grazing material as they are comparable in nutritional value to grass hay. Soybean residue is lower in nutritional value due to high levels of indigestible lignin.

Concerns surrounding the practice of grazing include potential soil compaction, residue compliance, and the removal of organic matter and nutrients. Proponents cite that compaction resulting from cattle grazing is generally limited to the top 6 inches of soil and that this shallow compaction has shown no adverse effects on subsequent crop yields, even in no-till.[1] Livestock grazing in northern regions typically occurs when soils are frozen, which minimizes compaction. In addition, freeze/thaw cycles in these regions may naturally alleviate soil compaction. In a typical grazing period, cattle grazing cornstalks or grain sorghum residue generally consume 25 to 50 percent of the available residue, depending on stocking density and grazing time.[1] Nebraska research suggests that cattle are only able to digest about half of that, returning the remainder back to the soil in the form of manure.[2] In one Nebraska study, an average of only 13 to 23 percent of the residue was removed during light grazing and heavy grazing, respectively, over approximately 65 days of grazing.[2]

The residue management and nutrient benefits of grazing may outweigh the potential negative effects.

Nebraska studies comparing yields of crops grown in grazed and un-grazed acres, with differing tillage and irrigation practices, have indicated that yields are generally either not affected or slightly increased by grazing. An ongoing corn-soybean rotation study initiated in 1996 at the University of Nebraska-Lincoln was designed to evaluate subsequent crop yields following fall-winter or spring grazing on irrigated and dryland acres. Averaged yields over the course of the study for the irrigated plots have shown a 2 bushel per acre yield increase for soybean following fall-winter grazing of corn stalks and a 1.3 bushel per acre yield increase with spring grazing, compared with no grazing (Table 1.3). No significant effect was observed with the other treatments.[3]

Table 1.3 Effect of fall-winter and spring grazing of corn stalks on average yield of the following crop (1996-2011)

FOLLOWING CROP	SPRING GRAZED YIELD (BU/ACRE)	FALL GRAZED YIELD (BU/ACRE)	UNGRAZED YIELD (BU/ACRE)
Soybean	61.7	62.4	60.4
Corn*	207	209	206

*The corn yield was for the second crop following grazing.

Source: McGee, A.L., Klopfenstein, T.J., Stalker, L.A., and Erickson, G.E. 2012. Effect of grazing corn residue on corn and soybean yields. 2013 Nebraska Beef Cattle Report. Publication MP98. University of Nebraska-Lincoln Extension.

The consensus of current research data suggests that on most soils the potential negative effects of grazing are minimal compared to the added residue management and nutrient benefits to both the cattle and soils that can be achieved.

Grazing may cause increased compaction on some soils and subsequently reduce crop yields.

In contrast to the study mentioned above, a cumulative negative effect of grazing was reported in no-till plots on a Pullman clay loam soil near Bushland, Texas; possibly due to compaction by trampling. This study described reduced storage of fallow precipitation in the soil and consequently, lower grain yields of the no-till wheat and sorghum that was sufficient enough to offset much of the grazing benefits.[4]

Effects of Removing Large Amounts of Residue

The removal of large amounts of crop residue, for example in forage crops such as silage corn, can have a negative impact on subsequent crop yields. This yield loss is due to increased erosion and deleterious effects on soil properties such as decreased soil organic matter and soil moisture, and greater fluctuations in soil temperature. This is especially impactful in dryland or limited water crop production.

A three-year study conducted in Kansas on rainfed and irrigated continuous corn under reduced tillage and no-till practices found that removal of 50 percent or more of the corn residue resulted in a loss of stored soil moisture and more abrupt soil temperature fluctuations in all locations of the study. Soil erosion also increased with residue removal in this study. Removal of crop residue had more negative effects on soil properties in rainfed than in irrigated soils.[5] Though grain yields of the subsequent corn crop in this study were not affected by residue removal, other studies have demonstrated that as greater amounts of residue are removed, grain yield and biomass are decreased. This yield loss is due to the negative effects that residue removal has on soil organic matter, soil water, and soil temperatures.[6,7] Discrepancies in yield response among studies may be due to differing tillage practices and soil types.

Drought in the Great Plains in recent years has depleted hay resources and cattle producers have turned to baled crop residue for feeding cows during the winter months. Baling crop residue has a similar negative effect on soil moisture storage as does harvesting silage corn; both of which reduce crop residue levels well below the recommended amounts.

In fields where large amounts of residue are being removed, management practices that may help to minimize these negative effects, such as reduced tillage and cover crops, should be considered. Additionally, with the removal of crop residues, organic matter and essential nutrients are also removed. Soil tests should be conducted to determine fertility needs for the subsequent crop prior to the next growing season.

[1]Rasby, R.J., Erickson, G.E., Klopfenstein, T.J., and Mark, D.R. 2008. Grazing crop residues with beef cattle. Publication EC278. University of Nebraska-Lincoln Extension.

[2]McGee, A.L., Harding, J.L., van Donk, S., Klopfenstein, T.J., and Stalker, L.A. 2013. Effect of stocking rate on cow performance and grain yields when grazing corn residue. 2013 Nebraska Beef Cattle Report. Publication MP98. University of Nebraska-Lincoln Extension.

[3]McGee, A.L., Klopfenstein, T.J., Stalker, L.A., and Erickson, G.E. 2012. Effect of grazing corn residue on corn and soybean yields. 2013 Nebraska Beef Cattle Report. Publication MP98. University of Nebraska-Lincoln Extension.

[4]Baumhardt, R.L., Schwartz, R.C., MacDonald, J.C., and Tolk, J.A. 2011. Tillage and cattle grazing effects on soil properties and grain yields in a dryland wheat-sorghum-fallow rotation. Agronomy Journal. vol 103(3): 914-922.

[5]Kenney, I., Blanco-Canqui, H., Presley, D.R., Rice, C.W., Janssen, K., and Olson, B. 2013. Soil and crop response to stover removal from rainfed and irrigated corn. Global Change Biology Bioenergy. published online.

[6]Wilhelm, W., Doran, J.W., and Power, J.F. 1986. Corn and soybean yield response to crop residue management under no-tillage production systems. Agronomy Journal. vol 78: 184–189.

[7]Wilhelm, W., Johnson, J.M.F., Hatfield, J.L., Voorhees, W.B., and Linden, D.R. 2004. Crop and soil productivity response to corn residue removal: A literature review. Agronomy Journal. vol 96: 1-17.

CONSERVATION COMPLIANCE

Beginning in 1985, some fields were designated as highly erodible lands by the Natural Resources Conservation Service (NRCS) and have been required to adhere to Conservation Compliance Guidelines set forth by the USDA. These guidelines mandate that highly erodible lands must be farmed in a manner that maintains a certain level of residue and minimizes soil erosion. Farmers found to be in violation of these guidelines can be made ineligible for Farm Service Agency (FSA) and NRCS program benefits. This ineligibility also extends to other lands in which that farmer has interests. Fields that are determined not to be highly erodible land are not required to maintain a conservation system to reduce erosion. To ensure that conservation compliance requirements are met, it's important for farmers to work closely with their local NRCS and FSA offices. Review and understand existing highly erodible land determinations on FSA maps and communicate with NRCS regarding what steps are required on these lands to ensure that an approved conservation system is being used. NRCS can develop a conservation plan using crop rotations, tillage methods, cover crops, and other conservation practices to ensure compliance with these provisions.

More information on the USDA, National Conservation Practice Standards can be found at www.nrcs.usda.gov/wps/portal/nrcs/detail/national/technical/references/. State conservation practice standards are available through the Field Office Technical Guide (FOTG). If no state conservation practice standard is available in the FOTG, contact the appropriate state office or the local USDA Service Center. National Conservation Practice Standards should not be used to plan, design, or install a conservation practice. Conservation practice standards should be developed locally to ensure that all state and local criteria are met, which may be more restrictive than national criteria.

Conservation compliance an important part of planning. 2014. Nebraska Farm Bureau. www.nefb.org.

USDA Farm Service Agency. www.fsa.usda.gov/FSA

KEY TAKEAWAYS

- Use conservation tillage systems which retain high amounts of residue, no-till or strip-till, to improve water infiltration and decrease soil water evaporation and soil erosion.
- In some soil/location combinations, periodic deep tillage may be required to mitigate compaction and increase infiltration in a no-till system.
- Uniform residue distribution is essential in order to observe the benefits of crop residues.
- Increasing small grain stubble height is an excellent way to increase snow retention while decreasing water evaporation.
- Alternating high and low residue crops is a good tool to manage residue levels on irrigated fields.
- In most areas, properly managed cattle grazing can be an effective residue management tool.

CHAPTER 2
IRRIGATION SCHEDULING

WATER RESTRICTIONS AND REDUCED CAPACITY

FUNDAMENTALS OF IRRIGATION SCHEDULING

DETERMINING SOIL MOISTURE AND EVAPOTRANSPIRATION

IRRIGATION SCHEDULING TECHNOLOGY

IRRIGATION SCHEDULING FOR CORN

IRRIGATION SCHEDULING FOR SOYBEAN

IRRIGATION STRATEGIES WITH LIMITED WATER RESOURCES

KEY TAKEAWAYS

Reductions in well capacity, increased pumping costs, and water policy restrictions have left farmers with little choice but to maximize the use of natural precipitation, stored soil moisture, and irrigation. The goal of irrigation management is to use water in the most profitable way while maintaining yields at sustainable production levels. Irrigation will need to be applied only when soil moisture measurements and crop growth stage warrant water inputs, and in a way that limits any waste or excess. With concerns over declines in groundwater levels, pumping restrictions, and increases in fuel prices, any overuse or loss of irrigation increases irrigation expenses without increasing income and wastes valuable resources. This chapter focuses on water management for grain crops.

WATER RESTRICTIONS AND REDUCED CAPACITY

As groundwater reserves in the Great Plains continue to decline, policies and regulations are evolving in an attempt to bring water consumption to sustainable levels. These policy changes include rules pertaining to water meters and reporting of water use, yearly water allocations, and limits or moratoriums on new irrigated acres. Kansas and Texas have some of the largest depletion rates in the eight states underlain by the Ogallala Aquifer.[1] In 2005, the North Plains Groundwater Conservation District of Texas set an annual pumping limit of 24 inches per acre. In 2012, the district reduced the limit to 18 inches.

A study conducted by Kansas State University suggests that in order to bring the removal rate close to the aquifer recharge rate, water consumption would need to be cut by 80 percent.[2] In response to these concerns, Kansas has seen some of the strictest water limits in the Great Plains. Farmers in Sheridan County, Kansas are limited to 55 inches of water per acre over five years. This equates to an average of 11 inches per acre per year, about a 20 percent cut in water use. Many areas in Kansas, Colorado, Texas, and Nebraska are facing reduced capacity as a result of decreased saturated thickness in their reservoirs. Some regions have seen a 300 percent increase in the time it takes to pump water (B. Olson, personal communication, May 9, 2014). For example, a well that had a flow rate of 1000 gallons per minute would only take two to three days to pump one inch of water per acre on a typical center pivot. With the reduction in pumping flow, this same well may only pump 300 gallons per minute and take eight to ten days to pump one inch of water.

[1]Evett, S.R. 2014. The future of irrigation on the US Great Plains. Proceedings of the 2014 CPIC. Burlington, Colorado, Feb 25-26.

[2]Steward, D.R., Bruss, P.J., Yang, X., Staggenborg, S.A., Welch, S.M., and Apley, M.D. 2013. Tapping unsustainable groundwater stores for agricultural production in the High Plains Aquifer of Kansas, projections to 2110. Proceedings of the National Academy of Sciences. vol 110(37): 3477-3486.

FUNDAMENTALS OF IRRIGATION SCHEDULING

Irrigation scheduling is a planning, measuring, and decision making process focused on the primary questions of how much water to apply and when and where to apply it. These determinations may be based on observations of crop water stress, weather-based estimates of crop water use, soil water content determinations, or some combination of these. To effectively use weather-based crop water use estimates, farmers need to estimate how much water is in the soil and available for plant uptake and how much water is being used from the soil in a given day.

Evapotranspiration

The most widely used form of irrigation scheduling is based on crop water use and soil water evaporation and how these two processes, combined with precipitation and stored soil moisture, are used to determine irrigation needs. In any irrigation scheduling discussion, it is important to understand the term evapotranspiration (ET). Evapotranspiration is used to describe the loss of moisture through evaporation (E) from the soil and transpiration (T) through the plant. Transpiration is the movement of water from the soil into plant roots, through plant stems and leaves, and back out into the atmosphere. Many factors impact ET and need to be considered when determining irrigation needs.

- **Crop species.** Some crops have higher water requirements than others. For example, corn versus winter wheat.
- **Crop growth stage.** Crop water requirements vary depending on growth stage. Young plants transpire less than larger plants due to a smaller leaf surface area. Many crops, such as corn, require the most water just prior to and during the reproductive growth stages.
- **Relative maturity.** Longer season corn and soybean will require more water over the growing season than short-season products.
- **Weather conditions.** Daily ET is influenced by solar radiation, air temperature, relative humidity, and wind. High air temperatures, low humidity, clear skies, and high winds cause a large evaporative demand.
- **Water holding capacity of the soil.** Fine textured soils hold more water than coarse textured soils. A soil's water holding capacity indicates both amount of water available for plant use and the maximum allowable depletion of the soil water.
- **Tillage system.** Minimizing soil disturbance from tillage and increasing surface crop residue can reduce soil water evaporation.

When to Apply Irrigation

The answer for when to apply irrigation is affected by the rate of ET, which over time influences the amount of plant available water in the soil. Plant available water is an important concept in irrigation scheduling. The water content of a soil that has been saturated by rainfall or irrigation and allowed to drain is at field capacity (100 percent plant available water). Plants can extract water from the soil up to a certain point at which the soil particles have a stronger affinity for the water than the plant roots. This point is called the permanent wilting point (0 percent plant available water) and is often defined as the soil water content at which the crop wilts and cannot recover if irrigated. The water held by the soil between field capacity and the permanent wilting point is considered plant available water.

The amount of plant available water differs greatly by soil texture. Ideally, irrigation is applied before available soil water content drops to a level at which plant stress will occur, which is before the permanent wilting point. This point is called the maximum allowable depletion level, also known as the management allowed depletion (MAD). See Figure 2.1 for a diagram of soil water content. The MAD will vary by crop species and crop developmental stage. The MAD may also vary by the circumstances of the individual farmer who may choose to irrigate before the soil becomes dry enough to limit plant growth and yield potential, or the farmer may choose to allow some plant stress to develop prior to an irrigation. For most crops, a MAD of 50 percent is acceptable. For sensitive, shallow rooted plants on heavy, compacted soils, a smaller MAD between 30 and 50 percent should be considered. A larger MAD of 50 to 70 percent may be used with stress-tolerant plants, deep root zones, or lighter soils.

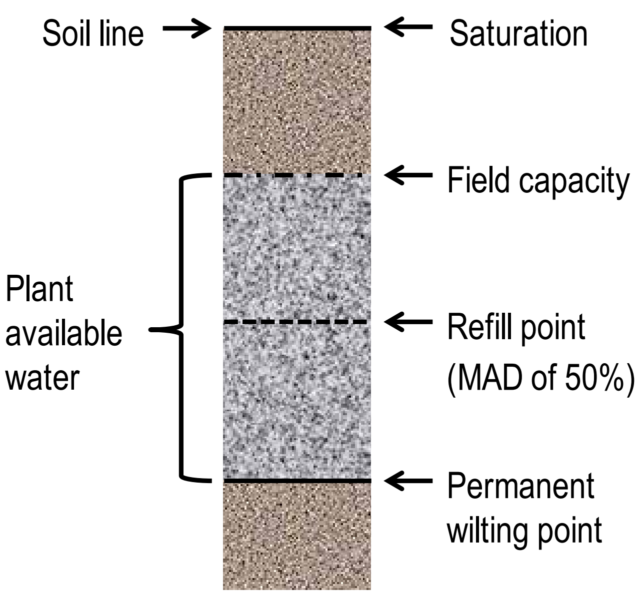


Figure 2.1 Soil water content.

How Much Irrigation to Apply

The answer for how much water to apply will depend on:

- The depth of the crop roots (related to plant growth stage)
- The water holding capacity of the soil (water in the soil profile that can be extracted by plants, related to soil type)
- The efficiency of the irrigation system (percent of the total output that makes its way to the root zone where plants can absorb it versus loss to evaporation, deep percolation, and runoff)

Another important term to define is available water holding capacity (AWHC), which is the amount of water that can be held in all horizons of the rooting zone that is available to the crop. By knowing the soil type, a farmer can determine the soil's water holding capacity. A table listing the water holding capacity of different soil types is presented later in this chapter (see Table 2.4). Irrigation should be targeted to the depth of the crop roots. Multiplying the soil's water holding capacity by the depth of the crop roots gives a general estimate of the AWHC of a volume of soil to that particular depth. Young plants may only have a rooting depth of 1 foot. Irrigation in excess of the AWHC of the soil at a specific stage of growth may not be utilized by the plants, and thus may be wasted. By using these three variables (rooting depth, water holding capacity, and irrigation efficiency) farmers can calculate the maximum amount of water to apply at one time if the soil moisture level is depleted. See the section in this chapter on Irrigation Scheduling for Corn for example calculations on how much water to apply in a given situation.

A farmer would not necessarily need to apply the full amount of irrigation needed to bring the water content of the soil back to field capacity, especially if rain may be in the forecast. When factoring in precipitation, it is important to note that not all of the rainfall will become available to plants. A portion of the rainfall could be lost to runoff and deep percolation depending on factors such as soil type, duration and intensity of rainfall, and soil moisture levels. In general, leaving room in the soil profile for a precipitation event is a wise way to save money on irrigation costs. However, this is a risky practice in arid and semi-arid regions where the probability of natural precipitation is lower. In these regions, farmers may want to fill the soil closer to field capacity rather than leave room for possible rain in order to avoid playing catch-up. This decision will need to be carefully weighed against plant growth stage (Is the plant in the reproductive stages where water stress is critical?) and water allocations remaining for the season.

Water Measurement as a Management Tool

Most farmers with limited water supplies have an impeller flow meter installed to monitor total volume of water pumped in response to a water allocation. Water measurement can provide the basis for evaluations to optimize irrigation applications. Water measurement data can help determine overall irrigation system efficiency, monitor system performance, detect well problems, monitor pumping plant performance, and simplify completion of the annual water use report. For information on selection, installation, and maintenance of an irrigation flow meter, consult the Kansas State publication Irrigation Water Measurement as a Management Tool.

Evett, S.R. 2007. Soil water and monitoring technology. p 25-84. In R.J. Lascano and R.E. Sojka (editors) Irrigation of agricultural crops. 2nd edition. Agronomy Monogram No. 30. ASA, CSSA, and SSSA. Madison, Wisconsin.

Kranz, W.L., Irmak, S., van Donk, S.J., Yonts, C.D., and Martin, D.L. 2008. Irrigation management for corn. NebGuide G1850. University of Nebraska-Lincoln Extension.

Rhoads, F.M. and C.D. Yonts. 2013. Irrigation scheduling for corn-why and how. NCH-20. In National Corn Handbook. University of Wisconsin Extension.

Rogers, D.H., Clark, G., and Alam, M. 2002. Irrigation water measurement as a management tool. Publication L878. Kansas State University Extension.

DETERMINING SOIL MOISTURE AND EVAPOTRANSPIRATION

Many tools are available for estimating soil moisture and ET, ranging from spreadsheets to sophisticated web-based applications that have access to soil databases and weather networks. Several basic strategies for irrigation scheduling are outlined below.

DAILY CROP EVAPOTRANSPIRATION ESTIMATES

An ET-based irrigation scheduling system uses cumulative daily crop ET along with water inputs from irrigation and precipitation to estimate daily soil water content to indicate when water reserves in the soil will be depleted below a certain threshold. Initially, a determination of the current amount of available water in the plant root zone is made to serve as a starting point to track water inputs and withdrawals. This requires soil water content estimation or measurement. From this starting point, the daily soil water balance is tracked by recording daily withdrawals of water using crop ET values and daily water inputs from precipitation or irrigation.

Crop ET estimates are made in relation to a fully irrigated alfalfa crop or a cool season grass, called a reference ET, and a crop coefficient that varies by crop and developmental stage. The crop coefficient is multiplied by the reference ET to get the estimate of actual crop ET for a particular field.

Reference ET

Reference ET values are dependent on weather conditions such as solar radiation, temperature, humidity, and wind speed. Because this value depends on climate and varies from location to location, it should be accessed from local sources for greatest accuracy. Several examples of online sources for daily reference ET values include:

- Colorado Agricultural Meteorological Network (www.CoAgMet.com)
- Kansas State University (www.ksre.ksu.edu/irrigate/ET/ETinfo.htm)
- University of Nebraska-Lincoln (http://elkhorn.unl.edu/ETGage/xml/NE_counties_2.jsp)
- High Plains Regional Climate Center (www.hprcc.unl.edu/awdn/et)
- Texas ET Network (http://texaset.tamu.edu)
- The local water district or County Extension Agent may also be able to provide information on reference ET values.

Crop Coefficients

The crop coefficient, denoted K_c, is the fraction of the reference crop ET that is used by the actual crop. For example, the crop coefficient for corn at the 4-leaf stage of growth in the Texas North High Plains is 0.45 (Table 2.1). This means, at the 4-leaf growth stage a corn crop in this region will have about 45 percent of the ET of a fully irrigated alfalfa crop. The crop coefficient for corn at the tassel stage is 1.25, or 125 percent of the ET of a fully irrigated alfalfa crop. Young seedlings generally have smaller crop coefficient values while crops at peak vegetative stage with canopies fully covering the ground will have larger crop coefficient values. Crop coefficients, like reference ET values, should be accessed from local sources for greatest accuracy. Some sources for crop coefficients include:

Table 2.1 Corn crop coefficients (K_c) from the Texas North High Plains

GROWTH STAGE	K_c VALUE
Seed	0.25
Emergence	0.35
4-leaf	0.45
5-leaf	0.70
6-leaf	0.85
8-leaf	1.00
10-leaf	1.15
12-leaf	1.20
14-leaf	1.25
Tassel	1.25
Silk	1.30
Blister	1.30
Milk	1.30
Dough	1.20
Dent	1.00
Black layer	0.70

Table modified from Fipps, G. Growers Guide: Using PET for determining crop water requirements and irrigation scheduling. Texas A&M AgriLife Extension.

- High Plains Regional Climate Center (www.hprcc.unl.edu/awdn/et)
- University of Nebraska-Lincoln (UNL NebGuide G1579, Using Modified Atmometers (ETgage) for Irrigation Management)
- Texas ET Network (http://texaset.tamu.edu)
- Colorado State University (www.ext.colostate.edu/pubs/crops/04707.html)
- Kansas State University, Alfalfa-based Penman Crop Coefficients for Western Kansas (www.ksre.ksu.edu/pr_irrigate/Reports/kstatereport.htm)
- The FAO (Food and Agriculture Organization of the United Nations) has published

a list of generalized crop coefficients which are used throughout the world where local values are not available. See the publication Crop Evapotranspiration – Guidelines for Computing Crop Water Requirements.

By knowing the crop growth stage and the reference ET, a simple calculation allows the estimation of crop water use for each field. If the reference ET for a given day is 0.26, the crop water use on that day for a tassel stage corn field in the Texas North High Plains is 0.33 inches (0.26 x 1.25).

Checkbook Method

The most basic method for irrigation scheduling, referred to as the checkbook method, involves manual recordkeeping of the different water input and withdrawal parameters mentioned above. Irrigation timing and amounts are also calculated manually from these parameters. For detailed information on the checkbook method and calculation worksheets, refer to Irrigation Scheduling: Checkbook Method, publication number EC709 from the University of Nebraska-Lincoln.

SOIL MOISTURE SENSORS

Soil moisture estimations should be periodically validated or updated by soil moisture sensors to prevent ET-based scheduling from failing due to divergence of soil moisture estimates from reality. If the actual crop water use for a field is significantly different from the ET-based estimate, this situation could lead to crop stress or over-irrigation. Comparing predicted soil moisture with actual soil moisture measurements every couple of weeks is a good strategy for ensuring the ET-based scheduling method is accurate.

Testing soil for moisture content can be accomplished by observing the soil's appearance and feel (the "feel" method), weighing soil samples before and after oven drying (gravimetric method), and by use of soil moisture sensing instruments. Soil moisture sensors can be placed at differing depths in the crop root zone to provide the farmer with a direct measure of changes in soil water content for determining when irrigation might be needed. Examples of some common soil moisture sensing instruments include: tensiometers (measure soil water tension or suction), electrical resistance blocks (measure the change in electrical resistance during wetting and drying cycles), capacitance probes and frequency domain reflectometry (FDR), time domain reflectometry (TDR), and time domain transmissometry (TDT) soil moisture sensors (measure a soil's dielectric constant).

Taking Accurate Measurements

For representative readings, measurements should be taken from the principle soil type, within the active crop root zone, and away from high spots, depressions where water may collect, and slope changes. Soil water content may vary greatly within a field, so multiple measurements throughout the field and at appropriate depths will be required to reduce error and oversimplification. Typical installations include one or more sensors for each foot of active rooting depth. Studies suggest that the variability amongst soil samples increases as soils dry, indicating that more measurements will be needed for accuracy as soil water content reaches the MAD.[1] For methods that can measure larger volumes of soil, such as gravimetric sampling, a minimum of three to four measurements at locations chosen to be representative of the field may be sufficient. A greater number of readings will be needed with soil moisture sensors that measure smaller volumes of soil, such as with capacitance probes.[1] When choosing locations in the field to measure soil water, it may be most cost effective and efficient to take measurements in areas where soil and plant properties are most representative of the field.

The depth to which a particular method can measure soil moisture and the resolution at increasing depths should also be considered. Ideally for irrigation scheduling, soil water should be measured to

Table 2.2 Advantages and disadvantages of different methods for measuring soil moisture

METHOD	ADVANTAGES	DISADVANTAGES
Appearance and feel	Easy, simple, accuracy dependent on experience	Lower accuracy, labor intensive
Gravimetric (oven drying)	High accuracy with increased sampling, direct measure	Very labor intensive, delays to obtain data
Tensiometers (soil water tension)	Instantaneous, approximates soil moisture content	High maintenance, tension breaks, freezing temperatures
Electrical resistance	Instantaneous, increased range, approximates soil moisture content	Slower response, less sensitive at low moisture, affected by soil salinity
Capacitance and FDR (frequency domain)	High accuracy, volumetric water content and salinity	Highly influenced by adjacent moisture/voids
TDR and TDT (time domain)	High accuracy, volumetric water content and salinity, robust calibration	High installation cost, highly influenced by adjacent moisture/voids

Table modified from Crookston, M.A. 2011. Utilizing soil moisture readings in irrigation scheduling. Proceedings of the 2011 CPIC. Burlington, Colorado, Feb 22-23.

well below the maximum depth of root water extraction, though this is not always attainable with most soil water measurement methods. Conventional TDR is one method that allows the flexibility of deeper measurements.

Installation and Calibration

Proper installation is important for accuracy and longevity of soil moisture sensors. Sensors must be in direct contact with undisturbed soil in order to provide accurate readings. During installation, ensure that damage to roots and soil structure is minimized and avoid air voids, large roots, rocks, and other obstructions. All soil moisture sensors should be calibrated in the field for the specific soil type they are used with, even if the manufacturer suggests otherwise. Laboratory calibrations are often made on re-packed soils, where tight soil-access tube contact is ensured and variability in the soil is minimized. These measurements may not be transferrable to the field, particularly for capacitance or other FDR sensors. Field calibration can provide more accurate readings because the sensor is placed in the actual soil to be studied.

Use ET-Based Scheduling in Combination with Soil Moisture Sensors

Soil moisture sensors and ET-based irrigation scheduling should be used in combination to corroborate each method's accuracy. For example, if soil moisture sensors are placed in a low area of the field where runoff water congregates, soil water determinations based on this method alone will likely be much higher than the rest of the field. Using ET-based scheduling in addition to soil moisture sensors would reduce the risk of under-watering or over-watering a crop based on erroneous measurements or poor estimations.

For more detailed information on soil moisture and monitoring technologies including a discussion of different soil moisture sensors, see Soil Water and Monitoring Technology by Steven Evett in Irrigation of Agricultural Crops, 2nd edition.

[1]Evett, S.R. 2007. Soil water and monitoring technology. p 25-84. In R.J. Lascano and R.E. Sojka (editors) Irrigation of agricultural crops. 2nd edition. Agronomy Monogram No. 30. ASA, CSSA, and SSSA. Madison, Wisconsin.

Andales, A.A. and J.L. Chávez. 2011. ET-based irrigation scheduling. Proceedings of the 2011 CPIC. Burlington, Colorado, Feb 22-23.

Crookston, M.A. 2011. Utilizing soil moisture readings in irrigation scheduling. Proceedings of the 2011 CPIC. Burlington, Colorado, Feb 22-23.

Fipps, G. Growers Guide: Using PET for determining crop water requirements and irrigation scheduling. Texas A&M AgriLife Extension.

Melvin, S.R. and C.D. Yonts. 2009. Irrigation scheduling: Checkbook method. Publication EC709. University of Nebraska-Lincoln Extension.

IRRIGATION SCHEDULING TECHNOLOGY

The recordkeeping and calculations needed for irrigation scheduling can be laborious and time consuming. Fortunately, irrigation software packages are becoming more common and more accessible. These applications require some initial input (crop specifics, soil type, planting or emergence dates) followed by periodic updates (precipitation and irrigation amounts), but do much of the calculation work for the farmer. The program provides daily reports to the user on when irrigation will be needed and how much, projects crop maturity dates, and offers other information. Many applications have the capabilities of field mapping, accessing soils databases, and automatic downloading of precipitation and calculated crop water use from online weather networks. Some applications may have advanced features such as irrigation optimization across multiple fields and economic analyses. Listed are several ET-based irrigation scheduling software programs and related resources offered by State Universities.

KanSched, Kansas State University (www.ksre.ksu.edu/mil)

KanSched can be used for multiple crops. This program uses ET data to help monitor soil water and schedule irrigation events. From the input values provided by the user, the program will calculate soil water availability on any given day. This will tell the user when soil water will drop below the MAD (when to apply) and what the root zone water deficit is, which tells the user how much water will be needed to bring soil water back to field capacity. The program can also be used to monitor the soil water content of non-irrigated fields.[1]

SoyWater, University of Nebraska-Lincoln (www.hprcc3.unl.edu/soywater)

SoyWater is an internet-accessible website for soybean irrigation scheduling. The program automatically acquires daily weather data, and from this and other user inputs, estimates the daily soybean crop ET values. The program then provides the user with the cumulative soil water depletion by the crop, which indicates when irrigation will be needed.

CornWater, University of Nebraska-Lincoln (www.hprcc3.unl.edu/cornsoywater/cornwater)

CornWater is a tool for determining when to irrigate a corn field. This internet-accessible website predicts real-time soil water status and corn water stress based on user-input crop management data, basic soil properties, and real-time weather data from a nearby weather station. CornWater recommends irrigation when crop water stress is predicted to occur within the next three days if no significant rainfall is expected.

eRAMS, Colorado State University (www.erams.com)

eRAMS provides online services for sustainable management of land, water, and energy resources. The web-based irrigation water management tool helps farmers and water managers determine real-time irrigation water requirements and predicts irrigation needs over a forecast period.

TexasET, Texas A&M University (http://texaset.tamu.edu)

This website contains local weather information, irrigation watering recommendations, and current and average ET data including reference ET values and crop coefficients for estimating crop ET.

For other irrigation scheduling calculators, ET networks, and additional information on water conservation, visit the Agricultural Water Conservation Clearinghouse found at http://agwaterconservation.colostate.edu/Default.aspx and click on Tools.

[1]Clark, G.A., Rogers, D.H., and Briggeman, S. KanSched an ET-based irrigation scheduling tool for Kansas summer annual crops. Kansas State University Extension.

IRRIGATION SCHEDULING FOR CORN

When and How Much to Apply

Corn is capable of using 50 percent of the available water stored in the soil before plant stress begins.[1] For a fully irrigated crop, soil water is replenished before reaching 50 percent depletion (when the soil water content is halfway between field capacity and permanent wilting point) to avoid plant stress and preserve yield potential.

Determining the MAD for a corn crop at a specific growth stage.

The maximum allowable depletion (MAD) of soil water can be determined from information on the rooting depth of the crop at a specific growth stage (Table 2.3), the water holding capacity of the soil (Table 2.4), and the efficiency of the irrigation system (Table 2.5). If the soil type is unknown, check with the local Natural Resources Conservation Service office, county soil surveys, or online at http://websoilsurvey.nrcs.usda.gov.

- For corn at silking, the rooting depth is approximately 3 feet.[1]
- At 3 feet, a sandy loam soil has a plant available water holding capacity of 4.2 inches (1.4 in water/ft soil depth x 3.0 ft root depth).
- Corn can use only 50 percent of that capacity before stress will begin, so the MAD would be 2.1 inches of water (4.2 in x 0.5).
- When soil water content drops to 2.1 inches in 3 feet of soil, irrigation or rainfall will need to supply 2.1 inches of water to bring the soil profile back to capacity. Another way to look at this is, in order to prevent crop stress, irrigation will need to be applied before the corn crop has used 2.1 inches of water.

Table 2.3 Average root depth of corn at various stages of growth

STAGE OF CORN DEVELOPMENT	ASSUMED ROOT DEPTH (FT)*
12-leaf	2.0
Early tassel (16-leaf)	2.5
Silking	3.0
Blister	3.5
Beginning dent	4.0

*Root development may be restricted to a depth less than that shown due to compaction or limiting layers.

Table modified from Rhoads, F.M. and C.D. Yonts. 2013. Irrigation scheduling for corn-why and how. NCH-20. In National Corn Handbook. University of Wisconsin Extension.

Table 2.4 Water holding capacity of different soil types

SOIL TEXTURAL CLASSIFICATION	WATER STORAGE CAPACITY (INCHES/FOOT)
Fine sand	1.0
Loamy sand	1.1
Sandy loam	1.4
Silty clay or clay	1.6
Fine sandy loam, silty clay loam, or clay loam	1.8
Sandy clay loam	2.0
Loam, very fine sandy loam, or silt loam topsoil; silty clay loam or silty clay subsoil	2.0
Loam, very fine sandy loam, or silt loam topsoil; medium textured subsoil	2.5

Table modified from Yonts, C.D. et al. 2008. Predicting the last irrigation of the season. NebGuide G1871. University of Nebraska-Lincoln Extension.

Table 2.5 Potential application efficiencies for well-designed and well-managed irrigation systems

IRRIGATION SYSTEM		POTENTIAL APPLICATION EFFICIENCY (%)
Sprinkler irrigation systems	LEPA	80-90
	Linear move	75-85
	Center pivot	75-85
Surface irrigation systems	Furrow (conventional)	45-65
	Furrow (surge)	55-75
	Furrow (with tailwater reuse)	60-80
Microirrigation systems	Bubbler (low head)	80-90
	Microspray	85-90
	Subsurface drip	>95
	Surface drip	85-95

Table modified from Irmak, S. et al. 2011. Irrigation efficiency and uniformity and crop water use efficiency. Publication EC732. University of Nebraska-Lincoln Extension.

Daily ET estimates can be used to determine when soil water will reach the MAD.

Continuing from the example above:

- With a MAD of 50 percent, the corn crop has an allowance of 2.1 inches of stored soil water at field capacity.
- If the corn crop is using 0.32 inches of stored soil water per day, there should be ample soil water for approximately 6.5 days (2.1 in ÷ 0.32 in/day).

See Table 2.6 and Figures 2.2 and 2.3 for examples of corn water use (ET) at different growth stages in two different regions (South Central Nebraska and the Texas High Plains).

Consider the efficiency of the irrigation system when determining how much water to apply.

If the irrigation equipment has 80 percent efficiency and a farmer wants to apply 2.1 inches of water, only 1.7 inches of the irrigation water will go to the plants (2.1 in of water x 0.8).

- To bring the field back to capacity, 2.6 inches of irrigation would need to be applied to account for the loss of water due to the inefficiency of the irrigation system (2.1 in of water needed for plants ÷ 0.8).
- Do not forget to account for effective rainfall when determining irrigation requirements.
- Some soil type and slope combinations may necessitate lower application depths to prevent runoff.

Table 2.6 Average crop water use (ET) by growth stage for 113-day maturity corn grown in south central Nebraska

GROWTH STAGE	AVERAGE WATER USE RATE (INCHES/DAY)	DURATION* (DAYS)	WATER USE DURING STAGE (INCHES)	WATER NEEDED CUMULATIVE (INCHES)
Emergence (VE)	0.08	0-10	0.8	0.8
4-leaf (V4)	0.10	11-29	1.8	2.6
8-leaf (V8)	0.18	30-46	2.9	5.5
12-leaf (V12)	0.26	47-55	1.8	7.3
Early tassel (R1)	0.32	56-68	3.8	11.1
Silking (R2)	0.32	69-81	3.8	14.9
Blister kernel (R3)	0.32	82-88	1.9	16.8
Beginning dent (R4.7)	0.24	89-104	3.8	20.7
Full dent (R5.5)	0.20	105-125	3.8	24.5
Maturity (R6)	0.10	126-140	1.4	25.9

*Long-term average number of days since planting required to progress from the previous growth stage to the next. For example, to go from the blister kernel stage to the beginning dent stage requires approximately 15 days (day 89 to day 104). Days to each growth stage were determined using the Hybrid-Maize Corn Growth Model for the period 1982-2005 at Clay Center, NE.

Table modified from Kranz, W.L. et al. 2008. Irrigation management for corn. NebGuide G1850. University of Nebraska-Lincoln Extension.

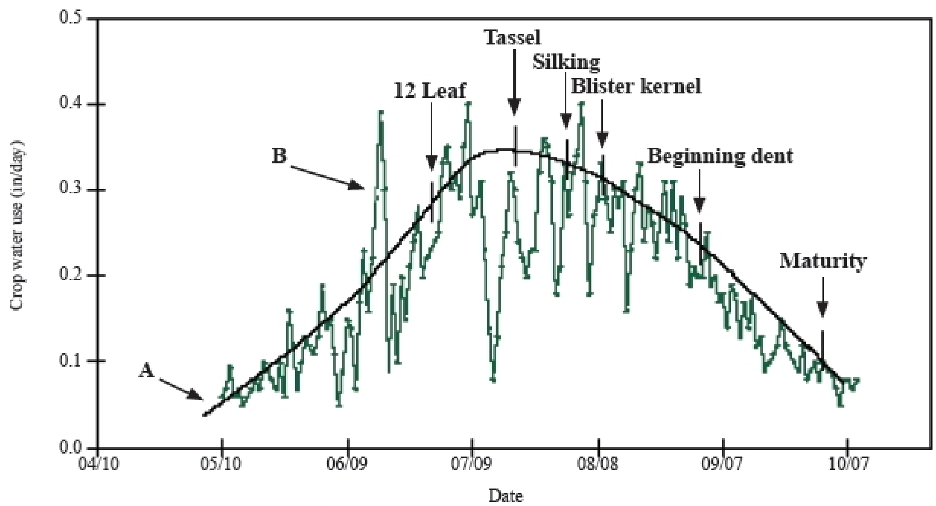


Figure 2.2 Long-term daily average (A) and individual year (B) corn water use with select growth stages in Nebraska.

Source: Kranz, W.L. et al. 2008. Irrigation management for corn. NebGuide G1850. University of Nebraska-Lincoln Extension.

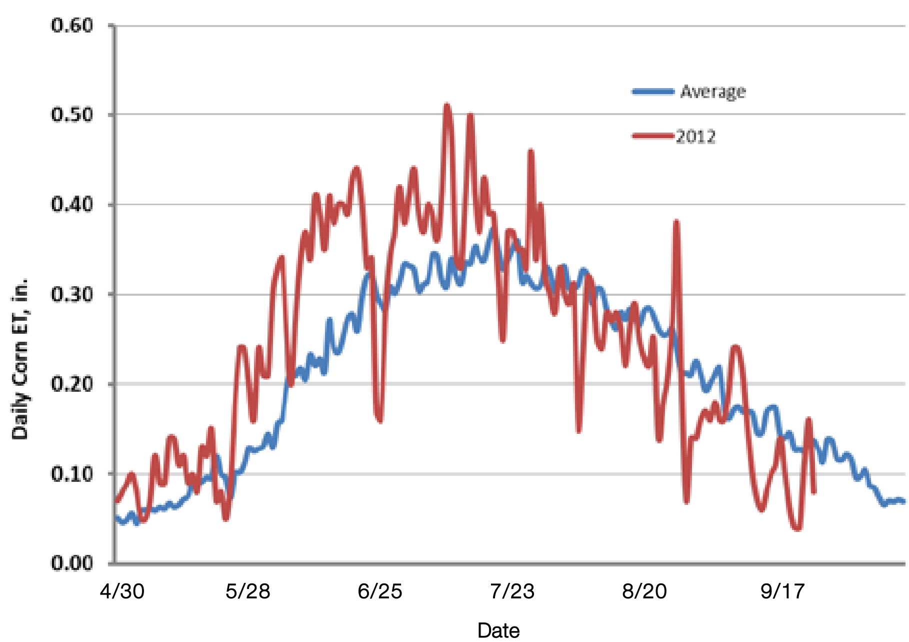


Figure 2.3 Corn water use in 2012 compared with average corn water use in Etter, TX

Source: Marek, T. et al. 2013. 2012 North Plains Research Field 12-200 limited irrigation corn production study. Publication AREC 2013-05. Texas A&M AgriLife Extension.

When water resources are limited, consider crop growth stage and economics.

When well capacity is limited or seasonal water allowances are restrictive, this type of full irrigation regimen where soil water is replenished at the MAD may not always be possible. Thus, the farmer will need to consider the crop growth stage and the economics of irrigation costs and crop market values to determine when irrigation will be most beneficial, keeping in mind that the reproductive growth stages are the most sensitive to water stress.

Planting

Irrigation is not recommended immediately following planting in regions where early season precipitation and stored soil moisture are adequate for seedling emergence and early plant development. Without the plant canopy to shade the soil surface, much of the irrigation would be lost to evaporation.[2] Farmers should rely on stored soil moisture and natural precipitation as much as possible during the early growth stages. The exception to this is when irrigation is needed for incorporation and/or activation of pre-emergence pesticides.

Vegetative Stages

The vegetative stages of corn are often considered the least sensitive stages to water stress and could provide an opportunity to limit irrigation applications without severe yield reductions.

Early Reproductive Stages

Water stress should be avoided during the reproductive stages (tasseling, silking, and pollination). Water stress during silking can have the greatest impact on yield potential due to desiccation of the silks and pollen grains, which will result in poor pollination.[2] It is important to know when crop demands will become greater than precipitation, typically during critical reproductive periods. Farmers with low capacity wells should attempt to have the soil profile near field capacity as crop demands begin to exceed precipitation.

Dough Through Dent Stages

Corn water use rates steadily decrease from the dough stage through maturity due to a lower evaporative demand (shorter days, lower temperatures, lower solar radiation), a loss of transpiring leaf area as lower leaves begin to die, and changes in plant physiology.[2] For maximum grain yield potential, researchers recommend that farmers in the Central Great Plains ensure available soil water in the upper 8 feet of the soil profile remains above 45 percent depleted after flowering and to maturity.[3] Allowing soils to dry at maturity is a good strategy for avoiding compaction caused by harvesting machinery on wet soils. Nebraska research suggests that soil moisture reserves can be brought down to below 50 percent depletion in the top 4 feet of soil towards the end of the dent stage without affecting yield.[2] Soil type and root restricting layers will affect the water holding capacity and the amount of extractable water in the soil, so MAD levels should be adjusted for local conditions.

When to Stop

Farmers should not rely on a traditional calendar date such as Labor Day (early September) to terminate the irrigation season because this does not take into account year-to-year variations in crop development and physiological maturity. For example, 16 years of studies in northwest Kansas found that corn crops reached physiological maturity between September 14th and October 10th.[3] For optimal grain development and to promote maximum yield potential, corn requires water right up until physiological maturity. Early irrigation termination can accelerate maturity, prohibiting kernels from reaching their full potential size and weight.[3] After physiological maturity (black layer), water is no longer needed for kernel growth and no yield benefits can be achieved with additional irrigation.

Continue to monitor soil moisture through physiological maturity.

Farmers should continue to monitor soil moisture throughout the grain filling stages in order to anticipate the soil water content at physiological maturity and ensure that enough water will remain in the soil to bring the crop through grain fill without inducing stress. This strategy will also avoid wasting irrigation water with an unnecessary application if soil water is sufficient.

Determining the MAD at crop maturity.

To estimate soil water content at physiological maturity, consider the predicted crop maturity date, the predicted water use by the crop up to maturity (Table 2.7), and the current soil water content. Note that Table 2.7 is for ET in Nebraska; crop water use rates will vary by region. Consider the previous calculation for determining the MAD at a specific growth stage. The same calculation can be used for determining the MAD at crop maturity. In the following example, a MAD of 55 percent is used (55 percent of the available soil water is depleted).

- For corn at physiological maturity (R6), consider the rooting depth to be approximately 4 feet.
- At 4 feet, a sandy loam soil has a total water holding capacity of 5.6 inches (1.4 in water/ft soil depth x 4.0 ft root depth).
- The desired MAD at maturity is 3.0 inches of water (5.6 in x 0.55). This means that 3.0 inches of available soil water have been depleted and 2.6 inches of available soil water are remaining at maturity.

Table 2.7 Normal water requirements for corn and soybean during the reproductive stages to maturity in Nebraska

GROWTH STAGE		APPROXIMATE DAYS TO MATURITY	WATER USE TO MATURITY (INCHES)
CORN			
R4	Dough	34	7.5
R4.7	Beginning dent	24	5.0
R5	1/4 milk line	19	3.75
	1/2 milk line (full dent)	13	2.25
	3/4 milk line	7	1.0
R6	Physiological maturity	0	0.0
SOYBEAN			
R4	End of pod elongation	37	9.0
R5	Beginning seed enlargement	29	6.5
R6	End of seed enlargement	18	3.5
R6.5	Leaves begin to yellow	10	1.9
R7	Beginning maturity	0	0.0

Table modified from Yonts, C.D. et al. 2008. Predicting the last irrigation of the season. NebGuide G1871. University of Nebraska-Lincoln Extension.

Determining how much water is needed to bring the corn crop through maturity.

At this point, the predicted water use by the crop to reach maturity should be considered. If the corn crop is at full dent, it will require approximately 2.25 inches of water to reach maturity (Table 2.7). For maximum water use efficiency, a farmer will want to supply only enough irrigation to bring available soil water to the desired depletion level at crop maturity.

- If the soil water content is at the MAD (3.0 inches of soil water have been depleted and 2.6 inches of available soil water are remaining) and the corn crop is at full dent stage, a farmer will only need to apply 2.25 inches of water.
- Filling the field to capacity (3.0 inches of additional water) would mean wasting ¾ of an inch of water (3.0 in - 2.25 in = 0.75 in of water not needed by the crop).

For further information and a useful end-of-season irrigation worksheet, see Predicting the Last Irrigation of the Season, Publication number G1871, by the University of Nebraska.

[1]Rhoads, F.M. and C.D. Yonts. 2013. Irrigation scheduling for corn-why and how. NCH-20. In National Corn Handbook. University of Wisconsin Extension.

[2]Kranz, W.L., Irmak, S., van Donk, S.J., Yonts, C.D., and Martin, D.L. 2008. Irrigation management for corn. NebGuide G1850. University of Nebraska-Lincoln Extension.

[3]Lamm, F.R. and A.A. Abou Kheira. 2009. Corn irrigation macromanagement at the seasonal boundaries – initiating and terminating the irrigation season. Proceedings of the 2009 CPIC. Colby, Kansas, Feb 24-25.

Fipps, G. Growers Guide: Using PET for determining crop water requirements and irrigation scheduling. Texas A&M AgriLife Extension.

Yonts, C.D., Melvin, S.R., and Eisenhauer, D.E. 2008. Predicting the last irrigation of the season. NebGuide G1871. University of Nebraska-Lincoln Extension.

IRRIGATION SCHEDULING FOR SOYBEAN

Soybean irrigation strategies differ from corn because more water is needed later in the reproductive growth stages. Soybean water use efficiency peaks at relatively small amounts of irrigation and then slowly declines with additional irrigation amounts.

When and How Much to Apply

Soybean, similar to corn and other annual crops, can tolerate some water stress during the vegetative stages, but requires adequate moisture during the reproductive stages to help promote maximum yield potential. The example used earlier for corn can be used for soybean and other crops to calculate when and how much irrigation to apply. See Figure 2.4 for average and individual year soybean water use (ET) at different growth stages in Nebraska.

Vegetative Stages

In the northern Great Plains, irrigation is generally not recommended for soybean during the vegetative growth stages unless soil moisture is extremely depleted.[1] The exception to this is when irrigation is needed for incorporation and/or activation of pre-emergence pesticides. Farmers should rely on stored soil moisture and natural precipitation during the early growth stages. Too much water early in the season can prolong the vegetative growth stage, which can result in delays in flowering, increased plant height, and lodging.[1] Limiting early season irrigation encourages plants to develop stronger, healthier root systems that grow deeper. The MAD for soybean, the point at which irrigation will need to be applied to avoid plant stress, should be no larger than 70 percent (30 percent of available water remaining) in the vegetative growth stages.[2]

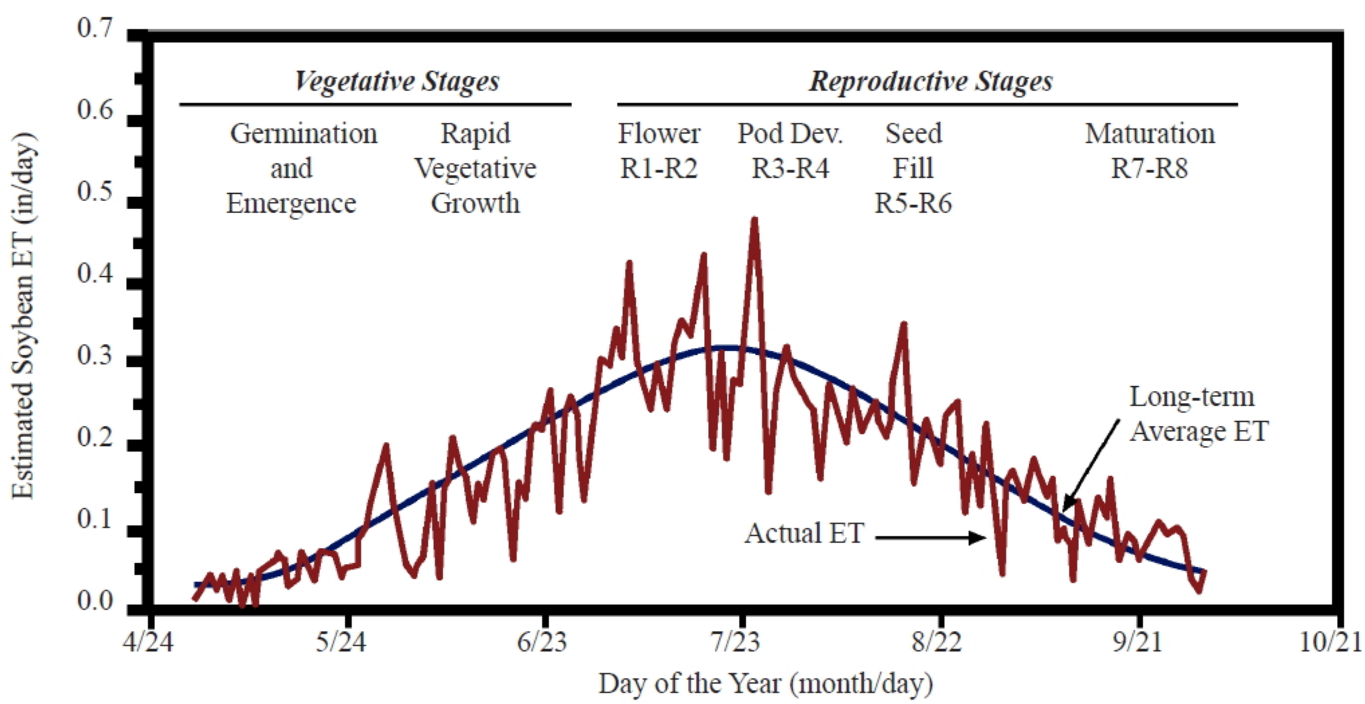


Figure 2.4 Long-term daily average and individual year soybean water use with select growth stages in Nebraska
Source: Kranz, W.L. and J.E. Specht. 2012. Irrigating Soybean. NebGuide G1367. University of Nebraska-Lincoln Extension.

In drier regions, such as the western and southern Great Plains, and with sandy loam or coarser soils, shallow root zones, or low capacity wells, the MAD should not exceed 50 percent.[3]

Reproductive Stages

Soybeans are most sensitive to water stress during the mid to late reproductive stages: pod development (R3 to R4) and seed fill (R5 to R6). Water stress during pod development and early seed fill can have the greatest impact on yield potential and result in a reduced number of seeds per pod and reduced seed size. Water may be required during flowering on soils with an insufficient water holding capacity (sandy soils) or when conditions are exceptionally dry.[1] When water is applied during flowering, it is especially important to supply adequate water during seed fill. This is because irrigating during flowering usually increases the number of seeds produced, but subsequent water stress during seed fill will reduce the seed size which can result in greater yield penalties than would have occurred if the crop had not been watered at all during flowering.[1] During the reproductive growth stages, the MAD should not exceed 50 percent.[1,2]

When to Stop

Soybean requires adequate water through the reproductive stages for optimal yield potential. Discontinuing irrigation before physiological maturity can result in yield penalties if the soil water content is not sufficient. The same irrigation termination strategy applies for soybean as described earlier for corn. In general, ensure that available soil water content will not drop below the MAD until after seed fill is complete (end of R7). An end-of-season MAD of 60 percent (40 percent of available water remaining) is applicable for soybean.[4]

Final irrigation can impact yield potential.

A study conducted in Nebraska in 2013 compared soybean yield response to different final irrigation treatments. Three irrigation treatments were applied after the R5 growth stage: 2 inches less than normal (irrigation until mid-R5), normal irrigation (irrigation until mid-R6), and 2 inches more than normal (irrigation until mid-R7). Study results showed a direct, positive relationship between additional water applied and yield response with the additional 2 inches irrigation treatment resulting in yield increases of 15 and 10 bushels per acre over the 2 inches less water treatment and normal treatment, respectively (Figure 2.5). The large yield response observed from the final irrigation is likely due to the lack of rainfall that occurred from August to mid-September of 2013 where less than 0.7 inches of precipitation was recorded and daily ET rates were relatively high. While this study was located at one site and is one year's worth of data, it does point out the need for farmers to be vigilant in their water management strategies and ensure that sufficient moisture remains in the soil for seed fill as there can be significant differences in precipitation and ET rates between years.[5]

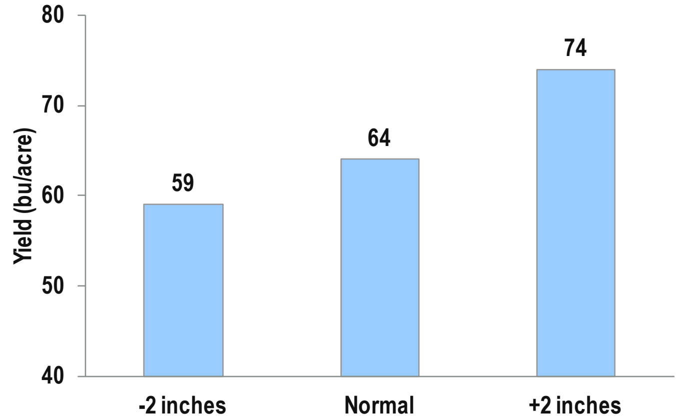


Figure 2.5 Soybean yield response to three final irrigation treatments.

Source: Soybean yield response to final irrigation. 2013. Gothenburg Learning Center Summary. Technology Development & Agronomy. CAM12052013.

[1] Kranz, W.L. and J.E. Specht. 2012. Irrigating Soybean. NebGuide G1367. University of Nebraska-Lincoln Extension.

[2] Helsel, D.G. and Z.R. Helsel. 1993. Irrigating Soybeans. Publication G4420. University of Missouri Extension.

[3] Klocke, N.L., Eisenhauer, D.E., Specht, J.E., Elmore, R.W., and Hergert, G.W. 1989. Irrigation of soybeans by growth stages in Nebraska. American Society of Agricultural Engineers. vol 5(3): 361-366.

[4] Yonts, C.D., Melvin, S.R., and Eisenhauer, D.E. 2008. Predicting the last irrigation of the season. NebGuide G1871. University of Nebraska-Lincoln Extension.

[5] Soybean yield response to final irrigation. 2013. Gothenburg Learning Center Summary. Technology Development & Agronomy. CAM12052013.

IRRIGATION STRATEGIES WITH LIMITED WATER RESOURCES

For the purpose of discussion in this handbook, we will define three common situations in relation to limited water resources:

- **Low capacity.** Wells having 350 gallons per minute or less that serve a 126 acre standard pivot.
- **Allocated water.** 12 inches average annual allocation or less with a well that has adequate capacity (more than 350 gallons per minute) that serves a 126 acre standard pivot.
- **Low capacity plus allocated water.** 12 inches average annual allocation or less with a less than 350 gallons per minute well that serves a 126 acre standard pivot.

Use Table 2.8 to determine daily and weekly application rate and the number of days it takes to apply 1 inch of water. For example, a 350 gallon per minute well on a 126 acre pivot can apply 0.15 inches of water per day and 1.0 inch per week. These daily rates can be compared to average crop water use for the particular location. Keep in mind that the application rates are gross application. Because of the inefficiencies of an irrigation system, the full amount applied will not all be available for water use by the plant.

Table 2.8 Daily irrigation application rate with different well capacities on a 126 acre pivot				
WELL CAPACITY (GPM)	APPLICATION RATE (GPM/ACRE)	AMOUNT APPLIED PER DAY (INCHES)	AMOUNT APPLIED PER WEEK (INCHES)	NUMBER OF DAYS TO APPLY 1 INCH
200	1.6	0.08	0.6	11.8
250	2.0	0.11	0.7	9.5
300	2.4	0.13	0.9	7.9
350	2.8	0.15	1.0	6.8
400	3.2	0.17	1.2	5.9
450	3.6	0.19	1.3	5.3
500	4.0	0.21	1.5	4.7
600	4.8	0.25	1.8	3.9
700	5.6	0.30	2.1	3.4
800	6.3	0.34	2.4	3.0
900	7.1	0.38	2.7	2.6
1000	7.9	0.42	3.0	2.4
1100	8.7	0.47	3.3	2.2
1200	9.5	0.51	3.6	2.0
1300	10.3	0.55	3.9	1.8
1400	11.1	0.59	4.2	1.7

Source: Developed by Derrel Martin, University of Nebraska-Lincoln; modified by Chuck Burr, University of Nebraska-Lincoln.

Corn yield and water use efficiency are both quite sensitive to the degree of water stress induced by water management in response to weather. What is considered full irrigation can sometimes reduce yield due to deep percolation losses of fertilizer. Crop water use efficiency is often greatest at less than full replacement of ET. Pumping costs can be substantial enough that some reduction in yield is profitable if water use efficiency is increased. Therefore, a carefully controlled deficit irrigation strategy can maximize crop water use efficiency or profit, and often both, while moving water use towards sustainability.

GROWTH STAGE TARGETED IRRIGATION

In cases when water allocations are limited, it may be more profitable to reserve irrigation until just prior to the reproductive growth stages as opposed to applying inadequate amounts of irrigation throughout the season, which can result in water stress during the critical water use periods. In order to help avoid yield losses, this approach will require wells with an adequate pumping rate that can replenish soil water levels quickly when needed. If a reproductive growth stage targeted irrigation strategy is used with severely limited well capacities (pumping rates less than 350 gallons per minute) irrigation should be started well before mid-July to stay ahead of crop demand. Avoid restricting irrigation during the vegetative stages to the point that the soil profile is severely depleted. Most farmers do not have irrigation systems with adequate capacity to replenish severely depleted soil water reserves fast enough to meet the crop's ET demands as it enters the reproductive growth stages.

Delayed Irrigation for Corn

A study conducted from 2009 to 2011 near Akron, Colorado investigated well capacity and irrigation timing on corn yield and profitability. Three treatments were compared: 1) season-long, full irrigation with a capacity of 5 gallons per minute per acre, 2) season-long irrigation with an inadequate capacity of 2.5 gallons per minute per acre, and 3) reproductive growth stage targeted irrigation on limited acres where irrigation was delayed until two weeks prior to tassel emergence and applied at a capacity of 6.7 gallons per minute per acre. When irrigation was restricted during the vegetative growth stages and then applied on the same schedule as the full irrigation plot, reductions in yield between the two treatments were not significant. However, season-long irrigation with inadequate capacities resulted in a grain yield loss of 25 percent during a drought year, likely due to insufficient amounts of water during the reproductive growth stages. In addition, this treatment also resulted in the lowest net return (Table 2.9).[1]

Several long-term field studies were conducted in Colby, Kansas to investigate early season corn water stress and its impact on yield. In one study, the first irrigation was delayed by 0, 1, 2, 3, 4, or 5 weeks. Throughout nine years of the study, statistically significant yield losses were observed with delayed irrigation in only three of the years and only in the plots with the longest irrigation delays. Crop ET rates were reported to be much higher and accompanied by extreme drought during the years when yield losses occurred.[2]

Delayed Irrigation for Soybean

In Nebraska and similar climates, irrigation can be delayed until full flowering (R2) or early podding (R3) on deep, medium to fine textured soils (high water holding capacity soils) without negatively impacting final soybean yield, even during years when early season precipitation is sparse. This is because high water holding capacity soils, such as a silty clay loam, will hold about 6 inches of water at field capacity for crop use during the early growth stages when water requirements and evaporative demands are lower and natural precipitation is more abundant.[3] This strategy could help farmers improve irrigation water use efficiency without sacrificing yield, especially in years with good early season precipitation. This is not the case in the Southern Plains states where early season precipitation is more variable.

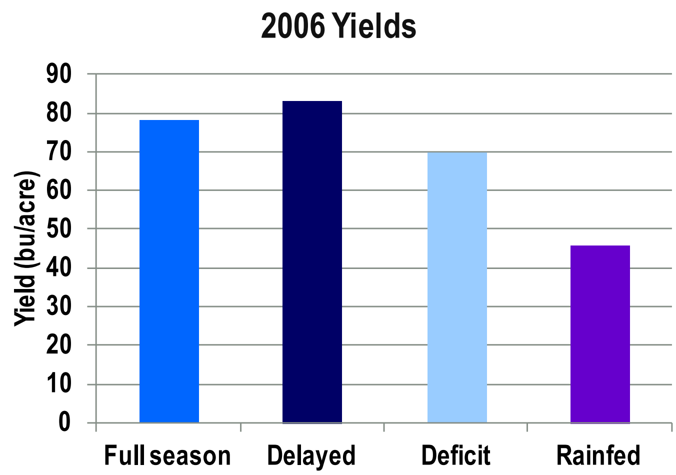
With this type of deferred irrigation, the soil water level should be at field capacity around the time of planting or seedling emergence and the soil water content must be brought back to normal levels once irrigation has commenced (at stage R2 or R3) to help avoid yield losses. This approach will require wells with adequate capacity (pumping rate) that can replenish soil water levels quickly in order to keep up with a higher ET demand during the reproductive growth stages. This practice is not recommended for coarse textured soils which have smaller water holding capacities or when root restricting layers are present at shallow depths.

This strategy was investigated by the University of Nebraska-Lincoln. Eight soybean cultivars were grown on a silt loam soil with the following treatments: full irrigation with a MAD of 35 percent, deferred irrigation until stage R3 where a MAD of 35 percent was used after R3, full season deficit irrigation that received 2/3 the amount of irrigation as the full irrigation treatment, and a rainfed control. Even though early season precipitation was below normal in each year of the study resulting in soil water deficits greater than 35 percent, yields of the deferred irrigation treatment and the full irrigation treatment were not significantly different. However, the season-long deficit irrigation treatment resulted in yields that were significantly lower than the full irrigation treatment (Figure 2.6).[3]

Table 2.9 Net return for three irrigation treatments in Akron, CO (2009-2011)

IRRIGATION TREATMENTS	DOLLARS PER ACRE PER YEAR
Inadequate	$356
Growth stage targeted	$599
Full	$620

Source: Schneekloth, J.P. et al. 2012. Irrigation capacity impact on limited irrigation management and cropping systems. Proceedings of the 2012 CPIC. Colby, Kansas, Feb 21-22.



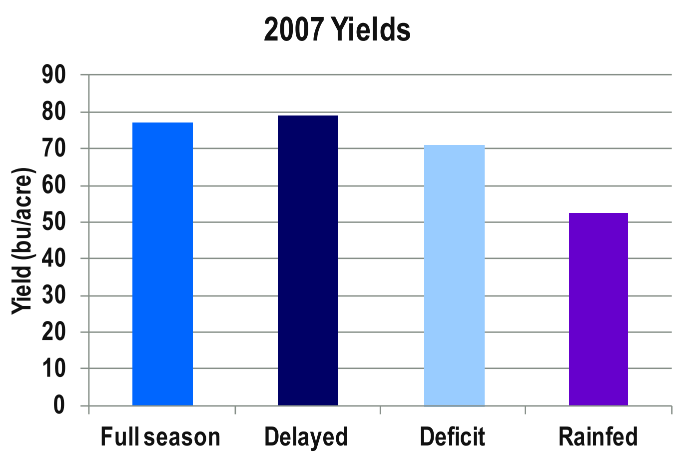


Figure 2.6 Soybean yield response to different irrigation strategies in Nebraska.
Source: Torrion, J.A. et al. 2014. Soybean irrigation management: Agronomic impacts of deferred, deficit, and full-season strategies. Crop Science. vol 54: 1-14.

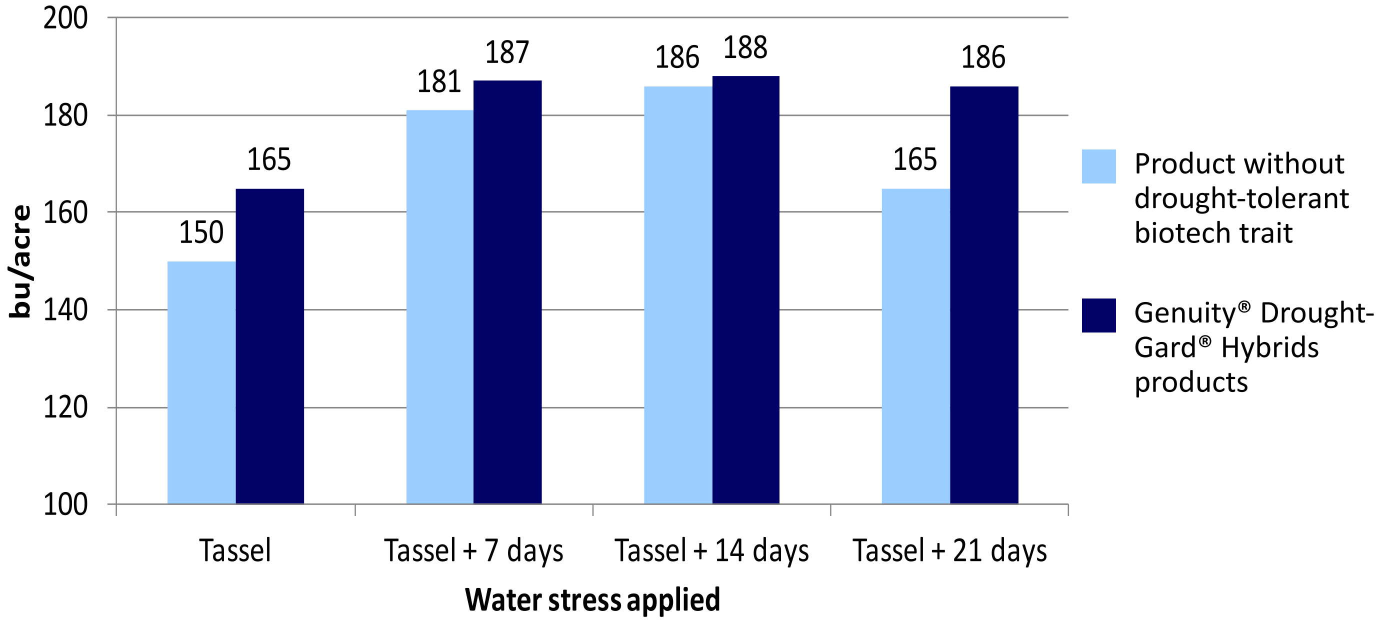


Figure 2.7 Yield response of Genuity® DroughtGard® Hybrids corn products and corn without the drought-tolerant biotech trait to varying levels of water stress.
Source: Aiken, R. 2013. DroughtGard® Hybrids irrigation timing—reproductive growth stages. Protocol 2013-01-B3-08. Annual Report. Kansas State University.

GENUITY® DROUGHTGARD® HYBRIDS

DroughtGard Hybrids corn products are part of a systems approach to drought mitigation combining top-yielding germplasm selected for its drought-tolerant characteristics, the inclusion of a drought-tolerant biotechnology trait, and agronomic best management practice recommendations. The systems approach is designed to help farmers manage risk and minimize yield loss when drought stress occurs. In a study conducted near Colby, Kansas, DroughtGard Hybrids corn products and a Monsanto corn product without the drought-tolerant biotech trait had no irrigation water applied for 10 to 14 days after the onset of tassel, 7 days after tassel, 14 days after tassel, and 21 days after tassel. Yields are shown in Figure 2.7 for each treatment with DroughtGard Hybrids products tending to have higher yields over corn without the drought-tolerant biotech trait.[4] DroughtGard Hybrids are discussed in detail in Chapter 5.

PRE-SEASON IRRIGATION

A technique used in the southern Great Plains when well capacity is limited and insufficient to fully meet crop requirements during peak water needs is to irrigate before planting a crop. This allows farmers to extend the irrigation season and to provide a relatively full profile before the crop is planted, which helps to buffer the crop from water stress later in the season. The yield benefit of pre-season irrigation appears to be greater with lower well capacities than with higher well capacities.

A study conducted near Tribune, Kansas indicated an increase in yields from pre-season irrigation as compared to the control with no pre-season irrigation. Pre-season irrigation at lower well capacities (0.1 and 0.15 inches per day) resulted in greater yield increases compared to the control than the higher well capacity (0.2 inches per day) (Figure 2.8).[5] Farmers with allocated water should be cautious when applying this technique as pre-season irrigation uses a portion of the allocation to fill the profile which could have been filled by precipitation. This technique works well on silt loam soils with high water holding capacities. There is little advantage for pre-season irrigation on sandy soils with low water holding capacity.

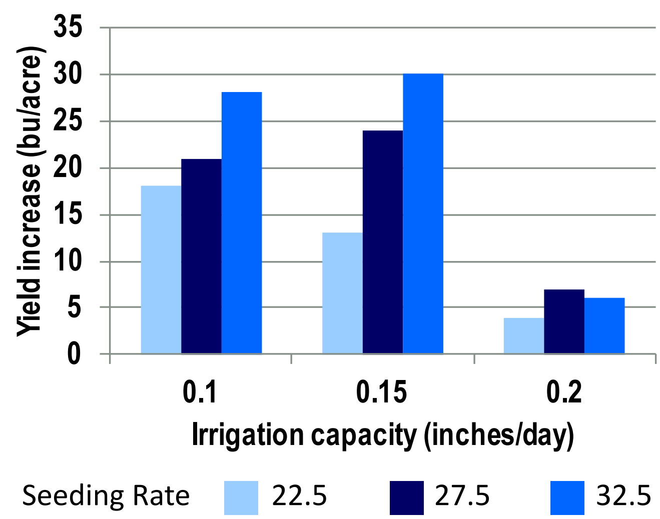


Figure 2.8 Yield increase from pre-season irrigation in Tribune, KS.
Source: Schlegel, A. et al. 2011. Preseason irrigation of corn with diminished well capacities. Proceedings of the 2011 CPIC. Burlington, Colorado, Feb 22-23.

REDUCE IRRIGATED ACRES

When well capacities are limited, consider cropping practices that result in fewer acres of an irrigated crop. Splitting the field between crops that have different water timing needs such as corn and wheat will result in fewer acres needing irrigation at any one point during the growing season. For example, peak water demand for wheat is in May and June while corn and soybean use the most water in July and August. For low capacity wells, this strategy allows the farmer to extend the irrigation season and to more closely match application rates with crop needs. Splitting the field between corn products of different maturities could also extend the critical pollination phase when sufficient irrigation is needed. To maximize the pollination period, plant a short-season product first and a longer season product several weeks later.

Case studies were used to determine when it is economical to begin switching irrigated acres to a rainfed crop. The recommendation is to maintain irrigated acres until estimated corn yield is 70 percent of full irrigated yield. For example, if fully irrigated corn yield is 200 bushels per acre, the threshold to move to reduced irrigated acres of corn would be 140 bushels per acre. If well capacity and/or water allocation is not adequate to produce 140 bushels per acre corn, consider fewer acres of corn or plant another crop. Crop prices have an effect on what crops to plant. Refer to one of the following software programs to help determine how many acres of an irrigated or dryland crop to plant:

- Water Optimizer, University of Nebraska-Lincoln (www.water.unl.edu/cropswater/optimizer)
- Water Allocator, Kansas State University (www.bae.ksu.edu/mobileirrigationlab/crop-water-allocator)

CROP ROTATION

The use of crop rotation is a common water conservation strategy in limited irrigation and dryland cropping systems. When alternating between crops with high and low water needs, farmers can reserve irrigation for the high water needs crop, such as corn and soybean, and conserve water on crops that need less water, such as winter wheat. For example, a crop rotation study was conducted by Kansas State University with an annual irrigation allowance of 10 inches. Continuous corn received 10 inches of irrigation per year but in the corn-wheat rotation the wheat received only 5 inches, reserving a total of 15 inches for the corn crop the following season. This extra 5 inches of water increased the level of irrigation to nearly full and resulted in increased corn yields of 40 bushels per acre over the yields from the continuous corn plots.[6]

WHEN TO ABANDON ACRES DURING EXTREME CONDITIONS

During the severe drought of 2011 in the southern High Plains region and the extreme drought of 2012, ET rates in affected areas were much larger than the amount of water irrigation systems could apply. During this time, many farmers were considering when to abandon a portion of the pivot in order to salvage some production and avoid an entire failed pivot of corn. Understanding when and how to prioritize acreage during extreme conditions is complicated. Below is an example situation that can be used as a reference.

Refer back to Table 2.8 which lists daily application rates with different well capacities. Select the current ET rate the crop is using, for example:

- If the daily ET rate is 0.42 inches per day, a system capacity of 7.9 gallons per minute per acre would be required to keep up with the needs of the corn crop (neglecting application efficiency).
- Dividing the current pump output by the system capacity shows how many acres could be irrigated just to keep up with crop ET. For a 300 gallon per minute well, a farmer could irrigate 38 acres. (300 gpm ÷ 7.9 gpm/acre).
- If the irrigation system had an efficiency rating of 90 percent, reduce this number by 10 percent. This example assumes there is little, if any, stored water in the soil profile and precipitation is not expected in the extended forecast.

[1]Schneekloth, J.P., Nielsen, D.C., and Schlegel, A. 2012. Irrigation capacity impact on limited irrigation management and cropping systems. Proceedings of the 2012 CPIC. Colby, Kansas, Feb 21-22.

[2]Lamm, F.R. and A.A. Abou Kheira. 2009. Corn irrigation macromanagement at the seasonal boundaries – initiating and terminating the irrigation season. Proceedings of the 2009 CPIC. Colby, Kansas, Feb 24-25.

[3]Torrion, J.A., Setiyono, T.D., Graef, G.L., Cassman, K.G., Irmak, S., and Specht, J.E. 2014. Soybean irrigation management: Agronomic impacts of deferred, deficit, and full-season strategies. Crop Science. vol 54: 1-14.

[4]Aiken, R. 2013. DroughtGard® Hybrids irrigation timing—reproductive growth stages. Protocol 2013-01-B3-08. Annual Report. Kansas State University.

[5]Schlegel, A., Stone, L., Dumler, T., and Lamm, F. 2011. Preseason irrigation of corn with diminished well capacities. Proceedings of the 2011 CPIC. Burlington, Colorado, Feb 22-23.

[6]Schlegel, A., Stone, L., Dumler, T., and Lamm, F. 2014. No-till crop rotations with limited irrigation. Proceedings of the 2014 CPIC. Burlington, Colorado, Feb 25-26.

Kranz, W.L. and J.E. Specht. 2012. Irrigating Soybean. NebGuide G1367. University of Nebraska-Lincoln Extension.

KEY TAKEAWAYS

- Using soil moisture sensors in combination with ET-based irrigation scheduling is an excellent strategy to validate soil moisture estimates to maintain the accuracy of irrigation scheduling.
- How much water to apply depends upon the depth of the crop roots, the water holding capacity of the soil, and the efficiency of the irrigation system.
- The vegetative stages of corn and soybean are the least sensitive to water stress, whereas the reproductive stages are the most sensitive.
    - For systems with water allocations, limiting water at the vegetative stages may be a viable option to conserve water as long as the irrigation system has the capacity to minimize water stress during reproductive stages.
    - For systems with limited well capacities, limiting water during the vegetative stages is not recommended as this may cause stress during the reproductive stages because the system may not have the capacity to catch up.
- Monitor soil moisture content through grain fill to determine the optimum time to stop irrigating.
- For systems with water allocations or low water output (less than 350 gallons per minute), splitting pivots between a high water requirement crop such as corn and a lower water requirement crop such as wheat can be a viable option to maximize production from the available water.
- For low capacity wells, consider using pre-season irrigation, using crop rotation to balance high water use crops and low water use crops, and reducing irrigated acres
- For water allocations of 12 inches or less, consider growth stage targeted irrigation or crop rotation to balance high water use crops and low water use crops.
- For low capacity wells and water allocations of 12 inches or less, consider using pre-season irrigation, using crop rotation to balance high water use crops and low water use crops, and reducing irrigated acres.

CHAPTER 3
TYPES OF IRRIGATION

IRRIGATION EFFICIENCY

CENTER PIVOT IRRIGATION

FURROW IRRIGATION SYSTEMS

LEPA

SUBSURFACE DRIP IRRIGATION

VARIABLE RATE IRRIGATION

IRRIGATION SYSTEMS COMPARISON

THE IMPORTANCE OF MAINTENANCE

KEY TAKEAWAYS

The type of irrigation system most commonly used has changed dramatically over the years. In the United States, surface irrigation comprised over 60 percent of the systems in 1979. Today, sprinkler systems water the majority of irrigated acres in the Great Plains (Figure 3.1). More recently, the use of subsurface drip irrigation has increased. Labor savings and application efficiency are among several reasons for changes in the types of systems used.

IRRIGATION EFFICIENCY

Irrigation efficiency can be defined from several points of view. This chapter will focus on application efficiency. Application efficiency describes how effective the irrigation system is in storing water in the crop root zone. More specifically, it is a measure of the fraction of the total volume of water delivered to the field that is stored in the root zone to meet the crop ET needs.

The three biggest losses from irrigation applications include:[1]

- Deep percolation below the root zone
- Evaporation from the soil and plant surfaces
- Runoff from the target site

Each irrigation system should be evaluated for its ability to limit these three losses while applying water uniformly. Water losses during furrow irrigation include: runoff, evaporation from water in the furrow, evaporation from the soil surface, and percolation below the root zone. Water losses during sprinkler irrigation include: wind drift and evaporation from droplets in the air, evaporation from the crop canopy, and evaporation from the soil surface.[2] Refer back to Table 2.5 in Chapter 2 for a list of potential application efficiencies of some common irrigation systems. More recent studies have shown that the application efficiency may approach 95 percent for the LEPA (low energy precise application) system and subsurface drip may approach 100 percent if managed correctly.[3,4]

More frequent irrigations could potentially result in greater water losses from plant canopy evaporation.

With some types of spray irrigation equipment, another potential loss of irrigation efficiency could occur with more frequent applications. For example, increasing the speed of the pivot results in a greater number of applications but with less water applied per application. With every pass of the pivot, a percentage of the water applied will evaporate from the wet soil and plant surfaces. The rate of evaporation from the crop canopy will depend on climate

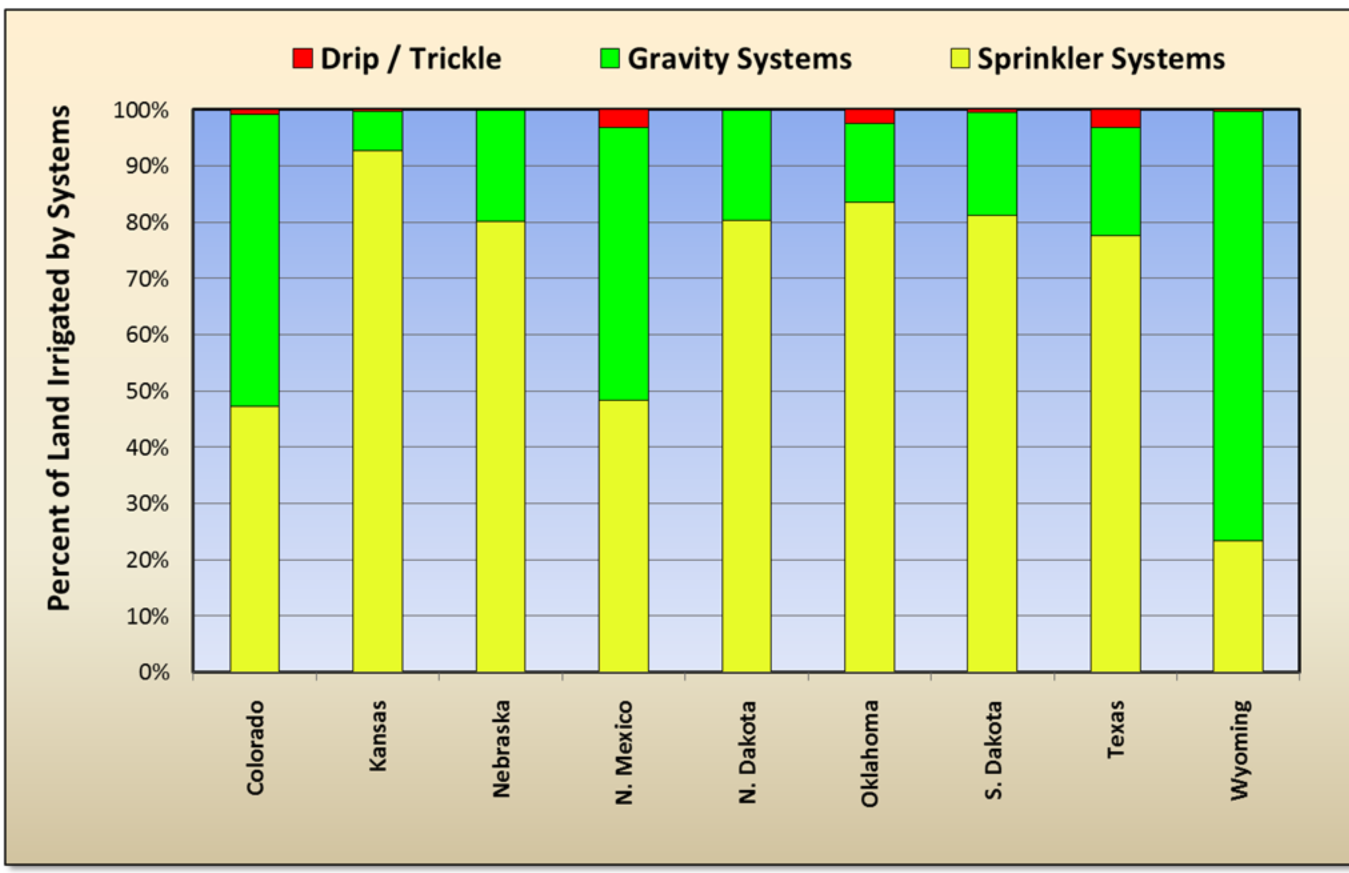


Figure 3.1 Types of irrigation systems used in the Great Plains. Photo courtesy of Derrel Martin, University of Nebraska-Lincoln. Source: USDA-NASS 2009 Census of Agriculture

demand, time available for evaporation to occur, and the surface area of the droplets. Net canopy evaporation is considered the greatest evaporative loss from most sprinkler or spray technologies.[1] Researchers in Texas observed a 3 percent evaporative loss (0.03 inches) from the plant canopy with a spray head sprinkler and an 8 percent loss (0.08 inches) with a low-angle impact sprinkler following a 1-inch application.[5] The cumulative loss of water is exacerbated when the canopy is more frequently wetted and allowed to evaporate between applications as opposed to applying the same amount of water in fewer applications. For example, if two applications of 0.5 inches was applied, the 0.08 inches could evaporate from the plant canopy twice, potentially amounting to 0.16 inches of plant canopy evaporation. This may not be as much of an issue with certain types of equipment such as LEPA (low energy, precision application) and LESA (low elevation, spray application) because canopy wetting is minimized with these systems.

A discussion follows on different types of irrigation systems, focused primarily on systems typical in the Great Plains region. Each system has its advantages and disadvantages and should be carefully considered before adoption. A more detailed discussion on best management practices for efficient application can be found in the following publication, Pathways to Effective Applications by Howell and Evett. Contact your local Extension Service for more information.

[1]Howell, T.A. and S.R. Evett. 2005. Pathways to effective applications. Proceedings of the 2005 CPIC. Sterling, Colorado, Feb 16-17.

[2]Irmak, S., Odhiambo, L.O., Kranz, W.L., and Eisenhauer, D.E. 2011. Irrigation efficiency and uniformity and crop water use efficiency. Publication EC732. University of Nebraska-Lincoln Extension.

[3]Schneider, A.D., Buchleiter, G., and Kincaid, D.C. 2000. LEPA irrigation developments. Proceedings of the National Irrigation Symposium. ASABE. Phoenix, Arizona, Nov 14-16.

[4]Schneider, A.D., Howell, T.A., and Evett, S.R. 2001. Comparison of SDI, LEPA, and spray irrigation efficiency. Presented at the 2001 ASABE Annual International Meeting. Paper number 012019. ASAE. 2950 Niles Rd., St. Joseph, MI 49085.

[5]Yonts, C.D., Kranz, W.L., and Martin, D.L. 2007. Water loss from above-canopy and in-canopy sprinklers. NebGuide G1328. University of Nebraska-Lincoln Extension.

CENTER PIVOT IRRIGATION

Center pivot sprinklers are classified into two main categories: impact sprinklers and spray heads. In general, sprinklers that have a higher operating pressure and larger wetted diameter have a lower application rate, but a high energy requirement and greater exposure to wind effects. As pressure is decreased, energy requirements and wind impact will be reduced, but application rates may be higher, which may lead to runoff unless field storage capacity is increased by furrow diking, leveling, or other intervention. Figure 3.2 shows the wetted distance and application rate for five types of sprinklers.

Impact Sprinklers

Over time, the nozzle angle of impact sprinklers has decreased from roughly 23 degrees to a range of 6 to 15 degrees. This decrease has reduced the pressure requirement and the impact by wind.

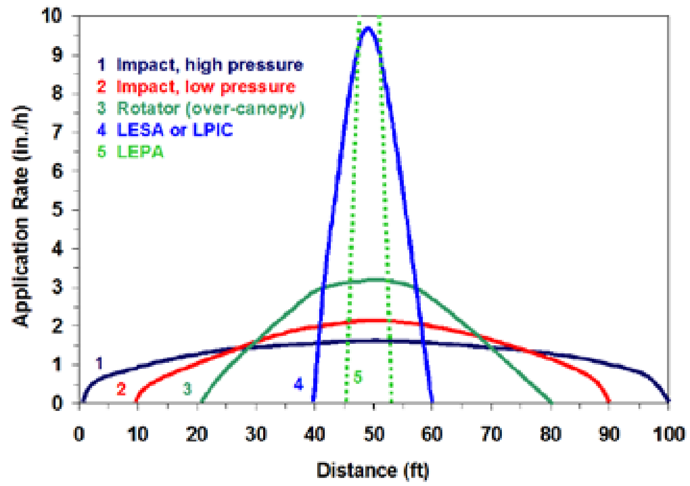


Figure 3.2 Illustration of the relative application rates for various sprinkler types under a center pivot.
Courtesy of Dr. Terry Howell, USDA-ARS, Bushland, Texas

These sprinklers are usually mounted on the pivot pipeline and typically produce a relatively large wetted diameter, which leads to smaller application rates. The smaller application rate allows the sprinkler package to be designed to closely match the soil infiltration rate. Runoff and erosion problems within a field usually occur on the outside spans where application rates are the greatest.

Spray Heads

There is much more diversity in options when considering spray heads, including simple nozzles with deflector plates to nozzles with spinning or moving plates. These options affect the wetted area and the pattern of water application. Some spray heads provide coverage that is similar in shape to a doughnut, with more water application near the outside of the wetted area and little applied near the center. Other spray heads provide more uniform coverage.

Spray Head Spacing and Height

Spray head spacing as well as height of placement of spray heads in the canopy can vary. As spray heads are moved closer to the soil surface less of the crop canopy is wetted, leading to higher application efficiency. Several iterations of these combinations can be found in the LESA (low elevation, spray application), LPIC (low pressure, in-canopy) and LEPA (low energy, precision application) methods. Typically, these spray methods involve spray head spacing at 10 feet or less. Spacing in-canopy spray heads greater than 10 feet may lead to poor coverage and dry areas due to the crop canopy interfering with the application pattern. When using spacing greater than 10 feet, consider mounting the spray heads just above the crop canopy for more uniform coverage. Figure 3.3 shows the location of sprinklers for four irrigation methods in tall and short crops.

Howell, T.A. 2006. Water losses associated with center pivot nozzle packages. Proceedings of the 2006 CPIC. Colby, Kansas, Feb 21-22.

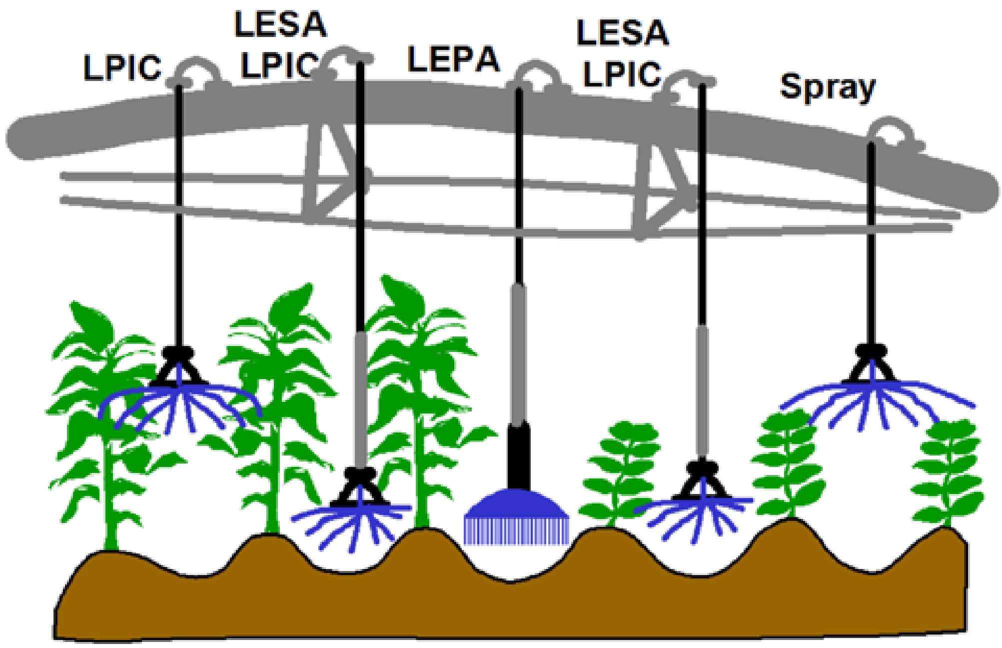


Figure 3.3 Illustration of the LEPA, LESA, LPIC and spray application concepts in tall and short crops.
Courtesy of Dr. Terry Howell, USDA-ARS, Bushland, Texas. Source: Howell, T.A. 2006. Water losses associated with center pivot nozzle packages. Proceedings of the 2006 CPIC. Colby, Kansas, Feb 21-22.

FURROW IRRIGATION SYSTEMS

Because gravity systems still comprise 10 to 20 percent of the irrigation systems in the Great Plains, a discussion on improving the application efficiency of furrow systems is warranted. However, in regions where irrigation water is limited through water allocations or low capacity wells, farmers should consider moving to a more efficient system so that more of the water applied to the field will be stored in the root zone and used to produce grain.

Improving Efficiency

When setting up a furrow system, length of run should be a primary consideration. Furrows that are too long may result in water being lost by deep percolation at the upstream end of the furrow by the time the downstream end is adequately watered. Generally, recommendations on the maximum length of irrigation runs include 600 feet on sandy soils and about 1,300 feet on medium textured soils. On some lower intake rate soils, the length of run may be as long as 2,600 feet and still distribute water uniformly.[1]

In order to reduce deep percolation it is important to irrigate the entire field as quickly as possible. A technique used to quickly irrigate a field includes irrigating every other furrow, which supplies water to one side of each furrow ridge. A benefit of irrigating every other furrow is the ability to store rainfall in the dry furrow in a recently irrigated field. Recirculating irrigation runoff water makes more effective use of irrigation water and labor. Reuse of runoff water decreases the amount of water pumped or delivered and can improve water application efficiencies by approximately 10 percent.[1]

Farmers should consider how much water is applied in an irrigation event and how it is distributed. The number of gates opened or tubes set (the set size) significantly impacts both how fast water advances across the field and the amount of water being applied. Farmers should evaluate soil surface conditions prior to irrigation and adjust the set size and corresponding stream size accordingly. For more information on improving the application efficiency of furrow irrigation, consult the University of Nebraska NebGuide G1338, Managing Furrow Irrigation Systems.

Surge Irrigation

Another technique that may improve furrow irrigation application efficiency is the use of surge irrigation. A surge valve is used to alternately send pulses of water down the furrow during advance cycles. Alternating wetting and drying allows soil particles in the bottom of the furrow to settle and may reduce the intake rate of the soil. If the intake rate is reduced, water may advance down the furrow faster. Once water reaches the end of the furrow, pulses of water are sent down the furrow during "soak" cycles. For more information on surge irrigation, consult the University of Nebraska NebGuide G1868, Surge Irrigation Management and the Kansas State University publication, Surge Irrigation L912.

Improving Infiltration

Many furrow irrigators have adopted ridge-till systems, which tend to build soil structure over time and improve infiltration rates. Compared to conventional tillage, ridge-till systems consume less fuel and labor. Care must be taken when using ridge-till for extended periods of time as infiltration rates may increase to the point of causing non-uniform application as it takes too long for the water to advance to the end of the furrow. Furrow packing or "slicking" has been used effectively with graded furrow irrigation to reduce excessive infiltration. Polyacrylamide polymers have been effective in reducing graded furrow percolation losses.[2]

[1]Yonts, C.D., Eisenhauer, D.E., and Varner, D.L. 2007. Managing furrow irrigation systems. NebGuide G1338. University of Nebraska-Lincoln Extension.

[2]Lentz, R.D., Sojka, R.E., Robbins, C.W., Kincaid, D.C., and Westermann, D.T. 2001. Polyacrylamide for surface irrigation to increase nutrient-use efficiency and protect water quality. Communications in Soil Science and Plant Analysis. vol 32(7&8): 1203-1220.

Rogers, D.H. and W.M. Sothers. 1995. Surge irrigation. Publication L-912. Kansas State University Extension.

Yonts, C.D. 2008. Surge irrigation management. NebGuide G1868. University of Nebraska-Lincoln Extension.

SUBSURFACE DRIP IRRIGATION

Subsurface drip irrigation (SDI) is a system where water is applied to the crop root zone through underground driplines or drip tape. SDI has the potential to be a highly efficient system if designed, maintained, and managed properly. This system also has the potential to become a point of frustration in the farmer's operation because of increased time commitment in fixing broken driplines or overcoming problems caused by poor design or maintenance. In addition, the farmer must monitor soil moisture to ensure that water application does not lead to deep percolation.

Basic Design

The basic design of an SDI system consists of a pump, water source, filter, driplines, and control panel. The pump pushes water through the filter and driplines and the control panel determines which section (zone) of the system the water will be applied to and for how long. Driplines are placed in the root zone of the crop and allow water to be applied efficiently with little loss. The length of driplines can be up to 0.5 mile. These lines can vary in the type of material they are made from but are typically made of plastic with emitters embedded into the line. There are different sizes of emitters with larger emitters allowing for greater water flow. Emitter placement can vary between 8 and 24 inches depending on the target irrigation rate. The thickness of the plastic dripline can also fluctuate with thin walled dripline being used for short-term situations and thicker dripline used for permanent installation. A trencher or shank is used to install the line at the target depth (12 to 18 inches below the soil surface) and the line is placed in an alternate row/bed pattern throughout the field with approximately 5 to 6 feet between lines. A flush-out system is installed at the end of the run for each dripline.

Water Filtration

Water filtration is extremely important to the long-term viability of an SDI system. If water filtration is not adequately addressed in the planning, the system will likely fail within a matter of a few years due to emitter clogging. Prior to installation, an extensive water test should be performed on the water source and a plan for removal of various water contaminants should be addressed. Contaminants can range from high calcium, magnesium, or sulfate levels to high levels of total suspended solids, among others. Water filtration systems can be developed to clean the water of most of these contaminants. Filtration systems may include screens, settling basins, disks, cyclonic, or sand media filters.

Potential Benefits

SDI has many potential benefits including:

- Increased irrigation efficiency and energy savings on a well maintained system
- Irrigation of irregularly shaped fields
- Decreased nutrient loss through reduced surface water loss
- Decreased loss of water through deep percolation
- Increased use of automation thus reducing labor
- Allows field operations when the field is being irrigated

For farmers managing fields with limited water, increased irrigation efficiency may be of greatest importance. The SDI system allows water and nutrients to be "spoon fed" to the crop over the growing season with 95 percent or greater irrigation efficiency. Since the water is pumped to the crop underground, much less water is lost to the environment through evaporation relative to that lost by surface application methods (sprinkler or furrow, flood, and basin methods). There is only a negligible, though measurable, loss of water to the system that occurs when the driplines are flushed out for routine maintenance.

The potential benefits of using SDI with deficit irrigation.
In a four-year study conducted in Colby, Kansas from 1997 to 2000 a daily application rate of 0.10 inches of water per day was applied to corn growing in a silt loam soil. In 2000, environmental conditions were exceptionally dry, but the 0.10 inches of water per day treatment yielded 80 percent of the maximum.[1] Other studies have indicated that SDI can support higher corn and grain sorghum yields over alternative irrigation systems when deficit irrigation was used (Figure 3.4).[2,3]

Potential Drawbacks

While many potential benefits exist, there are also numerous potential drawbacks to this system such as:

- Limited dripline lengths
- Inflexible design
- Potential clogging of emitters
- Damage to the driplines by rodents
- High initial investment costs

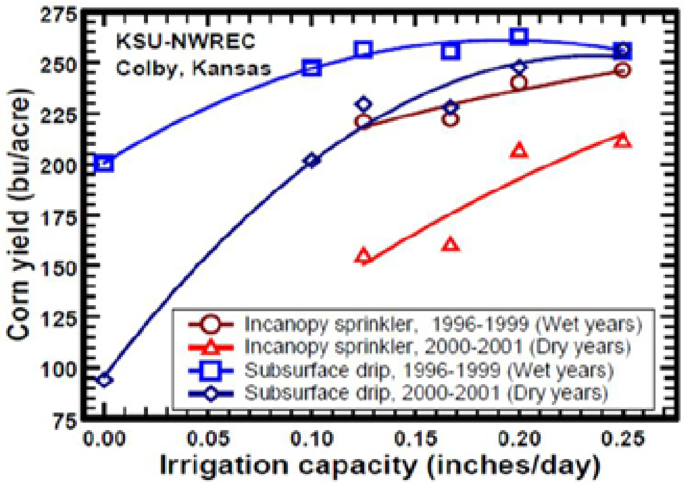


Figure 3.4 Corn yields for SDI and in-canopy sprinkler irrigation in wet years and dry years at Colby, KS.
Results are from different but similar studies, so these are not statistically different.
Source: Lamm, F.R. and D.H. Rogers. 2014. SDI for corn production – A brief review of 25 years of KSU research. Proceedings of the 2014 CPIC. Burlington, Colorado, Feb 25-26.

Another possible drawback can occur in years where spring precipitation is lacking. Because emitters are placed below the seed level, the system may not be able to apply sufficient moisture to germinate and establish the crop. Additionally, dry soil above the driplines can be a problem with surface or near surface fertilizer applications. Water must be available in the soil for fertilizer to move into the plant roots. For this issue, it is recommended that the drip system be equipped for fertigation. No-till systems can be a concern with SDI. The buildup of residue can attract rodents that can damage the driplines. Water loss due to rodent damage can be significant and decrease the application efficiency of the system. With the exception of the inability to supply sufficient moisture for seed germination, these potential drawbacks can be addressed with proper selection of the site, design, implementation, and continual maintenance of the system. It is also recommended that the field be deep ripped prior to installation to eliminate any possible compaction.

For more information on the SDI system, visit Kansas State University (www.ksre.ksu.edu/sdi/) or the University of Nebraska (http://water.unl.edu/cropswater/subsurface-drip) Extension Services.

[1]Lamm, F.R. and T.P. Trooien. 2001. Irrigation capacity and plant population effects on corn production using SDI. Proceedings of the Irrigation Association International Irrigation Technical Conference. San Antonio, Texas, Nov 4-6.

[2]Lamm, F.R. and D.H. Rogers. 2014. SDI for corn production – A brief review of 25 years of KSU research. Proceedings of the 2014 CPIC. Burlington, Colorado, Feb 25-26.

[3]Colaizzi, P.D., Schneider, A.D., Evett, S.R., and Howell, T.A. 2004. Comparison of SDI, LEPA, and spray irrigation performance for grain sorghum. Transactions of the ASABE. vol 47(5): 1477-1492.

LEPA

In areas with limited water supplies or low capacity wells, farmers should consider using irrigation methods, like LEPA, that improve application efficiency. LEPA is a low pressure irrigation method for uniformly applying small, frequent irrigations at or near ground level to individual furrows with a mechanical-move system accompanied by soil tillage methods or tillage plus crop residue management to increase surface water storage capacity. Adoption and success of LEPA is somewhat dependent on soils, topography, and management.

Unlike conventional sprinkler system design, which is based on the soil infiltration rate, LEPA design is based on the application volume per irrigation not exceeding the soil surface storage volume. Minimal losses from droplet evaporation, drift, and canopy evaporation with LEPA irrigation allow the farmer to apply high frequency irrigations. If LEPA nozzles are used in conjunction with basin or reservoir tillage, application efficiencies of 95 to 98 percent are attainable. However, without tillage to control runoff, runoff fractions exceeding 50 percent of the LEPA irrigation have been measured.[1] According to the Natural Resources Conservation Service (NRCS) Conservation Practice Standards for sprinkler irrigation systems, LEPA systems should not be used on fields with slopes greater than 1 percent on more than half of the field and nozzle spacing should not exceed two times the row spacing of the crop, not to exceed 80 inches. LEPA is not recommended if effective soil storage areas cannot be created and maintained. For example, on sandy soils, reservoir degradation occurs after repeated irrigation applications. LEPA does not work well in no-till systems because of the absence of furrow diking and problems with increased runoff.

The following are guidelines for the complete LEPA system:[2]

- The crop must be planted in a circular pattern on center pivots.
- Drop tubes must be placed at a height of 12 to 18 inches above the soil surface between every other row.
- Water must be discharged in the bubble mode or through double-end open socks to avoid wetting plant leaves.
- Surface basin storage (furrow dikes, dammer dikes, or implanted reservoirs) must be created to prevent any runoff and maintain infiltration uniformity.
- Alternate furrow irrigation with LEPA drag socks is recommended where infiltration rates and surface storage permit it as this can reduce soil wetting to half or less of total soil surface area, which reduces soil evaporation losses to nearer those experienced with subsurface drip irrigation.

[1]Schneider, A.D., Buchleiter, G., and Kincaid, D.C. 2000. LEPA irrigation developments. Proceedings of the National Irrigation Symposium. ASABE. Phoenix, Arizona, Nov 14-16.

[2]Yonts, C.D., Kranz, W.L., and Martin, D.L. 2007. Water loss from above-canopy and in-canopy sprinklers. NebGuide G1328. University of Nebraska-Lincoln Extension.

ASAE. 1999. Planning, design, operation and management of low energy precision application (LEPA) irrigation systems. Engineering Practice X531. ASAE. St. Joseph, MI 49085.

Lamm, F.R. 2004. Comparison of SDI and simulated LEPA sprinkler irrigation for corn. Proceedings of the 25th Annual International Irrigation Association Exposition and Technical Conference. Nov 14-16.

VARIABLE RATE IRRIGATION

Variable rate irrigation (VRI) technology, like other precision agriculture technologies, uses Global Positioning Systems (GPS) and Geographic Information Systems (GIS) to spatially optimize inputs. VRI allows for water to be applied at differing rates along center pivot and linear move irrigation systems depending on field characteristics such as soil type and slope. Information is sent to a control panel that can regulate individual or zones of sprinklers or the speed of the irrigation system across the field.

Determining the Need for VRI

A field that is uniform in soil type and topography which produces a crop that is uniform in health and yield may not warrant an investment in VRI. Many fields, however, are not uniform. A farmer may wish to vary the application depth in different areas of the field where soil type or slope differs or shut off irrigation in certain areas of the field such as in non-crop areas. Once the need for VRI has been determined, the next step is to gather field specifics using tools such as field mapping products and software programs or yield and soil maps. This data can provide an overview of the area and spatial arrangement of each different soil type in the field. Crop productivity indexes, available from the NRCS and some state universities, can be used to determine the production potential of each soil type present and thus, the yield benefits that VRI could provide. It is recommended to utilize a consultant in the consideration and set-up of a VRI system to help, not only in estimating the benefit of this technology in a particular field, but also to determine if something other than irrigation is limiting yields.

The soil and yield data that is gathered can be used to design an irrigation prescription for each of the different areas of the field. This prescription can, and often does, change throughout the growing season as ET rates change and the plant canopy becomes more dense. Detailed field scouting for soil moisture, aerial imagery, canopy temperature sensors, and soil moisture sensors are some of the tools that can be used to determine changes to the prescription throughout the season. Farmers with water constraints may have to consider a prescription that focuses on applying the optimum amount of irrigation on the soils that have the greatest yield potential.

Adoption of VRI

Although VRI has the potential to improve irrigation efficiency, the technology has yet to become widely adopted amongst farmers due to set-up (soil mapping) and equipment costs, challenges in writing prescriptions, and limited trained technical support. Currently, documented research on the water and energy conservation benefits of this technology is limited, which will be needed to support further adoption and promotion. Increasing restrictions to water policy will likely incentivize further adoption of this system. For example, the state of Texas recognizes VRI as a tool for water conservation in the 2014 Texas Water Report.

Evans, R.G., LaRue, J., Stone, K.C., and King, B.A. 2013. Adoption of site-specific variable rate sprinkler irrigation systems. Irrigation Science. vol 31(4): 871-887.

LaRue, J. 2014. Management considerations for variable rate irrigation. Proceedings of the 2014 CPIC. Burlington, Colorado, Feb 25-26.

O'Shaughnessy, S.A., Evett, S.R., and Colaizzi, P.D. 2014. Infrared thermometry as a tool for site-specific irrigation scheduling. Proceedings of the 2014 CPIC. Burlington, Colorado, Feb 25-26.

Texas Water Report: Going deeper for the solution. 2010. Publication 96-1746. www.TXWaterReport.org.

IRRIGATION SYSTEMS COMPARISON

With many options of irrigation systems to choose from, no single system stands out as the best fit for all situations. In limited water situations, systems should be chosen that provide the highest yield potential or greatest water use efficiency (WUE). Several studies comparing corn WUE at different irrigation levels in Bushland, Texas are summarized in Table 3.1. With full irrigation, WUE is very similar for all systems. However, with less than full irrigation, higher WUE is achieved with those systems that have higher application efficiency.[1] It stands to reason that systems that store the higher fraction of water in the root zone should achieve higher yield potentials and WUE in limited water conditions; however, other factors such as irrigation frequency likely play a role.

With deficit irrigation, systems with the highest efficiencies may provide the greatest return.

In a study conducted in Bushland, Texas in 2001, sorghum grain yields and WUE were compared with SDI, LEPA, and sprinkler irrigation at five different irrigation levels increasing in 25 percent

Table 3.1 Examples of corn WUE with various irrigation systems in Bushland, Texas

IRRIGATION METHOD	IRRIGATION FRACTION	WUE (BU/IN)
Surface	Full	5.46
	Vegetative deficit	4.98
	Pollination deficit	3.68
	Grain-filling deficit	4.49
LEPA	1.00	5.46
	0.80	5.87
	0.60	5.58
	0.40	5.58
	0.20	5.18
Subsurface drip	1.00	5.75
	0.67	6.19
	0.33	4.90

Source: Howell, T.A. 2001. Enhancing water use efficiency in irrigated agriculture. Agronomy Journal. vol 93: 281-289.

increments from no irrigation (0 percent) to full irrigation (100 percent). When only comparing SDI and LEPA to sprinkler irrigation such as LESA (low elevation, spray application) and MESA (mid-elevation, spray application), sorghum grain yields and WUE at lower irrigation levels (25 and 50 percent) favored SDI, but grain yields and WUE at higher irrigation levels (75 and 100 percent) favored sprinkler irrigation.[2] In a follow-up study conducted in 2004, SDI again resulted in greater sorghum grain yield and WUE at the lower irrigation levels and sprinkler irrigation outperformed SDI at the higher irrigation levels.[3] In other words, in the limited water situations, the highest grain yields and WUE were achieved by the most efficient irrigation systems, SDI followed by LEPA. The calculated WUE for each system actually declined when moving from limited irrigation to full irrigation. This indicates that the greatest return, bushels per inch of water, occurred with highly efficient systems under deficit irrigation strategies.

[1]Howell, T.A. 2001. Enhancing water use efficiency in irrigated agriculture. Agronomy Journal. vol 93: 281-289.

[2]Schneider, A.D., Howell, T.A., and Evett, S.R. 2001. Comparison of SDI, LEPA, and spray irrigation efficiency. Presented at the 2001 ASABE Annual International Meeting. Paper number 012019. ASAE. 2950 Niles Rd., St. Joseph, MI 49085.

[3]Colaizzi, P.D., Schneider, A.D., Evett, S.R., and Howell, T.A. 2004. Comparison of SDI, LEPA, and spray irrigation performance for grain sorghum. Transactions of the ASABE. vol 47(5): 1477-1492.

THE IMPORTANCE OF MAINTENANCE

Irrigation system maintenance issues can affect water application uniformity and thus reduce yield. In a "normal" year, application uniformity issues likely wouldn't be visible due to precipitation masking the effect. However, in a drought year, the impact is visible and the yield reduction is likely to be evident. Rings of lower yields on a yield map and issues such as those seen in Figure 3.5 taken in 2012 may indicate water delivery problems. The best time to check irrigation systems for poor application patterns is before planting. Later in the growing season, the corn height will likely obscure problems, especially if sprinkler nozzles are placed in the canopy.

Water application problems could be the result of:

- A detached sprinkler creating a geyser on the pivot pipeline
- A sprinkler that has stopped rotating or rotates out of control
- Declines in pumping water level so that the system flow rate and pressure no longer match the original design
- Leaking boots, gaskets, and other seals
- Plugged nozzles or emitters
- Sprinkler spacing that is too wide leaving un-watered plants
- Failing pressure regulators causing uneven application

Each of these issues can result in extra water being applied in some areas and insufficient water being applied in others. Even a minor maintenance issue can be significant in the amount of yield reduction it causes. For example, a malfunctioning sprinkler nozzle in the outermost portion of the pivot pipeline will impact a much greater percentage of the field than a nozzle located towards the center. In one study, this inconsistency amounted to a yield decrease of 30 to 40 bushels per acre for the affected field areas.[1]

Figure 3.5 Variability in rings under a center pivot may indicate nozzle or other water delivery problems.
Photo courtesy of Gary Zoubek, University of Nebraska-Lincoln.

Pivot Maintenance Checklist

The following list covers steps for maintaining and managing pivots for more effective irrigation:

- The sprinkler package should be installed properly.
- The system capacity should be adequate.
- The pump and pivot should be properly matched. The engine and pump speeds should be correct for the needed voltage or hydraulic pressure and for pressure at the pivot inlet, as well as for engine performance.
- Operate the center pivot system at the design pressure. A pressure gauge at the distal end of the pivot should be installed and periodically checked at its highest elevation. Pressure should be at least 5 psi above the pressure regulator rating.
- The system should be operated when crops are small. Look for broken or plugged sprinklers or pressure regulators as well as leaks. If there are concerns, a new regulator and sprinkler (with the proper nozzle) should be installed in the middle of each span in order to observe any differences between performance of new components and existing devices.
- Observe water application in the outermost span on the steepest portion of the field and on the soils with the lowest infiltration rate to look for runoff problems. If problems exist:
  - » The application depth may be reduced
  - » The use of reduced tillage may enhance surface storage and infiltration
  - » A different sprinkler package may be necessary
- Mechanical, electrical, and hydraulic components should be routinely maintained.

Determining Application Uniformity

The uniformity of water application from a center pivot system should be checked periodically, especially if the system is used to apply fertilizer and pesticides. The basic method for assessing application uniformity is outlined below.[2] For a more detailed explanation, refer to the University of Georgia publication, Evaluating and Interpreting Application Uniformity of Center Pivot Irrigation Systems.

- Cans or rain gauges are placed along the length of the pivot to capture water from the irrigation system. Gauge spacing should be comparable to the sprinkler spacing on the pivot (10- to 30-foot spacing).
- The irrigation system is brought up to proper operating pressure and allowed to pass over the gauges.
- The distance from the center of the pivot and the amount of water collected for each can or gauge is measured.
- From this data, a coefficient of uniformity is calculated as a percentage; recommendations are based off of this percentage:
  - » 90 to 100 - Excellent; no changes required
  - » 85 to 90 - Good; no changes required unless a problem area is obvious
  - » 80 to 85 - Fair; no improvements needed, but system should be monitored closely
  - » Below 80 - Poor; improvements needed, particularly if chemicals are to be injected
- This data can also be interpreted by plotting on a graph which shows where high or low applications are occurring along the pivot. See Figure 3.6 for an example.

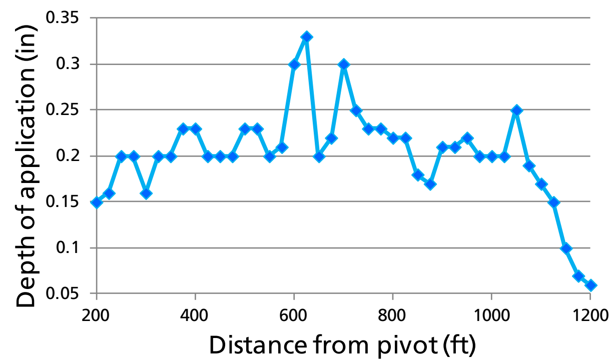


Figure 3.6 Plot of application uniformity data from a center pivot irrigation system.

Source: Figure modified from Harrison, K. and C. Perry. 2013. Evaluating and interpreting application uniformity of center pivot irrigation systems. Circular 911. University of Georgia Extension.

Because the calculations and interpretation of this data is mathematically involved, spreadsheets and software programs have been designed to assist farmers. The University of Georgia offers a free software program called ISAAC (Irrigation System Analysis and Computation) which can be accessed at http://striplingpark.org/downloads/. Other agencies that may have access to computer software programs for determining application uniformity include: the Natural Resource Conservation Service (NRCS), Soil and Water Conservation Commission (SWCC), Resource Conservation and Development (RC&D) agencies, your local county extension agent, or a private crop consultant.

[1]Yonts, C.D., Lamm, F., Kranz, W., Payero, J., and Martin, D. 2005. Impact of wide drop spacing and sprinkler height for corn production. Proceedings of the 2005 CPIC. Sterling, Colorado, Feb 16-17.

[2]Harrison, K. and C. Perry. 2013. Evaluating and interpreting application uniformity of center pivot irrigation systems. Circular 911. University of Georgia Extension.

Burr, C., Martin, D., Kranz, W., and Zoubek, G. 2014. Regular pivot maintenance can help ensure application efficiency. CropWatch, March 14, 2014. University of Nebraska-Lincoln Extension.

KEY TAKEAWAYS

- Center pivots are the most common and economical irrigation system to efficiently apply water over a wide range of environmental conditions.
  - » Nozzle selection and placement in or above the canopy impacts application efficiency and irrigation uniformity.
- LEPA and SDI are the two best choices of irrigation systems to use with limited water if field slope, soil type, and economics allow.
- To be successful with SDI:
  - » Proper selection of the site is important.
  - » The water source should be tested for contaminants and appropriate filtration should be addressed.
  - » Lines should be cleaned and flushed regularly.
- To be successful with LEPA:
  - » The crop must be planted in a circular pattern on center pivots.
  - » Drop hoses must be placed at a height of 12 to 18 inches above the soil surface in every other furrow.
  - » Water must be discharged in the bubble mode or through double-end open socks to avoid wetting plant leaves.
  - » Surface storage must be created to prevent any runoff and maintain uniform infiltration.
- Irrigation systems should be periodically inspected and properly maintained to maximize application efficiency.

CHAPTER 4
CROPPING PRACTICES

CORN CROPPING PRACTICES

SOYBEAN CROPPING PRACTICES

FERTILITY

KEY TAKEAWAYS

Agronomic management practices that promote early canopy closure can help increase crop yield potential while conserving soil moisture. A denser plant canopy that closes earlier in the season will capture the sun's energy more efficiently, providing the crop with a longer period for photosynthesis and thus, more energy for grain production. The cooler temperatures prevailing in late April and early May in many areas are much less conducive to soil water evaporation, whereas typical conditions in late May and June create a higher evaporative demand on soil moisture. Early planting takes advantage of the lower evaporative demand on soil water while the plant canopy is thin and soil is more exposed to solar radiation. As temperatures and evaporative demands increase, the plant canopy will be more dense, which provides better shading of the soil. Better shading reduces soil moisture loss to evaporation and preserves more soil water for plant use. Early planting, increasing planting densities, and narrowing rows are all strategies that promote a more dense canopy that closes quicker. In some cases, caution should be used in water-limited production regions. For example, though it is well documented that higher yields result from higher plant populations in most of the Corn Belt, this practice promotes more stressful conditions for the crop when water is limited.

CORN CROPPING PRACTICES

RELATIVE MATURITY

The production environment and cropping system should be carefully considered when choosing a corn product. Full-season corn products generally have greater yield potential than short-season corn products, though short-season products may yield greater than full-season products when planting is delayed past mid-June.[1] Full-season corn products require more water throughout the growing season than short-season products, though water requirements at any given stage may be the same. The study discussed below indicates that for every four-day reduction in corn maturity, one inch less water is required. However, this reduction in water savings by growing a short-season product is not likely to offset the loss in profit due to the significantly lower yield potential of the short-season product compared to a full-season product.[2]

Savings in irrigation costs from using short-season corn may not outweigh the value of the yield sacrificed.

A study was conducted in Bushland, Texas in 1998 to investigate the potential for reducing irrigation needs by using shorter-season corn. Researchers compared two corn products, full-season (115 RM) and shorter-season (98 RM), under typical irrigation regimes managed for full production. The short-season product required approximately 4.4 inches less water throughout the season than the full-season product. However, the short-season product used water at almost the same peak daily rates as the full-season product, indicating that the necessary irrigation capacity required to avoid yield losses due to water deficits could not be decreased appreciably (not by more than 5 to 10 percent) by using shorter-season corn without increasing the risk of yield reductions. The study concluded that the cost savings from using less water on short-season corn was nearly 6 to 8 times less than the value of the yield sacrificed.[2]

[1]Staggenborg, S.A., Fjell, D.L., Devlin, D.L., Gordon, W.B., Maddux, L.D., and Marsh, B.H. 1999. Selecting optimum planting dates and plant populations for dryland corn in Kansas. Journal of Production Agriculture. vol 12(1): 85-90.

[2]Howell, T.A., Tolk, J.A., Schneider, A.D., and Evett, S.R. 1998. Evapotranspiration, yield, and water use efficiency of corn hybrids differing in maturity. Agronomy Journal. vol 90: 3-9.

PLANTING DENSITY

Historically, increased yield potential has correlated with higher plant populations, which have been possible due to advancements in breeding and agronomic practices. However, higher than optimal plant densities can be detrimental under water-limited conditions and the risk of crop failure in unfavorable growing conditions increases as the plant density increases.[1] While higher than optimal planting densities may be undesirable, decreasing plant populations below the optimal density could result in greater evaporation of soil moisture due to a thinner plant canopy (less shading of the soil). Research suggests that the water requirements of corn only decrease with very low plant populations, so reducing plant density is not an effective strategy for water conservation.[1,2] Optimal plant populations are dependant on the corn product (maturity rating, stress tolerance, resistance to stalk lodging) and the local climate (length of the growing season, water availability).

Maximizing Yield Potential – Yield per Thousand

Optimizing the yield potential of a field requires matching the planting rate to inputs available to support plant growth and development. Since performance limiting factors can change from one growing season to the next, the difficulty lies in understanding whether long-term yield potential is limited by plant density or by the inputs (water, fertility, etc.) needed to support the plant. Yield per thousand (YPT) is a measure of the yield per thousand plants. YPT is driven by agronomic factors (yield level, planting date, and length of the growing season) and environmental factors (solar radiation, relative humidity, and evapotranspiration). As performance limiting factors increase, the ability of the plant to generate yield decreases, resulting in a lower YPT.

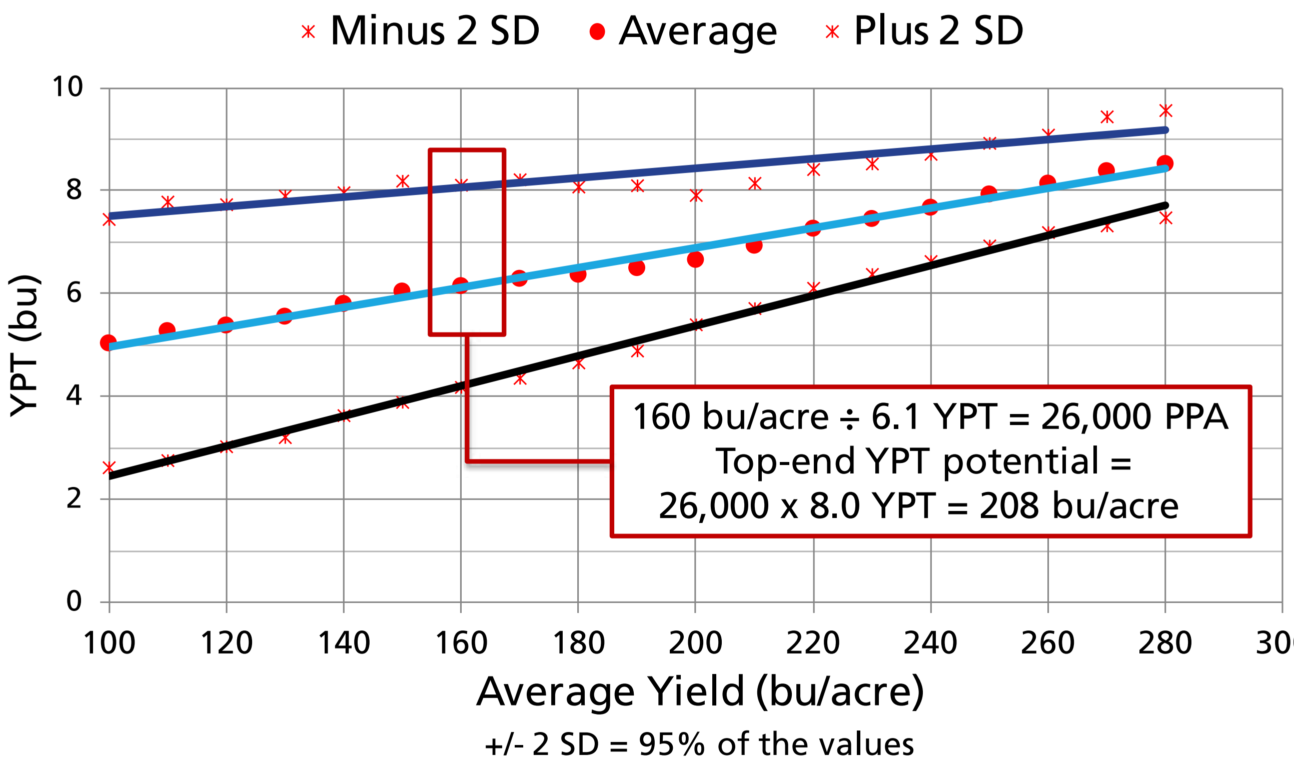


Figure 4.1 Variability of YPT changes by yield level, Western Corn Belt (CO, KS, NE, OK, SD, TX).

Figure 4.1 is a summary of the YPT from strip trials conducted by Monsanto from 2007 to 2011. This included 7,097 strip trials in Colorado, Kansas, Nebraska, Oklahoma, South Dakota, and Texas. The data shows a strong correlation of average YPT (red line) with yield level. In addition to plotting the average YPT, an upper limit and lower limit (black lines) were plotted using +/- 2 standard deviations (SD) from the average. This range encompasses approximately 95 percent of the observations. The upper limit represents the top-end YPT potential that could occur when conditions are favorable.

Using YPT estimates to maximize yield potential.

Your yield goal should be the most profitable yield that can be expected for the particular set of soil, climate, and management practices associated with your field. The yield goal can be determined by averaging the yields from the previous five years and multiplying by 105 percent, taking into account any extreme conditions that might have affected the average.[3] Extremely dry years would cause the average to be abnormally low and wetter years would cause the average to be abnormally high. Stored soil moisture at planting and changes in pumping capacity are also factors in estimating yield potential. The formula for determining YPT is: YPT = yield goal (bu/acre) ÷ planting rate x 1000.

- If the YPT of your field is toward the lower end of the range in Figure 4.1, consider changes in management other than increasing population.
- If your YPT is toward the high end of the range, consider increasing plant population to capture the upside yield potential of the field.

Using YPT to determine the optimum planting rate.

Yield per thousand can be used as a tool for determining the optimum planting rate given the yield potential of a field. The formula for determining planting rate from YPT is: planting rate = yield goal (bu/acre) ÷ YPT x 1000

- Suppose the yield potential of a pivot is 160 bushels per acre.
- According to Figure 4.1, a YPT of 6.1 bushels per thousand plants is a reasonable expectation.
- 160 bu/acre ÷ 6.1 bu/thousand plants x 1000 = 26,000 plants per acre as a reasonable population.
- Assuming 95 percent corn emergence, the farmer should plant 27,300 seeds per acre.

[1]Klein, R.N. and D.J. Lyon. 2011. Recommended seeding rates and hybrid selection for rainfed (dryland) corn in Nebraska. NebGuide G2068. University of Nebraska-Lincoln Extension.

[2]Allen, R.G., Pereira, L.S., Raes, D., and Smith, M. Crop evapotranspiration, guidelines for computing crop water requirements. FAO irrigation and drainage. Paper no. 56

[3]Shapiro, C.A., Ferguson, R.B., Hergert, G.W., Wortmann, C.S., and Walters, D.T. 2008. Fertilizer suggestions for corn. Publication EC117. University of Nebraska-Lincoln Extension.

Hickman, J.S. and J.P. Shroyer. 1994. Optimum planting practices. In Corn Production Handbook. Kansas State University Extension. 8-12.

PLANTING DATE

Early planting can increase the yield potential of corn if conditions remain favorable for germination and plant development, but caution should be taken when planting early. The optimal time to plant corn should be determined by soil temperature and soil moisture levels. Early planted corn generally requires more time to emerge than later planted corn. At soil temperatures of 50° to 55° F, it could take 20 days for the corn crop to emerge from a 2- to 3-inch soil depth. It may only take 10 days in soil temperatures of 60° to 65° F.[1] Corn seeds planted before conditions are favorable for germination may be exposed to suboptimal temperatures (below 50° F) for too long, causing them to sit dormant and become more vulnerable to diseases, insects, and animal predators.

Late planting can significantly affect corn yields. For example, a reduction in yield from 10 up to 60 percent can be expected when planting is delayed past mid-May in most of Kansas.[2] The effect of delayed planting on yields will depend on the growing environment and the timing, degree, and duration of environmental stress that the crop experiences. Grain yields can actually increase with delayed planting if early-season stresses occur. In most regions of the Great Plains, delayed and late planting dates often result in hotter, drier weather during critical developmental stages such as silking and pollination. An exception is the Texas Panhandle and similar extreme heat climates where late planting of corn is sometimes considered to avoid the hot, dry conditions that are typical during the normal planting season. To date, there are limited studies in this region measuring the performance of late planted corn relative to conventional planting dates. Ongoing studies by Texas A&M University aim to investigate this further.

Late planting often results in lower yields except when early season stresses occur.

A study conducted in three dryland locations in central Kansas in 2007 and 2008 investigated the effect of planting date on corn yields grown under three different environmental scenarios involving water and temperature stresses: low stress, extended season-long stress, and early-season stress. In this study, grain yields were reduced by 10 percent when planting was delayed from early April to late June and environmental stresses were low. Yield decreases in this treatment were more evident with late May and June planting dates. When extended, full-season stress occurred, grain yields were reduced by 60 percent for the delayed planted corn. In this treatment, grain yield was greatest for the early April planting date and decreased linearly with later planting. Conversely, grain yields of delayed planted corn were increased by 30 percent when early-season stresses occurred.[2] Another Kansas dryland study reported similar results where planting delayed until early June resulted in decreased yields in all plots with the exception of one plot where high temperatures and water stress early in the season resulted in late planted corn yielding greater than the early planted corn. In this study, an average 36 bushels per acre reduction in yield was reported across all plots when planting was delayed until early June.[3] Yield penalties due to late planting have also been reported in irrigated corn studies.[4]

One strategy recommended by Kansas State University to avoid heat stress during pollination is to utilize early maturing corn (90 to 110 RM) planted 10 to 14 days earlier than the recommended planting dates for the region, if conditions are favorable.[1] With this practice, corn will be in the reproductive and grain filling stages before the period of the season when heat and drought stress usually occurs. Another strategy commonly used to minimize risks associated with heat stress during pollination is to plant products with varying maturities. This practice spreads out the pollination period increasing the chances for economic returns should a period of unfavorable weather occur.

[1]Hickman, J.S. and J.P. Shroyer. 1994. Optimum planting practices. In Corn Production Handbook. Kansas State University Extension. 8-12.

[2]Sindelar, A.J., Roozeboom, K.L., Gordon, W.B., and Heer, W.F. 2010. Corn response to delayed planting in the central Great Plains. Agronomy Journal. vol 102(2): 530-536.

[3]Staggenborg, S.A., Fjell, D.L., Devlin, D.L., Gordon, W.B., Maddux, L.D., and Marsh, B.H. 1999. Selecting optimum planting dates and plant populations for dryland corn in Kansas. Journal of Production Agriculture. vol 12(1): 85-90.

[4]Grassini, P., Yang, H.S., Irmak, S., Rees, J.M., Burr, C.A., and Cassman, K.G. 2012. Yield gaps and input-use efficiency of high-yield irrigated corn in Nebraska. Publication EC106. University of Nebraska-Lincoln Extension.

SOYBEAN CROPPING PRACTICES

RELATIVE MATURITY

The rate of transition from vegetative growth to the reproductive stages and maturity is controlled by day length in soybeans. A full-season soybean product will transpire more water throughout the season and have a greater water demand than a short-season product planted in the same location.[1] Under optimal growing conditions, a full-season product will generally have greater yield potential than a short-season product as soybean yield is linearly related to transpiration (J.E. Specht, personal communication, July 3, 2014). Though the yield benefits of full-season products have been well documented, few studies have been conducted in the Great Plains region that compare the crop water use of different soybean maturity groups and whether or not the water savings for growing a short-season product could offset lower yields.

[1]Schapaugh, W.T. 1997. Selection of soybean varieties. In Soybean Production Handbook. Kansas State University Extension. 4-8.

PLANTING DENSITY

Research on optimal soybean planting density has shown mixed results, with some research indicating that increasing plant populations may not significantly improve yields and may not be economical when the high cost of seed is considered.[1] Soybean is adaptable in that the plant has the ability to adjust growth and development to compensate for different plant densities. Unlike

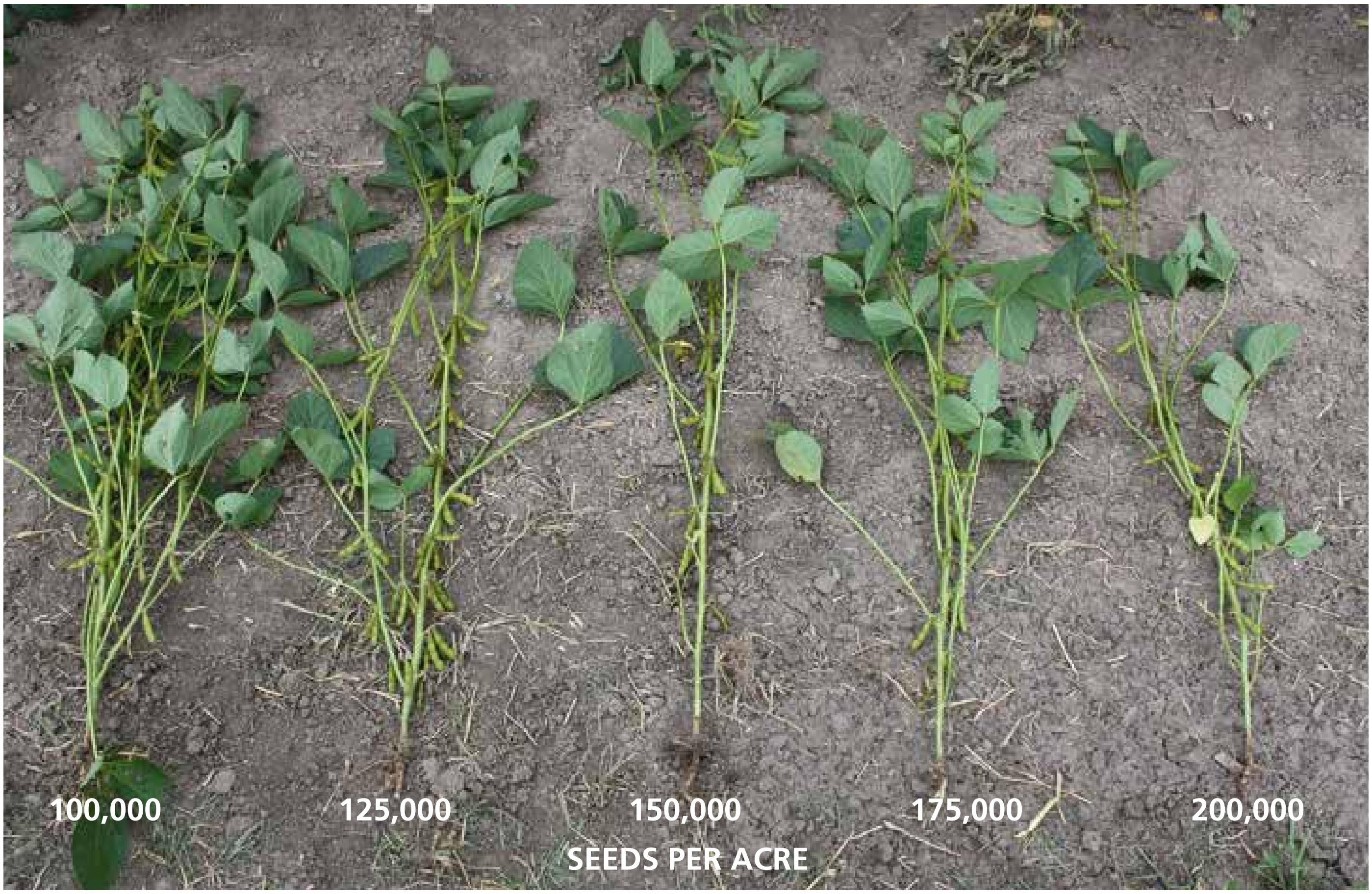


Figure 4.2 Soybean branching increases in low populations (same soybean product grown at different seeding rates). Source: Soybean planting rate demonstration. 2010. Gothenburg Learning Center Summary. Technology Development & Agronomy.

corn, which has been bred for reduced tillering, soybean plants have a greater ability to produce more branches and pods in low populations (Figure 4.2). It is important to consider higher populations when planting short-season soybeans and when planting late as this will promote a denser plant canopy. When planting soybean on soils with a low water holding capacity, such as sandy soils, plant populations should be reduced.[2]

Results from a three-year study in Nebraska (2006 to 2008) indicated that no statistically significant yield differences were found between planting populations of 120,000, 150,000 and 180,000 seeds per acre. The study recommended that farmers in Nebraska can save money on seed costs by planting at a rate of 120,000 seeds per acre in 30-inch rows without any significant effect on yield.[1]

[1]University of Nebraska-Lincoln. Quad county soybean population study. 2006-2008. Soybean Farm Research Production Studies. University of Nebraska-Lincoln Extension.

[2]Kok, H., Fjell, D.L., Kilgore, G.L. 1997. Seedbed preparation and planting practices. In Soybean Production Handbook. Kansas State University Extension. 8-11.

PLANTING DATE

Planting soybeans early helps to capitalize on a longer period for photosynthesis. Harvesting more of the sun's energy early in the season equates to more nodes per plant and thus, greater yield potential. Though the yield benefits of planting early are well documented, this practice is also risky because the likelihood of a late frost and seedling disease pressure is greater with early planting. It is important to consider soil temperature and soil moisture levels when planting soybean in order to minimize the risk of crop losses due to adverse weather. The optimal time to plant soybean is when soil temperatures will remain at or above 55° to 60° F. If weather conditions do not permit early planting or replanting is necessary after mid-June, avoid planting determinate soybeans. Instead, choose an early to mid-season, adapted, indeterminate soybean. Late planted soybeans will also benefit from narrower row widths (less than 20 inches) and higher planting densities (an increase of about 20 to 25 percent over normal rates) in order to accelerate canopy closure.[1]

The yield penalty of planting soybeans late can be substantial.

Research at the University of Nebraska-Lincoln has demonstrated that for each day soybean planting is delayed after May 1, the yield penalty can be as high as 5/8 bushel per acre in optimal growing conditions. In suboptimal conditions, the yield penalty of late planting may be as much as 1/4 bushel per acre.[2] Figure 4.3 shows a comparison of soybean canopy development with early planted versus late planted soybeans. By late June in Nebraska, the canopy of the early planted soybeans (late April and early May) is nearly closed (stage V6 to V8). On-farm studies in Nebraska compared the yields of soybean planted in late April to soybean planted in mid-May in various combinations of irrigated or dryland, no-till or ridge-till, and different row spacings. Results indicate that even in cold, wet springs, early planted soybean consistently out-yielded later planted soybean by 1 to 10 bushels per acre, with the average yield advantage being 3 bushels per acre across all treatments.[1]

[1]Specht, J.E., Rees, J.M., Zoubek, G.L., Glewen, K.L., VanDeWalle, B.S., Schneider, J.W., Varner, D.L., and Vyhnalek, A.R. 2012. Soybean planting date – when and why. Publication EC145. University of Nebraska-Lincoln Extension.

[2]Bastidas, A.M., Setiyono, T.D., Dobermann, A., Cassman, K.G., Elmore, R.W., Graef, G.L., and Specht, J.E. 2008. Soybean sowing date: The vegetative, reproductive, and agronomic impacts. Crop Science. vol 48: 727-740.

FERTILITY

Proper soil fertility management takes into consideration the nutrient requirements of each crop including the amount, source, time of application, and placement of nutrients. Nitrogen (N), phosphorus (P), and potassium (K) are the most critical elements necessary to help obtain maximum yield potential.

Soil Testing

Soil testing is an important management tool for determining soil pH and fertility needs. Key items to consider when soil sampling include: timing, spatial resolution, depth, and tillage system. Fall is the best time for soil analysis tests (with the exception of N), which are recommended every four years or less. To increase analysis and sampling consistency, fields should be sampled at the same time of year, ideally after harvest and before the ground freezes. Samples collected from the top 6 to 8 inches of the soil can be used to determine soil pH, lime needs, and the amount of organic matter, P, K, sulfur, and zinc present. To assess nitrate-N in the root zone, samples should be collected to a depth of 2 feet. Nutrients can become stratified in no-till or reduced tillage systems. If this is a concern, have a separate analysis conducted on the upper 2 inches of the soil cores. If dry soil conditions prohibit taking soil cores to the appropriate depth, wait until soil conditions improve.[1,2]

Figure 4.3 Comparison of the development of soybeans planted at four dates in June 2003 and 2004.
Photo courtesy of Dr. James Specht, University of Nebraska-Lincoln. Source: Bastidas, A.M. et al. 2008. Soybean sowing date: the vegetative, reproductive, and agronomic impacts. Crop Science. vol 48: 727-740.

Soil pH

Soil pH can greatly impact nutrient availability and crop growth and should be corrected prior to applying any fertilizer. For corn and soybean production, soil pH should be around 6.5. Soil pH decreases as basic compounds are removed by crops, leaching, or acid residual from N fertilizers. Low pH may result in reduced availability of calcium, magnesium, P, and K and can negatively impact N fixation. Lime can be applied to raise pH levels to the appropriate range. Use soil test data to determine the amount of lime required to bring the soil to an appropriate pH for optimal crop growth. Soils high in clay or organic matter have a greater ability to resist pH changes. Buffer pH is a value that is generated in the laboratory and is used to measure the reserve or stored acidity in the soil provided by the buffering capability of the clay and organic matter. These soils will require more lime to raise the pH than a sandy soil would require. High soil pH can reduce the availability of nutrients as well. High pH is difficult to lower, but awareness allows for management of associated risks.[2,3]

Nitrogen

Fertilizer applications of N should be based on the yield potential of the crop, N contributions from previous legume crops, the history of manure applications, N availability in the soil, and possibly N in irrigation water. Because N is very dynamic in the soil and availability changes throughout the season, soil N tests may help with determining available N in the soil and how much additional N may be needed. Nitrogen applications should be based on test results conducted very near to the time when N is in highest demand by the crop, which is during the rapid vegetative growth stage.[4]

There are several options to determine the amount of N to be applied depending on the season, soil type, tillage practice, and growth stage. Nitrogen applications are the most efficient when applied at the beginning of the rapid vegetative growth stage. Losses due to leaching and denitrification (conversion to atmospheric N) are minimized when N is applied at this time. Fertilizers containing nitrate are more prone to leaching. Leaching of N is more prevalent in well-drained, course textured soils. Anhydrous ammonia can be used as an alternative to nitrate because it is less susceptible to leaching. Caution should be used when applying urea to no-till ground because much of it could be lost to volatilization. Applications of urea should be made when temperatures are cold, immediately prior to rainfall or irrigation, or with a urease inhibitor to reduce the potential for volatilization. Mechanical incorporation of urea into the soil or subsurface injection is also recommended. Ammonium nitrate, ammonium sulfate, and ammoniated phosphates can be surface applied because they are less susceptible to volatilization.[2,4]

A well-nodulated soybean crop rarely requires N fertilization for fields with moderate yield potential. In fact, N fertilization early in the growing season can be detrimental to nodule development as the soybean plant will not initiate nodule development if excess N is available in the soil. For high yield potential soybeans, applying N at the R3 growth stage has the potential to increase yield.[5] Nitrogen stored in soybean residue will provide N for succeeding crops and should be considered when determining fertilizer needs.

Phosphorus and Potassium

Neither P nor K are as susceptible to loss as N. Phosphorus loss is mostly due to runoff and both P and K can be lost through crop removal. To maintain P and K levels, replace what is used by the crop each year. Some P and K can be returned to the soil from the breakdown of crop residue.[3]

Manure Applications

Manure can be broadcast applied over the soil surface or injected below the soil surface. The latter method is preferred to reduce volatilization and surface runoff and is especially important for reduced tillage and no-till operations. If manure is applied, remember to factor in this input when making fertilizer decisions. Fields scheduled to receive manure applications should be soil tested first. The manure must also be analyzed for N, P, K, and other nutrients. Nutrient levels in livestock manure can vary widely; using averages from research data is not a good substitute for proper analysis of the manure.[2]

For further information on soil fertility management including soil testing, nutrient deficiencies, lime and fertilizer application, and other related topics, visit the following resources:

- Kansas State University's Nutrient Planning Reference Guide found at (www.agronomy.k-state.edu/extension/soil-fertility)
- University of Nebraska's soil management resources found at (http://cropwatch.unl.edu/soils)
- Colorado State University's online publications found at (www.ext.colostate.edu/pubs/pubs.html#crop_soil)
- Talk to your local agronomist or the Gothenburg Learning Center for a copy of Monsanto's 2014 Advanced Agronomic Guide.

[1]Ferguson, R.B., Hergert, G.W., Shapiro, C.A., and Wortmann, C.S. 2007. Guidelines for soil sampling. NebGuide G1740. University of Nebraska-Lincoln Extension.

[2]Kansas State University. Nutrient planning reference guide: Managing soil and applied nutrients. Kansas State University Extension.

[3]Fernández, F.G. and R.G. Hoeft. Chapter 8: Managing soil pH and crop nutrients. Illinois Agronomy Handbook. 24th edition. University of Illinois Extension. 91-112.

[4]Fernández, F.G., Nafziger, E.D., Ebelhar, S.A., and Hoeft, R.G. Chapter 9: Managing nitrogen. Illinois Agronomy Handbook. 24th edition. University of Illinois Extension. 113-132.

[5]Wesley, T.L., Lamond, R.E., Martin, V.L., and Duncan, S.R. 1998. Effects of late-season nitrogen fertilizer on irrigated soybean yield and composition. Journal of Production Agriculture. vol 11(3): 331-336.

KEY TAKEAWAYS

- Agronomic management practices that promote early canopy closure can help increase crop yield potentials while conserving soil moisture.
- Early planting takes advantage of a lower evaporative demand on soil water early in the growing season and capitalizes on a longer period for photosynthesis.
- In some areas of the southern Great Plains with extreme heat conditions, planting corn later may help avoid heat stress during pollination.
- Plant corn and soybean at planting densities optimal for the local climate and available water resources to avoid stress and loss of yield potential.
- Maintaining proper soil fertility, including management of soil pH, is essential for optimal crop growth.
- Fertilizer inputs should be based on soil test results.

CHAPTER 5
CROP PROTECTION, TRAITS AND PRODUCTS

Crops experience a wide variety of stresses including insect feeding, disease, competition with weed species, drought, and extreme temperatures, among others. Frequently, more than one stress will affect the crop at any given time. To help preserve yield potential, a farmer will want to protect the crop from as many stresses as possible to allow the crop to better tolerate those stresses which cannot be controlled. For example, healthier plant roots can make better use of soil moisture. Protecting roots from insect feeding and seedling diseases early in the season is critical for establishing a healthy root system, which allows the plant to better tolerate moderate drought stress. Monsanto offers a variety of plant products with better tolerance to drought stress, insect feeding, and diseases, as well as crops that are resistant to herbicides for better and more consistent weed control. Molecular breeding tools have enhanced traditional breeding methods to speed the development of plants that are more tolerant to diseases and some abiotic stresses, such as tolerance to high salinity or high pH soils. Seed treatments improve seedling establishment by providing protection from many different insects, diseases, and nematodes.

GENUITY® DROUGHTGARD® HYBRIDS

Recent advances in crop breeding and biotechnology have enhanced drought tolerance and improved the yield potential of corn for drought-prone regions of the United States. Following the 2012 Ground Breakers® trials, the 2013 growing season marked Monsanto's first commercial introduction of Genuity DroughtGard Hybrids corn products. This represented the agriculture industry's first drought-tolerant biotech products.

Drought tolerance in crops is complex and involves many genes and physiological processes. Conventional breeding for drought tolerance is a slow process and is limited by the availability of suitable genes for breeding. Monsanto's DroughtGard Hybrids corn products are the result of conventional breeding (accumulating native traits for drought and disease tolerance and yield factors) as well as the inclusion of transgenic traits for enhanced drought tolerance, protection from insects, and weed control. DroughtGard Hybrids products can deliver Hydroefficiency™ by adapting to drought stress and using water more efficiently over time. Moisture remains in the soil or is "banked" and can be available to help maintain key plant functions while stressful conditions persist. Across environmental conditions, DroughtGard Hybrids products mitigate the impact of drought stress; providing consistent corn product performance from year to year.

The drought-tolerant biotech trait is available with the following corn products:

- Genuity® DroughtGard® Hybrids with VT Double PRO® corn
- Genuity® DroughtGard® Hybrids with VT Double PRO® RIB Complete® corn blend
- Genuity® DroughtGard® Hybrids with VT Triple PRO® corn
- Genuity® DroughtGard® Hybrids with VT Triple PRO® RIB Complete® corn blend

These options give farmers the added benefits of multiple modes of insect protection and broad spectrum weed control. For more information, visit www.genuity.com.

DroughtGard Hybrids Product Testing

All DroughtGard Hybrids products go through rigorous testing that evaluates performance under both drought and non-drought conditions. Sap flow sensors, which continuously measure water uptake by the plant, were used in 2011 to demonstrate the water conservation that the drought-tolerant biotech trait in DroughtGard Hybrids corn products confers to the plant under drought conditions. The sensors were placed around the base of the stalk of a corn plant containing the drought-tolerant biotech trait and a corn plant of nearly identical germplasm but without the drought-tolerant biotech trait. The sensors were placed on plants under both drought and fully irrigated conditions. When fully irrigated, there was essentially no difference in the flow of water up the stalk of the two plants. However, when drought stress was imposed (around the time of flowering), the corn plant with the drought-tolerant biotech trait acclimated to the stress and took up significantly less water from the soil compared to the corn plant without the trait. Figure 5.1 depicts the placement of the sap flow sensors and capacitance probes for measuring soil moisture. Figure 5.2 shows the average sap flow sensor readings (twelve replicates averaged) from the corn products with and without the drought-tolerant biotech trait.

Ground Breakers® Yield Trials

Around 250 farmers in the western Great Plains participated in Ground Breakers in 2012 - large-scale on-farm yield trials to compare DroughtGard Hybrids corn products against other products commonly grown in the region. This testing was targeted to dryland and limited irrigation production environments. That same year brought severe

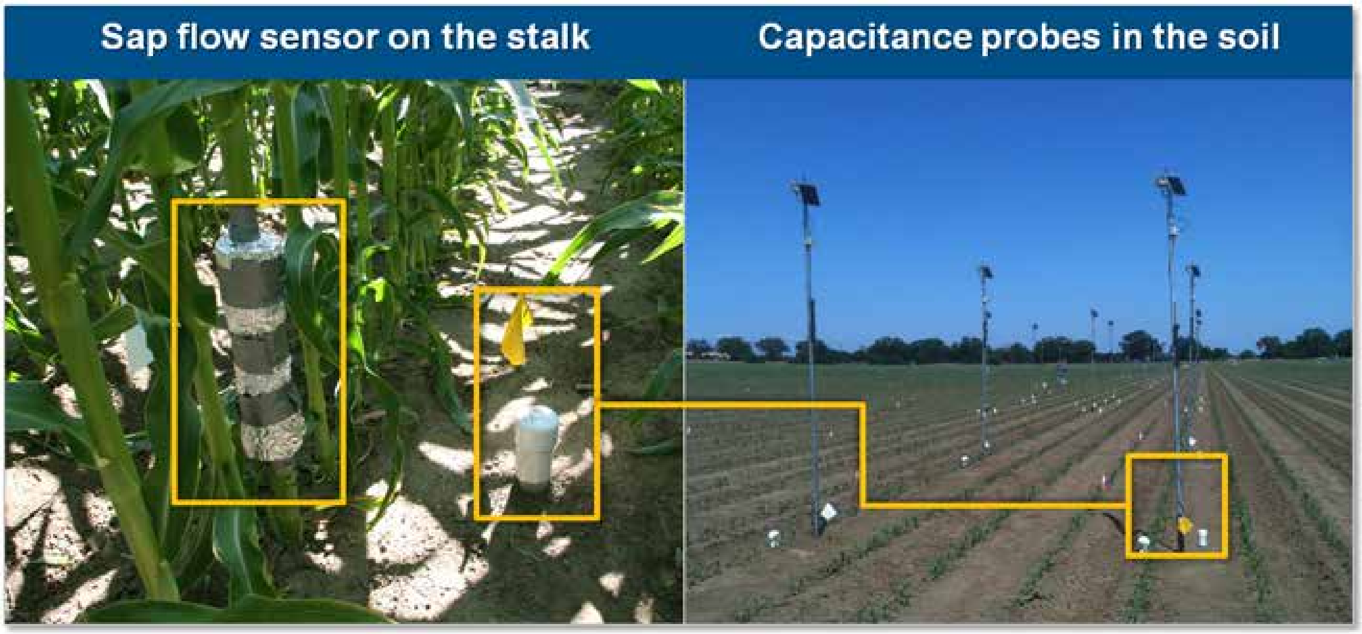


Figure 5.1 Sap flow sensor and capacitance probes used in the 2011 soil moisture and sap flow field study.
Sap flow sensor (left) continuously measures water uptake by the plant. Capacitance probes (middle and right) continuously measure soil water content.

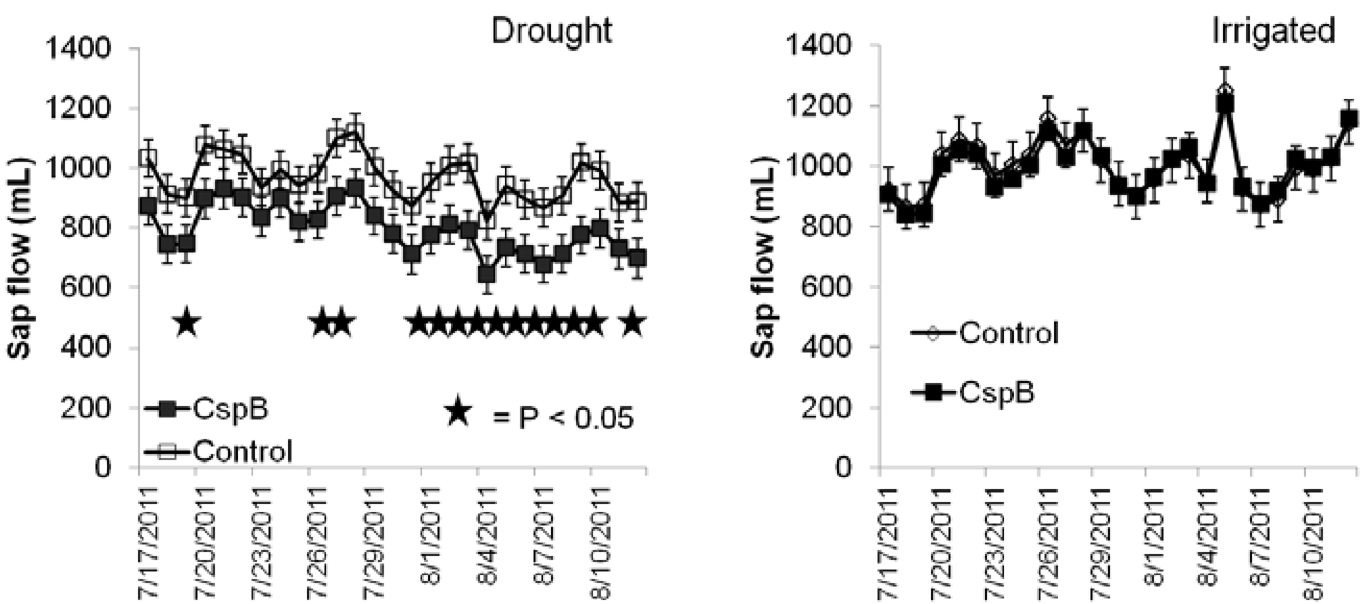


Figure 5.2 Average sap flow measurements under drought and irrigated conditions from the 2011 soil moisture and sap flow field study.
CspB = Corn plants containing the drought-tolerant biotech trait (12 replicates averaged)
Control = Corn plants without the drought-tolerant biotech trait (12 replicates averaged)

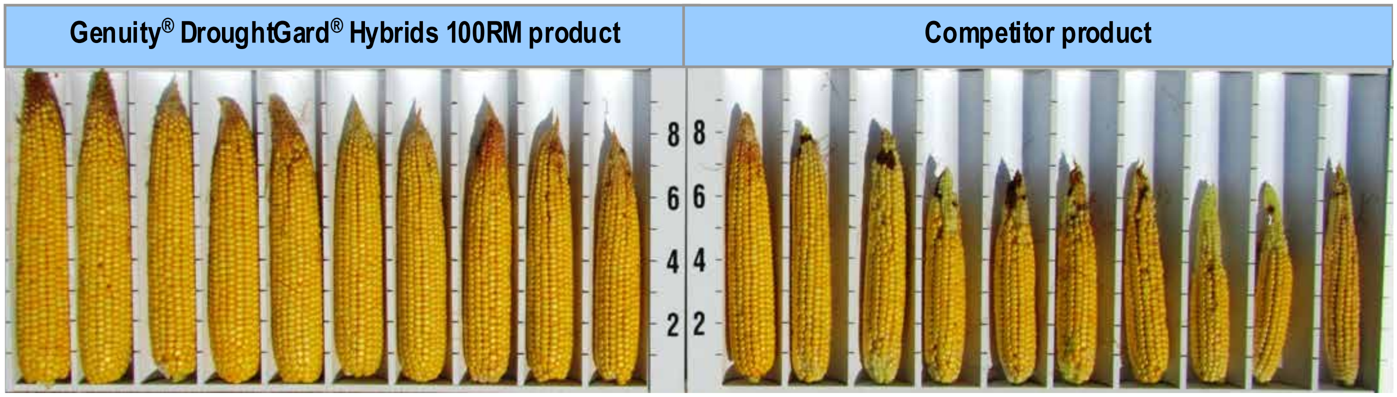


Figure 5.3 Results from the Ground Breakers® 2012 on-farm yield trials, Nickerson, KS.

drought across the heart of the US Corn Belt, appropriately putting DroughtGard Hybrids products to the test. Over 72 percent of the farmers surveyed who grew large block trials of DroughtGard Hybrids products reported increased performance of DroughtGard Hybrids products over the other corn products grown on their farms. In 2013, the first year of commercial planting of DroughtGard Hybrids corn products, yield trials demonstrated a yield advantage of greater than 5 bushels per acre with DroughtGard Hybrids products over competitive drought products.

INTEGRATED PEST MANAGEMENT

Integrated pest management (IPM) programs use comprehensive information on the life cycles of pests and their interaction with the environment to determine when pest densities will cause yield losses resulting in economic damages. Fields are closely monitored throughout the season for pest and disease issues and chemical control is used only when economic thresholds are reached. Management decisions are usually made on a field-by-field basis and control tactics will depend on the particular pest or disease present.

Crop rotation is an integral part of IPM.
Crop rotation can be an effective tool for controlling pests, particularly if the insect or pathogen of concern has a narrow host range and overwinters in crop residue or soil. By removing the primary host, the insect or disease cannot survive and reproduce, thereby reducing pest densities and disease inoculum making the pest more manageable when the host crop is planted again. Rotation away from the host crop for a year or more can control many insects and diseases of agricultural significance including corn rootworm, brown stem rot, and white mold. Rotation also allows farmers to diversify their herbicide program, selecting chemistries with different modes of action for better weed control and minimizing the risk of developing herbicide resistance.

An effective IPM plan should include:

- Development of a pest monitoring plan that considers the rotation system and management practices that affect insect behavior or disease life cycles for each field.
- Assessment of infestation levels during the crop season using the appropriate scouting techniques specific for each pest or disease of concern. Early detection and accurate assessment of pest numbers and distribution in a field are key factors for determining if and when control measures will be needed.
- Implementation of control measures once the specific action threshold for the insect or disease of concern has been reached.

WEED MANAGEMENT

Two primary herbicide tolerance biotech traits are commercially available in crops today. The most popular and widely used trait confers tolerance to glyphosate (such as Roundup® brand agricultural herbicides and other generics). The other trait confers tolerance to glufosinate (such as LibertyLink® trait). Crops containing a trait conferring tolerance to a specific herbicide can be sprayed with that herbicide for flexible and reliable weed control.

Roundup Ready® Xtend Crop System (pending regulatory approvals)

One of the future products to come from Monsanto's research and development pipeline, pending regulatory approvals, is Roundup Ready 2 Xtend™ soybeans. This product will contain the Genuity® Roundup Ready 2 Yield® trait technology, which confers tolerance to glyphosate, stacked with a trait that confers tolerance to the herbicide dicamba. This product is expected to be the industry's first with tolerance to both dicamba and glyphosate herbicides for better management of glyphosate-resistant broadleaf weeds such as Palmer amaranth, waterhemp, and marestail, along with other tough-to-control broadleaf weeds such as common lambsquarter's and velvetleaf.

Roundup Ready PLUS® Crop Management Solutions

Roundup Ready PLUS® Crop Management Solutions is a platform offered by Monsanto that provides a set of recommendations for managing weeds while sustaining the agronomic benefits of conservation tillage. The emphasis is placed on using residual herbicides with multiple modes of action to provide the best pre and post combination to manage tough weeds. The goal is to control weeds in the current growing season and reduce weed populations from year to year by managing weeds prior to seed set and avoiding practices that can promote shifts in weed populations that favor hardier genotypes or glyphosate resistance.

Weed management recommendations from the Roundup Ready PLUS platform include:

- A clean field at planting can help reduce weed competition for water and nutrients.
- Consider a crop rotation strategy that includes two or more crops.
- Periodic tillage when appropriate, may help to control weeds.
- Using products with multiple modes of action can help to limit the development of herbicide resistant weeds.
- Using the full labeled rate can help with maximum effectiveness and to avoid the development of resistance.
- Time post-emergence applications to control weeds in corn and soybean before they reach four inches tall.

For more information, visit www.roundupreadyPLUS.com and www.genuity.com.

INSECT MANAGEMENT

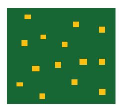
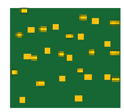
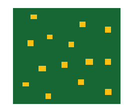
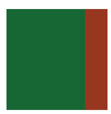
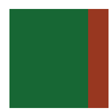
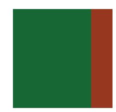
Many seed products are available today that contain in-plant protection from a number of above and below ground insect pests. Insect protection is provided by Cry proteins derived from genes from the soil bacteria *Bacillus thuringiensis* (*B.t.*). Wherever *B.t.* crops are planted, a refuge planted to the same crop without the *B.t.* trait is required to help prevent insects from developing resistance to the trait and preserve the long-term effectiveness of *B.t.* technologies. Refuge requirements vary depending on the *B.t.* crop being planted and region of the country. Genuity® corn products with built-in insect protection contain multiple modes of action for most corn pests, which allows some products to be planted with a smaller refuge of 5 or 10 percent in the Corn-Growing Area. Several corn seed products are also available with the refuge seed mixed in the bag, refuge-in-a-bag, allowing for easier planting and compliance. Genuity corn seed products come pre-treated with Acceleron® Seed Treatment Products for added early-season insect and disease protection.

Genuity® SmartStax® Technology

Products with Genuity SmartStax technology contain multiple modes of action for control of many above and below ground insect pests as well as tolerance to glyphosate and glufosinate herbicides. This pyramided approach of multiple traits with multiple modes of action allows farmers to reduce refuge planting from 20 percent to 5 percent, the lowest in the Corn-Growing Area. In addition, refuge-in-a-bag eliminates the need for a structured refuge and simplifies the planting process. Genuity® SmartStax® RIB Complete® corn blends can provide the best protection in fields with high corn rootworm pressure. SmartStax RIB Complete corn blends come standard with Poncho®/VOTiVO®, which is also an option on other Genuity corn products, for enhanced secondary insect and nematode protection.

Genuity® VT Double PRO® and Genuity® VT Triple PRO® Technology

Products with Genuity VT Double PRO technology contain two modes of action for the control of above ground insect pests along with tolerance to glyphosate herbicides. These products are recommended for the control of corn earworm in fields without corn rootworm pressure. Products with Genuity VT Triple PRO technology also contain two modes of action for above ground insect pests and tolerance to glyphosate as well as a single mode of action against corn rootworm. Both VT Double PRO and VT Triple PRO corn traits are available with the refuge-in-a-bag option. In the Corn-Growing Area, Genuity® VT Double PRO® RIB Complete® corn blends provide a 5 percent refuge and Genuity® VT Triple PRO® RIB Complete® corn blends provide a 10 percent refuge.

Table 5.1 Trait mode of action (MOA) for control/management of corn insects			
INSECT SPECIES	GENUITY® SMARTSTAX® TECHNOLOGY	GENUITY® VT TRIPLE PRO® TECHNOLOGY	GENUITY® VT DOUBLE PRO® TECHNOLOGY
	TRAIT MODE OF ACTION: * SINGLE MODE, ** DOUBLE MODE, *** TRIPLE MODE		
European corn borer	***	**	**
Southwestern corn borer	***	**	**
Northern corn rootworm	**	*	
Western corn rootworm	**	*	
Corn earworm	**	**	**
Fall armyworm	***	**	**
Western bean cutworm	*		
Black cutworm	*		
Herbicide tolerance	Roundup Ready® 2 Technology / LibertyLink®	Roundup Ready® 2 Technology	Roundup Ready® 2 Technology
Refuge in the Corn Growing Area	5% RIB 	10% RIB 	5% RIB 
Refuge in the Cotton Growing Area	20% structured 	20% structured 	20% structured 

Genuity® SmartStax® RIB Complete® corn is a corn seed blend of 95% *B.t.* seed and 5% non-*B.t.* seed, Genuity® VT Triple PRO® RIB Complete® corn is a corn seed blend of 90% *B.t.* seed and 10% non-*B.t.* seed, Genuity® VT Double PRO® RIB Complete® corn is a corn seed blend of 95% *B.t.* seed and 5% non-*B.t.* seed

DISEASE MANAGEMENT

Monsanto research scientists continue to use new breeding methods to evaluate a broad range of germplasm from around the world to select products with higher yield potential, improved geographical adaptation, improved agronomic traits, and enhanced tolerance to diseases. Improvements in disease tolerance are made in part by testing the response of diverse germplasm and pre-commercial products to diseases in both inoculated nurseries and by evaluating tolerance under natural high-pressure disease environments. In the lab, molecular breeding tools such as marker-assisted selection are used to enhance resistance breeding efforts and speed up the development of new products.

Product selection is often the best approach to managing crop diseases and preserving yield potential.

Monsanto seed products are individually rated for the level of tolerance to a number of economically significant diseases including leaf blights, rusts, and stalk rots in corn, and white mold and Phytophthora in soybean, among others. Disease tolerance ratings range from 1 to 9, with 1 being excellent resistance and 9 being poor resistance. Talk to your district sales manager for more information on specific seed ratings available in your area. Farmers should evaluate products and placement on a field-by-field basis, matching yield, agronomic traits, and disease tolerance to their unique farming operation. Depending on the disease, tools such as tillage, crop rotation, product placement, and fungicide applications can be used to help reduce disease pressure.

The most important option for managing Goss's wilt is selecting resistant corn products.

Monsanto has committed special efforts to evaluate tolerance to Goss's wilt in pre-commercial products in the western Corn Belt where the disease has become a significant problem. This effort has dramatically increased the number of corn products available to farmers with good to excellent tolerance to this disease. Goss's wilt has the potential to cause significant yield loss in susceptible corn products. The amount of yield loss depends on the growth stage at which plants are infected and the ability of the plant to slow the spread of the infection. Yield reductions are greatest when susceptible products are infected at vegetative growth stages.

Infection at later growth stages has lesser impact on yield, especially for products with moderate to high levels of resistance. Rotating to a non-host crop such as soybean and the use of tillage when necessary can aid in the decomposition of infected plant residue and effectively reduce sources of inocula in future growing seasons. Weed control is another important management consideration as weeds such as green foxtail, barnyardgrass, and shattercane act as alternative hosts for this disease.

Figure 5.4 Symptoms of Goss's Wilt on a corn leaf (top). Tolerant versus susceptible corn product for Goss's Wilt (bottom).

Acceleron® Seed Treatment Products

Seed treatments can improve plant health through protection from early-season diseases and insects and improve early-season vigor. A number of seed treatments are offered by Monsanto:

- Acceleron® Insecticide Seed Treatment Products for corn utilize the insecticide clothianidin to reduce damage caused by secondary pests including seedcorn maggot, white grub, wireworm, black cutworm, Japanese beetle larva, and chinch bug.
- Acceleron® Insecticide Seed Treatment Products for soybean include imidacloprid, which provides protection from early-season soybean aphids and bean leaf beetle.
- Acceleron® Fungicide Seed Treatment Products for corn contain an exclusive combination of metalaxyl, ipconazole, and trifloxystrobin as the active ingredients, which can provide protection from soil and seed-borne diseases including Rhizoctonia, Pythium, and Fusarium.
- Acceleron® Fungicide Seed Treatment Products for soybean use an exclusive fungicide combination of fluxapyroxad, pyraclostrobin, and metalaxyl to protect seedlings from Rhizoctonia, Pythium, Fusarium, and early-season Phytophthora. Fluxapyroxad adds an additional fungicide mode of action for more complete, consistent protection from Rhizoctonia and Fusarium.
- All Acceleron Seed Treatment Products for corn and Acceleron Fungicide Seed Treatment Products for soybean can be paired with Poncho®/VOTiVO® for an additional mode of action to protect against a wide range of nematode species.

Further information on managing weeds, insects, and diseases in corn and soybean, including detailed information on identification and scouting, can be found in Monsanto's 2014 Advanced Agronomic Guide. Talk to your local agronomist or the Gothenburg Learning Center for a copy of this guide.

Jackson, T.A., Harveson, R.M., and Vidaver, A.K. 2007. Goss's bacterial wilt and leaf blight of corn. NebGuide G1675. University of Nebraska-Lincoln Extension.

SUMMARY

In order to be successful in utilizing water efficiently to produce their crop, farmers need to implement a complete management plan that controls weeds, insects, and diseases and minimizes the effect of stresses such as drought. All of these factors can cause dramatic reductions in yield individually, and when combined, can reduce the ability of the crop to efficiently use soil water and reach full yield potential. With this in mind, Monsanto has a number of product solutions that work together to minimize the chance that any one factor or a combination of these factors will impact the yield potential of that crop.

KEY TAKEAWAYS

- Genuity® DroughtGard® Hybrids corn products represent a systems approach to managing drought risk, combining germplasm selected for its top-end yield potential and drought tolerant characteristics.
- On farm yield trials have demonstrated improved yields with Genuity DroughtGard Hybrids corn products over competitor products when grown under challenging drought conditions, and delivers top-end yield potential in favorable environments.
- Integrated pest management is an economically and environmentally sound way to protect yield potential under pest and disease pressures.
- Monsanto offers many seed products with built-in herbicide tolerance as well as online crop management resources which highlight best management practices for controlling weeds, including glyphosate-resistant weeds.
- Monsanto also offers many corn seed products with built-in insect protection to help control pests such as corn rootworm. Several of these products are available as refuge-in-a-bag seed blends for ease of planting and compliance.
- Monsanto continues to improve its plant germplasm for better tolerance to diseases with easy to understand tolerance ratings for each seed product.
- Monsanto's line of seed treatments called Acceleron® Seed Treatment Products help improve seedling vigor and protect seeds and seedlings from early-season insects and diseases.

NOTES

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Commercialization is dependent on multiple factors, including successful conclusion of the regulatory process. The information presented herein is provided for educational purposes only, and is not and shall not be construed as an offer to sell, or a recommendation to use, any unregistered pesticide for any purpose whatsoever. It is a violation of federal law to promote or offer to sell an unregistered pesticide.

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B.t. products may not yet be registered in all states. Check with your Monsanto representative for the registration status in your state.

IMPORTANT IRM INFORMATION: Genuity® RIB Complete® corn blend products do not require the planting of a structured refuge except in the Cotton-Growing Area where corn earworm is a significant pest. See the IRM/Grower Guide for additional information. Always read and follow IRM requirements.

Individual results may vary, and performance may vary from location to location and from year to year. This result may not be an indicator of results you may obtain as local growing, soil and weather conditions may vary. Growers should evaluate data from multiple locations and years whenever possible.

ALWAYS READ AND FOLLOW PESTICIDE LABEL DIRECTIONS. Roundup Ready® crops contain genes that confer tolerance to glyphosate, the active ingredient in Roundup® brand agricultural herbicides. Roundup® brand agricultural herbicides will kill crops that are not tolerant to glyphosate. Acceleron®, DroughtGard®, Genuity Design®, Genuity Icons, Genuity®, Ground Breakers®, Monsanto and Vine Design®, RIB Complete®, Roundup Ready 2 Technology and Design®, Roundup Ready 2 Xtend™, Roundup Ready 2 Yield®, Roundup Ready PLUS®, Roundup Ready®, Roundup®, SmartStax®, VT Double PRO® and VT Triple PRO® are trademarks of Monsanto Technology LLC. Leaf Design® is a registered trademark of Monsanto Company. LibertyLink® and the Water Droplet Design®, Poncho® and VOTiVO® are registered trademarks of Bayer. Herculex® is a registered trademark of Dow AgroSciences LLC. Respect the Refuge and Corn Design® and Respect the Refuge® are registered trademarks of National Corn Growers Association. All other trademarks are the property of their respective owners. 141110125054 011415CAM

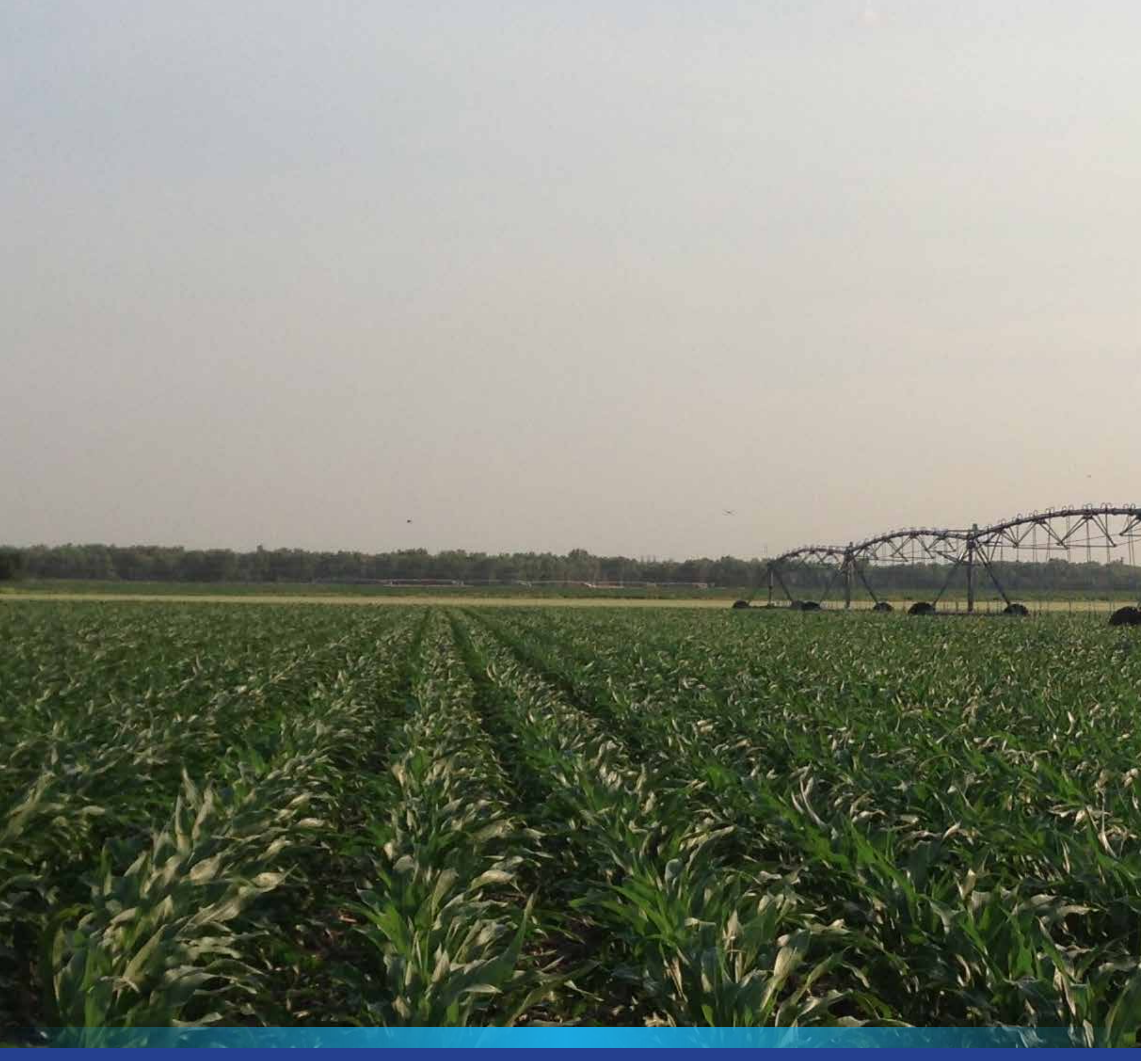
Insect Resistance Management
Planting Refuges, Preserving Technology

Before opening a bag of seed, be sure to read, understand and accept the stewardship requirements, **including applicable refuge requirements for insect resistance management,** for the biotechnology traits expressed in the seed as set forth in the Monsanto Technology/Stewardship Agreement that you sign. By opening and using a bag of seed, you are reaffirming your obligation to comply with the most recent stewardship requirements.

RESPECT THE REFUGE®

Roundup Ready 2 TECHNOLOGY®

LIBERTY LINK®



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