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DEFICIT IRRIGATION OF GRAIN AND OILSEED CROPS

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INTRODUCTION

Deficit irrigation is an alternative to full irrigation where water is applied to crops in amounts that are anticipated to support transpiration at less than the maximum potential level. Under such circumstances, one might expect crop growth and yield to be less than that achieved under full irrigation. However, profitable production of certain crops can be achieved using deficit irrigation with considerable savings in water used or when the water supply is constrained. Deficit irrigation of field crops has been discussed in several research papers and reviews (English and Nuss, 1982; Musick and Walker, 1987; English et al., 1990; Musick, 1994; Fereres and Soriano, 2007; and Geerts and Raes, 2009).

Since the goal of most irrigation strategies is to optimize net economic returns under the constraints imposed by available resources, it might be wise when examining the deficit irrigation toolbox to allow some variance from the strictest definition of the term. For example, in some cases, net economic returns may be optimized by growing less land area with a less deficit irrigation strategy. For the purposes of this discussion, the topic of interest is coping with a deficient or marginal irrigation water supply that might have spatial and/or temporal aspects that must be considered. So, as the discussion moves forward, it will become evident that in some cases producers are truly applying less than the full irrigation amount to a parcel of land and in other cases the producer is trying to avoid deficit irrigation. Of course, in many cases the strategy may be a combination of mitigation and partial avoidance of deficit irrigation.

Although there are a number of ways to organize a deficit irrigation toolbox, here we will assume it is organized into these three sections:

- Agronomic management
- Irrigation management and macromanagement
- Irrigation system and land allocation management

As is the case with all good mechanics, producers facing deficit irrigation must be able to choose and utilize the best tools for the task immediately at hand and recognize when one or more additional tools are needed as the project progresses. Additionally, some of these deficit irrigation tools have temporal aspects, that is, they may be only available as adjustments for the dormant-season, in-season, or the long-term. The overall purpose of this paper is to illustrate the concepts of the tools in the tool box and not to exhaustively demonstrate how to use them. As some of the tools interact with each other, it may be useful to peruse the entire toolbox.

AGRONOMIC MANAGEMENT

A number of tools to mitigate and/or avoid deficit irrigation reside within the agronomic management section of the toolbox (Table 1). A few blank rows are provided to list additional tools that might be in your toolbox.

Table 1. Primary agronomic management tools to address deficit irrigation for grain and oilseed crops and their temporal availability.

Deficit Irrigation Management Tool	Temporal Availability		
	Dormant Season	In-Season	Long Term
Crop Selection	Yes	No	Yes
Crop Hybrid or Variety	Yes	No	Yes
Crop Rotations and Cropping Systems	Yes	No	Yes
Tillage and Residue Management	Yes	Sometimes	Yes
Nutrient Management	Yes	Yes	Yes
Plant Density and/or Row Spacing	Yes	No	Yes
Weed and Pest Management	Sometimes	Yes	Yes

Crop Selection

Crop selection has long been a tool to cope with deficit irrigation and/or a deficient irrigation water supply. Some crops are more sensitive to water stress than others and this may be particularly the situation for their economic yield (i.e., often the grain or oilseed yield rather than the biomass yield). However, one is well advised to consider the water sensitivity paradox; a water sensitive crop may have greater water productivity than a less water sensitive crop.

Deficit or limited irrigation presents a challenge for irrigators growing corn. Corn is sensitive to water stress at all stages of growth and grain yields are usually linearly related to water use from the dry matter threshold (the amount of water use where grain yield begins to accumulate) through the point of maximum yield. Deficit or limited irrigation of corn is difficult to implement successfully without reducing grain yields (Stewart et al. 1977; Musick and Dusek, 1980; Eck, 1986; Howell et al., 1989; Lamm et al., 1993; and Howell, et al., 1995). However, some strategies are more successful than others at maintaining corn yields under limited irrigation. Fully irrigated corn was found to be most profitable and having lowest risk of nine different water allocation schemes in Kansas (Lamm et al., 1993), but some other scenarios were profitable with some acceptance of risk. Grain sorghum is relatively tolerant of water stress and can be a good choice for deficit irrigation (Schneider and Howell, 1999; Schneider and Howell, 1995; Stewart et al., 1983), but is also less responsive to irrigation. Irrigated wheat can also be a good choice for deficit irrigation in the southern Great Plains (Schneider and Howell, 1997; Musick et al., 1994), but in some areas of northern Kansas, the response of wheat to irrigation has been minimal. One of the primary advantages of wheat in coping with deficit irrigation or an insufficient water supply in the US Great Plains is that the wheat growing season has less overall evaporative demand and that the season is temporally displaced from the other principal irrigated crops. Soybean is somewhat similar to corn in sensitivity to water stress, but typically requires a slightly smaller total amount of irrigation (Lamm et al., 2007). Sunflower has a considerably shorter growing period than corn and soybeans and requires less total irrigation, although all three crops' peak evapotranspiration rates are similar (Lamm et al., 2007). Summer crop yields were simulated for 42 years of actual weather data (1972-2013) from Colby, Kansas using 1 inch sprinkler irrigation events with an application efficiency of 95%. Irrigations were scheduled as needed according to the weather-based water budget but were limited to various irrigation capacities (Figure 1).

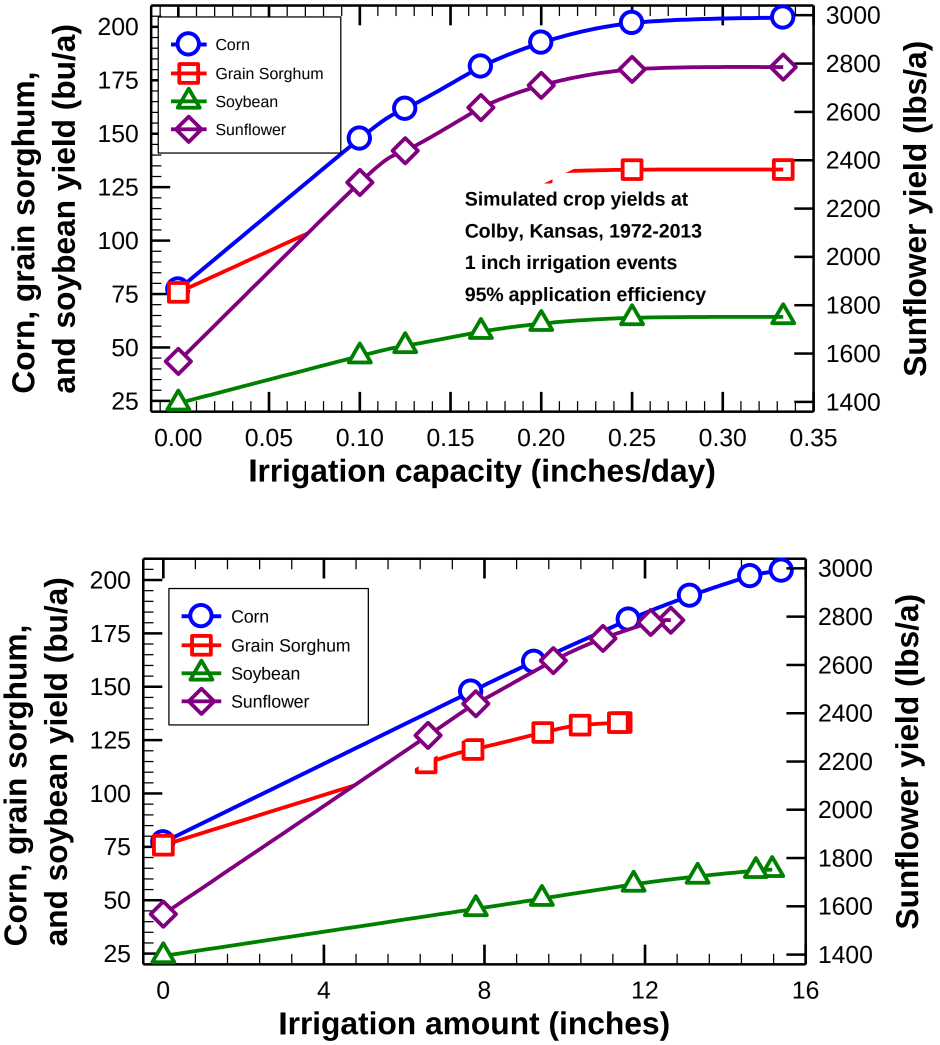

Figure 1. Simulated crop yields for corn, grain sorghum , soybean and sunflower as affected by irrigation capacity (top panel) and their corresponding response to total irrigation amount (bottom panel) at Colby, Kansas for 42 years (1972-2013) at an application efficiency of 95%. Note: These are average yield responses. Yield responses for individual years would vary considerably from those shown .

The graphs indicate that corn benefits from greater irrigation capacities and irrigation amounts, whereas grain sorghum yield plateaus at a lesser irrigation capacity and irrigation amount. Ultimately, crop selection depends on production costs and crop revenues. Irrigated land area devoted to grain sorghum in Kansas is actually decreasing and much of this is probably closely tied to economics. In a cropping simulation, similar to the one above, conducted for the period 1972-2005, it was concluded that dryland grain sorghum production was more profitable than any of irrigated grain sorghum scenarios (Lamm and Stone, 2005). However, sometimes irrigation capacity is shared across multiple crops to reduce the amount of risk. For example, maybe a portion of the land is grown in stress-tolerant grain sorghum to effectively increase the irrigation capacity for another portion of the land area growing water-sensitive corn. Of course, the economics of irrigated crop production vary greatly from year to year. Producers may wish to compare crop production as affected by the projected water supply using the Crop Water Allocator software developed by faculty at K-State (Klocke et al. 2006).

Irrigation water requirements of the various crops also vary temporally. Wheat was already mentioned as a possible crop that could allow shifting of irrigation water when the principal limitation is irrigation capacity. Similarly, a summer crop's peak water needs vary between months (Figure 2). Some producers may plant portions of their fields to sunflowers and only irrigate them when irrigation needs of other crops are declining.

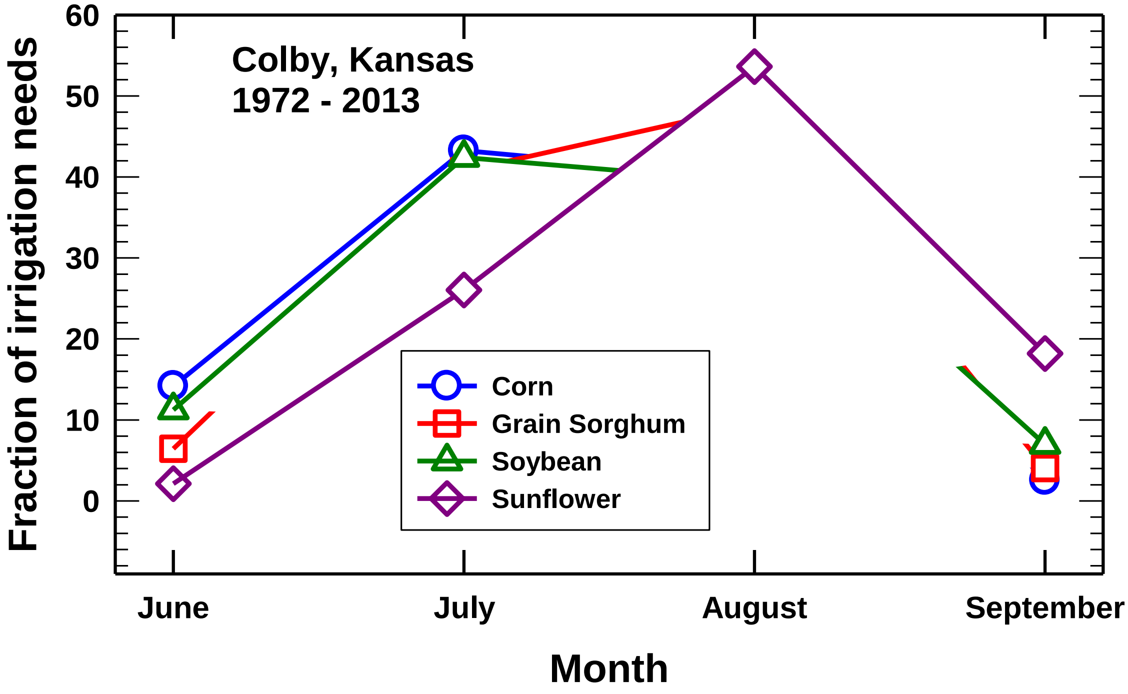

Figure 2. Average fraction of irrigation needs by month for corn, grain sorhum, soybean and sunflower at Colby, Kansas, 1972-2013.

Crop Hybrid or Variety

Some crop hybrids and varieties are more sensitive than others to water stress. Although it remains to be seen whether newer drought tolerant hybrids and varieties will actually result in decreased irrigation needs, it does appear that crop yield is better protected from water stress (e.g., kernel set on corn has improved over the years). Hybrid selection can result in greatly different yields even under the same full irrigation level. Maximum corn yield averaged 75 bu/acre greater (29% greater) than the minimum corn yield in crop performance tests conducted from 1996 through 2010 at the KSU Northwest Research-Extension Center at Colby, Kansas (Figure 3). Producers are advised to choose hybrids and varieties carefully so they can maximize their "crop per drop".

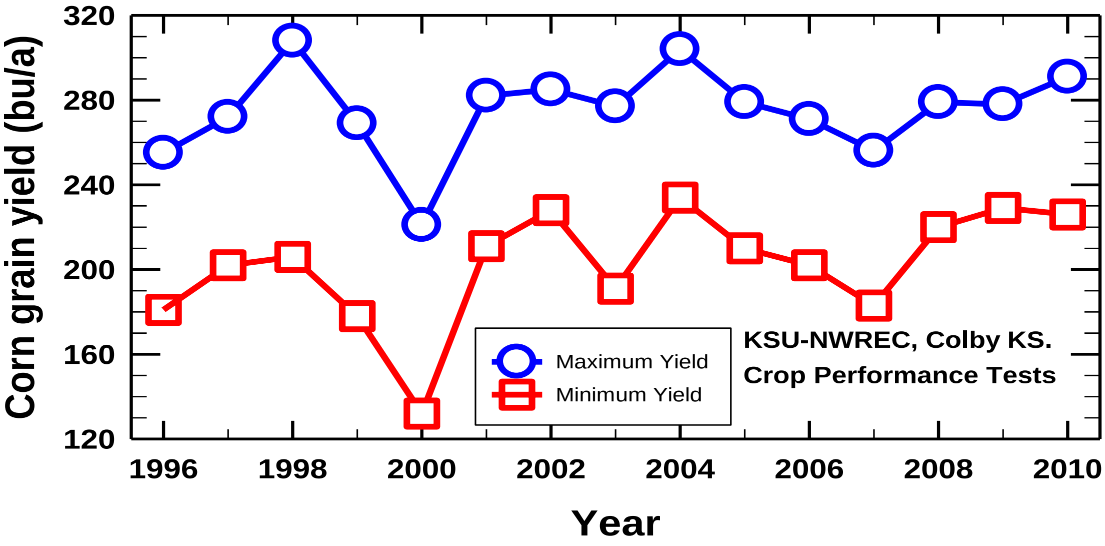

Figure 3. Variation in corn hybrid yields in KSU-NWREC performance tests during the period 1996 through 2010.

Crop Rotations and Cropping Systems

Previous crops leave behind residual soil assets, such as soil water, nutrients and increased organic matter, which can be used to offset application of these inputs and their associated costs in the coming year. For example, irrigated corn requires ample supplies of water and nutrients late in the cropping season to ensure optimum yields, so producers often choose sunflower as a rotational crop after corn in order to utilize the residual soil water and nutrients. In addition to the economic benefit, producers obtain environmental benefits of reduced usage of scarce water resources and reduced potential of nutrient leaching. Anecdotally, it has been observed that continuous corn is less common in west central Kansas than in northwest and southwest Kansas where the Ogallala saturated thickness is greater. Crop rotations also tend to reduce pest problems and to some extent weed pressures often associated with monocultures. Producers should consider crop rotation as a valuable tool to help manage a deficient or declining water supply.

Tillage and Residue Management

Residue management techniques such as no tillage or conservation tillage have long been accepted to be very effective tools for dryland water conservation in the Great Plains (Greb 1979). However, Klocke (2004) posited that residue management can be even more important in reducing soil water evaporation under irrigation. Reporting on an earlier two year study from Nebraska, soil water evaporation savings under a corn canopy with straw covering the soil averaged 0.2, 2.6 and 3.8 inches for dryland, limited irrigation, and full irrigation, respectively. In a later three year study in Kansas, Klocke et al. (2009) reported evaporative ratios (E/ETc) within a corn canopy averaging 0.30, 0.15 and 0.17 for bare soil, corn stover and wheat residue, respectively.

Strip tillage and no tillage had numerically greater corn grain yields (approximately 8% and 6% greater) than conventional tillage in all four years of a study conducted at the KSU Northwest Research-Extension Center, Colby Kansas (Lamm et al., 2009). The benefits of using strip tillage or no tillage increased as irrigation capacity became more deficit (Figure 4). Both strip tillage and no tillage should be considered as improved alternatives to conventional tillage, particularly when irrigation capacity is limited.

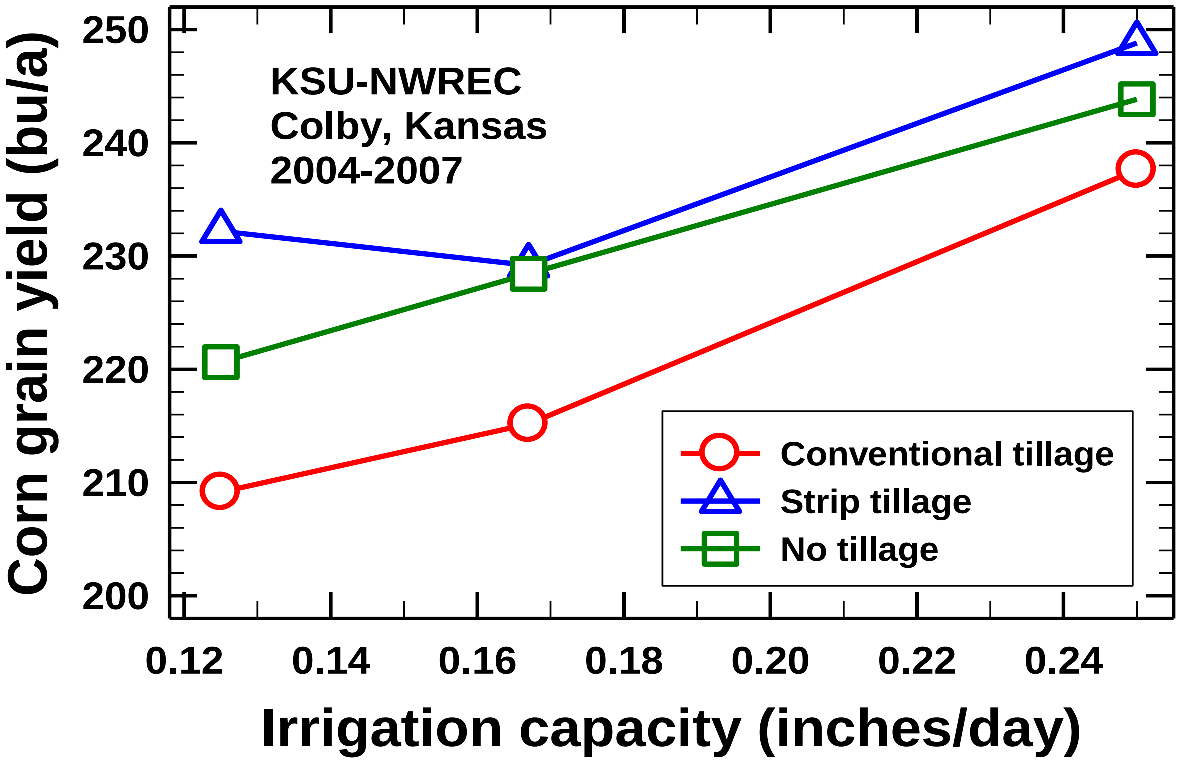

Figure 4. Corn grain yield as affected by tillage management and irrigation capacity in a four year study at Colby, Kansas.

Nutrient Management

Nutrient management can play an important role in increasing the effective use of irrigation and has been the subject of several review articles (Hatfield et al., 2001; Raven et al., 2004; Waraicha et al.,2011). Proper nutrient management increases plant growth and yield response allowing the crop to optimize use of available water supplies. Appropriate nitrogen fertilization nearly doubled corn yields without much increase in water use (Figure 5) in a two year study of subsurface drip-irrigated corn in western Kansas (Lamm et al., 2001).

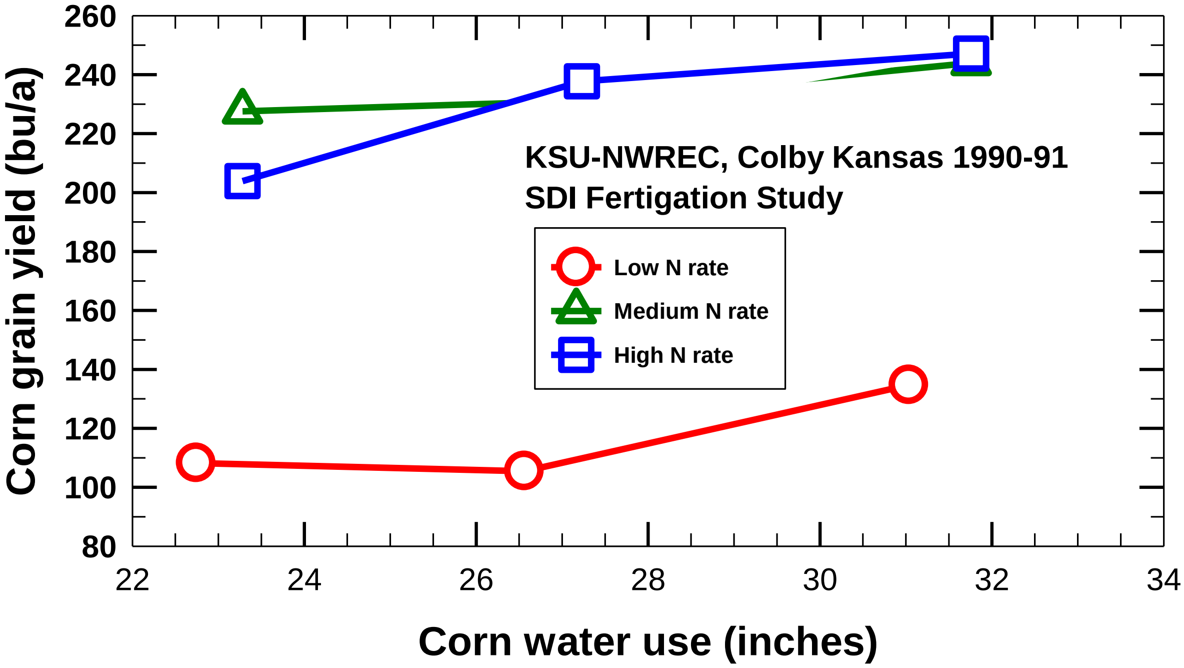

Figure 5. Corn yield as affected by nitrogen fertigation level and irrigation level in a subsurface drip irrigation study, Colby, Kansas, 1990-1991.

Plant Density and/or Row Spacing

Plant density or plant population can have an effect on water use and water use efficiency. When irrigation is severely deficit, it may be wise to reduce corn plant density to increase the probability of successful pollination and subsequent growth. As an example, Roozeboom et al. (2007) recommended corn plant densities for western Kansas of 14,000 to 20,000, 24,000 to 28,000, and 28,000 to 34,000 for dryland, limited irrigation, and full irrigation scenarios, respectively. After the corn crop reaches a leaf area index (LAI) of approximately 2.7, all of the incoming energy is captured (Rogers, 2007) and additional increases in LAI do not result in increased water use. As LAI for irrigated corn often reaches 5 or greater in the central Great Plains, plant density has to be greatly reduced to actually reduce corn water use. A key factor in managing corn plant density is assuring that pollination and kernel set are achieved. Establishing greater kernels/area often requires increased plant density. Medium to higher plant densities (30,000 to 33,000 plants/acre) generally resulted in greater corn yields (Figure 6) in a four year sprinkler-irrigated study in western Kansas (Lamm et al., 2009).

Adjustments to row spacing and planting geometry may be effective in reducing soil water evaporation losses in some cases for corn and grain sorghum in the central Great Plains. However, results to date suggest these adjustments are most likely to be advantageous only at the lower end of the range of crop yields (Olson and Roozeboom, 2012).

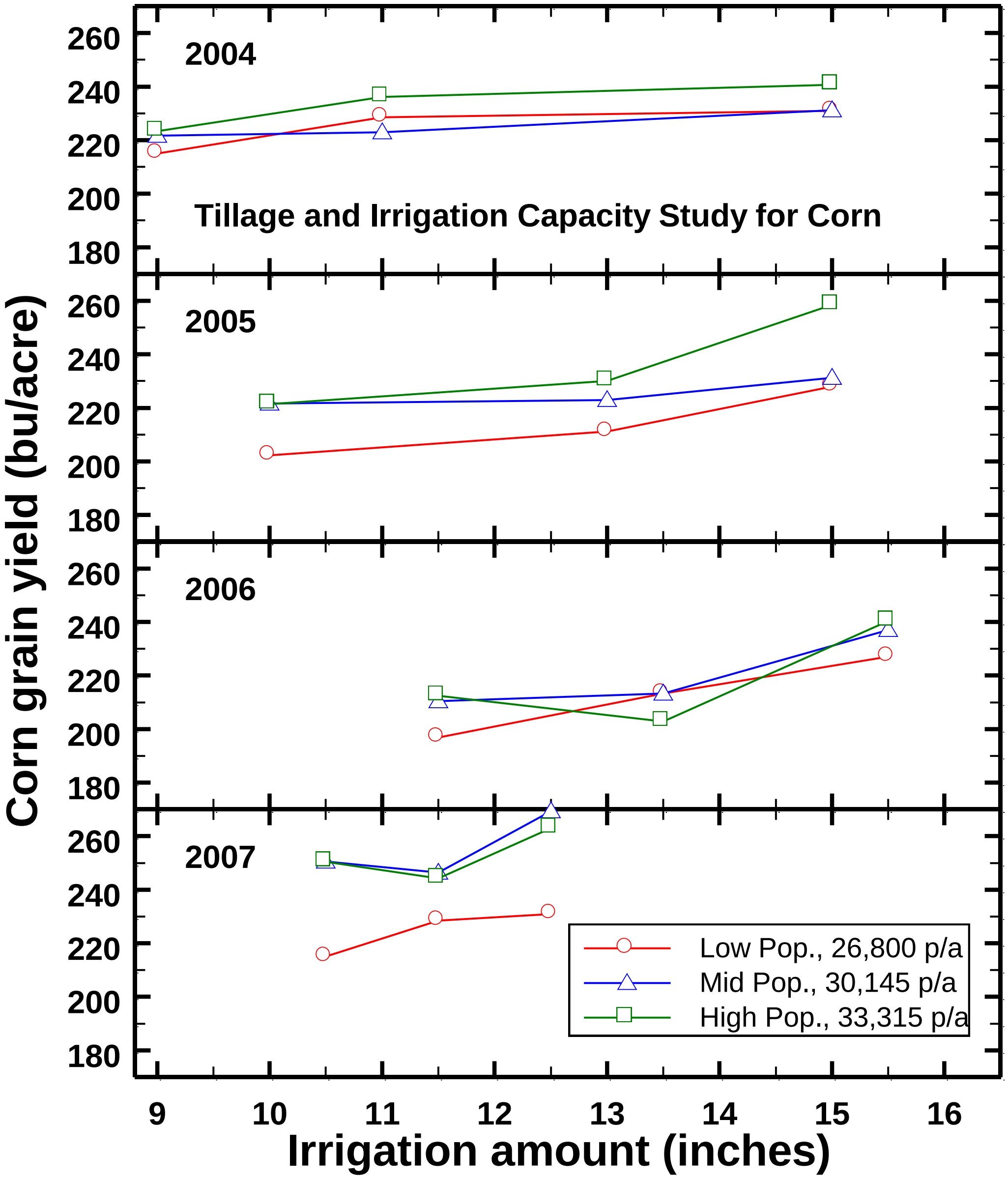

Figure 6. Corn grain yield as affected by irrigation amount and plant population, 2004-2007, KSU Northwest Research-Extension Center, Colby Kansas.

Weed and Pest Management

Weed and pest management is important in coping with deficit irrigation. Weeds may directly compete for water and nutrients and insect pests may interfere with plant growth and limit the crop's economic yield (i.e., usually the grain or oilseed). Some pests thrive under deficit irrigation conditions. For example, spider mites increase under the hotter and drier conditions associated with corn water stress. Spider mite damage that has occurred to corn's photosynthetic ability cannot be reversed even by substantial precipitation, although a reduction in the number of mites may occur. Producers coping with deficit irrigation should actively and consistently observe their crop fields managing weed and insect pests as they arise.

IRRIGATION MANAGEMENT AND MACROMANAGEMENT

A number of tools to mitigate and/or avoid deficit irrigation reside within the irrigation management and macromanagement section of the toolbox (Table 2). A few blank rows are provided to list additional tools that might be in your toolbox.

Table 2. Primary irrigation management and macromanagement tools to address deficit irrigation for grain and oilseed crops and their temporal availability.

Deficit Irrigation Management Tool	Temporal Availability		
	Dormant Season	In-Season	Long Term
Irrigation Scheduling	No	Yes	Yes
Timing of Irrigation	No	Yes	Yes
Initiation of the Irrigation Season	No	Yes	Yes
Termination of the Irrigation Season	No	Yes	Yes
Dormant Season Irrigation	Yes	No	Yes

Irrigation Scheduling

The most common definition of irrigation scheduling is simply the determination of when and how much water to apply. It is not uncommon to hear a central Great Plains producer indicate that they could not possibly consider irrigation scheduling because they always are in a deficit irrigation condition from the beginning to the end of the cropping season. Although this may seem intuitively correct, there are actually many years when the irrigation capacity even for marginal systems would not have to be fully utilized. Often early in the season, a deficit irrigation capacity may exceed the crop evapotranspiration rate. Simulated irrigation schedules for corn indicate that 80% or more of the maximum observed irrigation requirement is only required in 50 and 60% of the years for severely deficit irrigation capacities of 1 inch/8 days and 1 inch/10 days, respectively (Figure 7). Additionally, producers using irrigation scheduling can make better decisions about how to handle a triage situation (i.e., abandoning a portion of the field to better protect another portion).

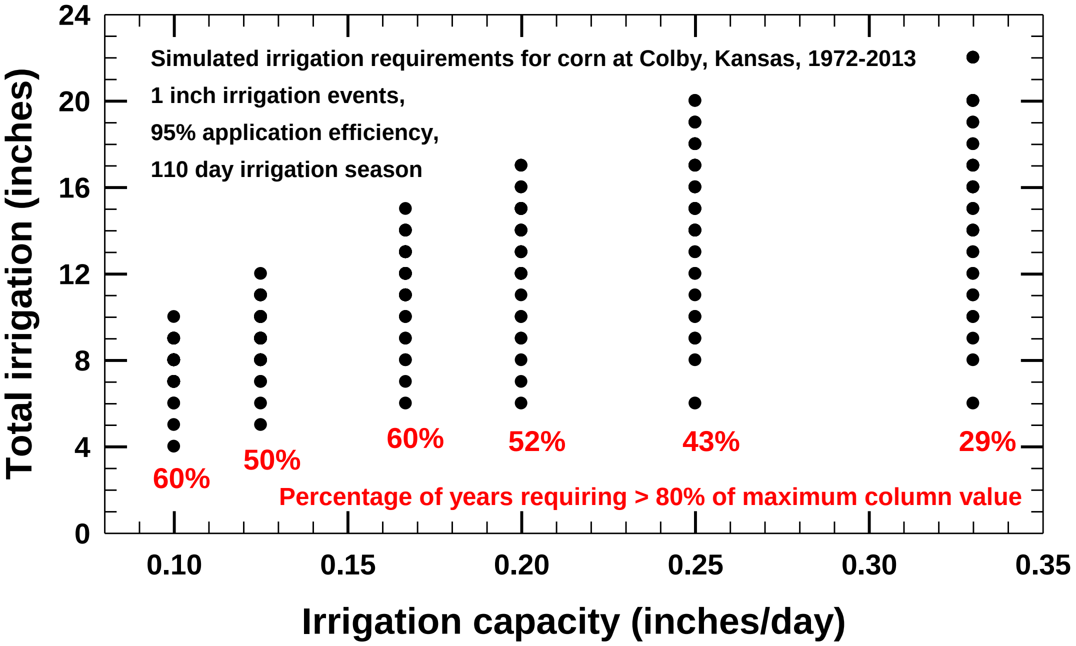

Figure 7. Simulated corn irrigation requirements for Colby, Kansas, 1972-2013 as possible with various irrigation capacities. Each indicated capacity has the 42 years shown, with some years lying on top of each other. The percentage of years requiring 80% or more of the maximum possible irrigation is shown below each capacity. As irrigation capacity increases, the percentage of years requiring 80% or more of the maximum irrigation tends to decrease.

Timing of Irrigation

Timing irrigation to the critical growth stages is a deficit irrigation strategy that can be effective in some situations. This technique may be most applicable when deficit irrigation is limited by total amount of irrigation. Examples of such scenarios would be an institutional constraint (e.g., 12 inches/year to a parcel of land) or when surface water availability constrains the application window (e.g., canal or reservoir releases). Timing of irrigation is less applicable for irrigation systems with marginal irrigation capacity and when stretched water resources limit adjustments to the irrigation event cycle. Since center pivot sprinklers irrigating from marginal groundwater wells are common in the central Great Plains landscape, timing of irrigation is a less applicable tool for many producers.

Initiation of the Irrigation Season

The determination of when to initiate the irrigation season is an irrigation macromanagement decision that can greatly affect the total irrigation amount. Ideally, the producer would delay irrigation as long as possible with the hope that timely precipitation would augment the crop water needs. A recent summary by Lamm and Aboukheira (2009) suggests that corn probably has more inherent ability to handle early season water stress than is practical to manage with the typical irrigation capacities that occur in the central Great Plains. Producers should use a good method of day-to-day irrigation scheduling during the pre-anthesis period. To a large extent, the information being used to make day-to-day irrigation scheduling decisions during the pre-anthesis period can also be used in making the macromanagement decision about when to start the irrigation season. This is because, even though the corn has considerable innate ability to tolerate early season water stress, most irrigation systems in the central Great Plains do not have the capacity (e.g., gpm/acre) or practical capability (e.g., run-off or deep percolation concerns) to replenish severely depleted soil water reserves as the season progresses to periods of greater irrigation needs (i.e., greater ETc and less precipitation). However, there is some flexibility in timing of irrigation events within the vegetative growth period. In years of lower evaporative demand, corn grown on this soil type (i.e., deep silt loam) in this region can extract greater amounts of soil water without detriment. Timeliness of irrigation and/or precipitation near anthesis appeared to be very important in establishing an adequate number of kernels/area which in this study was greatly correlated with final yield. Although, timing of irrigation is difficult with typical systems in the central Great Plains, the results suggest that monitoring soil water reserves and evaluating early season evaporative demand may allow for delays in initiating the irrigation season in some years.

Termination of the Irrigation Season

Irrigators in the central Great Plains sometimes terminate the corn irrigation season on a traditional date such as August 31 or Labor Day (First Monday in September) based on long term experience. However, there can be a large variation on when the irrigation season can be safely terminated (Table 3). A more scientific approach might be that season termination may be determined by comparing the anticipated soil water balance at crop maturity to the management allowable depletion (MAD) of the soil water within the root zone. Some publications say the MAD at crop maturity can be as high as 0.8 (Doorenbos and Kassam, 1979). Extension publications from the Central Great Plains often suggest limiting the MAD at season's end to 0.6 in the top 4 ft. of the soil profile (Rogers and Sothers, 1996). These values may need to be re-evaluated and perhaps further adjusted downward (smaller MAD value) based on a report by Lamm and Aboukheira (2009). They concluded that producers growing corn on deep silt loam soils in the central Great Plains should attempt to limit the management allowable depletion of available soil water in the top 8 ft. of the soil profile to 45%.

Table 3. Anthesis and physiological maturity dates and estimated irrigation season termination dates* to achieve specified percentage of maximum corn grain yield from studies examining post-anthesis corn water stress, KSU Northwest Research-Extension Center, Colby, Kansas, 1993-2008. Note: This table was created to show the fallacy of using a specific date to terminate the irrigation season. Note: Because there was not an unlimited number of irrigation termination dates, sometimes the date required for a specified percentage of maximum grain yield was the same as the date for the next higher percentage. After Lamm and Aboukheira (2009).

	Date of Anthesis	**Date of Maturity**	**Irrigation Season Termination Date For**		
			80% Max Yield	**90% Max Yield**	**MaxYield**
Average	**19-Jul**	**27-Sep**	**2-Aug**	**13-Aug**	**28-Aug**
Standard Dev.	**3 days**	**6 days**	**13 days**	**19 days**	**13 days**
Earliest	**12-Jul**	**14-Sep**	**17-Jul**	**17-Jul**	**12-Aug**
Latest	**24-Jul**	**10-Oct**	**14-Sep**	**21-Sep**	**21-Sep**

* *Estimated dates are based on the individual irrigation treatment dates from each of the different studies when the specified percentage of yield was exceeded.*

Dormant Season Irrigation.

Dormant season irrigation for crops such as corn has been advocated for the semi-arid Great Plains since the early 20th century, and the practice has been debated for nearly as long. Knorr (1914) found that at Scottsbluff, Nebraska, fall irrigation normally increased corn yields. Farrell and Aune (1917) found opposite results at Belle Fourche, South Dakota. Knapp (1919) recommended winter irrigation for most of western Kansas with the exception of sandy soils. The advantages of preseason irrigation (Musick and Lamm 1990) are: 1) provide water for seed germination; 2) delay the initiation of seasonal irrigation; 3) improve tillage and cultural practices associated with crop establishment; and 4) more fully utilize marginal irrigation systems on additional land area. The disadvantages are that it may: 1) increase production costs; 2) increase irrigation requirements; 3) lower overall irrigation efficiencies; and 4) lower soil temperatures. Lamm and Rogers (1985) developed an empirical model to aid in decisions concerning fall preseason irrigation for corn production in western Kansas. Available soil water at spring planting was functionally related to overwinter precipitation and initial available soil water in the fall. They concluded in most years, fall preseason irrigation for corn is not needed to recharge the soil profile in northwest Kansas, unless residual soil water remaining after corn harvest is excessively low. A recent survey of sprinkler irrigated corn fields in western Kansas has irrigated that on average, producers are leaving residual available soil water in the 8 ft. profile at approximately 60% of field capacity (Lamm et al., 2012). However, there was large variation between producers (Figure 8) emphasizing the need for each producer to evaluate their own field.

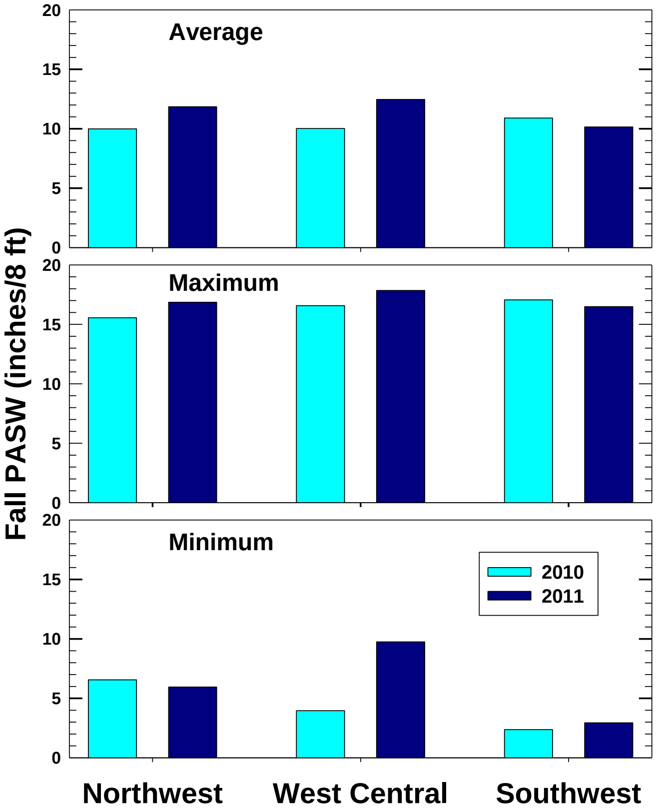

Figure 8. Effect of western Kansas region on average, maximum and minimum measured plant available soil water (PASW) in the 8 ft. soil profile in irrigated corn fields after harvest for the fall periods in 2010 and 2011.

In a recent field study (2006 to 2009) at the KSU Southwest Research Extension Center site near Tribune, Kansas, Schlegel et al. (2012) found preseason irrigation to be profitable for corn production with irrigation capacities ranging from 0.1 to 0.2 inches/day. Preseason irrigation increased grain yields an average of 16 bu/acre. The crop water productivity was not significantly affected by well capacity or preseason irrigation.

IRRIGATION SYSTEM AND LAND ALLOCATION MANAGEMENT

A number of tools to mitigate and/or avoid deficit irrigation reside within the irrigation system and land allocation management section of the toolbox (Table 4). A few blank rows are provided to list additional tools that might be in your toolbox.

Table 4. Primary irrigation system and land allocation management tools to address deficit irrigation for grain and oilseed crops and their temporal availability.

Deficit Irrigation Management Tool	Temporal Availability		
	Dormant Season	In-Season	Long Term
Irrigation System Selection	Yes	No	Yes
Managing Water Losses	Yes	Yes	Yes
Fine Tuning the Irrigation System	Yes	Yes	Yes
Land/Water Allocation	Yes	Possibly	Yes

Irrigation System Selection

No irrigation system can save water without good management imparted by the producer. However, some irrigation systems are easier to manage than others. Additionally, some systems although perhaps more complicated in design and number of components may inherently result in better water management. This concept can perhaps be considered as "purchasing improved management capabilities upfront". It has been said that one of the principal reasons that pressurized irrigation systems such as center pivot sprinklers (CP) and subsurface drip irrigation (SDI) are considered easier to manage than surface irrigation is because they remove the surface water transport phenomenon from the management. Many producers in the central Great Plains have converted from surface irrigation to center pivot sprinklers and a few are using SDI, all with a goal of better utilizing a limited and declining water resource. There is some evidence from the Great Plains that SDI may be able to stabilize yields at a greater level under deficit irrigation than CP assuming both are managed well (Lamm et al., 2010).

Managing Water Losses

Under deficit irrigation nearly all water losses result in yield reduction. It is common for the slope of the water production function for corn under deficit irrigation to be 12 to 15 bushels/inch and values of nearly 20 bushels/inch have been reported. Howell and Evett (2005) characterized the *"Big Three"* irrigation water losses as deep percolation, evaporation losses from soil, air, or plant, and irrigation runoff. An excellent tabular discussion of the management of these losses with irrigation systems, tillage management, and irrigation scheduling is provided by Howell and Evett (2005).

Fine Tuning the Irrigation System

There are some irrigation system adjustments that can be considered “fine tuning” the system but are never-the-less important to deficit irrigation management. This listing will not be exhaustive but may spur producers to look for that hidden extra capacity. Here are some system-related practical ways irrigators might use to effectively increase irrigation capacities for crop production (Lamm and Stone, 2005):

- Remove end guns or extra overhangs to reduce center pivot system irrigated area
- Clean groundwater well to see if irrigation capacity has declined due to encrustation
- Determine if pump in well is really appropriate for the irrigation system design and operating pressure.
- Replace, rework or repair worn pump

Land/Water Allocation

As it was stated in the second paragraph of this paper, deficit irrigation may be avoided by more closely matching the irrigated land area to the available water source. As economically painful as this may seem, this has always been the design criteria for irrigation systems in arid regions. Our semi-arid and more humid regions have just been able to successfully gamble with this criterion. Utilizing this management strategy might be economically painful because:

- it will likely reduce income in years with ample rainfall
- it may negatively affect land values if land is then considered non-irrigated
- it could reduce economic activity in the community as less inputs are bought and less outputs are sold.

However, if water resources and pumping rates continue to decline, the drought persists, and/or climate change imposes drier and warmer conditions, reducing the irrigated land area to avoid deficit irrigation may be the wisest decision. The previously discussed KSU-NWREC simulation modeling will be used to explore this topic further.

Corn yields were simulated for 42 years of weather data from Colby, KS. (1972-2013). Well-watered corn ETc ranged from 17.6 to 27.1 inches with average of 23.1 inches for these 42 years of record. In-season precipitation ranged from 3.1 to 21.2 inches with average of 11.8 inches. Full irrigation ranged from 6 to 22 inches with average of 15.7 inches. The marginal water productivity, WP (slope) was 17 bu/acre-in, which might result in an economic benefit of 65 to $85/acre-in. The yield threshold was 10.9 inches of ETc. Yields were simulated for irrigation capacities of full irrigation, 1 inch every 4, 6, 8 or 10 days and also for dryland conditions. As irrigation capacity decreases (Figure 9 and Table 5), corn yields decrease from the fully irrigated yields for some years and the variability in yields also increases. Typically, crop yields increase with increasing ETc, although this response is not a direct cause and effect. Rather in many cases, increased ETc is also reflecting better growing conditions (e.g., increased sunlight, warmer temperatures). As irrigation capacity decreases, the positive aspects of greater ETc on yield begins to disappear and the slope is relatively flat for an irrigation capacity of 1 inch/10 days (Figure 9). Under dryland conditions, corn yields typically decreased over the entire range of increasing ETc experienced at Colby, Kansas during this 42 year period.

Through reductions in irrigated land area, a producer could regain irrigation capacity, increase crop yield, and reduce their own risk. The short term marginal benefits to the individual producer should increase due to less input costs being associated with the non-irrigated acres. The Crop Water Allocator software (Klocke et al., 2006, accessible at http://www.bae.ksu.edu/mobileirrigationlab) may be a useful planning tool to producers in determining the optimum cropping scenario.

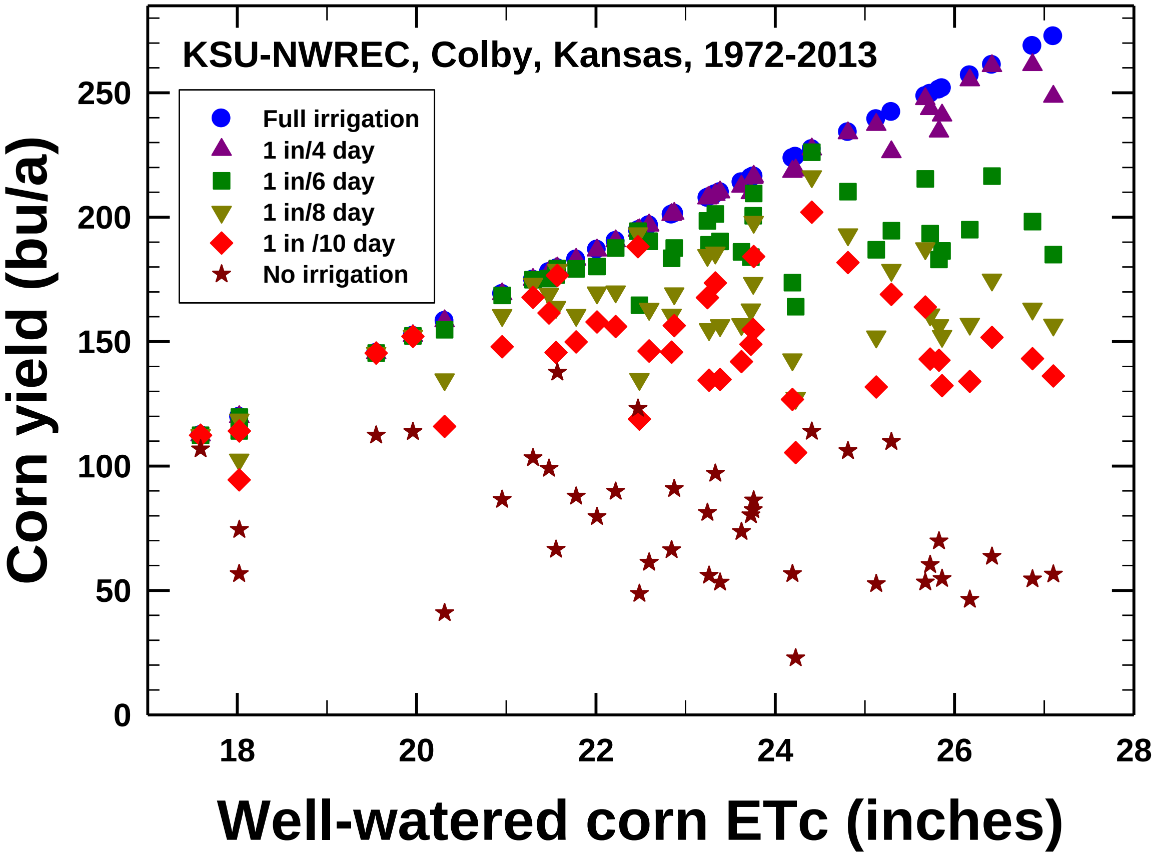

Figure 9. Simulated corn yields as a function of the calculated well-watered corn evapotranspiration for the 42 year period, 1972-2013, Colby, Kansas as affected by irrigation capacity.

Table 5. Effect of irrigation capacity on simulated corn yields for the 42-year period, 1972-2013, Colby, Kansas.

Irrigation capacity	Maximum yield	Mean Yield	Minimum Yield	Yield variation from full irrigation for maximum yield at maximum well-watered ETc
Full	273	204	112	-
1 inch/4 day	261	202	112	-4.4%
1 inch/6 day	226	181	112	-17.2%
1 inch/8 day	216	162	103	-20.9%
1 inch/10 day	202	148	94	-26.0%
Dryland	138	77	23	-49.5%

SUMMARY

As water supplies for irrigation become less available due to either hydrological or institutional constraints, irrigation producers and water managers face more uncertainty in production and increase economic risk. Increased uncertainty and risk can be mitigated through use of improved management practices or management tools. These tools can only be used effectively if producers know and understand which tool is appropriate to their situation.

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