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COMPARISON OF SOIL WATER SENSING METHODS FOR IRRIGATION MANAGEMENT AND RESEARCH

S.R. Evett*, T.A. Howell, and J.A. Tolk
Soil and Water Management Research Unit
USDA-ARS, Bushland, TX
*Voice: 806-356-5775, Fax: 806-356-5750
Email: srevett@cprl.ars.usda.gov

ABSTRACT

As irrigation water resources decrease and deficit irrigation becomes more common across the Great Plains, greater accuracy in irrigation scheduling will be required. With deficit irrigation a smaller amount of soil water is held in reserve and there is less margin for error. Researchers investigating deficit irrigation practices and developing management practices must also have accurate measures of soil water content – in fact, the two go hand in hand. New management practices for deficit irrigation will require more accurate assessments of soil water content if success is to be ensured. This study compared several commercial soil water sensing systems, four of them based on the electromagnetic (EM) properties of soil as influenced by soil water content, versus the venerable neutron moisture meter (NMM), which is based on the slowing of neutrons by soil water. While performance varied widely, the EM sensors were all less precise and less accurate in the field than was the NMM. Variation in water contents from one measurement location to the next was much greater for the EM sensors and was so large that these sensors are not useful for determining the amount of water to apply. The NMM is still the only sensor that is suitable for irrigation research. However, the NMM is not practical for on-farm irrigation management due to cost and regulatory issues. Unfortunately, our studies indicate that the EM sensors are not useful for irrigation management due to inaccuracy and variability. A new generation of EM sensors should be developed to overcome the problems of those currently available. In the meantime, tensiometers, electrical resistance sensors and soil probes may fill the gap for irrigation management based on soil water sensing. However, many farmers are successfully using irrigation scheduling based on crop water use estimates from weather station networks and reference ET calculations. When used in conjunction with direct field soil water observations to avoid over irrigation, the ET network approach has proved useful in maximizing yields.

INTRODUCTION

For most uses and calculations in irrigation management and research, soil water content (θ_v, $m^3\ m^{-3}$) is expressed as a volume fraction,

$$\theta_v = \frac{\text{volume of soil water}}{\text{total volume of soil}} \qquad [1]$$

Volume per volume units are used in most calculations of soil water movement and crop water uptake, including those in irrigation scheduling computer programs or back-of-the-envelope checkbook type calculations. These units make it easy to convert water contents, θ_v, measured in a soil profile over a given depth, z, to an equivalent depth of water (θ_z) by multiplying the water content by the depth: $\theta_z = \theta_v z$. The units of θ_z are the length units of z, typically mm, cm or inches. For example, the depth of irrigation water, I_{zUL}, that a uniform soil can accept without large losses to deep percolation is limited on the upper bound by the depth of the root zone, z_r, and the difference between the mean water content of the root zone, θ_r, and the water content at field capacity, θ_{FC}; that is, $I_{zUL} = z_r(\theta_{FC} - \theta_r)$. For soils that have differences in soil texture with depth, similar calculations can be done layer by layer using the different texture-specific field capacity values and water contents available from most soil surveys or computer programs (e.g., http://staffweb.wilkes.edu/brian.oram/soilwatr.htm)..

Soil texture is quantified by the relative percentages by mass of sand, silt, and clay after removal of salts and organic matter. Both texture and structure determine the soil-water characteristic curve, which quantifies the relationship between soil water content and soil water potential, which is the strength with which the soil holds water against removal by plants. This relationship differs largely according to texture (Fig. 1), but can be strongly affected by organic matter and salt contents. The range of plant-available water (PAW) possible for a given soil is determined by two limits. The upper limit, also know as the field capacity, is often defined as the soil water content of a previously saturated soil after 24 h of free drainage into the underlying soil. The field capacity can be viewed as the water content below which the soil does not drain more rapidly than the crop can take up water. In heavier textured (i.e., more clayey) soils, this limit is often characterized as the water content at −0.10 kPa soil water potential. In more sandy ("lighter") soils, the upper limit may be more appropriately placed at −0.33 kPa soil water potential. The difference in soil water potentials that are related to the upper limit of PAW is due to the relatively large conductivities for water flux in lighter soils near saturation, which means that lighter soils will drain more rapidly. The lower limit of PAW, also known as the permanent wilting point, is often defined as the soil water content at which the crop wilts and cannot recover if irrigated. The soil water potential associated with the lower limit varies with both the crop and the soil; but is often taken to be −1500 kPa. The amount of PAW differs greatly by soil texture. For example, as illustrated in Figure 1, a clay soil may have a plant available water content range of 0.19 to 0.33 $m^3\ m^{-3}$, or 0.14 $m^3 m^{-3}$ PAW; whereas a silt loam may have a larger PAW content range of 0.08 to 0.29 $m^3 m^{-3}$, or 0.21 $m^3 m^{-3}$ PAW. Sandy soils tend to have small amounts of PAW, such as the 0.04 $m^3 m^{-3}$ for the sandy loam illustrated in Fig. 1 or the 0.06 $m^3 m^{-3}$ reported by Morgan et al. (2001a) for an agriculturally important fine sand in Florida. Thus, irrigation management often focuses on applying smaller amounts of water more frequently on sandy soils.

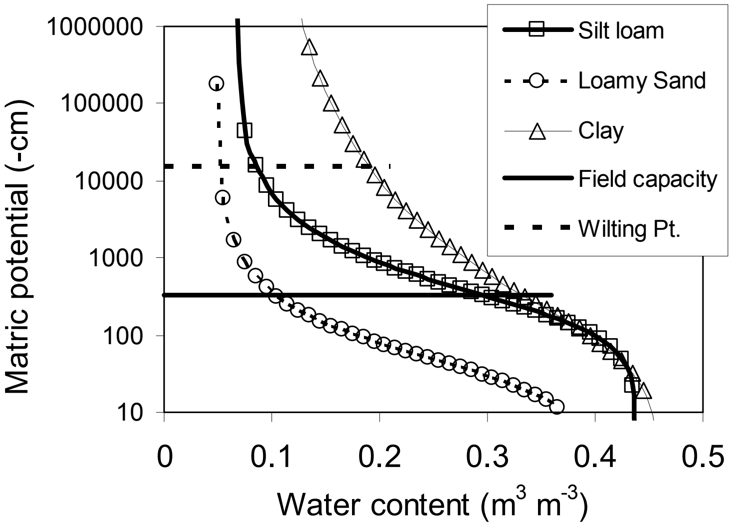

Figure 1. The soil water content vs. soil water matric potential relationship for three soil textures as predicted by the Rosetta pedotransfer model (Schaap et al., 2001). Horizontal lines are plotted for the field capacity, taken as −333 cm (~−33 kPa), and for the wilting point, taken as −15 000 cm (~−1500 kPa).

Crops differ in their ability to extract water from the soil, with some crops not capable of extracting water to even −1500 kPa, and others able to extract more water, reaching potentials even more negative than -1500 kPa (Ratliff et al., 1983, Tolk, 2003) (Fig. 2). Confounding this issue is the soil type effect on rooting density and on the soil hydraulic conductivity, both of which influence the lower limit of PAW for a particular crop. The fact that soil properties vary with depth means that the lower limit of PAW may be best determined from field, rather than laboratory, measurements.

The available soil water holding capacity (AWHC) is a term used to describe the amount of water in the entire soil profile that is available to the crop. Because water in the soil below the depth of rooting is only slowly available, the AWHC is generally taken as the sum of water available in all horizons in the rooting zone, calculated for each horizon as the product of the horizon depth and the PAW for that horizon. For example, for a crop rooted in the A and B horizons of a soil the AWHC is the product of the PAW of the A horizon times its depth plus the PAW of the B horizon times the rooted depth in the B horizon (Table 1).

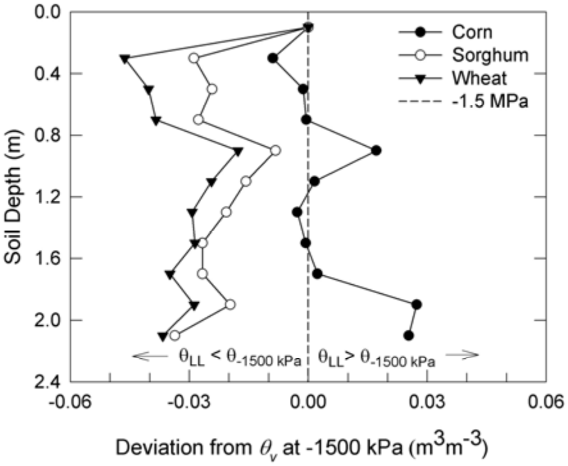

Figure 2. Deviation of the lower limit of water extraction, θ_{LL}, measured in the field using a neutron probe, from that measured at −1500 kPa in the laboratory on soil cores taken at several depths in the soil. Data are for corn, sorghum and wheat crops grown in a Ulysses silt loam (Tolk, 2003).

Table 1. Example calculation of available water holding capacity (AWHC) in the rooting zone of a crop rooted to 0.95-m depth in a soil's A and B horizons, each with a different value of plant available water (PAW).

Horizon	Depth range (cm)	Rooting depth (cm)	Rooted depth (cm)		PAW ($m^3\ m^{-3}$)		AWHC (cm)
A, silt loam	0 to 20	0 to 20	20	×	0.21	=	4.2
B, clay	20 to 100	20 to 95	75	×	0.14	=	10.5
						Sum	14.7

For irrigation scheduling using the management allowed depletion (MAD) concept (Fig. 3), irrigation is initiated when soil water has decreased to the θ_{MAD} level. The θ_{MAD} value may be chosen such that the soil never becomes dry enough to limit plant growth and yield, or it may be a smaller value that allows some plant stress to develop. Choice of the θ_{MAD} value needs to consider the irrigation capacity (flow rate per unit land area), which determines how quickly a given irrigation amount can be applied to a specified sized field. It is common to irrigate at some value of water content, θ_{MAD+}, that is larger than θ_{MAD}. This is done to ensure that the error in water content measurement, which may cause inadvertent over estimation of water content, is not likely to cause irrigation to be delayed until after water content is actually smaller than θ_{MAD}. Minimizing the difference, $d = \theta_{MAD+} - \theta_{MAD}$, allows the irrigation interval to be increased. It is desirable to know the number of samples required to estimate the water content to within d of θ_{MAD} at the $(1 - \alpha)$ probability level. Knowing the sample standard deviation, S, of soil water content measurements, the required number of samples, n, can be estimated as

$$n = \left(\frac{u_{\alpha/2} S}{d} \right)^2 \qquad [2]$$

where $u_{\alpha/2}$ is the ($\alpha/2$) value of the standard normal distribution, and ($1 - \alpha$) is the probability level desired (eg. 0.95 or 0.90). Equation [2] is valid for normally distributed values that are independent of one another and for the population standard deviation estimated from the sample standard deviation, S, of a large number of samples.

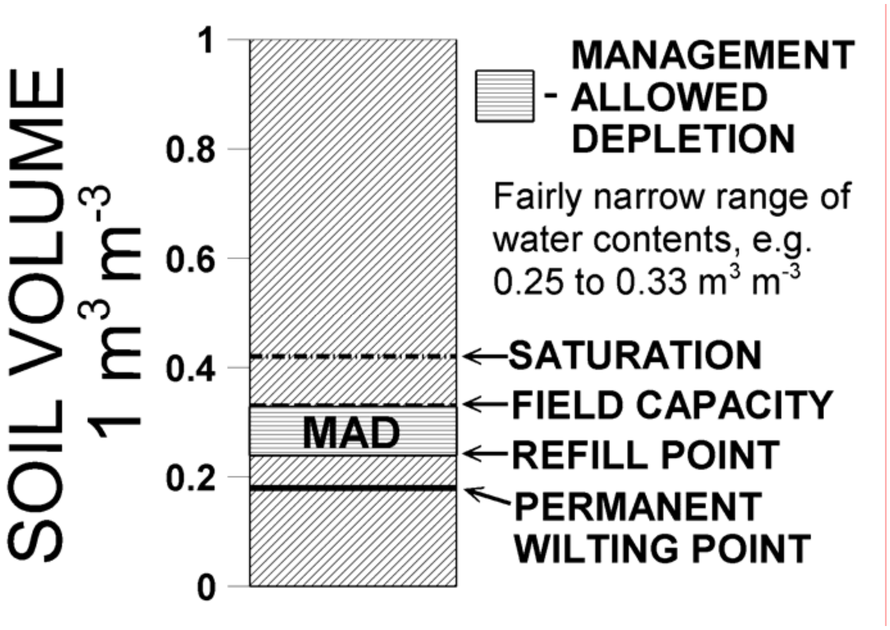

Figure 3. Illustration of the soil profile indicating fractions of the total soil volume (here represented by unity) that are occupied by water at four key levels of soil water content. For this silty clay loam, the soil is full of water at saturation (0.42 $m^3 \, m^{-3}$), drains easily to field capacity (0.33 $m^3 \, m^{-3}$), and reaches the permanent wilting point (15 bars) at 0.18 $m^3 \, m^{-3}$ water content. To avoid stress in a crop such as corn, irrigations are scheduled when the soil water content reaches or is projected to reach 0.25 $m^3 \, m^{-3}$, the value of θ_{MAD} for this soil and crop.

Because this analysis depends on the sample standard deviation determined by repeated readings with a particular device, it encapsulates the variability of readings from that device; but it does not include bias (non-random error) that may be present in the device readings due to, for example, inaccurate calibration. Aside from large-scale spatial variability, the calibration is a potentially large source of error; and this error is not reduced by repeated sampling (Vauclin et al., 1984). Thus, careful field calibration is essential to minimize such bias (Hignett and Evett, 2002; Greacen, 1981). In most cases, this analysis may be applied to values of soil profile water storage that are calculated on the basis of samples at multiple depths.

For example using the data for the three soils in Fig. 1, the differences between the values of water content at field capacity, θ_{FC}, and at the permanent wilting point, θ_{PWP}, are the plant available water, θ_{PAW} (Table 2). Assuming that the management allowed depletion is 0.6 of θ_{PAW}, the allowable ranges of water content during irrigation scheduling are 0.126, 0.085, and 0.022 $m^3 m^{-3}$ for silt loam, clay, and loamy sand, respectively (Table 2). These narrow ranges place high accuracy demands on soil water sensing equipment. Assuming that soil-specific calibrations have been performed to minimize bias, and that the accuracy of calibration is an acceptably small value (as determined by the RMSE of regression << MAD range), a specific sensor must still provide an acceptably precise mean value of field readings (that is, standard deviation of readings at multiple locations < MAD range).

Table 2. Example calculation of management allowed depletion (MAD, $m^3 m^{-3}$) in three soils with widely different textures. The small range of MAD severely tests the abilities of most soil water sensors, particularly for the loamy sand soil.

Horizon	θ_{FC} ($m^3 m^{-3}$)	θ_{PWP} ($m^3 m^{-3}$)	θ_{PAW} ($m^3 m^{-3}$)		MAD fraction		MAD ($m^3 m^{-3}$)
silt loam	0.086	0.295	0.209	×	0.6	=	0.126
loamy sand	0.066	0.103	0.037	×	0.6	=	0.022
clay	0.190	0.332	0.142	×	0.6	=	0.085

The ability to provide an acceptably precise mean value of field readings using a cost-effective number of access tubes or sensors in the soil is where some sensors are lacking (Table 3). In particular, the capacitance sensors appear to be very sensitive to small-scale variations in soil water content, and thus require many more access tubes to attain a precision equal to that attained with much fewer NMM or gravimetric samples. Another example is data from Australia showing that the standard deviation of profile water contents reported by the EnviroSCAN system was 12.36 cm compared with S of 0.93 cm for the NMM in the same flood irrigation basin (Evett et al., 2002b).

If no other information were available about soil water variability, sampling a field for profile water content would typically require many profiles to be sampled, either directly or using water content sensor(s) in access tubes. However, distribution of profile water content tends to be temporally stable in some fields, at least over a growing season (Vachaud et al., 1985; Villagra et al., 1995). This means that there are locations in the field where the profile water content is usually very representative of the mean for the field, or of the extremes (Fig. 4) (Evett, 1989). Irrigators recognize this when they observe the crop in a field for water stress or when they probe the soil for water content. For example, an irrigator may ignore drier crops at the edge of a field, or a low, wet corner of the field when assessing the need to irrigate. The tendency is to make observations in places that show the mean behavior of the field. This is not an adequate way of choosing observation locations for a scientific experiment for which blocking, randomization, replication and other considerations are required for statistical validity. But, for irrigation management in production agriculture, the choosing of measurement locations on the basis of observed soil and plant properties that are representative of the field may be the most cost effective and efficient method.

Table 3. Calculation using Eq. [2] of the number of access tubes (*N*) needed to find the mean profile water storage in a field to a precision *d* (cm) at the (1 - α) probability level ($\mu_{\alpha/2}$ is the value of the standard normal distribution at α/2) for a given field-measured standard deviation (*S*, cm) of profile storage. Data are from ten access tubes for each device, spaced at 10-m intervals in transects that were 5-m apart.

		α =	0.05	0.10
		$\mu_{\alpha/2}$ =	1.96	1.64
		d (cm) =	1	0.1
Method	**Soil condition**	***S* (cm)**	***N***	***N***
Diviner 2000†	Irrigated	1.31	6.6	464
	Dryland	2.42	22.5	1584
EnviroSCAN†	Irrigated	1.52	8.9	625
	Dryland	2.66	27.2	1914
Delta-T PR1/6†	Irrigated	2.72	28.4	2002
	Dryland	12.16	568.0	40006
Sentry 200AP†‡	Overall	3.78	54.9	3866
Trime T3	Irrigated	0.75	2.2	152
	Dryland	2.38	21.8	1533
Gravimetric by push tube	Irrigated	0.45	0.8	55
	Dryland	0.70	1.9	133
CPN 503DR NMM	Irrigated	0.15	0.1	6
	Dryland	0.27	0.3	20

† Capacitance type sensors

‡ Estimated from data of Evett and Steiner (1995)

The previous paragraph not withstanding, the scheduling of irrigations on the basis of a single profile water content measurement in a field is prone to large errors. Also, there is strong evidence that actively growing vegetation can reduce or eliminate the temporal stability of water content, particularly in the root zone (Hupet and Vanclooster, 2002) and in fields with little topographic relief. A reasonable minimum for the NMM or gravimetric sampling is three to four profile water content measurements at locations chosen to be representative of the field (Tollner et al., 1991). For other methods, such as the capacitance sensors, that sense smaller volumes resulting in larger values of S, the number of profile measurements needed may be much greater (Table 3).

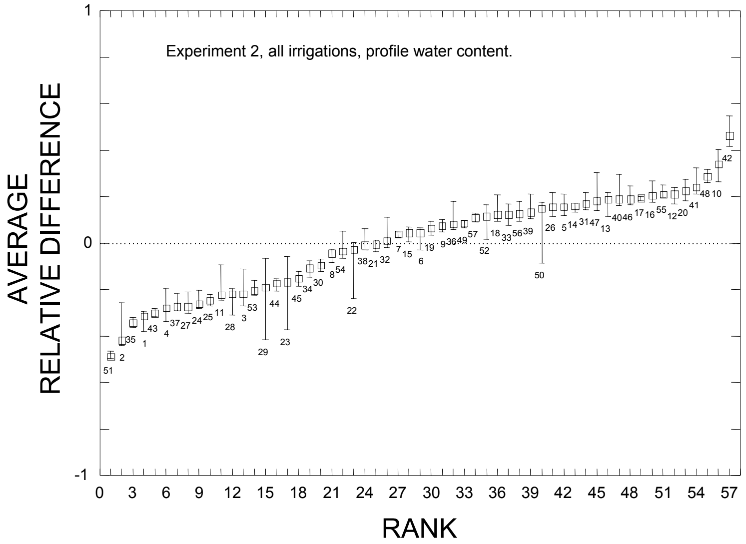

Figure 4. Ranking of locations by their average relative difference from the field mean profile water content. Vertical bars indicate the range of values observed over the course of the experiment. Location 21 in particular was close to the mean profile water content at all times.

TWO FIELD STUDIES

Electromagnetic (EM) soil water sensing systems are rapidly entering the soil water sensor market. Common systems use sensors based on capacitance or time domain reflectometry (TDR) principles. For three capacitance soil water sensing systems (Sentek EnviroSCAN[1], Sentek Diviner 2000, and Delta-T PR1/6), the Trime T3 quasi-TDR soil water sensing system, and the neutron moisture meter (NMM), we developed soil-specific calibrations for the A, Bt, and calcic Bt horizons of the Pullman soil at Bushland, TX (Evett et al., 2006). We applied these calibrations to data acquired in a wheat field in 2003 in order to investigate the variability of soil water estimates without the confounding factor of inaccurate factory calibrations. There were ten access tubes for each system, arranged in linear transects. After the first three measurement cycles, half of the winter wheat field (containing five access tubes) was irrigated to see how the five systems were able to sense the differences in water content. Access tubes were spaced 10-m apart. In addition to the five soil water sensing methods, gravimetric samples were taken with an hydraulic push probe (Giddings) in transects on some of the sampling dates. Sampling points were spaced 10-m apart; and samples were 10-cm in height and had a volume of 75.5 cm^3. The data in Table 3 are from this study.

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[1] The mention of trade or manufacturer names is made for information only and does not imply an endorsement, recommendation, or exclusion by USDA-Agricultural Research Service.

Profile water contents reported by the six methods differed considerably (Figure 5), particularly in the degree of water content variability and the shape of the profile, which is influenced by over and under estimation of water content at different depths. The smallest variability of water content was reported by the NMM; and the NMM data matched the direct gravimetric data better than any other sensor. Variability of gravimetric measurements was only slightly larger than that of the NMM; and variability of Trime T3 results was somewhat more variable, but still representative of the profile water content in much the same way as the NMM. In this field, the depth to the $CaCO_3$-enriched (caliche) layer was ~120 cm. As shown by the NMM and gravimetric results, inherent soil water variability was larger in the caliche horizon below 120 cm than in the Bt and A horizons above 120 cm. The larger variability below 120 cm is due to the presence of prairie dog burrows that are present in the softer caliche soil (Fig. 5, right). These are invariably found in soil pits dug at the Bushland research station. The burrows contain soil that has washed in from the overlying Bt and A horizons; and they typically exhibit smaller bulk density than the overlying and surrounding soil. Depending on the presence or absence of macropore flow, typically occurring in soil cracks in the overlying A and Bt horizons of this soil, the soil in burrows may exhibit larger or smaller water content than surrounding soil.

While all of the EM sensors exhibited more variability than the NMM, the three capacitance sensors exhibited the most variability as well as a tendency to severely underestimate water content in the A horizon above 50-cm depth. This could be indicative of a weakness in the soil-specific calibrations of Evett et al. (2006), or it might be due to poor contact of the plastic access tubes in this soil after more than seven months in the soil. Particularly near the top of the access tubes, vibration from repeated instrument insertion and extraction can cause small annular air spaces to develop between the soil and access tube. Also, shrinkage and swelling of the soil could create air space around the tubes near the surface where the soil is unconstrained. The NMM is not sensitive to such small air gaps, but they can permit water movement down the outside tube walls. The under estimation by the capacitance sensors was so consistent that we think it is due to a very strong dependency of the calibration equation coefficients on clay content of the soil, which increases strongly with depth in this soil. The variability in water contents illustrated in Fig. 5 is reflected in the values of *S* in Table 3.

A second study was done in a drip irrigated sweet pepper field near Five Points, CA, in the San Joaquin Valley on a Panoche clay loam soil in 2005. Data are presented for two periods in the season (Fig. 6). The first period was during the irrigation season as pepper fruits were developing; and the second period was during field dry down after irrigation had been suspended, but the crop was still transpiring. Sensors studied were the NMM, and three capacitance sensors: the Delta-T PR2/6 (successor to the PR1/6), the Sentek Diviner 2000 and the Sentek

EnviroSCAN. Data from the NMM showed that, below the surface, the soil water content profile was nearly uniform with depth at both dates, though the decrease in water content during dry down was evident. Gravimetric data (not shown) from the same field showed the same uniformity of water content with depth as did the NMM. Data from the PR2/6 indicated that the water content was much more variable, and that water content increased with depth during the dry down period. Neither indication is true. What is true is that this soil becomes increasingly saline during the irrigation season, and that salinity increases with depth in the profile at the end of the season. Thus, the increasing water contents with depth from the PR2/6 are the result of this sensor being sensitive to salinity, not an indication that water content increased with depth. Data shown are using the factory calibration for clay soils for the PR2/6, which resulted in both over and under estimation of water contents, depending on the depth. Data for the EnviroSCAN and Diviner 2000 for the same two periods are similar. They show more variability than actually existed at the scale of crop water uptake; and similar to the PR2/6, they showed a false increase of water content with depth late in the season, probably due to salinity increasing with depth. Again, the use of factory calibrations resulted in some large over and under estimations of water content.

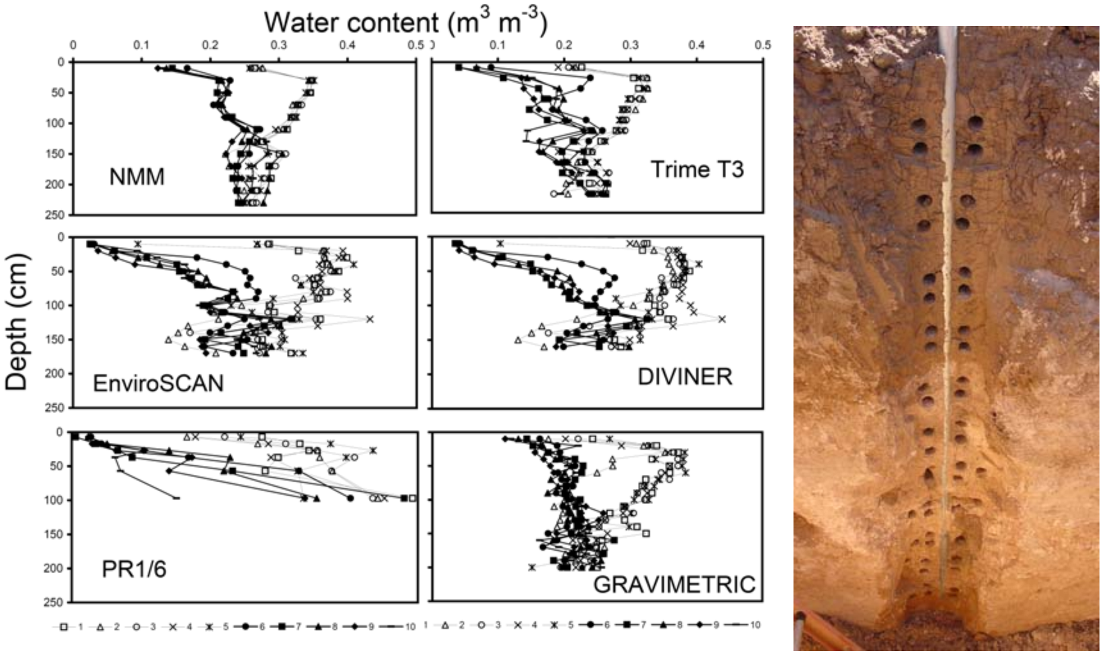


Figure 5. (Left) Profile water contents for ten transect locations for each of five sensor systems, in a winter wheat field on 5 November, 2003, compared with gravimetric measurements. Half of the field (five transect locations) was irrigated. Sensing methods were frequency domain (EnviroSCAN, Diviner 2000, and PR1/6), quasi-TDR (Trime T3), and the neutron moisture meter (NMM). (Right) Photograph of the Pullman soil profile to 2-m depth showing the lighter colored caliche horizon.

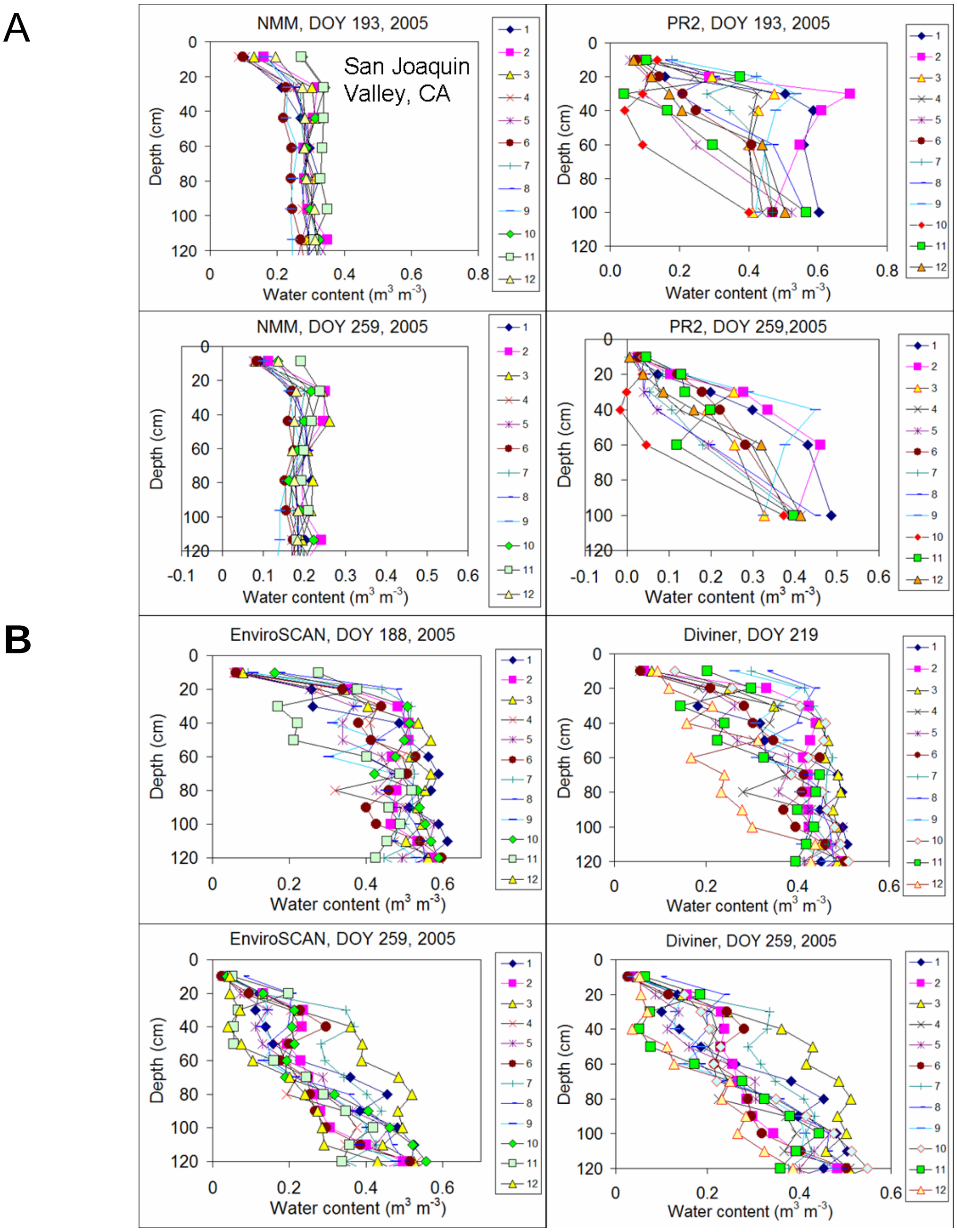


Figure 6. Water content data from two periods for each sensor during a 2005 study in California. The first period was during the irrigation season as pepper fruits were developing; and the second period was during field dry down after irrigation had been suspended, but the crop was still transpiring. Sensors studied were the NMM and the Delta-T PR2/6 (shown in A), and the Sentek Diviner 2000 and EnviroSCAN (B).

EFFECT OF SALINITY

World wide, 20% of irrigated soils are salt affected (Hachicha and Abd El-Gawed, 2003). Sensitivity to soil salinity, measured as the bulk electrical conductivity (BEC), limits the applicability of frequency domain or power loss sensors in many irrigated soils in which BEC varies across the field (Fig. 7) and with time (Fig 8). Variations of BEC of as much as 12 dS m^{-1} can occur over distances of less than one meter (Burt et al., 2003), and differences equally as large can occur from year to year or even within an irrigation season in one location (Hanson et al., 2003). Abdel gawad et al. (2003) measured periodic soil solution EC variations of 5 to 6 dS m^{-1} under drip irrigation in Syria. Mmolawa and Or (2000) measured a BEC change from 0.3 to 2.3 dS m^{-1} in a few hours under drip irrigation of corn. While it is possible to calibrate most sensors for a particular BEC, in these situations of temporally and spatially variable BEC, such a calibration is not applicable. From the available data, it is clear that errors larger than 50% in soil water content at a single location, and errors similarly large in soil profile water content are possible given the range of BEC values measured. Spatial and temporal variations of BEC are not confined to drip irrigation, but are present under furrow, flood, and sprinkler irrigation as well.

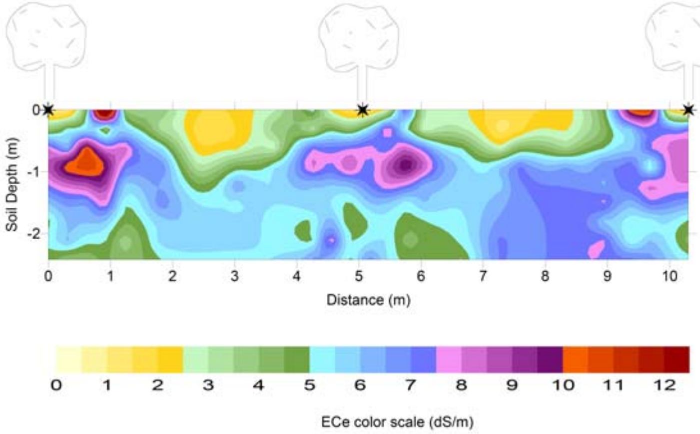


Figure 7. Variations in EC of saturation paste soil extracts (EC_e) in two dimensions of a pistachio plantation that was drip irrigated in California. (Burt et al., 2003)

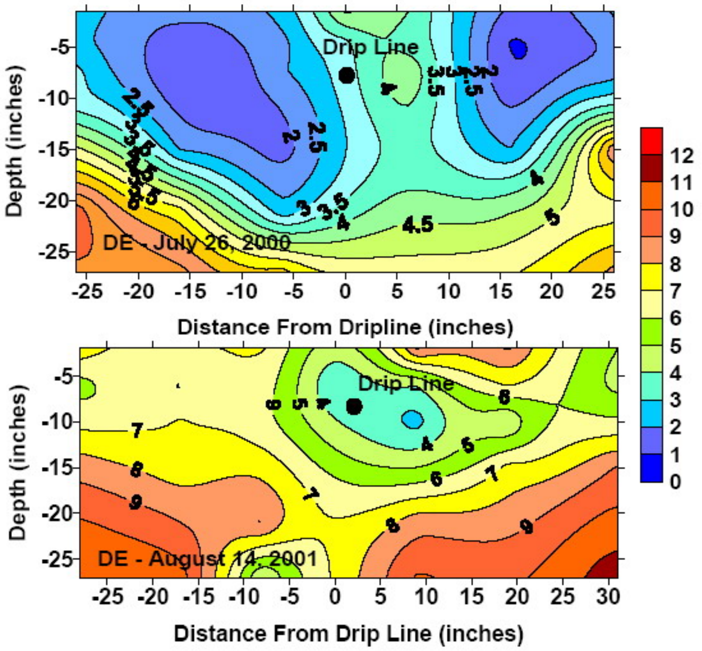


Figure 8. Variations in EC from saturation paste soil extracts from a single location in a drip-irrigated tomato field in California in two different years. No yield variation was found. (Hanson et al., 2003)

Sensors based on electromagnetic principles are often also sensitive to clay content and type even in non-saline soils. This is because clays exhibit varying degrees of charge and are associated with cations or anions in the soil solution to varying degrees. Commonly, clays exhibit negative charge and are associated with cations to a degree that is evaluated as the cation exchange capacity (CEC). As the soil content of high CEC clay increases, the soil becomes more electrically lossy, that is, more capable of affecting the movement of electrical fields. This affects the frequency of oscillation of capacitance systems and the power loss of power loss systems in a way that is separate from, but not completely independent of, the soil water content. Examples include the much different calibration equations developed for the several soils existing under one center pivot irrigation system in France (Fig. 9) (Ruelle et al., 2003, personal communication), and the different calibration equations reported by Baumhardt et al. (2000) at Lubbock, TX, and Morgan et al. (1999) for the Sentek EnviroSCAN system.

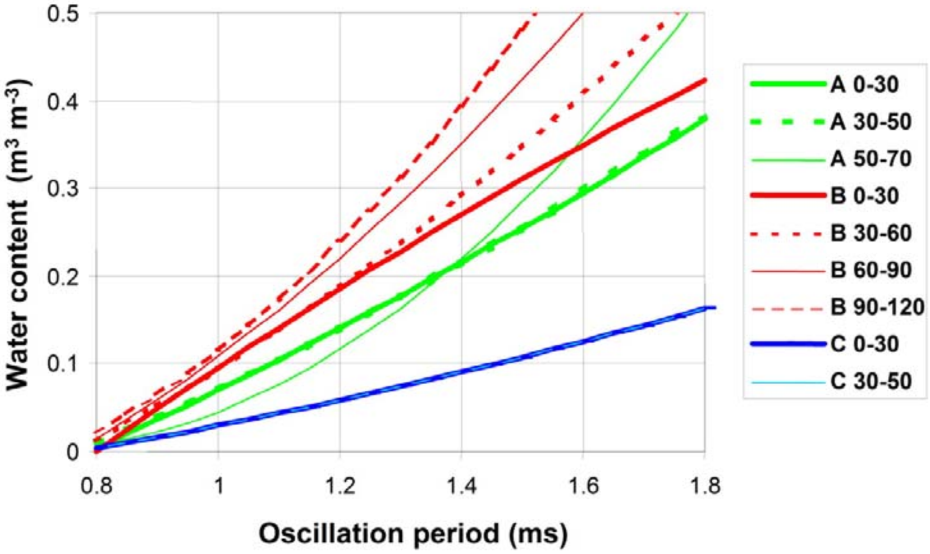


Figure 9. Calibrations of the model CS615 soil water probe from Campbell Scientific, Inc. in nine different soil layers of three different soils (A, B, and C), illustrating the wide variance in calibration equations for different layers in a particular soil and among soils (Ruelle et al., 2003, personal communication).

GRANULAR MATRIX SENSORS

Several types of granular matrix sensors (GMS) are on the market. The sensor consists of a porous medium in which are embedded two wires, often connected to wire mesh electrodes inside the sensor. The reading is of the electrical resistance in the medium between the wires or mesh electrodes. Often, a quantity of gypsum (calcium sulfate) is included to buffer the soil water solution and decrease effects of salinity on the resistance. The greater the soil water tension, the less water is in the porous medium, and the greater the electrical resistance. Calibration may be done in a porous medium covering a pressure plate, which is subjected to several values of pressure in a pressure chamber. Calibrations are soil specific, so it is wise to use the soil to be measured as the porous medium. Installation and contact problems are similar to those for a tensiometer or gypsum block, including contact problems in coarse sands and shrink/swell clays. At tensions less than 30 kPa, Taber et al. (2002) found that tensiometers responded more rapidly than GMS sensors in silt loam, loam, and coarse sand. As with gypsum blocks, reading requires an alternating current to minimize effects of capacitive charge build up and ionization. Lack of precision and calibration drift over time may limit use of GMS for determining soil water potential gradients.

The useful range of readings is approximately −10 to −200 kPa matric potential, though Morgan et al. (2001b) were able to use GMS sensors to −5 kPa in a fine sand. Sensors may be manually read or data logged (resistance reading). Some hysteresis is noted with these sensors; and they are temperature sensitive (as much as 20 kPa per 10°C, Shock, 2003). Like gypsum blocks, GMS may be installed to practically any useful depth, limited only by wire length. Fewer problems with soil contact are noted with GMS. The usefulness of GMS systems for irrigation scheduling has been illustrated by work done with onions, potato (Fig. 10), alfalfa, and sugar beet in the Malheur Valley of Oregon (Shock, 2003; Shock et al., 2003). Because of soil and irrigation variability, at least six sensors should be used to provide data for irrigation scheduling (Shock, 2003). For irrigation science, the GMS can be useful if calibrated for the soil over a range of temperatures and soil water potentials, and if soil temperature is measured at the location of each sensor so that calibration corrections for temperature can be applied. Automatic irrigation scheduling has been successfully implemented using GMS for high-value row crops (Shock et al., 2002) and for landscapes (Qualls et al., 2001).

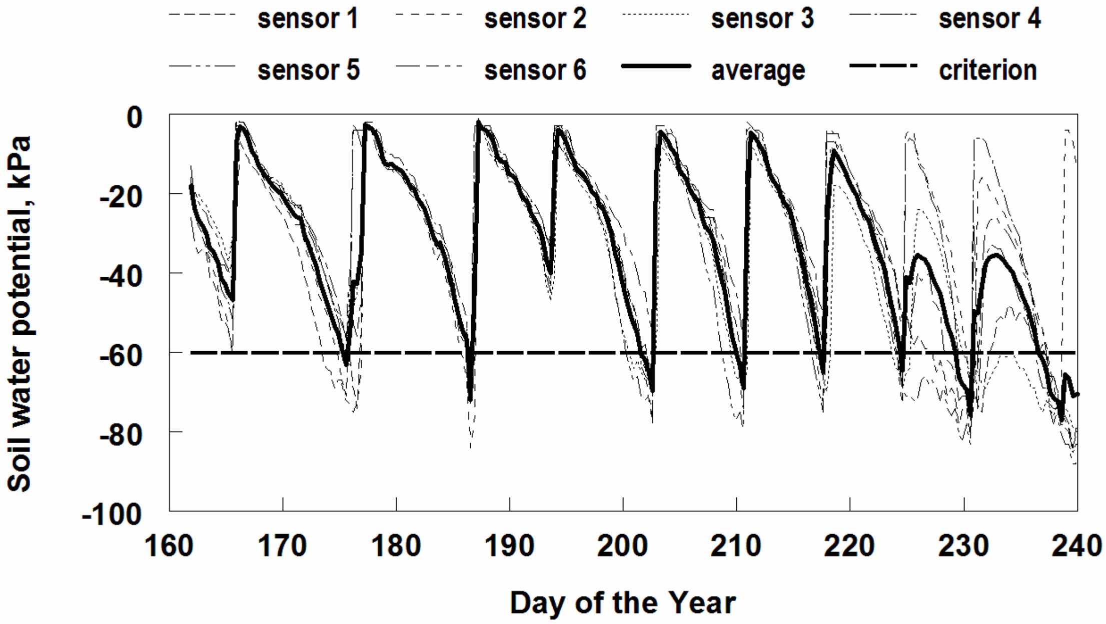
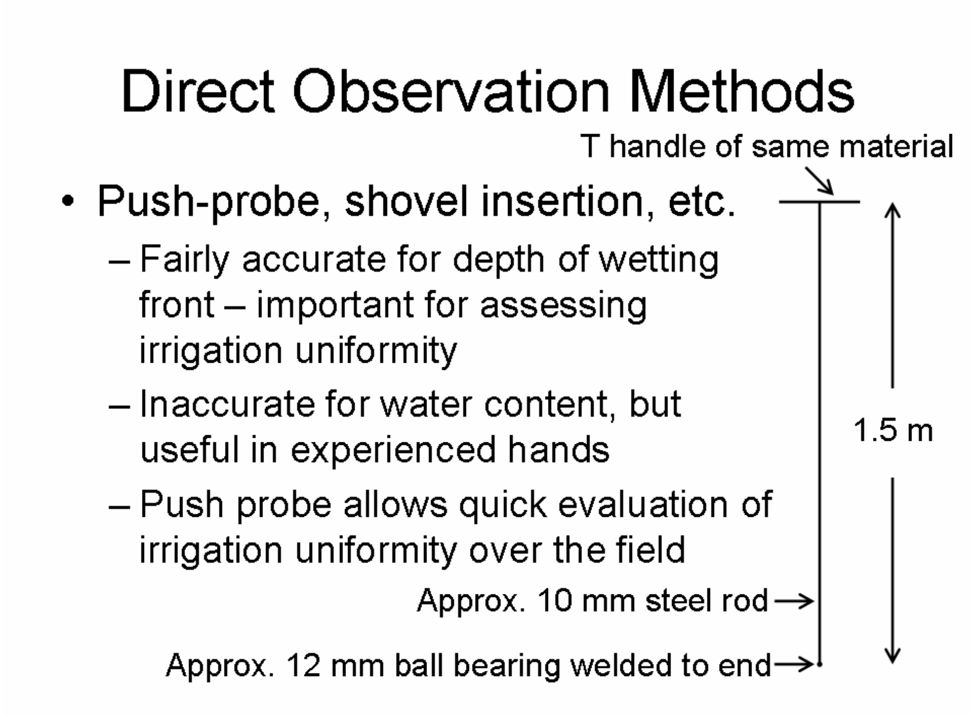


Figure 10. Soil water potential in a sprinkler-irrigated potato field as sensed with six granular matrix sensors datalogged using a Hansen model AM400 data logger, showing very good control of soil water potential. Note the dry-down period at the end of the irrigation season (Shock et al., 2003)

DIRECT OBSERVATION

Direct observations can be very useful in guiding irrigation management. The soil feel and appearance method involves squeezing a ball of soil in the hand and comparing its feel and appearance to photographs that show the appearance of different soil textures at various water contents. The USDA-NRCS publishes a handy guide with the photographs and descriptions of how the soil feels in the hand at different water contents. While it is an approximate guide, this method is fairly simple, and when used by an experienced irrigator can give the amount to irrigate. It does require a trip to field, during which the leaf and crop appearance can also be assessed (curl, color, wilting). Usually, these are apparent only after stress is enough to limit yield. The feel and appearance guide can be found at http://www.mt.nrcs.usda.gov/technical/ecs/agronomy/soilmoisture/index.html.

Another method of direct observation common in irrigated Great Plains soils is the push probe (Fig. 11). The probe consists of a 3/8 or ½-inch diameter steel rod with a T handle at the top and a ball bearing of slightly larger diameter welded to the bottom end. The ball bearing makes a hole larger than the diameter of the rod so that most of the resistance to penetration into the soil is at the ball, not due to friction between the soil and the rod. An experienced irrigator can fairly quickly assess variability in irrigation infiltration depth across a field, and perhaps most importantly can identify deep wetting of the profile that can result in deep percolation losses. Water lost to deep percolation carries with it costly fertilizers, the loss of which can reduce yield appreciably. Indeed, among farmers who have been over irrigating in the past, it is a common observation that reduction in water application is accompanied by increase in yield.



Direct Observation Methods

- Push-probe, shovel insertion, etc.
  - Fairly accurate for depth of wetting front – important for assessing irrigation uniformity
  - Inaccurate for water content, but useful in experienced hands
  - Push probe allows quick evaluation of irrigation uniformity over the field

Figure 11. The push probe, a useful device for assessing irrigation penetration depth and relative water content.

CONCLUSIONS

The relatively expensive and high tech capacitance and other electromagnetic (EM) sensors are too inaccurate to be useful for assessing when and how much water to apply through irrigation. Sensitivities to soil bulk electrical conductivity, whether derived from clay type and content or from salt content, are too great with the current crop of EM sensors. A new generation of EM sensors should be developed to overcome the problems of those currently available. The neutron moisture meter, even though posing negligible health hazard, faces stiff regulation and is useful mostly for research. Granular matrix sensors (resistance blocks) are useful in some soils and are particularly justified when produce quality is a concern. Direct observation remains the most used method of irrigation scheduling. Although not addressed in this paper, producers who can take advantage of a weather station network that provides crop water use estimates based on reference evapotranspiration are successfully using those networks to schedule irrigations. When used in conjunction with direct observations (e.g. push probes) to avoid over irrigation, the ET network approach has proved useful in maximizing yields. One example is the Texas High Plains ET Network (http://txhighplainset.tamu.edu/) (Howell, 1998; Howell et al., 1998; Marek et al., 1998). For a more in-depth and technical discussion of soil water properties and soil water sensing systems, see Evett (2007).

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CROP RESIDUE AND SOIL WATER

D.C. Nielsen
Research Agronomist
USDA-ARS
Central Great Plains Research Station
Akron, CO
Voice: 970-345-0507 Fax: 970-345-2088
Email: David.Nielsen@ars.usda.gov

INTRODUCTION

Final crop yield is greatly influenced by the amount of water that moves from the soil, through the plant, and out into the atmosphere (transpiration). Generally, the more water that is in the soil and available for transpiration, the greater the yield. For example, dryland wheat yield is strongly tied to the amount of soil water available at wheat planting time (Fig. 1). In this case an additional inch of water stored in the soil at wheat planting time would increase yield by 5.3 bu/a. For wheat selling at $4.00/bu, that inch of stored soil water is worth over $21/a. Similar relationships can be defined for other crops. But the point is that in the Great Plains where precipitation is low and erratic, an important production factor is storing as much of the precipitation and irrigation that hits the soil surface as possible.

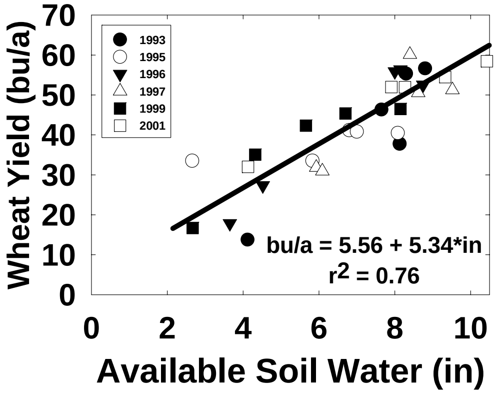

Fig. 1. Relationship between winter wheat grain yield and available soil water at wheat planting at Akron, CO.

FACTORS AFFECTING WATER STORAGE

Time of Year/Soil Water Content

The amount of precipitation that finally is stored in the soil is determined by the precipitation storage efficiency (PSE). PSE can vary with time of year and the water content of the soil surface. During the summer months air temperature is very warm, with evaporation of precipitation occurring quickly before the water can move below the soil surface. Farahani et al. (1998) showed that precipitation storage efficiency during the 2 ½ months (July 1 to Sept 15) following wheat harvest averaged 9%, and increased to 66% over the fall, winter, and spring period (Sept 16 to April 30) (Fig. 2). The higher PSE during the fall, winter, and spring is due to cooler temperatures, shorter days, and snow catch by crop residue. From May 1 to Sept 15, the second summerfallow period, precipitation storage efficiency averaged -13% as water that had been previously stored was actually lost from the soil. The soil surface is wetter during the second summerfallow period, slowing infiltration rate, and increasing the potential for water loss by evaporation.

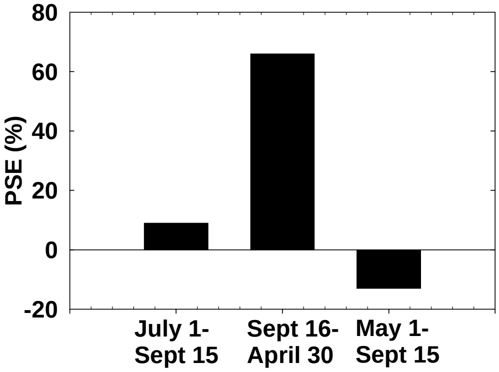

Fig. 2. Precipitation Storage Efficiency (PSE) variability with time of year. (after Farahani, 1998)

Residue Mass and Orientation

Studies conducted in Sidney, MT, Akron, CO, and North Platte, NE (Fig. 3) demonstrated the effect of increasing amount of wheat residue on the precipitation storage efficiency over the 14-month fallow period between wheat crops.

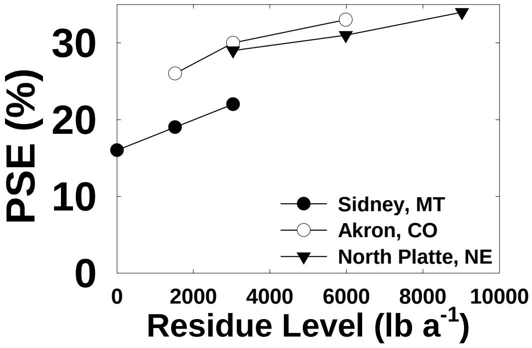

Fig. 3. Precipitation Storage Efficiency (PSE) as influenced by wheat residue on the soil surface. (after Greb et al., 1967)

As wheat residue on the soil surface increased from 0 to 9000 lb/a, precipitation storage efficiency increased from 15% to 35%. Crop residues reduce soil water evaporation by shading the soil surface and reducing convective exchange of water vapor at the soil-atmosphere interface. Additionally, reducing tillage and maintaining surface residues reduce precipitation runoff, increase infiltration, and minimize the number of times moist soil is brought to the surface, thereby increasing precipitation storage efficiency (Fig. 4).

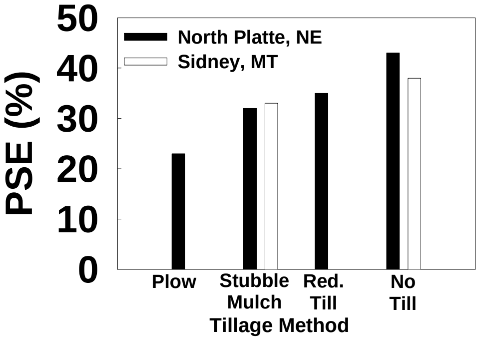

Fig. 4. Precipitation Storage Efficiency (PSE) as influenced by tillage method in the 14-month fallow period in a winter wheat-fallow production system. (after Smika and Wicks, 1968; Tanaka and Aase, 1987)

Snowfall is an important fraction of the total precipitation falling in the central Great Plains, and residue needs to be managed in order to harvest this valuable resource. Snowfall amounts range from about 16 inches per season in southwest Kansas to 42 inches per season in the Nebraska panhandle. Akron, CO averages 12 snow events per season, with three of those being blizzards. Those 12 snow storms deposit 32 inches of snow with an average water content of 12%, amounting to 3.8 inches of water. Snowfall in this area is extremely efficient at recharging the soil water profile due in large part to the fact that 73% of the water received as snow falls during non-frozen soil conditions.

Standing crop residues increase snow deposition during the overwinter period. Reduction in wind speed within the standing crop residue allows snow to drop out of the moving air stream. The greater silhouette area index (SAI) through which the wind must pass, the greater the snow deposition (SAI = height*diameter*number of stalks per unit ground area). Data from sunflower plots at Akron, CO showed a linear increase in soil water from snow as SAI increased in years with average or above average snowfall and number of blizzards. Typical values of SAI for sunflower stalks (0.03 to 0.05) result in an overwinter soil water increase of about 4 to 5 inches (Fig. 5).

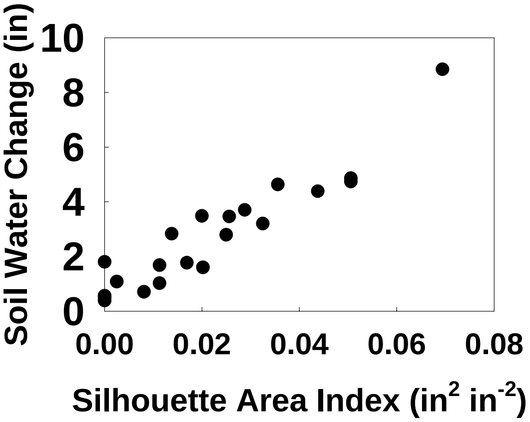

Fig. 5. Influence of sunflower silhouette area index on over-winter soil water change at Akron, CO. (after Nielsen, 1998)

Because crop residues differ in orientation and amount, causing differences in evaporation suppression and snow catch, we see differences in the amount of soil water recharge that occurs (Fig. 6). The 5-year average soil water recharge occurring over the fall, winter, and spring period in a crop rotation experiment at Akron, CO shows 4.6 inches of recharge in no-till wheat residue, and only 2.5 inches of recharge in conventionally tilled wheat residue. Corn residue is nearly as effective as no-till wheat residue in recharging soil water, while millet residue gives results similar to conventionally tilled wheat residue.

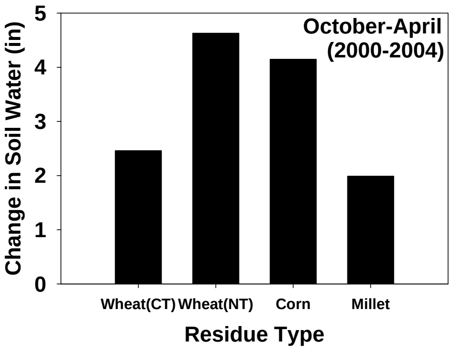

Fig. 6. Change in soil water content due to crop residue type at Akron, CO.

Good residue management through no-till or reduced-till systems will result in increased soil water availability at planting. This additional available water will increase yield in both dryland and limited irrigation systems by reducing level of water stress a plant experiences as it enters the critical reproductive growth stage.

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CONVENTIONAL, STRIP, AND NO TILLAGE CORN PRODUCTION UNDER DIFFERENT IRRIGATION CAPACITIES

Dr. Freddie Lamm
Research Irrigation Engineer
Email: flamm@ksu.edu

Dr. Rob Aiken
Research Crop Scientist
Email: raiken@ksu.edu

KSU Northwest Research-Extension Center
105 Experiment Farm Road, Colby, Kansas
Voice: 785-462-6281 Fax: 785-462-2315

ABSTRACT

Corn production was compared from 2004 to 2006 for three plant populations (25,400, 28,600 or 32,000 plants /acre) under conventional, strip and no tillage systems for irrigation capacities limited to 1 inch every 4, 6 or 8 days. Corn yield increased approximately 12% from the lowest to highest irrigation capacity in these three years of varying precipitation and near normal crop evapotranspiration. Strip tillage and no tillage had 8.8% and 7% higher grain yields than conventional tillage, respectively. Results suggest that strip tillage obtains the residue benefits of no tillage in reducing evaporation losses without the yield penalty sometimes occurring with high residue. The small increases in total seasonal water use (< 1.5 inch) for strip tillage and no-tillage compared to conventional tillage can probably be explained by the higher grain yields for these tillage systems.

INTRODUCTION

Declining water supplies and reduced well capacities are forcing irrigators to look for ways to conserve and get the best utilization from their water. Residue management techniques such as no tillage or conservation tillage have been proven to be very effective tools for dryland water conservation in the Great Plains. However, adoption of these techniques is lagging for continuous irrigated corn. There are many reasons given for this lack of adoption, but some of the major reasons expressed are difficulty handling the increased level of residue from irrigated production, cooler and wetter seedbeds in the early spring which may lead to poor or slower development of the crop, and ultimately a corn grain yield penalty as compared to conventional tillage systems. Under very high production systems, even a reduction of a few percentage points in corn yield can have a significant economic impact. Strip tillage might be a good compromise between conventional tillage and no tillage, possibly achieving most of the benefits in water conservation and soil quality management of no tillage, while providing a method of handling the increased residue and increased early growth similar to conventional tillage. Strip tillage can retain surface residues and thus suppress soil evaporation and also provide subsurface tillage to help alleviate effects of restrictive soil layers on root growth and function. A study was initiated in 2004 to examine the effect of three tillage systems for corn production under three different irrigation capacities. Plant population was an additional factor examined because corn grain yield increases in recent years have been closely related to increased plant populations.

GENERAL STUDY PROCEDURES

The study was conducted under a center pivot sprinkler at the KSU Northwest Research-Extension Center at Colby, Kansas during the years 2004 to 2006. Corn was also grown on the field site in 2003 to establish residue levels for the three tillage treatments. The deep Keith silt loam soil can supply about 17.5 inches of available soil water for an 8-foot soil profile. The climate can be described as semi-arid with a summer precipitation pattern with an annual rainfall of approximately 19 inches. Average precipitation is approximately 12 inches during the 120-day corn growing season.

A corn hybrid of approximately 110 day relative maturity (Dekalb DCK60-19 in 2004 and DCK60-18 in 2005 and 2006) was planted in circular rows on May 8, 2004, April 27, 2005 and April 20, 2006, respectively. Three seeding rates (26,000, 30,000 and 34,000 seeds/acre) were superimposed onto each tillage treatment in a complete randomized block design.

Irrigation was scheduled with a weather-based water budget, but was limited to the 3 treatment capacities of 1 inch every 4, 6, or 8 days. This translates into typical seasonal irrigation amounts of 16-20, 12-15, 8-10 inches, respectively. Each of the irrigation capacities (whole plot) were replicated three times in pie-shaped sectors (25 degree) of the center pivot sprinkler (Figure 1). Plot length varied from to 90 to 175 ft, depending on the radius of the subplot from the center pivot point. Irrigation application rates (i.e. inches/hour) at the outside edge of this research center pivot were similar to application rates near the end of full size systems. A small amount of preseason irrigation was conducted to bring the soil water profile (8 ft) to approximately 50% of field capacity in the fall and as necessary in the spring to bring the soil water profile to approximately 75% in the top 3 ft prior to planting. It should be recognized that preseason irrigation is not a recommended practice for fully irrigated corn production, but did allow the three irrigation capacities to start the season with somewhat similar amounts of water in the profile.

The three tillage treatments (Conventional tillage, Strip Tillage and No Tillage) were replicated in a Latin-Square type arrangement in 60 ft widths at three different radii (Centered at 240, 300 and 360 ft.) from the center pivot point (Figure 1). The various operations and their time period for the three tillage treatments are summarized in Table 1. Planting was in the same row location each year for the Conventional Tillage treatment to the extent that good farming practices allowed. The Strip Tillage and No-Tillage treatments were planted between corn rows from the previous year.

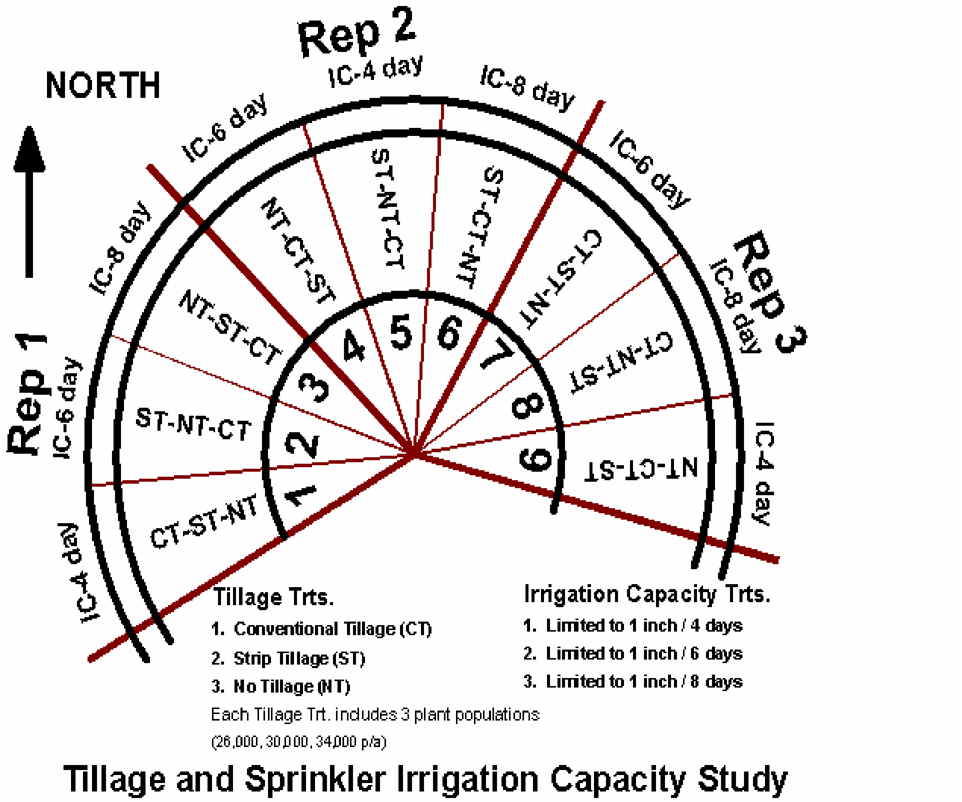

Figure 1. Physical arrangement of the irrigation capacity and tillage treatments.

Fertilizer N for all 3 treatments was applied at a rate of 200 lb/acre in split applications with approximately 85 lb/ac applied in the fall or spring application, approximately 30 lb/acre in the starter application at planting and approximately 85 lb/acre in a fertigation event near corn lay-by. Phosphorus was applied with the starter fertilizer at planting at the rate of 45 lb/acre P2O5. Urea-Ammonium-Nitrate (UAN 32-0-0) and Ammonium Superphosphate (10-34-0) were utilized as the fertilizer sources in the study. Fertilizer was incorporated in the fall concurrently with the Conventional Tillage operation and applied with a mole knife during the Strip Tillage treatment. Conversely, N application was broadcast with the No Tillage treatment prior to planting.

A post-plant, pre-emergent herbicide program of Bicep II Magnum and Roundup Ultra was applied. Roundup was also applied post-emergence prior to lay-by for all treatments, but was particularly beneficial for the strip and no tillage treatments. Insecticides were applied as required during the growing season.

Weekly to bi-weekly soil water measurements were made in 1-ft increments to 8-ft. depth with a neutron probe. All measured data was taken near the center of each plot. These data were utilized to examine treatment differences in soil water conditions both spatially (e.g. vertical differences) and temporally (e.g.

differences caused by timing of irrigation in relation to evaporative conditions as affected by residue and crop growth stage).

Table 1. Tillage treatments, herbicide and nutrient application by period.

Period	Conventional tillage	Strip Tillage	No Tillage
Fall 2003	1) One-pass chisel/disk plow at 8-10 inches with broadcast N, November 13, 2003.	1) Strip Till + Fertilizer (N) at 8-10 inch depth, November 13, 2003.	
Spring 2004	2) Plant + Banded starter N & P, May 8, 2004. 3) Pre-emergent herbicide application, May 9, 2004.	2) Plant + Banded starter N & P, May 8, 2004 3) Pre-emergent herbicide application, May 9, 2004.	1) Broadcast N + Plant + Banded starter N & P, May 8, 2004 2) Pre-emergent herbicide application, May 9, 2004.
Summer 2004	4) Roundup herbicide application near lay-by, June 9, 2004 5) Fertigate (N), June 10, 2004	4) Roundup herbicide application near lay-by, June 9, 2004 5) Fertigate (N), June10, 2004	3) Roundup herbicide application near lay-by, June 9, 2004 4) Fertigate (N), June 10, 2004
Fall 2004	1) One-pass chisel/disk plow at 8-10 inches with broadcast N, November 05, 2004.	*Too wet, no tillage operations*	
Spring 2005	2) Plant + Banded starter N & P, April 27, 2005. 3) Pre-emergent herbicide application, May 8, 2005.	1) Strip Till + Fertilizer (N) at 8-10 inch depth, March 15, 2005. 2) Plant + Banded starter N & P, April 27, 2005 3) Pre-emergent herbicide application, May 8, 2005.	1) Broadcast N + Plant + Banded starter N & P, April 27, 2005 2) Pre-emergent herbicide application, May 8, 2005.
Summer 2005	4) Roundup herbicide application near lay-by, June 9, 2005 5) Fertigate (N), June 17, 2005	4) Roundup herbicide application near lay-by, June 9, 2005 5) Fertigate (N), June 17, 2005	3) Roundup herbicide application near lay-by, June 9, 2005 4) Fertigate (N), June 17, 2005
Fall 2005	1) One-pass chisel/disk plow at 8-10 inches with broadcast N, November 10, 2005.	1) Strip Till + Fertilizer (N) at 8-10 inch depth, November 10, 2005.	
Spring 2006	2) Plant + Banded starter N & P, April 20, 2006. 3) Pre-emergent herbicide application, April 22, 2006.	2) Plant + Banded starter N & P, April 20, 2006 3) Pre-emergent herbicide application, April 22, 2006.	1) Broadcast N + Plant + Banded starter N & P, April 20, 2006 2) Pre-emergent herbicide application, April 22, 2006.
Summer 2006	4) Roundup herbicide application near lay-by, June 6, 2006 5) Fertigate (N), June 13, 2006	4) Roundup herbicide application near lay-by, June 6, 2006 5) Fertigate (N), June 13, 2006	3) Roundup herbicide application near lay-by, June6, 2006 4) Fertigate (N), June 13, 2006

Similarly, corn yield was measured in each of the 81 subplots at the end of the season. In addition, yield components (above ground biomass, plants/acre ears/plant, kernels/ear and kernel weight) were determined to help explain the treatment differences. Water use and water use efficiency were calculated for each subplot using the soil water data, precipitation, applied irrigation and crop yield.

RESULTS AND DISCUSSION

Weather Conditions

Summer seasonal precipitation was approximately 2 inches below normal in 2004, near normal in 2005, and nearly 3 inches below normal in 2006 at 9.99, 11.95 inches, and 8.99 inches, respectively for the 120 day period from May 15 through September 11 (long term average, 11.86 inches). In 2004, the last month of the season was very dry but the remainder of the season had reasonably timely rainfall and about normal crop evapotranspiration (Figure 2). In 2005, precipitation was above normal until about the middle of July and then there was a period with very little precipitation until the middle of August. This dry period in 2005 also coincided with a week of higher temperatures and high crop evapotranspiration near the reproductive period of the corn (July 17-25). In 2006, precipitation lagged behind the long term average for the entire season. Fortunately, seasonal evapotranspiration was near normal as it also was for the other two years (long term average of 23.07 inches).

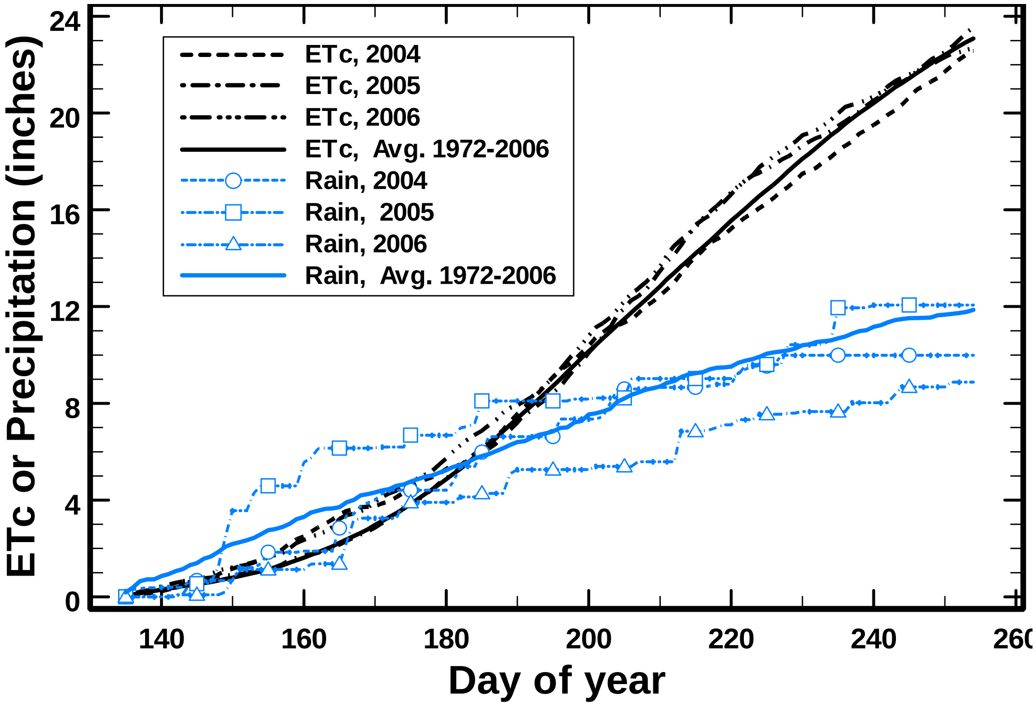

Figure 2. Corn evapotranspiration and summer seasonal rainfall for the 120 day period, May 15 through September 11, KSU Northwest Research-Extension Center, Colby Kansas.

Irrigation requirements were lowest in 2004 with the 1 inch/4 day treatment receiving 12 inches, the 1 inch/ 6 day treatment receiving 11 inches and the 1 inch/8 day treatment receiving 9 inches (Figure 3).

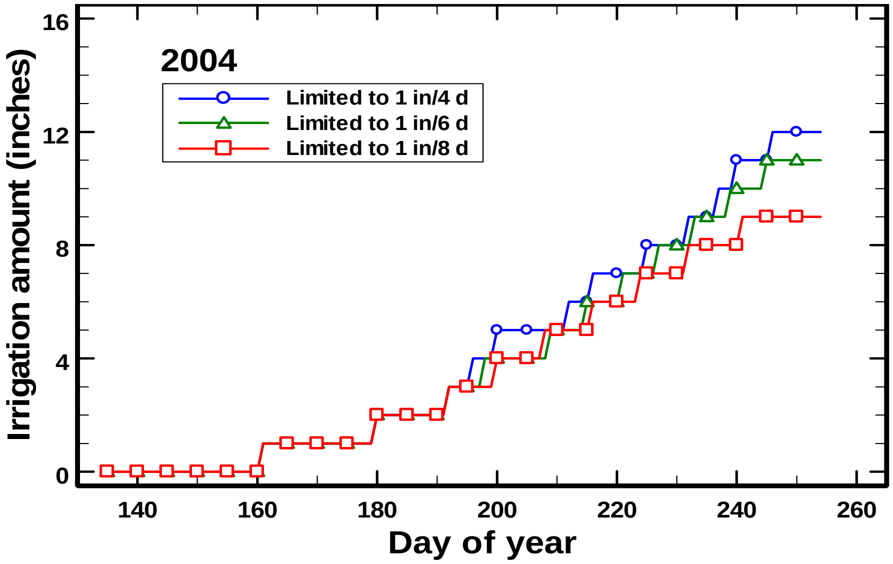

Figure 3. Seasonal irrigation for the 120 day period, May 15 through September 11, 2004 for the three irrigation treatments in an irrigation capacity and tillage study, KSU Northwest Research-Extension Center, Colby Kansas.

The irrigation amounts in 2005 were 15, 13, and 10 inches for the three respective treatments (Figure 4).

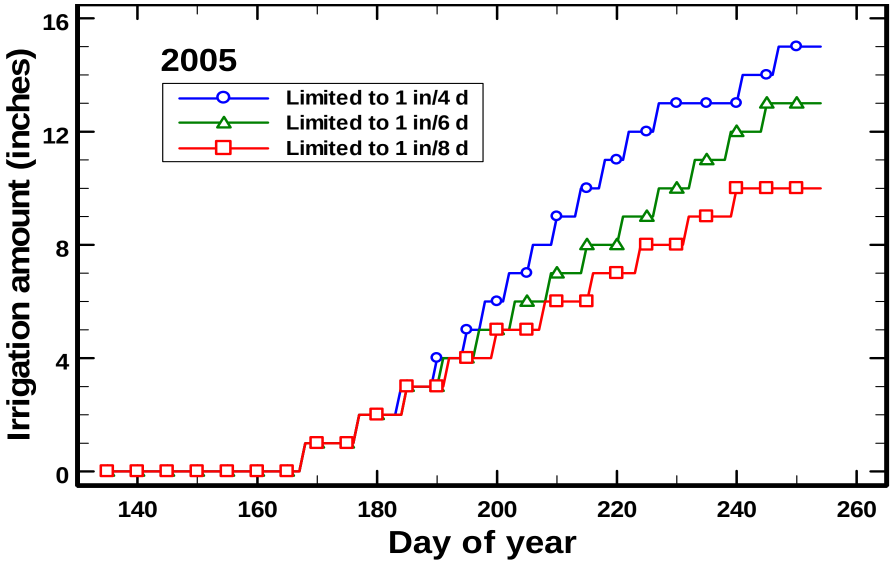

Figure 4. Seasonal irrigation for the 120 day period, May 15 through September 11, 2005 for the three irrigation treatments in an irrigation capacity and tillage study, KSU Northwest Research-Extension Center, Colby Kansas.

The irrigation amounts were highest in 2006 at 15.5, 13.5, and 11.50 inches for the three respective treatments (Figure 5).

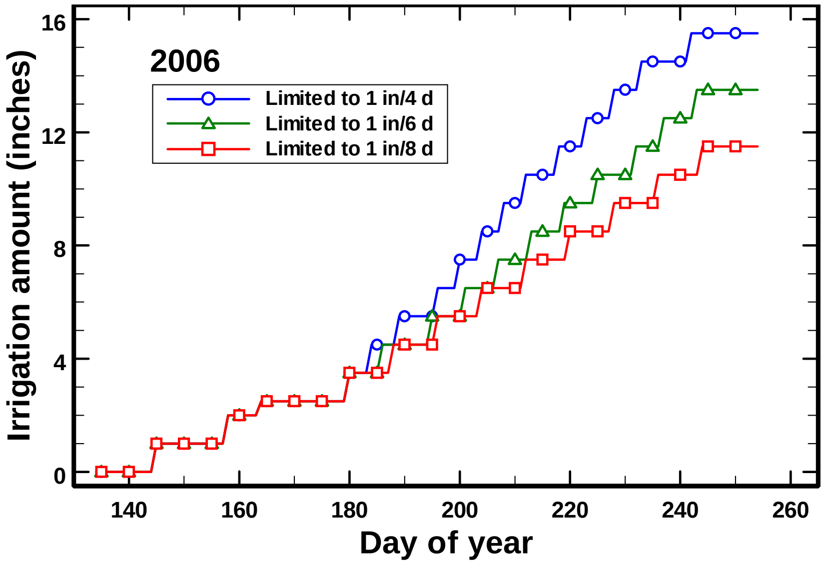

Figure 5. Seasonal irrigation for the 120 day period, May 15 through September 11, 2006 for the three irrigation treatments in an irrigation capacity and tillage study, KSU Northwest Research-Extension Center, Colby Kansas.

Crop Yield and Selected Yield Components

Corn yield was relatively high for all three years ranging from 161 to 262 bu/acre Table 2 through 4, and Figure 6). Higher irrigation capacity generally increased grain yield, particularly in 2005 and 2006. Strip tillage and no tillage had higher grain yields at the lowest irrigation capacity in 2004 and at all irrigation capacities in 2005 and 2006. Strip tillage tended to have the highest grain yields for all tillage systems and the effect of tillage treatment was greatest at the lowest irrigation capacity. These results suggest that strip tillage obtains the residue benefits of no tillage in reducing evaporation losses without the yield penalty sometimes associated with the higher residue levels in irrigated no tillage management.

Higher plant population had a significant effect in increasing corn grain yields (Tables 2 through 4, Figure 7) on the average about 10 to 20 bu/a for the lowest and highest irrigation capacities, respectively. Higher plant population gives greater profitability in good production years. Assuming a seed cost of $1.49/1,000 seeds and corn harvest price of $3.75/bushel, this 14 to 20 bu/acre yield advantage would increase net returns approximately $27 to $65/acre for the increase in plant population of approximately 6,100 seeds/acre. Increasing the plant population by 6100 plants/a on the average reduced kernels/ear by 48 and reduced kernel weight by 1.5 g/100 kernels (Tables 2 through 4). However, this was compensated by the increase in population increasing the overall number of kernels/acre by 12.8% (data not shown).

Table 2. Selected corn yield component and total seasonal water use data for 2004 from an irrigation capacity and tillage study, KSU Northwest Research-Extension Center, Colby, Kansas.

Irrigation Capacity	**Tillage System**	**Target Plant Population (1000 p/a)**	**Grain Yield bu/acre**	**Plant Population (p/a)**	**Kernels /Ear**	**Kernel Weight g/100**	**Water Use (inches)**
1 in/4 days	Conventional	26	229	27878	550	37.1	23.0
(12 inches)		30	235	29330	557	36.2	22.6
		34	234	32234	529	34.6	22.0
	Strip Tillage	26	245	27588	537	38.9	23.5
		30	232	30492	519	37.0	24.4
		34	237	33106	514	35.5	24.3
	No Tillage	26	218	25846	548	37.7	22.0
		30	226	29330	539	36.8	23.6
		34	251	33686	553	33.8	23.2
1 in/6 days	Conventional	26	226	25265	557	39.0	23.0
(11 inches)		30	222	29621	522	34.9	23.6
		34	243	32525	522	36.0	23.9
	Strip Tillage	26	235	27298	558	36.9	23.3
		30	224	28750	556	35.0	24.4
		34	237	33396	487	35.6	24.4
	No Tillage	26	225	26426	537	37.8	24.5
		30	222	29040	556	34.6	25.0
		34	229	32234	545	32.8	23.4
1 in/8 days	Conventional	26	198	24684	509	37.5	22.1
(9 inches)		30	211	29330	531	34.5	22.4
		34	216	31654	494	34.9	22.0
	Strip Tillage	26	227	25846	644	34.2	23.8
		30	229	29911	518	35.6	21.8
		34	234	32815	507	35.1	23.2
	No Tillage	26	220	27007	541	36.6	22.5
		30	225	29621	528	34.5	23.2
		34	220	32815	506	32.2	22.6

Table 3. Selected corn yield component and total seasonal water use data for 2005 from an irrigation capacity and tillage study, KSU Northwest Research-Extension Center, Colby, Kansas.

Irrigation Capacity	Tillage System	Target Plant Population (1000 p/a)	Grain Yield bu/acre	Plant Population (p/a)	Kernels /Ear	Kernel Weight g/100	Water Use (inches)
1 in/4 days	Conventional	26	218	23813	644	37.9	28.3
(15 inches)		30	238	27588	594	37.3	28.6
		34	260	30202	579	37.1	27.3
	Strip Tillage	26	238	24394	620	39.6	28.3
		30	251	27878	590	38.3	26.6
		34	253	31073	567	36.8	29.1
	No Tillage	26	228	24974	628	38.3	28.1
		30	254	26717	660	37.4	27.7
		34	262	31363	606	35.8	28.5
1 in/6 days	Conventional	26	203	24684	546	37.7	26.4
(13 inches)		30	221	27588	544	37.5	25.8
		34	208	31073	472	36.2	25.3
	Strip Tillage	26	226	24394	604	38.9	26.7
		30	207	28169	487	38.4	27.1
		34	248	31944	560	36.0	26.2
	No Tillage	26	205	24684	565	38.2	26.7
		30	224	29040	547	36.6	27.2
		34	234	31654	512	37.1	25.7
1 in/8 days	Conventional	26	187	24394	523	37.5	22.8
(10 inches)		30	218	27298	536	37.5	22.5
		34	208	31654	452	37.3	24.8
	Strip Tillage	26	212	23813	648	34.9	23.8
		30	216	27588	579	35.8	24.1
		34	240	31363	537	36.1	24.5
	No Tillage	26	208	24103	608	37.4	24.6
		30	211	27588	537	36.2	22.9
		34	216	31073	502	36.4	24.7

Table 4. Selected corn yield component and total seasonal water use data for 2006 from an irrigation capacity and tillage study, KSU Northwest Research-Extension Center, Colby, Kansas.

Irrigation Capacity	Tillage System	Target Plant Population (1000 p/a)	Grain Yield bu/acre	Plant Population (p/a)	Kernels /Ear	Kernel Weight g/100	Water Use (inches)
1 in/4 days	Conventional	26	239	29330	542	38.1	27.1
(15.5 inches)		30	213	31073	476	36.4	26.6
		34	212	35138	434	36.1	26.9
	Strip Tillage	26	232	29330	514	39.1	27.7
		30	236	31363	483	38.2	27.4
		34	260	33106	522	38.6	27.5
	No Tillage	26	211	28459	497	37.9	26.3
		30	263	31363	535	40.3	27.5
		34	248	34558	516	35.7	27.0
1 in/6 days	Conventional	26	161	29040	422	34.1	24.8
(13.5 inches)		30	208	31944	446	37.1	24.6
		34	169	33977	374	35.0	25.0
	Strip Tillage	26	207	29040	492	36.6	26.1
		30	215	31363	484	36.7	25.9
		34	216	34267	476	34.7	26.5
	No Tillage	26	230	29330	541	36.8	25.9
		30	218	30202	516	35.9	25.6
		34	223	32815	484	36.7	25.5
1 in/8 days	Conventional	26	172	28169	417	37.8	23.5
(11.5 inches)		30	191	31654	411	37.7	22.0
		34	191	33977	385	37.2	22.6
	Strip Tillage	26	214	29330	565	32.7	24.6
		30	220	31944	510	34.4	24.6
		34	230	34558	479	35.7	24.3
	No Tillage	26	204	28750	501	36.9	24.4
		30	220	31363	497	35.8	24.6
		34	216	33977	458	35.6	24.9

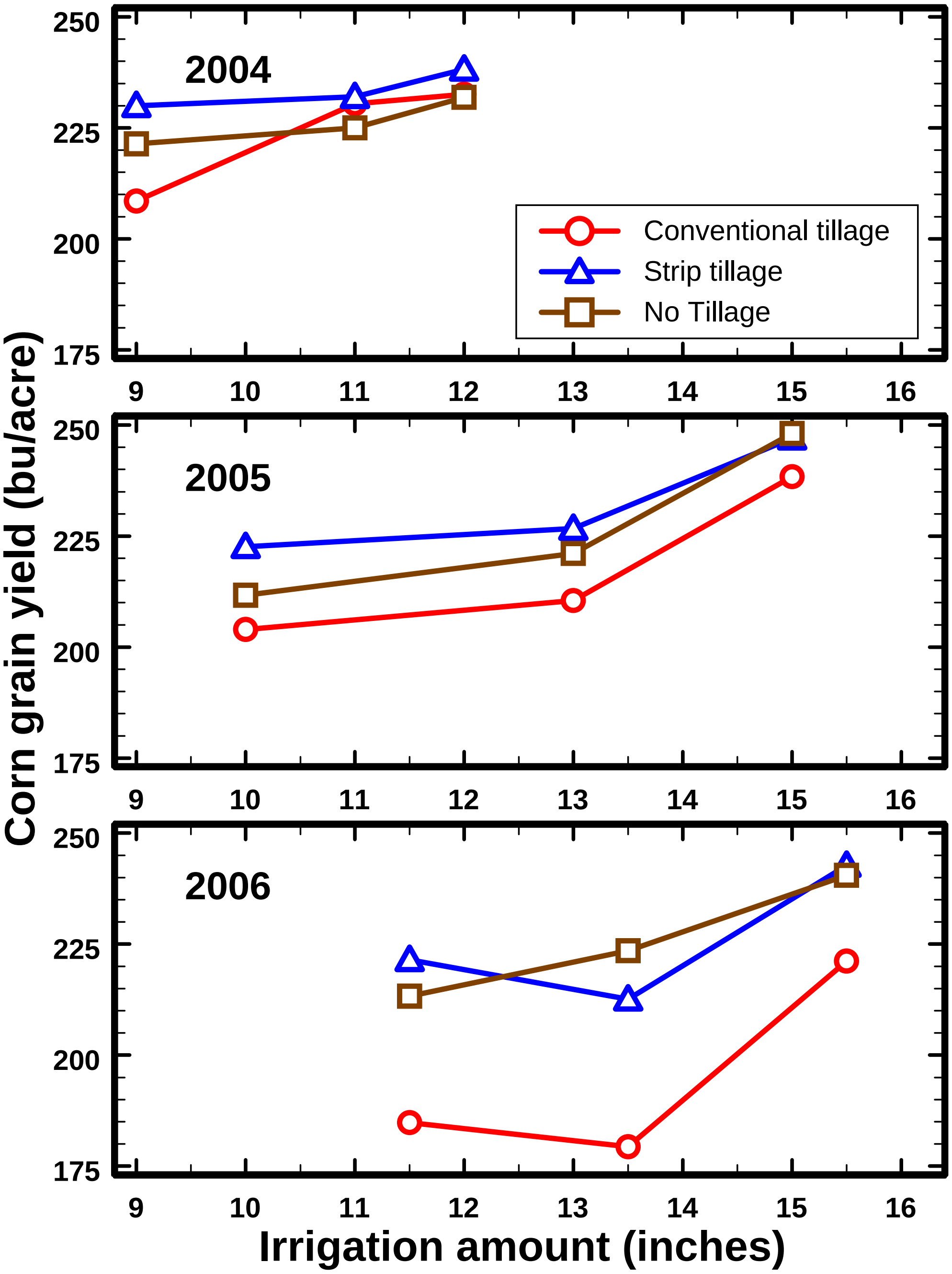

Figure 6. Corn grain yield as affected by irrigation capacity and tillage, 2004 to 2006, KSU Northwest Research-Extension Center, Colby Kansas.

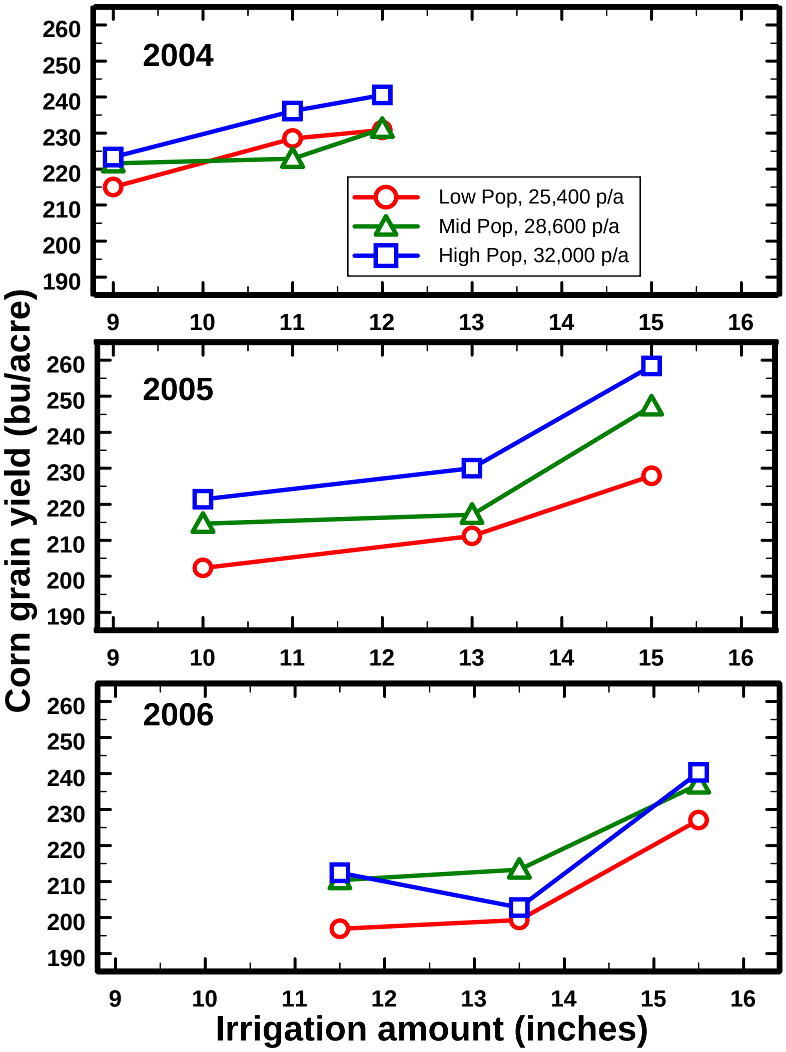

Figure 7. Corn grain yield as affected by irrigation capacity and plant population, 2004-2006, KSU Northwest Research-Extension Center, Colby Kansas.

The number of kernels/ear was lower in 2004 and 2006 compared to 2005 (Table 2 through 4, Figure 8). The potential number of kernels/ear is set at about the ninth leaf stage (approximately 2.5 to 3.5 ft tall) and the actual number of kernels/ear is finalized by approximately 2 weeks after pollination. Greater early season precipitation in 2005 (Figure 2) than 2004 and 2006 may have established a higher potential for kernels/acre and then later in the 2005 season greater irrigation capacity or better residue management may have allowed for more kernels to escape abortion. The time the actual kernels/acre was being set in 2005 was a period of high evapotranspiration (Figure 2) and also coincided with multiple irrigation events for the 1inch /4 days irrigation capacity.

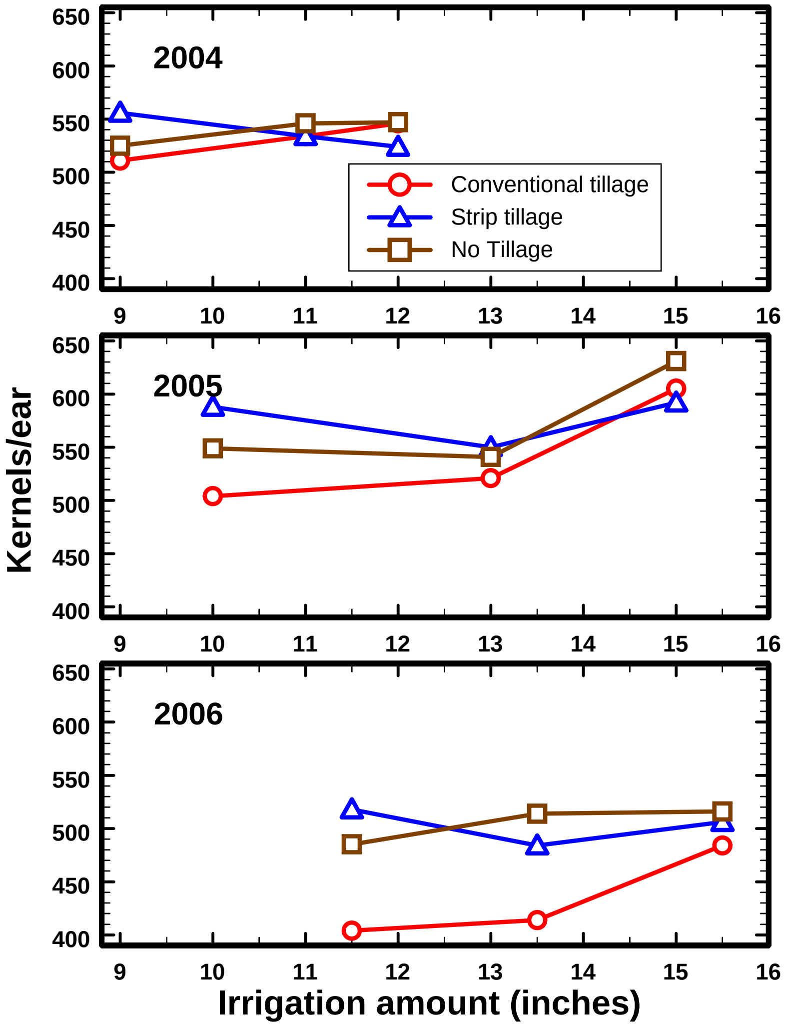

Figure 8. Kernels/ear as affected by irrigation capacity and plant population, 2004-2006, KSU Northwest Research-Extension Center, Colby Kansas.

Final kernel weight is affected by plant growing conditions during the grain filling stage (last 60 days prior to physiological maturity) and by plant population and kernels/ear. Deficit irrigation capacities often will begin to mine soil water reserves during the latter portion of the cropping season, so it is not surprising that kernel weight was increased with increased irrigation capacity (Tables 2 through 4, Figure 9). Tillage system also affected kernel weight, but it is thought by the authors that the effect was caused by different factors at the different irrigation capacities. At the lowest irrigation capacity, final kernel weight was highest for conventional tillage because of the lower number of kernels/ear. However, this higher kernel weight did not compensate for the decreased kernels/ear, and thus, grain yields were lower for conventional tillage. Strip tillage generally had higher kernel weights at higher irrigation capacity than the conventional and no tillage treatments for some unknown reason.

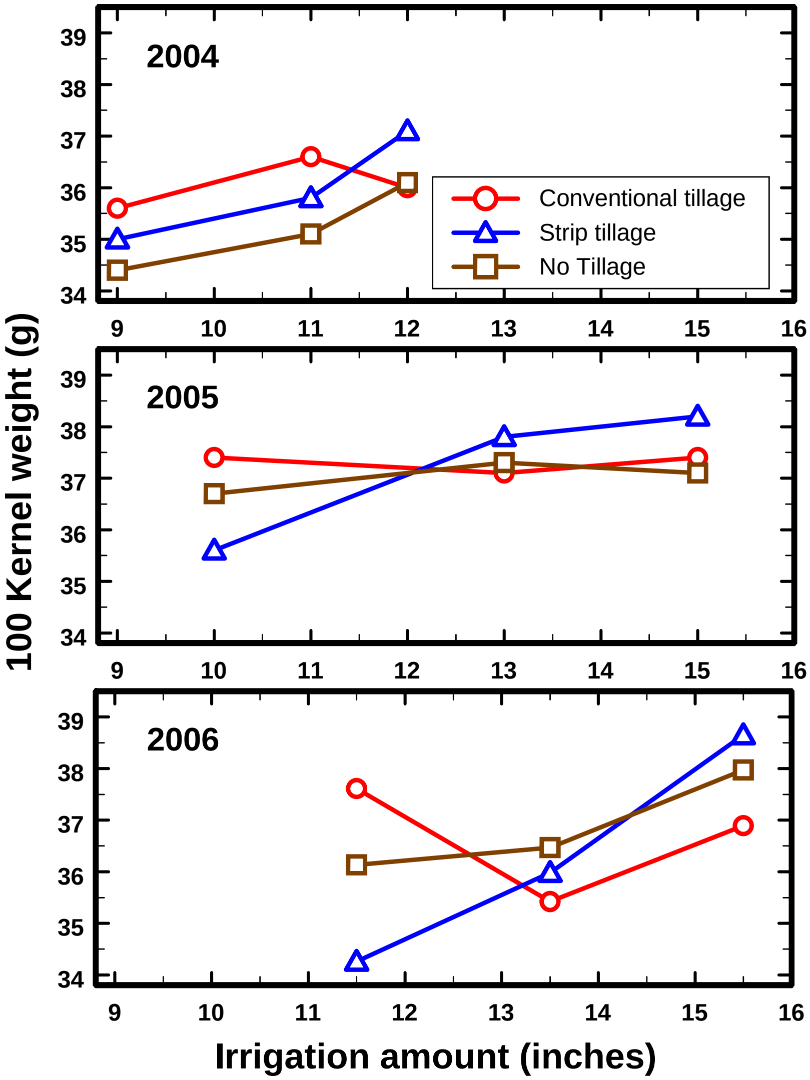

Figure 9. Kernel weight as affected by irrigation capacity and plant population, 2004-2006, KSU Northwest Research-Extension Center, Colby Kansas.

The changing patterns in grain yield, kernels/ear, and kernel weight that occurs between years and as affected by irrigation capacity and tillage system may be suggesting that additional factors besides differences in plant water status or evaporative losses is affecting the corn production. There might be differences in rooting, aerial or soil microclimate, nutrient status or uptake to name a few possible physical and biological reasons.

Total seasonal water use in this study was calculated as the sum of irrigation, precipitation and the change in available soil water over the course of the season. As a result, seasonal water use can include non-beneficial water losses such as soil evaporation, deep percolation, and runoff. Intuitively, one might anticipate that good residue management with strip tillage and no-tillage would result in lower water use than conventional tillage because of lower non-beneficial water losses. However, in this study, strip tillage and no-tillage generally had higher water use (Tables 2 through 4, Figure 10). The small increases in total seasonal water use (< 1.5 inch) for strip tillage and no-tillage compared to conventional tillage can probably be explained by the higher grain yields for these tillage systems (approximately 10 bu/a). Another possibility is that there were increased deep percolation losses in 2005 because of the higher early season precipitation.

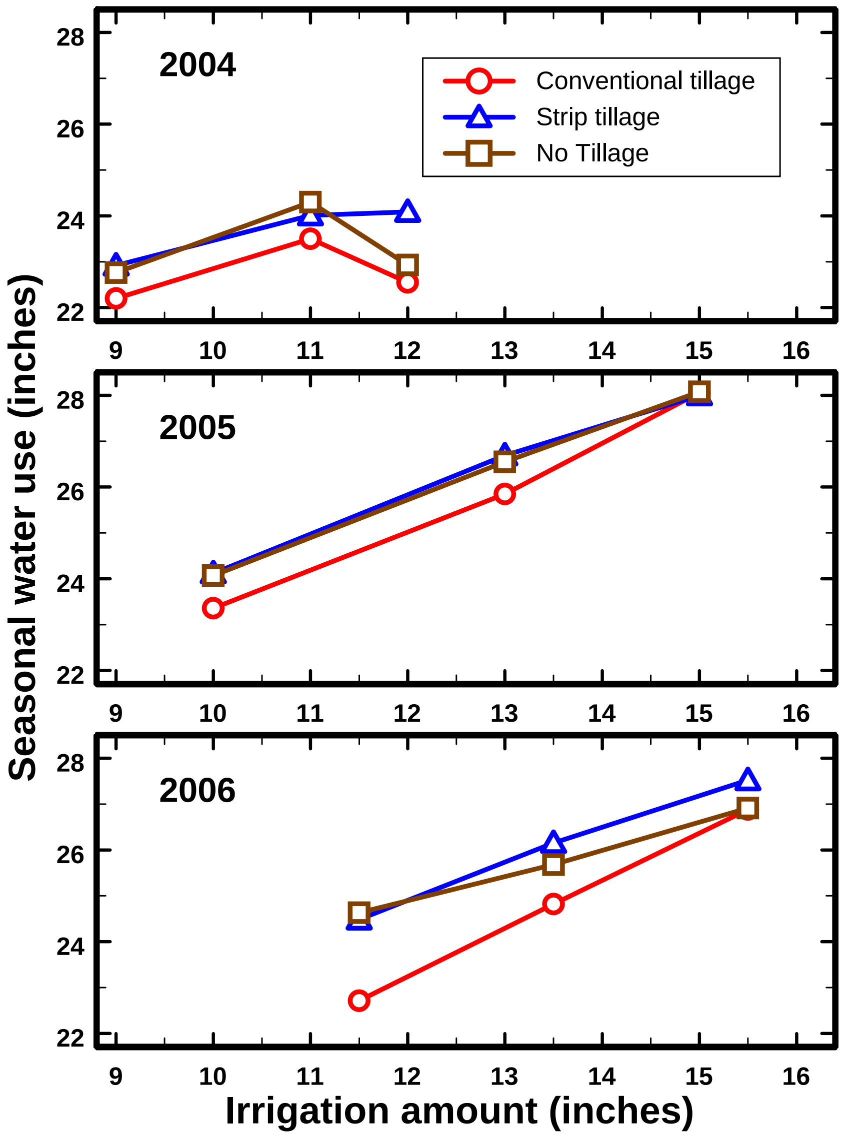

Figure 10. Total seasonal water use (sum of irrigation, precipitation, and seasonal changes in available soil water) as affected by irrigation capacity and plant population, 2004-2006, KSU Northwest Research-Extension Center, Colby Kansas.

CONCLUDING STATEMENTS

Corn grain yields were high all three years (2004 to 2006) with varying seasonal precipitation and near normal crop evapotranspiration. Strip tillage and no tillage generally performed better than conventional tillage. Increasing the plant population from 25,400 to 32,000 plants/acre was beneficial at all three irrigation capacities. The study will be continued in 2007 to determine if the production trends will remain as residue levels continue to increase.

ACKNOWLEGEMENTS

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Applying strip tillage treatments in the fall of 2005 in preparation for 2006 cropping season, KSU Northwest Research-Extension Center, Colby, Kansas.

Strategies to Maximize Income with Limited Water

Tom Trout
Research Leader, Agricultural Engineer
USDA-ARS Water Management Research Unit
Ft. Collins, CO
970-492-7419
Thomas.Trout@ars.usda.gov

The best economic strategy for water limited agricultural production will often be maximizing income per unit of water available. This requires information about the crop response (yield) to water applied, ways to maximize the effectiveness of rainfall and efficiency of irrigation, forecasts of future weather, the costs and value of production, and strategies to optimally allocate the limited water supply. Growers can make better decisions if they can predict at the beginning of the cropping season what crops and how many acres to plant. Then during the season, they need to know where and when to apply their limited water supply for the next week and the remainder of the season. They also could benefit from understanding the economic risks that result from inaccurate forecasts of irrigation water supply, weather, and crop and input prices. This is a very complex problem best solved with the help of Decision Support Systems that incorporate simulation models of crop growth; projections of weather; and inputs of available irrigation water, production costs, and crop prices.

Water Production Functions

The core information required to best use limited water is the yield response of crops to water. The Water Production Function, WPF (sometimes called water use efficiency, WUE), for a crop in terms of yield produced per unit of water applied, provides basic information needed to best allocate limited water supplies. Yield response to water for numerous crops has been studied by many researchers for many years. However, developing WPFs that are applicable to conditions different from the experimental conditions is difficult. Response of a crop to applied irrigation water depends on rainfall amount, soil water storage and soil type, timing of irrigations, evaporative demand, irrigation method and efficiency, and crop cultivar. Since it is impossible to include all of these variables in experimental trials, trials are often designed to mimic local conditions.

I believe a preferred approach is to base WPF trials on basic water balances so the information is most transferable to other conditions. By basing the function on water consumed by the crop (transpiration, Tc) rather than applied water, most of the effects of irrigation method and rainfall are eliminated. The effects of irrigation method and efficiency, effective rainfall, and soil water storage can then be factored back in based on local conditions. This method requires measurement of crop transpiration. Crop water transpiration can be calculated by accurate measurement of water applied and stored in the root zone, measured changes in soil water storage, and estimates of soil evaporation. This is most easily done with metered drip irrigation where small irrigations can be accurately and uniformly applied and surface evaporation is small. Lysimeters can accurately measure transpiration, but are too expensive for most applications. Transpiration can also be estimated with micrometeorological measurements such as Bowen Ratio or Eddy Correlation.

Transpiration of a well-watered "baseline" crop (Tc) can be estimated using reference evapotranspiration equations (ETo) and a basal crop coefficient (Kcb) based on growth stage and planting configuration. By calculating water transpiration of a deficit irrigated crop relative to that of the well-watered crop, much of the influence of weather during the experiment (temperature, humidity, wind, and solar radiation) can be accounted for. Reference ET for an area and time period is then used to modify the transpiration level in the relative WPF for local weather conditions, and the crop coefficient, Kcb, is used to adjust for crop conditions. The well-watered crop should produce maximum yields for a given set of conditions (soils, fertility, cultivar, and climate). It is convenient to also calculate WPF yields relative to the maximum yield of the well-watered crop. Thus, the yields of cultivars that respond similarly to water stress but have different yield potential can be estimated based on their potential yield. Figure 1 shows an example of a generic "normalized" WPF that can be converted to a WPF for local conditions using actual or predicted irrigation efficiencies, effective rainfall, climatic conditions, and yield potential.

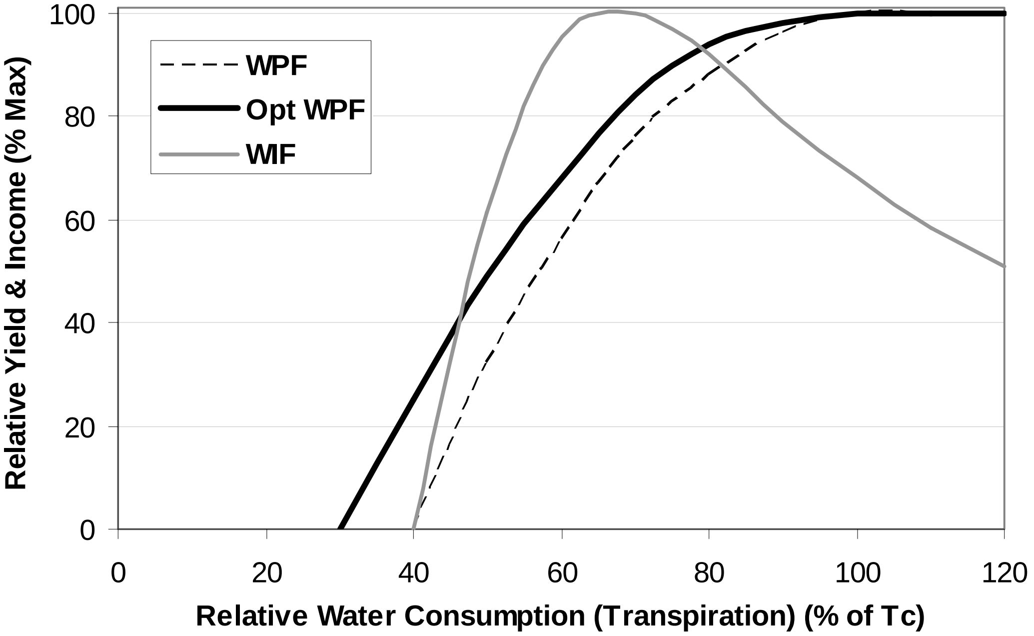


Figure 1. Depiction of a normalized Water production Function (WPF) with uniform water application, an "optimum" WPF with water strategically allocated among growth stages, and a Water Income Function (WIF)

Water Production Functions are based on water applied or consumed over an entire season. However, timing of water applications and the resulting water deficits experienced by the crop through the growing season can greatly affect the yield response. Irrigation applications in WPF experiments should be sufficiently frequent that impacts of fluctuating soil water content and crop stress are small. Drip irrigation allows frequent, efficient irrigation. The preferred scheduling approach would be to trigger frequent water applications based on plant stress indicators such as canopy temperature, leaf water potential, stomatal conductance, or soil water potential. However, these stress indicators are difficult to measure accurately and yield response to stress is not well quantified for most crops. An alternative scheduling approach is to base water applications (irrigation + effective rainfall) on a fraction of predicted water use of the well-watered crop (ie. replace percentages of Tc after each x mm of water use or x days). The plant phenological (growth rate, yield) and physiological (canopy temperature, leaf water potential, stomatal conductance, soil water potential) responses can be measured for the target deficits (ie. 50% of full water). Stress indicators can then be compared to measured deficits and yield. These scheduling methods assume water applications can be controlled and scheduled. Rainfall will sometimes exceed intended application levels and temporarily increase soil water content above targeted levels. Irrigation must be delayed after rainfall until the desired water deficit levels are reached again.

The response of crop yield and quality to water stress varies with the stage of growth. For example, many grain crops are less sensitive to stress during vegetative growth than during reproductive development. Some minimum soil water content is required to germinate and establish a stand. Deficits during maturation may positively or negatively effect crop quality and value. Thus, uniformly applied deficits often do not produce the maximum yield or value for a given water consumption. To maximize the WPF for many crops, the target deficit or stress level must be varied with stage of growth. For example, if the target seasonal water consumption is 70% of Tc, the best strategy might be to apply at 50% of Tc during vegetative and 90% of Tc during the reproductive stage. Because these relative growth stage responses to stress are not well known, it is possible that a given seasonal WPF could be improved with better allocation of water among growth stages. A goal of research is to quantify the relative response to stress at each growth stage so that a given seasonal allocation of water can be optimally applied.

Crop simulation models provide the opportunity to incorporate complex plant physiological processes that determine response to stress over time. They can also incorporate the effect of water supply limitations during certain portions of the season. Currently, most simulation models do not adequately model stress effects, but improvements based on improved understanding of plant physiology and data from well designed WPF experiments are being made. All WPF studies should include adequate plant measurements to allow calibration and improvement of simulation models.

Water *Income* Functions

A Water Income Function, WIF, can be calculated from the WPF using input costs and crop prices. Because water costs (and possibly fertilizer and pest control costs) may increase with increasing water applications, the maximum income may occur at less than maximum yield, as depicted in Figure 1. With this WIF, the marginal return to water can be calculated and the amount of land that should be planted for a given water supply to maximize income can be predicted. If a grower has potential to grow several crops, the WIF for each crop can be combined in a system that optimizes the amount of each crop that should be grown. This Decision Support System, DSS, will predict the crop mix and intensity for a predicted water supply and other conditions. Constraints on the cropping mix such as availability of equipment and labor or market limits can be imposed to meet specific situations of growers.

As the season progresses, water supply, rainfall, weather, input costs and crop prices, and crop growth may deviate from the initial projections. Crop simulation models within the DSS can then update the WPFs for current conditions and project how to best allocate the remaining water. Such systems can consider more complex factors than is otherwise possible. Models and DSS must adequately incorporate the biology, physics, and economics of the farming operation and environment to make good predictions of yields and income.

Research Plans

The ARS Water Management Research Unit is carrying out field experiments to develop WPFs for 4 crops in rotation (corn, dry beans, wheat, sunflower) under two tillage systems (conventional and minimum tillage). Irrigation water will be applied through a metered drip irrigation system to maximize uniformity and minimize evaporative losses. Measurements will include:

- Irrigation water applications
- Rainfall
- ETo calculated with an on-site weather station
- ETc with Bowen Ratio Equipment
- Crop growth, canopy cover and Leaf Area Index (LAI) measured weekly
- Soil water content measured weekly (neutron probe and TDR)
- Crop stress (canopy temperature, leaf water potential, stomatal conductance) measured weekly.
- Yield and quality

The research will be closely coordinated with the ARS Agricultural Systems Research (ASR) unit who will use the results to improve and validate existing crop simulation models (RZWQM and DSSAT). They will also predict optimal allocations of irrigations among growth stages and how to allocate remaining water. The research will also be coordinated with a CSU agricultural economist who will carry out the economic analysis. The final objective is to develop a DSS that incorporates WPFs, crop simulation models, and economics into one system.

IRRIGATION WATER CONSERVING STRATEGIES FOR CORN

Steve Melvin
Extension Educator
University of Nebraska
Cooperative Extension
RR3, Box 23C
Curtis, NE 69025
Phone 308-367-4424
E-mail smelvin1@unl.edu

Jose Payero
Queensland Department of Primary
Industries and Fisheries
203 Tor Street, Toowoomba,
Queensland 4350, Australia
Phone +61-7-4688-1513
E-mail:
Jose.payero@dpi.qld.gov.au

INTRODUCTION

Irrigation water management has always been important to the people in southwest Nebraska. It was evident to the farmer in the area from the earliest days that the land was very productive with adequate water. Thus, over the years a large portion of the area has had irrigation systems developed. Today, due to numerous factors, water shortages and allocations have become a reality for the farmers.

Finding a way to conserve irrigation water has been an ongoing research topic since the 1920's at the University of Nebraska West Central Research and Extension Center at North Platte. The studies have found that corn yield are closely related to crop evapotranspiration (ET) and that usually yields would be lowered if ET is lowered (Payero et al., 2006a; Payero et al., 2006b; Payero et al., 2006c; Payero et al., 2006d). Additional studies have found that no significant yield reduction occurred when irrigation was delayed and corn was moderately stressed during the vegetative stage. However, significant yield reductions were found when stress occurred during the pollination and grain filling stages (Gilley et all., 1980).

The University of Nebraska-Lincoln Extension started the Republican River Basin Irrigation Management Project in 1996, funded by the US Bureau of Reclamation to help area farmers understand and adopt these water saving methods (Schneekloth and Norton, 2000) (Klocke et al., 2004). Starting in 2002, line-source irrigation based plots have been used to demonstrate three irrigation strategies on farmers= fields. The layout makes a good field day site because the three irrigation strategies are all within a few hundred feet. The line source irrigation system shows full application depth to dryland in a range of just 50 ft.

Fields days were held at each of the sites each year (except the Curtis site in 2003 because it was badly hailed). Counting these sites, and the other sites demonstrating irrigation scheduling tools, twenty-five field days have been conducted with about 760 people attending over the past five years. The scope of this paper is limited to showing the yield and water use data generated by the project and some of the keys to making these strategies work on the farm.

METHODOLOGY

The Republican River Basin Irrigation Management Project has been conducted in producer fields growing irrigated corn. The farmers have planted and cared for the crop, with the timing and quantity of water application being the main variable. The other changes that were made to the farmer=s crops were created in smaller subplots by thinning the corn stand and creating skip row areas. The population data will not be discussed in this paper.

Irrigation Management Strategies

The purpose of the plots were to demonstrate and compare three irrigation strategies for west central Nebraska. They included the traditional fully watered strategy and two that conserve water (Melvin et al., 2005). The names and descriptions of the strategies are as follows:

a. **Fully Watered**-the traditional Best Management Practice (BMP) irrigation management strategy focused on keeping soil-water at a high enough level to prevent moisture stress from being a limiting factor for yield. The goal of the strategy was to maintain the plant available soil-water (in the active root zone) between field capacity and 50% depletion from planting through maturity. Usually the soil was kept one-half to one inch below field capacity to allow for rain storage. After the hard dough stage, the soil was allowed to dry down to 60% depletion.

b. **Water Miser BMP** - the Water Miser BMP irrigation management strategy focused on saving water during the less sensitive vegetative growth stages and fully watering during the critical reproductive growth stages. Irrigation was delayed until about two weeks before tassel emergence of the corn, unless soil-water became 70% depleted (in the active root zone). Once the crop reached the reproductive growth stage, the plant available soil-water was maintained in a range between field capacity and 40% depletion. Usually the soil was kept one-half to one inch below field capacity to allow for rain storage. After the hard dough stage, the soil was allowed to dry down to 60% depletion.

c. **Deficit Irrigation**-The deficit irrigation management strategy focuses on correctly timing the application of a restricted quantity of water, both within the growing season as well as over a several year period. The intent is to stabilize yields between years by applying irrigation based on soil-water depletion. Less water will be applied during wetter years, while more will be applied through the drier years, with an average over the years equaling the available quantity of water. The management strategy is to delay the application of water until about two weeks before tassel emergence for corn, unless soil-water becomes 70% depleted. Once the crop reaches the reproductive growth stage the plant available soil-water (in the active root zone) is maintained in a range between 30 to 60% depletion. It is allowed to dry down to 70% depleted after the hard dough stage. The idea is that these depletion numbers should be changed based on the amount of water the producer has to work with. More research is needed to determine guidelines for differing water use levels.

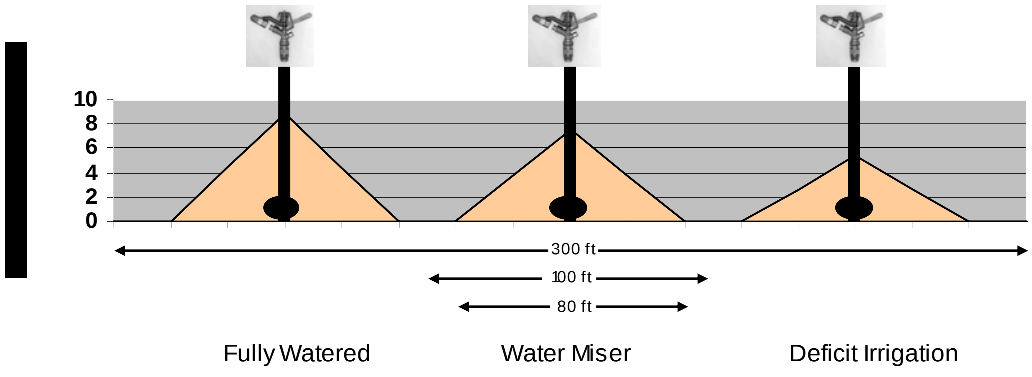
Cooperators and Site Selection

The cooperators were picked with the help of the local Extension Educators and irrigation district managers in southwest Nebraska. They were picked because of their willingness to work with the project, interest in water issues, excellent crop production skills, and location of their fields. The plots were placed on the edge of the field along a public road to facilitate viewing all season by people traveling past the field. Big signs explaining the demonstrations were placed at each site. The demonstrations were conducted at three sites each year with the exception of 2003 when only two sites were harvested because one dropped out at the last minute. The sites have included farms near the Nebraska towns of Arapahoe, Culbertson, Curtis, Holbrook, and Holdrege.

Plot Layout and Management

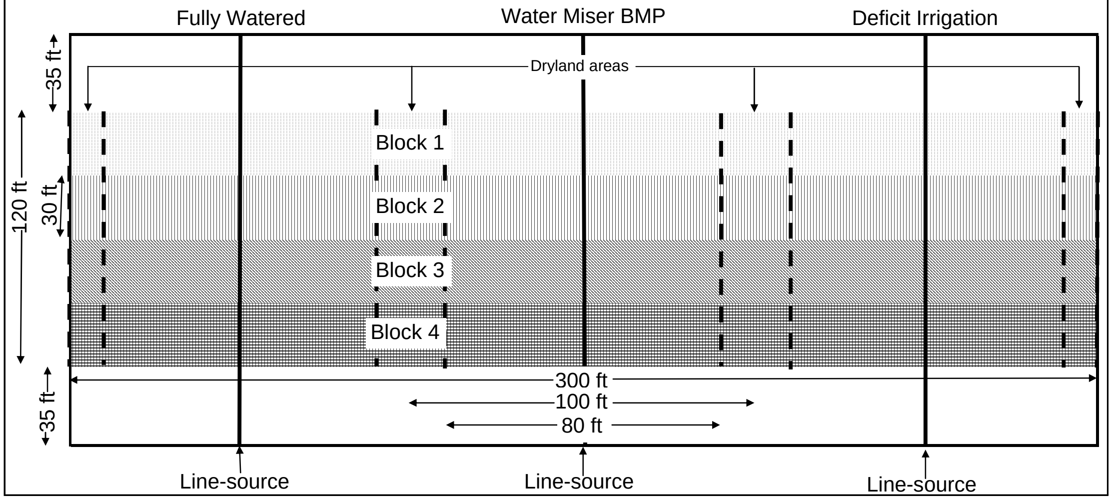
The irrigation demonstration sites used three line-source sprinkler laterals to show the Fully Watered, Water Miser BMP or Deficit Irrigation strategies. A line-source irrigation system refers to a set of sprinklers that are placed in the field and left in the same location for the season (Figure 1). The sprinkler spacing within the line was 10 ft and the spacing between the lines was 100 ft (Figure 2). The sprinkler used had a wetted diameter of 80 ft, creating a 20 ft strip between the lines that does not receive any irrigation to represent dryland conditions. This configuration creates a watering pattern of the planed application depth next to the sprinkler line and a gradual decrease in the depth of application until about 40 ft from the line where no water is

Figure 1. Front view of the demonstration plot showing the three line-source sprinkler system.



applied. The advantage of the setup is that it gives the planed depth of irrigation plus a gradient from the planed depth to dryland. The sprinkler lines extended 35 ft past each end of the treatment area to create the correct overlap of the sprinkler pattern. The plot size including the overall sprinkler line length was 300 ft by 190 ft.

Figure 2. Top view of the demonstration plot showing the three line-source sprinkler system and 4 block for treatments along the lines



The tillage and cropping methods were the normal practices for that farmer and were primarily conventionally tilled furrow irrigated fields. The timing and the amount of water applied were the only management variables. The irrigation scheduling and water application was done by the project manager. Soil moisture data was gathered every two weeks by the neutron attenuation method. ET data from the High Plains Regional Climate Center was used to predict irrigation needs in-between. An irrigation scheduling spreadsheet was used to manage the data and calculate the application depth for each week. The soil types were all silt loam and ranged in water holding capacity from about 1.9-2.5 in/ft. The water application rate was limited to a net application of 2 inches per week (about the same as a 750 GPM center pivot on 125 acres) to simulate a typical system for the area.

RESULTS AND DISCUSSION

The plot yields have been measured each year by either hand harvesting or with a plot combine. The data has been collected and summarized across the 100 ft width of each of the line-source sprinkler systems. This represents ten yields points that range from the planed irrigation depth to dryland, eight that received irrigation and two that were dryland. Table 1 shows the yields and the amount of water that was applied to the three strategies at the farmer=s irrigated populations (26-31,000 plants per acre at harvest). The data is for the center two plots, one on each side of the sprinkler lines. The applied water numbers are a net irrigation amount and would need to be increased by five to ten percent to represent a center pivot.

Table 1. 2003-2006 Average of Corn Yields and Water Use by Management Strategy and Site

	Management Strategy		
	Fully Wate	Water Mis	Def.
Site	Average Yields (bu/acre)		
Holbrook	193	197	
Culbertson	150	165	117
Holdrege	239	244	233
Curtis	219	223	177
Arapahoe	192	185	171
All Sites[1]	198	203	174
Percent of **Fully Watered** Yield	100	102	88
Site	Applied Water (acre-inches/acre)		
Holbrook	10.0	6.6	
Culbertson	10.1	9.0	5.6
Holdrege	6.0	4.7	3.4
Curtis	9.5	9.5	7.0
Arapahoe	8.9	8.1	6.9
All Sites[1]	8.9	7.6	5.5
Percent of **Fully Watered** Applied Water	100	85	62

[1] Yield and applied water are weighted by the number of years of data at each site.

Table 1 contains 10 site years of data, two from Holbrook (2003-04), two from Culbertson (2003-04), two from Holdrege (2004-05), two from Curtis (2005-

06), and two from Arapahoe (2005-06). The data for 2002 is not included in this table because of startup problems.

Yields and Water Usage

The yields and water usage from 2003-2006 averaged over the five sites are shown in Table 1. It shows that the Water Miser BMP strategy obtained 102% of the yield, as compared with the Fully Watered strategy, requiring only 85% as much irrigation or 1.3 inches less. Using the Deficit Irrigation strategies, 88% of the Fully Watered yield was obtained, using only 62% of the irrigation water.

The Water Miser and Fully Watered yields were only four bushels apart and were very close to the farmer=s yield in the rest of the field. Considering these facts, the Water Miser and the Fully Irrigated strategies produced essentially the same yield and the yields were not limited by a lack of water. However, the Water Miser strategy reduced the pumping requirement by 1.3 inches. So the advantage is in saving on pumping costs which range in southwest Nebraska from $2.50 to $15.00 per acre. Thus, the Water Miser would create a savings of $3.25 to $19.50 per acre in pumping cost.

An economic comparison of the Deficit Irrigation is shown in Table 2 over a range of corn prices and irrigation water pumping costs. This table is important to study and find where each irrigation system would fall because in southwest Nebraska pumping cost are extremely variable. Also, with the price change in corn over the past year, the economic returns have changed as well. An important point to understanding how to interpret this chart is that the corn price is to be the cash price less the harvest, storage, and marketing costs. This number can easily be $0.40 to $0.50 per bushel less than the cash price.

Working through an example of using the chart will make this point clearer. Assuming the cash sales price for corn is $3.50 per bushel and the combining, grain cart, trucking to the bin, drying costs, storage costs, trucking to market, and marketing costs would equal $0.50 per bushel, than the corn price to use in this chart would be $3.00 per bushel. The idea is getting to the value of the corn standing in the field, because if we do not produce it, we do not need to spend the money to harvest and market it. The chart ignores any reduced input costs for nitrogen, seed, etc. associated with planning for a lower yield goal. Using the $3.00 price for corn and with the average pumping cost of $7.50 per acre-in, the Deficit Irrigation would return $48.02 per acre less than the Fully watered. The difference would be made up of $73.18/acre less corn to sell and a savings of $25.16/acre on pumping costs.

A second example with higher pumping costs and lower corn prices is worth looking at. Consider if the price of corn is $2.00 per bushel and the harvest cost would still be $0.50 per bushel or a net price of $1.50 per bushel and the pumping costs were $12.50 per acre-inch. Looking these numbers up on the chart reveals that even though the yield would be 24 bushels less with the Deficit Irrigation than the Fully Watered, the bottom line would be $7.94 per acre better. The difference would be made up of $36.59/acre less corn to sell and a savings of $41.93/acre on pumping costs.

Table 2. Sensitivity analysis over a range of water costs and corn prices comparing the Fully Watered to the Deficit Irrigation strategy (using the 24.4 bushels per acre less corn produced and the 3.4 inches less water used for the Deficit Irrigation strategy from Table 1).

Comparison of Deficit to Fully Watered Strategies

	Cost to apply 1 inch of water/acre, $/a					
Corn price, $/bu less harvest cost	$2.50	$5.00	$7.50	$10.00	$12.50	$15.00
$1.50	-$28.20	-$19.82	-$11.43	-$3.04	$5.34	$13.73
$2.00	-$40.40	-$32.01	-$23.63	-$15.24	-$6.85	$1.53
$2.50	-$52.59	-$44.21	-$35.82	-$27.44	-$19.05	-$10.67
$3.00	-$64.79	-$56.40	-$48.02	-$39.63	-$31.25	-$22.86
$3.50	-$76.99	-$68.60	-$60.21	-$51.83	-$43.44	-$35.06
$4.00	-$89.18	-$80.80	-$72.41	-$64.02	-$55.64	-$47.25

Table 2 shows that in most situations the Deficit Irrigation strategy is not the highest profit method if adequate water is available. However, when water supply is not adequate to fully water, the more important question is, should one consider reducing acres to more fully water the crop or deficit irrigate more acres. To fully analyze this problem is beyond the scope of this paper, but in general it is usually more profitable to deficit water more acres. For more help analyzing these decisions, use the Water Optimizer program. It is a University of Nebraska-Lincoln Extension product designed to be a decision support tool to help make these types of decisions when irrigation water is in short supply. The Water Optimizer program and an instruction manual can be down loaded at http://extension.unl.edu/wq/index.htm.

Keys to Making the Water Miser BMP Strategy Work on the Farm

The Republican River Basin Irrigation Management Project=s original goal was to help farmers use less water in irrigated crop production, not just show that it could be done. So, lets talk about some of the important things that need to be done by producers to make these strategies work on their farms. Taking the time to get good information and putting it into an irrigation scheduling system is the key. Knowing when to start irrigating for the season, what to do after a rain, and when to stop for the season are the main questions to be answered. The differences between each systems capacity or it=s ability to deliver water to the field varies greatly and is another important point to focus on. Some systems need to run every hour of every day all summer to irrigate the field adequately and others need only run three or four days per week. Add this to the variability of the rain that each field receives and it emphasizes the importance of recording how much water the field has received.

In almost all cases, the producer's fields received more irrigation water than the Fully Irrigated treatments and yet resulted in essentially the same yields. The differences were usually that the fields were irrigated earlier in the season and quicker after a rain. Moreover, the field was wetter when the corn matured. The advantage that the plot manager had was better soil moisture readings, good rainfall records for each individual field, and accurate irrigation application amounts. This information was put into an irrigation scheduling program that was used to manage the data and help determine when the next irrigation would be needed and how much to apply. The biggest advantage of the scheduling program was organizing the data and helping determine the last irrigation.

The four keys to making the Water Miser BMP work are:

1. Invest in soil moisture monitoring equipment and use it. Spending the money to purchase devices that log the readings as they are taken is worth the extra cost.
2. Critically evaluate when to start irrigating. Most producers start irrigating before it is needed, particularly with center pivots that can water the entire field in 2-4 days. The crop should be lowering the soil moisture levels in the second foot of soil (depth of 12 to 24 inches) before irrigation is started. Caution: On low capacity systems, start irrigating as soon as the field can store the irrigation water.
3. Keep good rain and irrigation application records and compare them to what the ET has been for the field. The problem is that every irrigation system has a different capacity and every field receives a different amount of rain, so running all system about the same numbers of hours will over water some fields and under water others.
4. Starting at the dough stage, calculate the amount of rain and irrigation that is needed to get the crop to maturity. The water levels in the soil depths from 12 to 36 inches should be getting dryer by the start of the dough stage. The goal is to have the soil moisture level lowered to 40 percent of plant available water by maturity. Delay the last irrigation with center pivots as long as possible to see if a late rain will provide the needed water.

CONCLUSIONS

The Republican River Basin Irrigation Management Project has provided numerous educational opportunities that have helped farmers produce top yields while using less water. It has also generated valuable on-farm real world numbers for the management strategies that conserve irrigation water.

The Water Miser BMP and Deficit Irrigation strategies proved to be valuable water conserving practices at the research level and have now shown to be effective in plots in farmers= fields across south west Nebraska.

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CRITERIA FOR SUCCESSFUL ADOPTION OF SDI SYSTEMS

Danny H. Rogers
Extension Engineer, Irrigation
K-State Research and Extension
Biological & Ag Engineering
Manhattan, KS
drogers@ksu.edu

Freddie R. Lamm
Research Irrigation Engineer
K-State Research and Extension
Northwest Research-Extension Center
Colby, Kansas
flamm@oznet.ksu.edu

Kansas State University

INTRODUCTION

Subsurface drip irrigation (SDI) systems are currently being used on about 15,000 acres in Kansas. Research studies at the NW Kansas Research and Extension Center of Kansas State University begin in 1989 and have indicated that SDI can be adapted for efficient, long-term irrigated corn production in western Kansas. This adaptability has been demonstrated on other deep-rooted irrigated crops grown in the region by demonstration plots and producer experience. Many producers have had successful experiences with SDI systems; however most experienced at least some minor technical difficulties during the adoption process. However, a few systems have been abandoned or failed after a short use period due to problems associated with inadequate design, inadequate management, or a combination of both.

Both research studies and on-farm producers experience indicate SDI systems can result in high yielding crop and water-conserving production practices, but only if the systems are properly designed, installed, operated and maintained. SDI systems in the High Plains must also have long life to be economically viable when used to produce the relatively low value field crops common to the region. Design and management are closely linked in a successful SDI system. A system that is not properly designed and installed will be difficult to operate and maintain and most likely will not achieve high irrigation water application uniformity and efficiency goals. However, proper design and installation does not ensure high SDI efficiency and long system life. An SDI system must be operated at design specifications and utilize good irrigation water management procedures to achieve high uniformity and efficiency. An SDI is also destined for early failure without proper maintenance. This paper will review important criteria for successful adoption of SDI for Kansas irrigated agriculture.

MINIMUM SDI SYSTEM COMPONENTS FOR WATER DISTRIBUTION AND EFFICIENT SYSTEM OPERATION

Design considerations must account for field and soil characteristics, water quality, well capabilities, desired crops, production systems, and producer goals. It is difficult to separate design and management considerations into distinct issues as the system design should consider management restraints and goals. However, there are certain basic features that should be a part of all SDI systems, as shown in Figure 1. Omission of any of these minimum components by a designer should raise a red flag to the producer and will likely seriously undermine the ability of the producer to operate and maintain the system in an efficient manner for a long period of time. Minimum SDI system components should not be sacrificed as a design and installation cost cutting measure. If minimum SDI components cannot be included as part of the system, serious consideration should be given to an alternative type of irrigation system or remaining as a dryland production system.

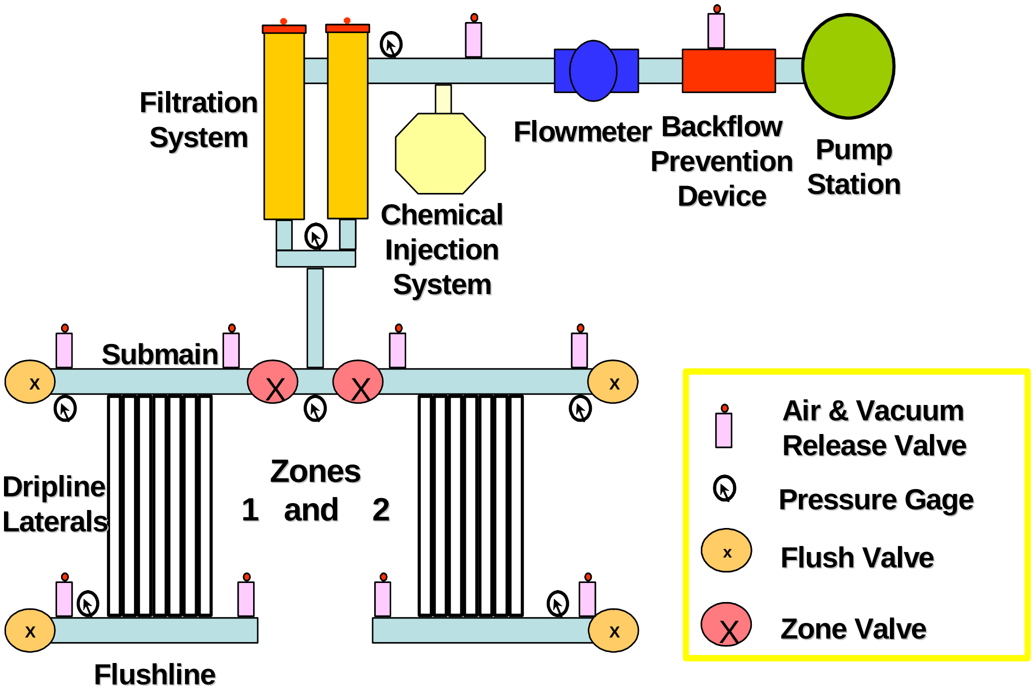


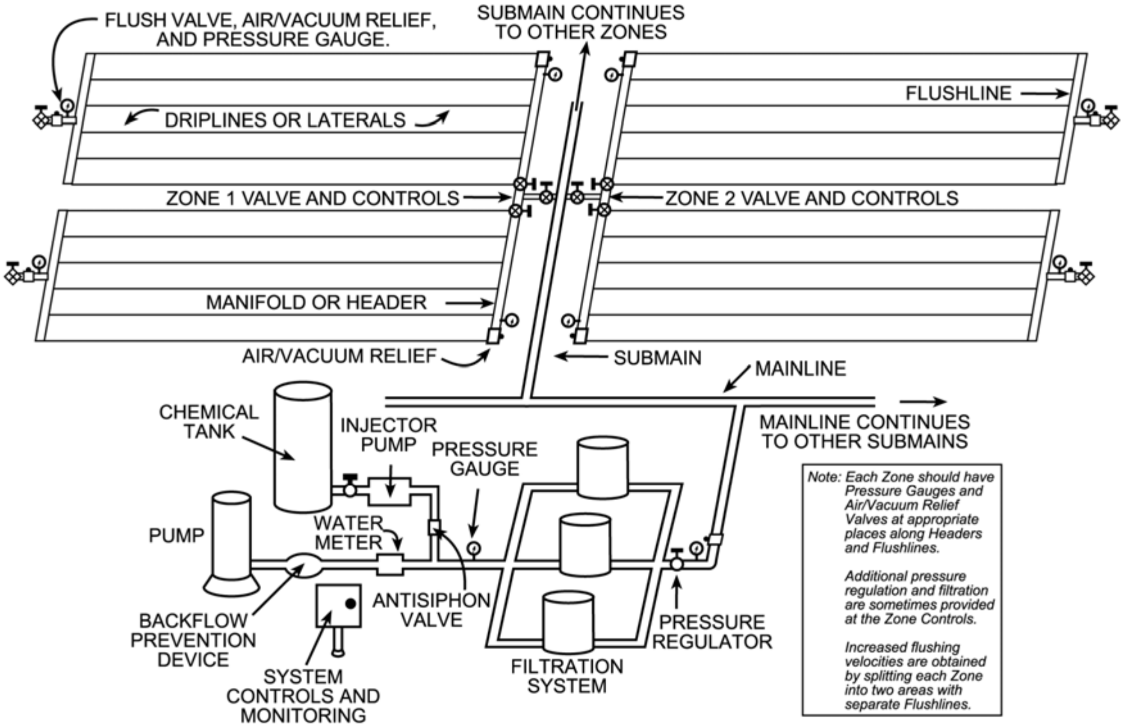
Figure 1. Minimum components of an SDI system. (Components are not to scale) K-State Research and Extension Bulletin MF-2576, Subsurface Drip Irrigation (SDI) Component: Minimum Requirements.

The water distribution components of an SDI system are the pumping station, the main, submains and dripline laterals. The size requirements for the mains and submains would be similar to the needs for underground service pipe to center pivots or main pipelines for surface flood systems. Size is determined by the flow rate and acceptable friction loss within the pipe. In general, the flow rate and acceptable friction loss determines the dripline size (diameter) for a given dripline lateral length. Another factor is the land slope. An SDI system consisting of only the distribution components would have no method to monitor system performance and the system would not have any protection from clogging or any methods to conduct system maintenance. Clogging of dripline emitters is the primary reason for SDI system failure.

The actual characteristics and field layout of an SDI system will vary from site to site, but often irrigators will want to add additional capabilities to their system. For example, the SDI system in Figure 2 shows additional valves that allow the irrigation zone to be split into two flushing zones. The ability to flush SDI systems is essential. Filter systems are generally sized to remove particles that are approximately 1/10 the diameter of the smallest emitter passageway. However, this still means small particles pass through the filter and into the driplines. Overtime, they can clump together and/or other biological or chemical processes can produce materials that need removal to prevent emitter clogging. The opening of the flushline valves and allowing water to pass rapidly through carrying away any accumulated particles flushes the driplines. A good design should allow flushing of all pipeline and system components. If the well or pump does not have the capacity to provide additional flow and pressure to meet the flushing requirements for the irrigation zone, splitting of the zone into two parts may be an important design feature. The frequency of flushing is largely determined by the quality of the irrigation water and to a degree, the level of filtration. A good measure of the need to flush is to evaluate the amount of debris caught in a mesh cloth during a flush event. If little debris is found, the flushing interval might be increased but heavy accumulations might mean more frequent flushing is needed.

The remaining components, in addition to the water distribution components of Figure 1, are primarily components that allow the producers to monitor the SDI system performance, to protect or maintain performance by injection of chemical treatments, and to allow flushing. The injection equipment can also be used to provide additional nutrients or chemicals for crop production. The backflow preventive device is a requirement to protect the source water from accidental contamination should a backflow condition occur.

The flow meter and pressure gauges are essentially the operational feedback cues to the manager. In SDI systems, all water application is underground. In most properly installed and operated systems, no surface wetting occurs during irrigation, so no visual cues are available to the manager concerning the system operating characteristics. The pressure gauges at the control valve of each zone allow the measurement of the inlet pressure to driplines. Decreasing flow and/or increasing pressure can indicate clogging is occurring. Increasing flow with decreasing pressure can indicate a major line leak. The pressure gauges at the distal ends of the dripline laterals are especially important in establishing the baseline performance characteristics of the SDI system. Flowrate and pressure measurement records can be used as a diagnostic tool to discover operational problems and determine appropriate remediation techniques (Figure 3).



Note: Each Zone should have Pressure Gauges and Air/Vacuum Relief Valves at appropriate places along Headers and Flushlines.

Additional pressure regulation and filtration are sometimes provided at the Zone Controls.

Increased flushing velocities are obtained by splitting each Zone into two areas with separate Flushlines.

Figure 2. An example layout for a well designed SDI system.

Anomaly A: The irrigator observes an abrupt flowrate increase with a small pressure reduction at the Zone inlet and a large pressure reduction at the Flushline outlet. The irrigator checks and finds rodent damage and repairs the dripline.

Anomaly B: The irrigator observes an abrupt flowrate reduction with small pressure increases at both the Zone inlet and the Flushline outlet. The irrigator checks and finds an abrupt bacterial flare-up in the driplines. He immediately chlorinates and acidifies the system to remediate the problem.

Anomaly C: The irrigator observes an abrupt flowrate decrease from the last irrigation event with large pressure reductions at both the Zone inlet and Flushline outlet. A quick inspection reveals a large filtration system pressure drop indicating the need for cleaning. Normal flowrate and pressures resume after cleaning the filter.

Anomaly D: The irrigator observes a gradual flowrate decrease during the last four irrigation events with pressure increases at both the Zone inlet and Flushline outlet. The irrigator checks and find that the driplines are slowly clogging. He immediately chemically treats the system to remediate the problem.

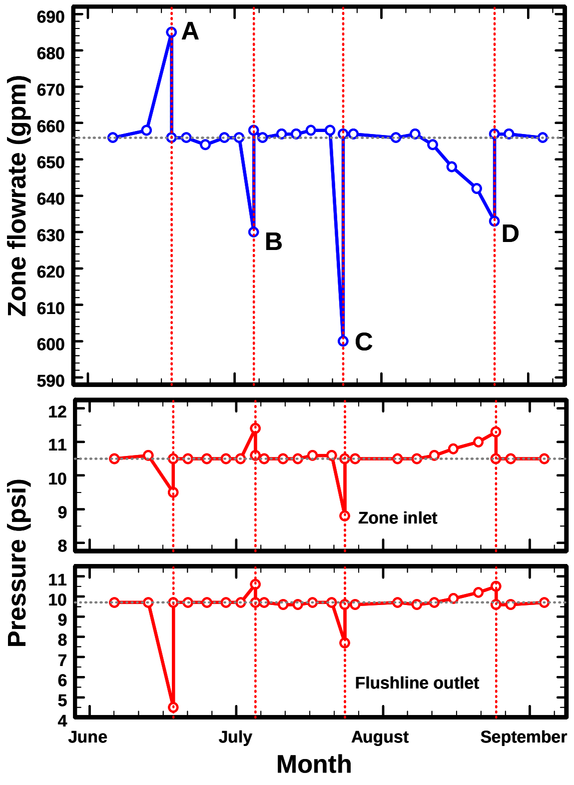


Figure 3. Hypothetical example of how pressure and flowrate measurement records could be used to discover and remediate operational problems.

The heart of the protection system for the driplines is the filtration system. The type of filtration system needed will depend on the quality characteristics of the irrigation water. Clogging hazards are classified as physical, biological or chemical. The illustration in Figure 1 depicts a pair of screen filters, while Figure 2 shows a series of sand media filters. In some cases, the filtration system may be a combination of components. For example, a well that produces a lot of sand in the pumped water may require a cyclonic sand separator in advance of the main filter. Sand particles in the water would represent a physical clogging hazard. Another common type of filtration system is the disc filter.

Biological hazards are living organisms or life by-products that can clog emitters. Surface water supplies may require settling basins and/or several layers of bar screen barriers at the intake site to remove large debris and organic matter. Sand media filtration systems, which consist of a bank of two or more large tanks with specially graded filtration sand, are considered to be well suited for surface water sources. Water sources that have a high iron content, can also be vulnerable to biological clogging hazards, such as when iron bacteria flare-up in a well. Control of bacterial growths generally requires water treatment in addition to filtration.

Chemical clogging hazards are associated with the chemical composition or quality of the irrigation water. As water is pulled from a well and introduced to the distribution system, chemical reactions can occur due to changes in temperature, pressure, air exposure, or also by the introduction of other materials into the water stream. If precipitants form, they can clog the emitters.

The chemical injection system is often considered to be a part of the filtration system but it can also be used to inject nutrients or chemicals to enhance plant growth or yield. There are a variety of types of injectors that can be used; the choice of unit depends on the desired accuracy of injection of a material, the rate of injection, and the agrochemical being injected. There are also state and federal laws that govern the type of injectors, required safety equipment (Figure 4), appropriate agrochemicals and application amounts that can be used in SDI systems. Always follow all applicable laws and labels when applying agrochemicals. Many different agrochemicals can be injected, including chlorine, acid, dripline cleaners, fertilizers, and some pesticides. Producers should never inject any agrochemical into their SDI system without knowledge of the agrochemical compatibility with the irrigation water. For example, many phosphorus fertilizers are incompatible with many water sources and can only be injected using additional precautions and management techniques. If a wide variety of chemicals are likely to be injected, then the system may require more than one type of injection system. The injection systems in Figures 1 and 2 are depicted as a single injection point, located upstream of the main filter. Some agrochemicals might require an injection point downstream from the filter location to prevent damage to the filter system. However, this should only be done by experienced irrigators or with an expert consultant, since the injection bypasses the protection of the filter system.

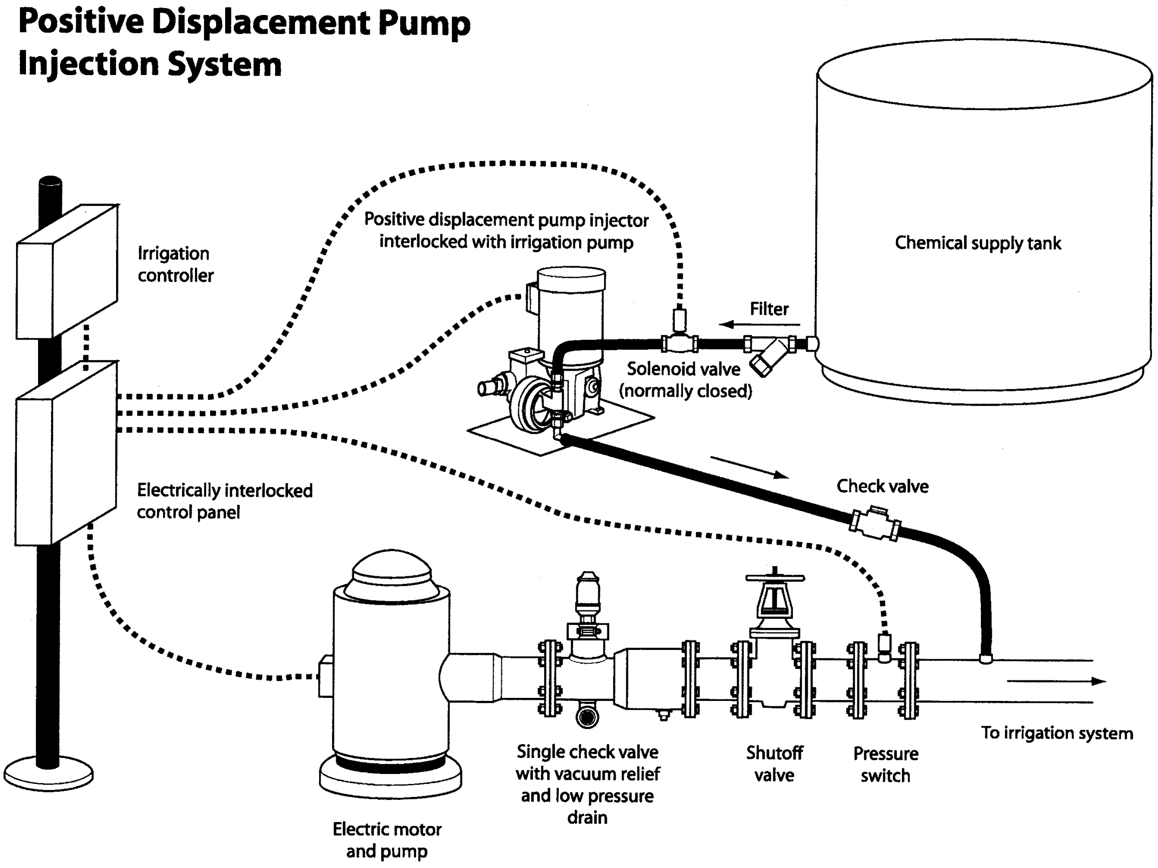


Figure 4. Typical layout for an injection system showing many of the safety interlocks and backflow prevention devices required to prevent contamination of the environment. (Courtesy of L.J. Schwankl, Univ. of California-Davis).

Chlorine is commonly injected to disinfect the system and to minimize the risk of clogging associated with biological organisms. Acid injection can also lower the pH chemical characteristic of the irrigation water. For example, high pH water may have a high clogging hazard due to a mineral dropping out of solution in the dripline after the filter. The addition of a small amount of acid to lower the pH to slightly acidify the water might prevent this hazard from occurring.

Water quality can have a significant effect on SDI system performance and longevity. In some instances, poor water quality, such as high salinity, could cause soil quality and crop growth problems. However, with proper treatment and management, water with high mineral loading, water with nutrient enrichment or water with high salinity can be used successfully in SDI systems. However, no system should be designed and installed without first assessing the quality of the proposed irrigation water supply.

WATER QUALITY ANALYSIS RECOMMENDATIONS

Prevention of clogging is the key to SDI system longevity and prevention requires understanding of the potential problems associated with a particular water source. Information on water quality should be obtained (Table 1) and made available to the designer and irrigation manager in the early stages of the planning process so that suitable system components, especially the filtration system, and management and maintenance plans can be selected.

Table 1. Recommended water quality tests

1. Electrical Conductivity (EC) - measured in ds/m or mmho/cm - a
   measure of total salinity or total dissolved solids;

2. pH - a measure of acidity -
   where 1 is very acid, 14 is very alkali, and 7 is neutral;

3. Cations - measured in meq/L, (milliequivalent/liter), includes;
   Calcium (Ca),
   Magnesium (Mg), and
   Sodium (Na);

4. Anions - measured in meq/L, includes:
   Chloride (Cl),
   Sulfate (SO_4),
   Carbonate (CO_3), and
   Bicarbonate (HCO_3);

5. Sodium Absorption Ratio (SAR) - a measure of the potential for sodium in the water to develop sodium sodicity, deterioration in soil permeability and toxicity to crops. SAR is sometimes reported as Adjusted (Adj) SAR. The Adj. SAR value better accounts for the effect on the HCO_3 concentration and salinity in the water and the subsequent potential damage by sodium to the soil.

6. Nitrate nitrogen (NO_3 - N) - measured in mg/L(milligram/liter);

7. Iron (Fe),
   Manganese (Mn), and
   Hydrogen Sulfide (H_2S) - measured in mg/L;

8. Total suspended solids - a measure of particles in suspension - in mg/L;

9 Bacterial population - a measure or count of bacterial presence in # / ml, (number per milliliter);

10. Boron* - measured in mg/L;

11. Presence of oil**

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* The boron test would be for crop toxicity concern.

** Oil in water would be concern for excessive filter clogging. It may not be a test option at some labs, and could be considered an optional analysis.

Results for Tests 1 through 7 are likely to be provided in a standard irrigation water quality test package. Tests 8 through 11 are generally offered by water labs as individual tests. The test for presence of oil may be a test to consider in oil producing areas of the state or if the well to be used for SDI has experienced surging, which may have mixed existing drip oil in the water column into the pumped water. The fee schedule for Tests 1 through 11 will vary from lab to lab and the total cost for all recommended tests may be a few hundred dollars. This is still a minor investment in comparison to the value offered by the test in helping to determine proper design and operation of the SDI system.

PRODUCER RESPONSIBILITIES

As with most investments, the decision lies with the investor. Good judgments generally require a good understanding of the fundamentals of the particular opportunity and/or the recommendations from a trusted and proven expert. While the microirrigation (drip) industry dates back over 40 years now and its application in Kansas as SDI has been researched since 1989, a network of industry support is still in the early development phase in the High Plains region. Individuals considering SDI should spend time to determine if SDI is a viable systems option for their situation. They might ask themselves:

What things should I consider before I purchase a SDI system?

1. Educate yourself before contacting a service provider or salesperson by
    a. Seeking out university and other educational resources. Good places to start are the K-State SDI website at http://www.oznet.ksu.edu/sdi/ and the Microirrigation forum at http://www.microirrigationforum.com/. Read the literature or websites of companies as well.
    b. Reviewing minimum recommended design components as recommended by K-State. http://www.oznet.ksu.edu/sdi/Reports/2003/mf2576.pdf
    c. Visit other producer sites that have installed and used SDI. Most current producers are willing to show them to others.
2. Interview at least two companies.
    a. Ask them for references, credentials (training and experience) and sites (including the names of contacts or references) of other completed systems.
    b. Ask questions about design and operation details. Pay particular attention if the minimum SDI system components are not met. If not, ask why? System longevity is a critical factor for economical use of SDI.
    c. Ask companies to clearly define their role and responsibility in designing, installing and servicing the system. Determine what guarantees are provided.
3. Obtain an independent review of the design by an individual that is not associated with sales. This adds cost but should be minor compared to the total cost of a large SDI system.

SUMMARY AND CONCLUSIONS

Subsurface drip irrigation offers a number of agronomic production and water conservation advantages but these advantages can only be achieved with proper design, operation, and maintenance, so that the SDI system can have an efficient, effective, and long life. One management change from current irrigation systems is the need to understand the SDI system sensitivity to clogging by physical, biological and/or chemical agents.

Before designing or installing an SDI system, be certain a comprehensive water quality test is conducted on the source water supply. Once this assessment is complete, the system designer can alert the manager of any potential problems that might be caused by the water supply. The old adage "an ounce of prevention is worth a pound of cure" is very appropriate for SDI systems. Early recognition of developing problems and appropriate action can prevent larger problems. While this may seem daunting at first, as with most new technology, most managers quickly will become familiar with the system and its operational needs.

The SDI operator/manager also needs to understand the function and need for the various components of an SDI system. There are many accessory options available for SDI systems that can be included during the initial design and installation phases, and even added at a later time, but more importantly, there are minimum design and equipment features that must be included in the basic system. SDI can be a viable irrigation system option, but should be carefully considered by producers before any financial investment is made.

The SDI operator/manager should monitor and record zone flowrates and pressures during ever irrigation event so that through observation of short and long term performance trends, operational problems can be discovered and remediated immediately.

OTHER AVAILABLE INFORMATION

The above discussion is a very brief summary from materials available through K-State. The SDI related bulletins and irrigation-related websites are listed below:

MF-2361	*Filtration and Maintenance Considerations for Subsurface Drip Irrigation (SDI) Systems* *http://www.oznet.ksu.edu/sdi/Reports/2003/mf2361.pdf*
MF-2576	*Subsurface Drip Irrigation (SDI) Components: Minimum Requirements* *http://www.oznet.ksu.edu/sdi/Reports/2003/mf2576.pdf*
MF-2578	*Design Considerations for Subsurface Drip Irrigation* *http://www.oznet.ksu.edu/sdi/Reports/2003/mf2578.pdf*

MF-2590 *Management Consideration for Operating a Subsurface Drip Irrigation System* http://www.oznet.ksu.edu/sdi/Reports/2003/MF2590.pdf

MF-2575 *Water Quality Assessment Guidelines for Subsurface Drip Irrigation* http://www.oznet.ksu.edu/sdi/Reports/2003/mf2575.pdf

MF 2589 *Shock Chlorination Treatment for Irrigation Wells* http://www.oznet.ksu.edu/sdi/Reports/2003/mf2589.pdf

Related K-State Research and Extension Irrigation Websites:

Subsurface Drip Irrigation http://www.oznet.ksu.edu/sdi/

General Irrigation http://www.oznet.ksu.edu/irrigate/

Mobile Irrigation Lab http://www.oznet.ksu.edu/mil/

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SALT THRESHOLDS FOR LIQUID MANURE APPLICATIONS THROUGH A CENTER PIVOT

Bill Kranz
Associate Professor Biological Systems Engineering
University of Nebraska
Haskell Agricultural Laboratory
Concord, Nebraska
VOICE: 402-584-3857 FAX: 402-584-3859
wkranz1@unl.edu

and

Charles Shapiro and Charles Wortmann
Department of Agronomy and Horticulture
University of Nebraska

INTRODUCTION

Application of liquid manure to growing crops is often a convenient and agronomically acceptable means of land application. Center pivots have been adapted to apply a broad range of fertilizers and pesticides. Development of large animal production facilities has added manure application to the list of materials that can be applied via center pivots. Al-Kaisi, et al. (2002) reported on the impact of using a center pivot to apply dilute swine lagoon water to cropland in Colorado. However, some producers have learned the hard way that manure contains some good and some bad materials. Occasionally, crop damage occurs as a result of application of concentrated manure presumably because of high salt concentrations.

Sprinkler application of animal manure to growing crops is a different issue than most of the salinity research that has been conducted across the country. Soluble salt levels in liquid manures are often higher than in the saline water used for irrigation in the western U.S. When irrigating with saline irrigation water the major problem is buildup of salt over time due to removal of the water by the crop leaving the salts behind. However, application of manure occurs at relatively low rates per acre and the annual rainfall or irrigation tends to leach the undesirable salts from the profile between applications. An additional concern with center pivot application of concentrated swine manure is the potential for plant damage (phytotoxicity) due to high ammonia levels.

Crop damage due to sprinkler application of manure with high EC levels occurs because of the direct contact of the salt with plant leaves and potentially the roots. Early research reporting the salinity thresholds for induced foliar injury concluded that since damage was caused by salt absorption into plant tissues, foliar application should be avoided in hot, dry, windy conditions that produce high potential evapotranspiration (PET). It was noted that species varied in the rate of foliar absorption of salts, such as: sorghum < cotton = sunflower < alfalfa = sugar beet < barley < potato. However, the susceptibility to injury was not related to salt absorption, as injury varied as: sugar beet < cotton < barley = sorghum < alfalfa < potato (Maas, et al., 1985; Maas, 1982). They found that leaf absorption of salts may be affected by leaf age, with generally less permeability in older leaves, and by angle and position of the leaf, which may affect the time and amount of leaf salt exposure. Producers need to know what the safe levels are and the effect of timing on potential plant damage for corn and soybeans.

The goal of the project was to establish the safe level of salt that could be applied to corn and soybean at different stages of growth. To accomplish this goal, a range of swine manure concentrations was applied to a growing crop in a manner that simulated application via a center pivot.

METHODS

Salt and ammonia concentration data from over 2700 manure samples were obtained from a private laboratory to determine the range in concentrations that should be evaluated in the field research. The EC level is an indication of the salt concentration in the manure sample. Figure 1 is a summary of the samples analyzed where the median EC level was 6.7 dS m^{-1} with a range from 0.1 to 70 dS m^{-1}. The median ammonia concentration was 497 ppm NH_4-N with a range from 0.03 to 12646 ppm NH_4-N.

The field research was conducted at the Haskell Agricultural Laboratory of the University of Nebraska located near Concord, Nebraska. The soil was a Kennebec silt loam with a pH of 7.3, and 3.5% soil organic matter. Corn (cv. Pioneer Brand 34N43) was planted on 16 May 2003 at 27,000 seeds per acre. Soybean (cv. Garst 2502) was planted on 28 May 2003 at 189,000 seeds per acre. Field plots were 8-30 inch rows wide and 35 feet long randomly arranged with three replications. The experimental area was irrigated with a lateral-move sprinkler irrigation system equipped with low-pressure spray nozzles mounted on top of the pipeline. The EC of the irrigation water was 0.6 dS m^{-1}. Irrigation was applied as needed to maintain greater than 50% available water in the rootzone. Irrigation supplied 8 inches of irrigation water to both crops, and precipitation supplied 14.4 inches between 1 May and the end of the season.

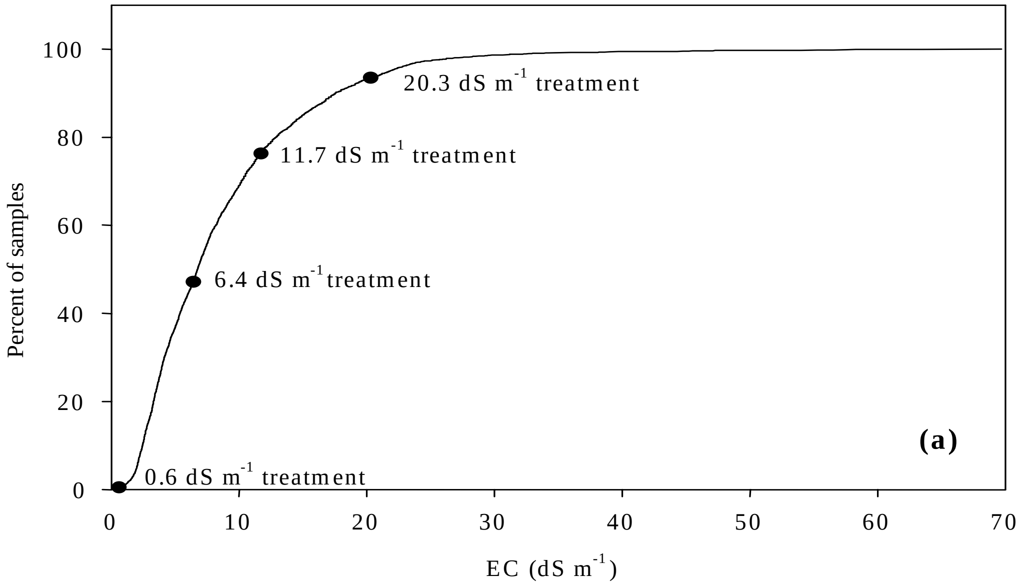

Figure 1. Cumulative distribution of electrical conductivity of liquid manure submitted for analysis to a commercial laboratory in Nebraska. The concentrations used in this study are also presented.

Swine manure from a commercial confined feeding operation was pumped from an under-building storage pit through a 2 mm screen to remove large solids. The liquid manure was passed through a 0.4 mm screen and then pumped to transfer tanks equipped to continuously agitate the liquid. Multiple screening was necessary to prevent the applicator nozzles from plugging during application. The EC of the solutions was determined using a conductivity meter (ATI Orion model 130, Analytical Technology, Inc., Boston, Mass.) calibrated with either a 1 or 10 dS m^{-1} solution. Liquid manure samples for both applications were collected from the supply tank outlet between the tank and the applicator and sent to Ward Laboratories to determine EC and nutrient concentration (Table 1).

The screened manure was diluted with fresh water to create four levels of EC in the liquid manure. The original manure had an EC level of 20.3 dS m^{-1}. Fresh water was added to dilute the manure down to 6.4 and 11.7 dS m^{-1}. Fresh water with an EC of 0.6 dS m^{-1} was used as a control treatment.

A portable applicator was developed and attached to the boom of a Hi-Boy sprayer (Figure 2). The applicator consisted of 21 nozzles arranged in a 3-nozzle wide by 7-nozzle long grid with a spacing of 3 feet between nozzles in each direction. The liquid manure application treatments consisted of a single application of four soluble salt concentrations applied at one of two selected

Table 1. Chemical analysis of liquid manure applied to corn and soybean at Concord, Nebraska, in 2003 (all values in lb/ac except where noted).

	EC Level (dS m^{-1})[1]							
	0.6		6.4		11.7		20.3	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Organic N	0.04	0.04	23.8	3.1	63.6	22.0	179.2	41.0
Ammonium N	0.5	0.1	78.6	9.6	170.4	6.0	365.7	15.9
P as P_2O_5	0.6	0.4	33.7	4.6	112.8	61.3	301.0	72.9
K as K_2O	0.9	0.1	60.7	5.6	130.6	8.8	281.5	26.3
S	3.5	0.5	12.2	1.8	25.5	4.5	53.4	7.1
Ca	8.9	1.0	19.4	1.6	57.9	36.2	131.6	33.0
Mg	2.0	0.1	8.9	0.9	23.2	10.6	57.9	13.4
Na	2.5	0.1	13.8	1.2	27.7	1.2	59.7	3.6
Soluble salts	37.0	1.3	412.4	43.6	753.5	24.2	1303.1	65.0
EC (dS m^{-1})	0.60	0.00	6.4	0.67	11.7	0.38	20.3	1.01
pH	7.87	0.72	6.9	0.12	6.6	0.06	6.2	0.12
Dry matter (%)	0.05	0.01	0.5	0.05	1.8	0.97	4.2	0.86

[1] Mean EC levels for the fresh water used as a control treatment and liquid manure dilutions applied to corn and soybean.

growth stages of corn and soybean. The first application was applied on July 2when corn was at the V7 growth stage and soybean was in the V3 stage (Ritchie, et al., 1996; Ritchie and Hanway, 1984). Air temperatures during application were in the upper 80’s. The second application was applied on July 24 when corn was at the V14 stage and soybean was at the R1 stage. Air temperatures during application were again in the upper 80’s. Approximately 0.5 inches of liquid manure was applied over a 10-minute period to corn and soybeans at each EC level.

Figure 2. Applicator used to apply liquid swine manure to corn and soybean.

RESULTS

Soybean

Each of the production indices was decreased by the 20.3 dS m^{-1} liquid manure for both application times (Table 2). Soybean plant population at harvest was less with the V3 application of 20.3 dS m^{-1} liquid manure than with the 0.6, 6.4, or 11.7 dS m^{-1} treatments, but the R1 application did not affect plant population. Leaf area was damaged by the V3 application but the plants recovered due to less inter-plant competition from a reduced plant population. Thus, the final plant LAI was not significantly different between application dates except for the 20 dS m^{-1} application.

Table 2. Effects of EC level of liquid manure and application time on soybean plant populations, leaf area, dry matter production, and grain yield for the 2003 growing season.

	EC Level (dS m^{-1})				Analysis of Variance[1] (P > F)		
	0.6	6.4	11.7	20.3	Time	EC Level	T × R[2]
Harvest population (pl/ac)							
V3[3]	93800	102700	92000	24300	0.001*	0.003*	0.26
R1 (V7)[3]	100900	106200	102700	104400			
P > F	0.67	0.82	0.55	<0.0001*			
LAI							
V3	4.6	4.5	2.2	0.3	0.85	0.0001*	0.03*
R1 (V7)	3.5	4.1	2.5	1.5			
P > F	0.06	0.46	0.48	0.03*			
Whole-plant dry matter at maturity (lb/ac)							
V3	7447	7893	7395	1071	0.52	< 0.0001*	0.07
R1 (V7)	6760	7400	7044	3909			
P > F	0.50	0.63	0.73	0.01*			
Grain yield (bu/ac)							
V3	43	39	40	5	0.12	< 0.0001*	0.02*
R1 (V7)	42	41	38	23			
P > F	0.57	0.40	0.32	<0.0001*			

[1] Statistical significance of ANOVA main effects are given by the probability of the F-test ($\alpha = 0.05$); significant differences are indicated by *.

[2] T × R is the timing × rate interaction.

[3] V3 and V7 are leaf stage at the time of application. R1 is the stage of growth, but V7 indicates that seven trifoliates were on the plant at the time of application.

When averaged over both application timings, grain yields were the same for the 0.6, 6.4, and 11.7 dS m^{-1} manure applications, averaging 41 bu/ac, as compared to 14 bu/ac for the 20.3 dS m^{-1} application. Soybean with the 20.3 dS m^{-1} application at R1 had much higher grain yield (23 bu/ac) than with the 20.3 dS m^{-1} application at V3 (5 bu/ac). Thus, swine manure applied at EC levels less than 11.7 dS m^{-1} have little impact on final yield despite causing plant damage at lower concentrations early in the growing season.

Corn

Corn growth was less affected than soybean, and damage was detected only with the V8 application at the 20.3 dS m^{-1} concentration (Table 3). The V14 application caused even less damage, likely due to salt tolerance of the fully developed cuticle on the corn leaves. The V8 application of 20.3 dS m^{-1} concentration caused some stunting of plants but no plant death. Overall, the manure increased the corn yields when applied at V14 (178 bu/ac) compared to V8 (165 bu/ac).

Table 3. Effects of EC level of liquid manure and application time on corn plant populations, leaf area, dry matter production and grain yield for the 2003 growing season.

	EC Level (dS m^{-1})				Analysis of Variance[1] (P > F)		
	0.6	6.4	11.7	20.3	Time	EC Level	T × R^2
Mature plant population (pl acre)							
V8[3]	23522	24103	22216	24684	0.12	0.11	0.04*
V14[3]	22506	25410	25555	24394			
P > F	0.33	0.22	0.005*	0.78			
Leaf area (cm^2 $plant^{-1}$)							
V8	5161	5211	5149	4428	0.09	0.41	0.17
V14	4899	5667	5326	5543			
P > F	0.53	0.29	0.67	0.02*			
Whole plant dry matter at maturity (lbs/ac)							
V8	6987	7800	6883	5784	0.15	0.04*	0.35
V14	6894	7654	7944	6874			
P > F	0.89	0.82	0.11	0.11			
Grain yield (Mg ha^{-1})							
V8	175	181	154	149	0.02*	0.08	0.02*
V14	164	186	179	185			
P > F	0.28	0.65	0.02*	0.003*			

[1] Statistical significance of ANOVA main effects are given by the probability of the F-test ($\alpha = 0.05$); Significant differences are indicated by *.
[2] T × R is the Timing × Rate statistical interaction.
[3] V8 and V14 are leaf stages at the time of application.

Weather conditions following liquid manure application may be important to crop tolerance. Crop damage is expected to be more severe under dry, hot, and windy conditions (Nielson and Cannon, 1975; Maas et al., 1982) with more foliar absorption of salts at higher temperatures (Busch and Turner, 1967). Although this study was conducted during one growing season, the weather conditions were within the range of most likely conditions for the time of application.

The liquid manure applications in this study were greater than typically applied by farmers in order to induce measurable damage. Application through a center pivot may keep the foliage wet and the salts soluble longer than the approximate 10 min in our study, especially near the center of the pivot circle. Our application rate was 0.5 ac-inches, but some pivots can apply as little as 0.2 ac-in), reducing the total amount of soluble salts applied and the potential for leaf damage.

SUMMARY

Producers can use inexpensive EC meters to estimate the potential for damage with liquid manure application. Application of liquid manure to corn and soybean through a sprinkler system is feasible with proper management. The results support the hypothesis that growth stage and liquid manure soluble salt concentration (EC levels) influence plant damage. Based on the conditions of this study, liquid manure with EC levels greater than 6.4 dS m^{-1} should not be applied to soybean during early vegetative growth. Liquid manure with EC levels less than 11.7 dS m^{-1} can be applied to corn and to soybean after flowering. If the soybean plants are not defoliated as a result of liquid manure application, yield is not likely to be reduced. Crop tolerance to soluble salt application is greater during the reproductive growth stages of the season than during the early vegetative stages. Applications of liquid manures that keep the foliage wet for longer periods than used in this study should be done on an experimental basis to make sure phytotoxicity is not increased by increased wetting periods.

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LAND APPLICATION OF ANIMAL WASTE ON IRRIGATED FIELDS

Alan Schlegel, Loyd Stone, H. Dewayne Bond, and Mahbub Alam,
Kansas State University
Voice: 620-376-4761 Fax: 620-376-2278
Email:schlegel@ksu.edu

ABSTRACT

Animal wastes are routinely applied to cropland to recycle nutrients, build soil quality, and increase crop productivity. This study evaluates established best management practices for land application of animal wastes on irrigated corn. Swine (effluent water from a lagoon) and cattle (solid manure from a beef feedlot) wastes have been applied annually since 1999 at rates to meet estimated corn P or N requirements along with a rate double the N requirement (2xN). Other treatments were N fertilizer (60, 120, and 180 lb N/a) and an untreated control. Corn yields were increased by application of animal wastes and N fertilizer. Over-application of cattle manure has not had a negative effect on corn yield. For swine effluent, over-application has not reduced corn yields except for 2004, when the effluent had much greater salt concentration than in previous years, which caused reduced germination and poor early growth. All animal waste and N fertilizer treatments increased soil solution NO_3-N concentration (5-ft depth) compared with the untreated control. Application of animal wastes on a N requirement basis resulted in similar NO_3-N concentrations as fertilizer N applied at 180 lb/a (approximate recommended rate). The 2xN application caused NO_3-N concentrations to about double for both swine and cattle wastes. Application of swine effluent based on P requirement produced similar NO_3-N concentrations as the 2xN rate because of the relatively low P content in the effluent.

INTRODUCTION

This study was initiated in 1999 to determine the effect of land application of animal wastes on crop production and soil properties. The two most common animal wastes in western Kansas were evaluated; solid cattle manure from a commercial beef feedlot and effluent water from a lagoon on a commercial swine facility.

MATERIALS AND METHODS

The rate of waste application was based on the amount needed to meet the estimated crop P requirement, crop N requirement, or twice the N requirement (Table 1). The Kansas Dept. of Agriculture Nutrient Utilization Plan Form was used to calculate animal waste application rates. Expected corn yield was 200 bu/a. The allowable P application rates for the P-based treatments were 105 lb P_2O_5/a since soil test P levels were less than 150 ppm Mehlich-3 P. The N recommendation model uses yield goal less credits for residual soil N and previous manure applications to estimate N requirements. For the N-based swine treatment, the residual soil N levels after harvest in 2001, 2002, and 2004 were great enough to eliminate the need for additional N the following year. So no swine effluent was applied to the 1xN treatment in 2002, 2003, or 2005 or to the 2xN requirement treatment since it is based on 1x treatment (Table 1). The same situation occurred for the N based treatments using cattle manure in 2003. Nutrient values used to calculate initial applications of animal wastes were 17.5 lb available N and 25.6 lb available P_2O_5 per ton of cattle manure and 6.1 lb available N and 1.4 lb available P_2O_5 per 1000 gallon of swine effluent (actual analysis of animal wastes as applied varied somewhat from the estimated values, Table 2). Subsequent applications were based on previous analyses. Other nutrient treatments were three rates of N fertilizer (60, 120, and 180 lb N/a) along with an untreated control. The N fertilizer treatments also received a uniform application of 50 lb/a of P_2O_5. The experimental design was a randomized complete block with four replications. Plot size was 12 rows wide by 45 ft long.

The study was established in border basins to facilitate effluent application and flood irrigation. The swine effluent was flood-applied as part of a pre-plant irrigation each year. Plots not receiving swine effluent were also irrigated at the same time to balance water additions. The cattle manure was hand-broadcast and incorporated. The N fertilizer (granular NH_4NO_3) was applied with a 10 ft fertilizer applicator (Rogers Mfg.). The entire study area was uniformly irrigated during the growing season with flood irrigation in 1999-2000 and sprinkler irrigation in 2001-2006. The soil is a Ulysses silt loam. Corn was planted at about 33,000 seeds/a in late April or early May each year. Grain yields are not reported for 1999 because of severe hail damage. Hail also damaged the 2002 and 2005 crop. The center four rows of each plot were machine harvested after physiological maturity with yields adjusted to 15.5% moisture. Nitrate concentration in the soil solution at the 5 ft depth was determined periodically through the growing season in 2003 and 2004. The 5-ft depth is below the effective rooting depth of corn, so any nitrate movement past this depth is assumed non-recoverable by the corn plant. Suction-cup lysimeters (placed at 5-ft depth) are used to collect the soil water samples. The first samples are collected shortly after corn planting and then every 1-2 week intervals during the growing season as long as sufficient water is present at the 5-ft depth to allow collection. The samples are kept refrigerated after collection until delivered to the KSU Soil Testing laboratory for nitrate-N analysis.

RESULTS

Corn yields were increased by all animal waste and N fertilizer applications in 2006, as has been the case for all years except in 2002 where yields were greatly reduced by hail damage (Table 3). The type of animal waste affected yields in 5 of the 7 years with higher yields from cattle manure than from swine effluent. Averaged across the 7 yr, corn yields were 14 bu/a greater following application of cattle manure than swine effluent on an N application basis. Over application (2xN) of cattle manure has had no negative impact on grain yield in any year. However, over-application of swine effluent reduced yields in 2004 because of considerably greater salt content (2-3 times greater electrical conductivity than any previous year) causing germination damage and poor stands. No adverse residual effect from the over-application was observed in 2005.

The concentrations of NO_3-N in the soil solution at the 5-ft depth for eight sampling periods in 2003 are shown in Table 4. The NO_3-N concentrations were stable between time periods but quite variable among replications. All animal waste and N fertilizer treatments increased solution NO_3-N concentration compared with the untreated control. Application of animal wastes on a N requirement basis resulted in similar NO_3-N concentrations as fertilizer N applied at 180 lb/a (approximate recommended rate). Although for both cattle and swine wastes, no fresh applications were made in 2003 for the N based treatments because of sufficient residual soil N (for swine effluent, there was also no fresh application made in 2002). The 2x N application caused NO_3-N concentrations to more than double for both swine and cattle wastes. Application of swine effluent based on P requirement produced similar NO_3-N concentrations as the 2x N rate because of the relatively low P content in the effluent.

Compared with the 2001 values (data not shown), some treatments showed considerably higher NO_3-N concentrations in 2003. The three treatments (cattle manure applied at 2x N basis and swine effluent applied at 2x N basis or P basis) that had soil solution concentrations >100 mg kg^{-1} of NO_3-N in 2001 showed increases in NO_3-N concentrations in 2003 indicating continual accumulation of NO_3-N at the 5-ft depth. It would be expected that over-application of cattle manure (2x N basis) could result in increased soil solution NO_3-N concentrations. Similarly, since the swine effluent used in this study was relatively low in P, the application rates necessary to meet P requirements over-supplies N as shown by the elevated soil solution NO_3-N concentrations. However, for the 2xN swine effluent treatment there was no effluent applied in 2002 or 2003. With no additional effluent applied since the 2001 water samples were collected, the higher concentration of NO_3-N at the 5-ft depth in 2003 indicates movement of NO_3-N from the upper profile rather than from fresh applications.

Table 5 shows the NO_3-N concentrations in the soil solution at the 5-ft depth for eight sampling periods in 2004. Soil solution NO_3-N concentrations were similar for the untreated control and the low rate of N fertilizer, but increased by all other treatments. In general, soil solution NO_3-N concentrations were greater in 2004 than 2003. It would be expected that the soil solution NO_3-N concentrations for the N based swine effluent treatments would be greater because of the higher N content of the effluent in 2004 (with application rates based on average N content causing greater N loading than targeted). However, soil solution NO_3-N concentrations were also greater following applications of cattle waste based on N requirement and the higher rates of N fertilizer.

CONCLUSIONS

Animal wastes are routinely applied to cropland to recycle nutrients, build soil quality, and increase crop productivity. This study evaluated established best management practices for land application of animal wastes on irrigated corn. Swine (effluent water from a lagoon) and cattle (solid manure from a beef feedlot) wastes were applied annually for eight years at rates to meet estimated corn P or N requirements along with a rate double the N requirement (over-application). Corn yields were increased by application of both animal wastes, compared with no fertilizer. Over-application of cattle manure did not have a negative effect on corn yield. For swine effluent, over-application reduced corn yields only in one year, when the effluent had much greater salt concentration than in previous years, which caused reduced germination and poor early growth. Over-application of animal wastes tended to increase nitrate concentration in the soil solution below the corn root zone. However, applying swine effluent based on crop N requirements or cattle manure based on crop P requirements resulted in solution nitrate concentrations below the root zone similar to those from recommended rates of inorganic N fertilizer.

Acknowledgement: Project supported in part by Kansas Fertilizer Research Fund and Kansas Dept. of Health and Environment.

Table 1. Application rates of animal wastes, Tribune, KS, 1999 to 2006.

Application basis *	Cattle manure							
	ton/a							
	1999	2000	2001	2002	2003	2004	2005	2006
P req.	15.0	4.1	6.6	5.8	8.8	4.9	3.3	6.3
N req.	15.0	6.6	11.3	11.7	0	9.8	6.8	6.3
2XN req.	30.0	13.2	22.6	22.7	0	19.7	13.5	12.6
	Swine effluent							
	1000 gal/a							
	1999	2000	2001	2002	2003	2004	2005	2006
P req.	28.0	75.0	61.9	63.4	66.9	74.1	73.3	66.0
N req.	28.0	9.4	37.8	0	0	40.8	0	16.8
2XN req.	56.0	18.8	75.5	0	0	81.7	0	33.7

* The animal waste applications are based on the estimated requirement of N and P for a 200 bu/a corn crop.

Table 2. Analysis of animal waste as applied, Tribune, KS, 1999 to 2006.

Nutrient content	Cattle manure							
	lb/ton							
	1999	2000	2001	2002	2003	2004	2005	2006
Total N	27.2	36.0	33.9	25.0	28.2	29.7	31.6	38.0
Total P_2O_5	29.9	19.6	28.6	19.9	14.6	18.1	26.7	20.5
	Swine effluent							
	lb/1000 gal							
	1999	2000	2001	2002	2003	2004	2005	2006
Total N	8.65	7.33	7.83	11.62	7.58	21.42	13.19	19.64
Total P_2O_5	1.55	2.09	2.51	1.60	0.99	2.10	1.88	2.60

Table 3. Effect of animal waste and N fertilizer on irrigated corn, Tribune, KS, 2000-2006.

		Grain yield							
Nutrient source	Rate basis[†]	2000	2001	2002	2003	2004	2005	2006	Mean
		bu/acre							
Cattle manure	P	197	192	91	174	241	143	236	182
	N	195	182	90	175	243	147	217	178
	2 X N	195	185	92	181	244	155	213	181
Swine effluent	P	189	162	74	168	173	135	189	155
	N	194	178	72	167	206	136	198	164
	2 X N	181	174	71	171	129	147	196	152
N fertilizer	60 N	178	149	82	161	170	96	178	145
	120 N	186	173	76	170	236	139	198	168
	180 N	184	172	78	175	235	153	200	171
Control	0	158	113	87	97	94	46	122	103
$LSD_{0.05}$		22	20	17	22	36	16	18	12
ANOVA									
Treatment		0.034	0.001	0.072	0.001	0.001	0.001	0.001	0.001
Selected contrasts									
Control vs. treatment		0.001	0.001	0.310	0.001	0.001	0.001	0.001	0.001
Manure vs. fertilizer		0.089	0.006	0.498	0.470	0.377	0.001	0.001	0.013
Cattle vs. swine		0.220	0.009	0.001	0.218	0.001	0.045	0.001	0.001
Cattle 1x vs. 2x		0.900	0.831	0.831	0.608	0.973	0.298	0.646	0.705
Swine 1x vs. 2x		0.237	0.633	0.875	0.730	0.001	0.159	0.821	0.043
N rate linear		0.591	0.024	0.639	0.203	0.001	0.001	0.021	0.001
N rate quadratic		0.602	0.161	0.614	0.806	0.032	0.038	0.234	0.042

[†] Rate of animal waste applications based on amount needed to meet estimated crop P requirement, N requirement, or twice the N requirement.

No yields reported for 1999 because of severe hail damage. Hail reduced corn yields in 2002 and 2005.

Table 4. Nitrate concentration in soil solution at the 5-ft soil depth in 2003 following application of animal wastes and N fertilizer.

Nutrient source	Application Basis*	Time of Sampling								
		May 21	May 29	June 10	June 18	June 23	July 2	July 9	July 16	Mean
		Soil solution NO_3-N, ppm								
Cattle manure	P	45	31	46	38	41	43	45	44	42
	N	75	69	68	62	64	52	61	49	63
	2 X N	322	375	375	348	375	310	371	378	357
Swine effluent	P	264	280	281	280	283	278	296	299	283
	N	106	112	122	103	99	89	94	100	103
	2 X N	272	306	264	288	299	281	290	291	286
N fertilizer	60 N	23	20	22	19	21	18	22	22	21
	120 N	48	41	40	23	31	35	36	24	35
	180 N	102	98	105	84	86	64	71	73	85
Control	0	8	5	7	3	3	4	4	4	5
ANOVA (P>F)										
Treatment		0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	
Selected contrasts										
Control vs. treatment		0.028	0.034	0.019	0.020	0.012	0.014	0.006	0.005	
Animal waste vs. fert.		0.003	0.003	0.001	0.001	0.001	0.001	0.001	0.001	
Cattle vs. swine		0.139	0.145	0.188	0.090	0.109	0.038	0.070	0.047	
Cattle 1x vs. 2x		0.003	0.001	0.001	0.001	0.001	0.001	0.001	0.001	
Swine 1x vs. 2x		0.038	0.032	0.070	0.018	0.008	0.006	0.004	0.004	
N rate linear		0.306	0.371	0.278	0.380	0.367	0.488	0.432	0.406	
N rate quadratic		0.833	0.805	0.719	0.653	0.709	0.907	0.849	0.647	

* The animal waste applications are based on the estimated requirement of N and P for a 200 bu/a corn crop.

Table 5. Nitrate concentration in soil solution at the 5-ft soil depth in 2004 following application of animal wastes and N fertilizer.

Nutrient source	Application Basis*	Time of Sampling May 26	June 4	June 8	June 15	June 23	June 27	July 7	July 14	Mean
		Soil solution NO_3-N, ppm								
Cattle manure	P	108	109	111	102	111	99	105	111	107
	N	321	335	344	358	306	282	293	294	317
	2 X N	322	418	421	300	454	402	424	405	393
Swine effluent	P	355	366	357	505	476	446	546	531	448
	N	145	127	128	219	146	141	169	170	156
	2 X N	203	303	327	325	247	395	540	307	331
N fertilizer	60 N	14	4	5	7	4	4	4	3	6
	120 N	116	119	109	129	111	120	139	135	122
	180 N	170	183	180	177	201	211	218	234	197
Control	0	8	5	4	4	2	2	1	1	3
ANOVA (P>F)										
Treatment		0.005	0.002	0.003	0.008	0.001	0.001	0.002	0.001	
Selected contrasts										
Control vs. treatment		0.006	0.005	0.007	0.009	0.007	0.003	0.024	0.001	
Animal waste vs. fert.		0.005	0.002	0.002	0.004	0.003	0.001	0.001	0.001	
Cattle vs. swine		0.795	0.753	0.772	0.241	0.993	0.285	0.063	0.258	
Cattle 1x vs. 2x		0.995	0.409	0.465	0.642	0.185	0.248	0.294	0.249	
Swine 1x vs. 2x		0.663	0.248	0.213	0.547	0.535	0.039	0.015	0.217	
N rate linear		0.064	0.060	0.078	0.122	0.059	0.036	0.069	0.013	
N rate quadratic		0.728	0.748	0.834	0.686	0.921	0.883	0.779	0.822	

* The animal waste applications are based on the estimated requirement of N and P for a 200 bu/a corn crop.

MANAGEMENT CONSIDERATIONS FOR CENTER PIVOTS WHEN APPLYING WASTEWATER

Jake LaRue, P.E.
Valmont Irrigation
Valley, Nebraska
Voice: (402) 359-6041
jlarue@valmont.com

Summary:

How often in the news today do we ever hear anything positive about a waste water reuse project? This paper will briefly discuss the relationship of the three elements of a good wastewater reuse project, equipment, agronomic practices and management. The focus will then be on management concepts to be considered when using center pivots while applying wastewater. Particularly the paper will focus on the impact of management to the overall project performance. Examples of wastewater reuse management situations will be presented and discussed. From the discussion a list of parameters will be developed and discussed which are considered critical to a wastewater project's overall success to not only the livestock and farm but the general public as well. Only agricultural projects will be included in the discussion but many of the same drivers apply to industrial and municipal wastewater reuse projects.

Introduction:

To begin let's consider that using a center pivot for wastewater reuse is **not** the same as using a center pivot for crop production. All stakeholders – livestock operation, farm operation, neighbors and the public, must be considered if a project is to be a long term success. Land application of wastewater with mechanical move irrigation equipment – both center pivot and linear has been successfully used for many years. Mechanized irrigation, due to its characteristics, including limited labor input, application uniformity, ease in handling large volumes of effluent and particularly the ability to apply to an actively growing crop with minimal negative impact to the crop is considered to have advantages for wastewater reuse. Since the early 1980's the equipment and techniques for irrigating with fresh water have changed dramatically and many of these changes have been incorporated into mechanized equipment used for land application (Gilley, 1983). While these changes have brought significant improvements, in today's world we must take into account other issues and particularly public perception of a wastewater reuse application system. Equipment applications are important but equally so are the agronomic practices and management. If any of these three are not integrated together into the overall package, there is a strong potential for problems and/or project failures. How the irrigation equipment is selected has been discussed in more detail in a previous paper (LaRue, 2006). As an example it is possible to have runoff from a field if the equipment application, agronomic practices and management are not all integrated together.

Discussion:
Livestock operations producing meat or milk have little to no interest in crop production except as a possible spot to ‘dump’ their problem. In general they want to have no problems and minimize their expense in ‘disposing’ of their meat and milk production by-product, the wastewater stream. As stated earlier, to have a successful (defined as meeting all stakeholder expectations) wastewater reuse project requires the three key project elements to work together – equipment, agronomic practices and management. Poor application of any of these can lead to project failure and worse the potential for legal implications. An example would be the wastewater application package of the center pivot is designed so it does not exceed the soil intake rate but the agronomic practices do not maintain any residue on the surface and the farmer decides to apply a depth of 2 ½ inches per pass. No matter how well the center pivot equipment options were selected there is the strong potential for runoff and/or excessive wheel tracks leading to the center pivot becoming stuck. Either of these jeopardizes the overall performance of the wastewater reuse package and potentially could lead to legal action.

Besides the typical irrigation application parameters that need to be considered there are others as well particularly the wastewater storage, nutrient management plan, neighbors and maybe most importantly the expectations of the involved parties. All of these must be managed and not just casually. If the livestock owner is also the farm owner the situation is simplified and there is more chance for coordination of management. But if the livestock owner is not the farm operator, we have a different situation that will impact the management of the center pivot. Let us now discuss some specific situations.

1) Swine farrowing operation –
    a. Hog operation does not own the land
    b. Issue
        i. Level of the lagoon in the spring and fall
            1. The farmer wants to get the field dried out as early as possible in the spring to allow tillage and planting operations and keep the field dry for harvest in the fall
            2. The hog operator needs to begin pumping as soon as possible in the spring to maintain free board on the lagoon and pump the lagoon down in the fall

Is this an equipment, agronomic or management problem?

Solution
- This requires a combination of the all of the above
- Management impact can be:

        - In barn management of water and volumes going to a lagoon. Significant variations in the volumes of wastewater generated per sow are seen in the field.
        - Management of communication with the farmer
            - Both sides need to be sensitive to the needs of the other
            - Structure of financial arrangements so both sides understand the impact.
                - If the lagoon ‘runs over’ and reaches a stream this could have significant financial impact to the livestock operation
                - Delayed planting and/or harvest may impact the yield potential of the crop

2) Swine finishing operation -
    a. Hog operation owns the land
    b. Issue
        i. For the farm - Center pivot frequently gets stuck

Is this an equipment, agronomic or management problem?

Solution

- Equipment and management probably have the most potential for solutions
- Management suggestions:
    - Evaluate the relationship of center pivot options and agronomic practices
        - Does the wastewater application package make sense for the agronomic practices?
    - Try to apply the maximum application depth per pass that does not lead to runoff to maximize the time between wastewater application cycles to allow the wheel tracks to dry.
    - Consider varying the application depth or even shutting off portions of the center pivot for problem areas
        - Be sure to account for this area in the nutrient management plan

3) Dairy operation –
    a. Dairy operation owns the land
    b. Issue
        i. For dairy and farm - Complaints from neighbors about odor when applying wastewater

Is this an equipment, agronomic or management problem?

Solution

- Equipment and management probably have the most potential for solutions
- Management suggestions:
  - Use common sense – do not apply when the wind is blowing sufficiently to cause drift and the direction is toward the neighbors
  - Talk with the neighbors so they understand you are sensitive to their concerns
  - Apply at night and early mornings

4) Beef operation –
   a. Beef operation does not own the land
   b. Issues
      i. For the feed lot – The storage is primarily for storm water runoff and must keep the level in storage low to be able to handle potential storm events
      ii. For the farm - Meeting crop water needs

Is this an equipment, agronomic or management problem?

Solution

- Management and agronomic practices probably have the most potential for a solution
- Management suggestions:
  - Try to balance wastewater applications as much as possible with the crop needs
  - Re-evaluate the storage size and design
  - Structure of financial arrangements so both sides understand the impact.
    - If the storm water storage 'runs over' and reaches a stream this could have significant financial impact to the feedlot operation
    - Lack of waste water may impact the yield potential of the crop

Conclusions:

Land application using mechanical move irrigation equipment has proven very beneficial to many reuse projects and can be cost effective over the life of the project. However not meeting the expectations of all stakeholders can lead to significant problems for the project and long term acceptance. One of the keys to successful waster water reuse projects is an integrated approach combining equipment, agronomic practices and management.

An analysis of the situations above would indicate some of the issues which management can impact to be:

- If the wastewater producer does not own the land, must manage the communication with the farmer.
- Management must be sensitive to the local concerns about odor, impact on visual landscape and other possible concerns.
- The management must be reviewed periodically to ensure operation is meeting the design basis and the nutrient management plan as well as any changing operating constraints.
- Management must take into account the financial impact to all involved parties.

Key management considerations for the center pivots would be:

- Use some common sense!
- Manage closely the soil moisture status and do not exceed what the soil and crop canopy can hold with the application depth.
- Manage applications to apply during the night and early morning whenever possible.
- Manage applications to avoid windy days that may tend to cause drift.
- Manage the center pivot to ensure the wheel tracks in the field have an opportunity to dry as much as possible between irrigation cycles.
- Manage the interactions of equipment, agronomic practices and management.
- Manage communication between all of the involved parties.

References:

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Personal communication with wastewater reuse projects.

INFLUENCE OF NOZZLE PLACEMENT ON CORN GRAIN YIELD, SOIL MOISTURE AND RUNOFF UNDER CENTER PIVOT IRRIGATION

Joel P. Schneekloth and Troy Bauder
Regional Irrigation and Water Quality Specialists
Colorado State University Cooperative Extension
Fort Collins and Akron, Colorado
Voice: 970-345-0508 Fax: 970-345-2088
email:jschneek@coop.ext.colostate.edu

Maximizing irrigation efficiency is of enormous importance for irrigators in the Central Great Plains to conserve water and reduce pumping costs. High temperatures, frequently strong winds and low humidity increase the evaporation potential of water applied through sprinkler irrigation. Thus, many newer sprinkler packages have been developed to minimize water losses by evaporation and drift. These systems have the potential to reduce evaporation losses as found by Schneider and Howell (1995). Schneider and Howell found that evaporation losses could be reduced by 2-3% as compared to above canopy irrigation. Many producers and irrigation companies have promoted placing sprinklers within the canopy to conserve water by reducing the exposure of the irrigation water to wind. However, runoff losses can increase due to the reduced wetted diameter which increases the application rate greater than soil infiltrate capacity. Schneider and Howell (2000) found that furrow dikes were necessary to prevent runoff with in-canopy irrigation.

In 2003 and 2004, a study was conducted comparing sprinkler nozzle placement near Burlington, Colorado in cooperation with a local producer. The objective of this study was to determine the impact of placing the sprinkler devices within the canopy upon soil moisture, runoff and crop yield. A secondary objective was to determine the usefulness of in-season tillage on water intake and preventing runoff.

METHODS

For this study, the current configuration of a center pivot irrigation system owned by our cooperating farmer was utilized. This configuration included drops with spray heads at approximately 1.5 feet (in-canopy) above the ground surface. The sprinkler heads on the seventh and outside span of the center pivot were raised to approximately 7 feet above ground level (above canopy). This nozzle height allowed for an undisturbed spray pattern for a majority of the growing season. The sprinkler heads on the sixth span of the center pivot remained at the original height (in-canopy). In 2003, the nozzles were raised by attaching the flexible drop hose using truss rod slings. Because the farmer decided not to irrigate this field in 2004, the study was moved to an adjacent pivot in 2004. The pivot nozzles were raised by replacing the drop hoses and ‘j-tubes’ on this system. In 2004 the nozzle heights in the outside span were left at 1.5 feet above ground level and the next span into the field were raised to 7 feet. Spacing was 5-feet between nozzles for both site-years.

For the 2003 growing season, three in-season tillage treatments were replicated three times under each of the sprinkler heights. The three tillage treatments were cultivation, inter-row rip and basin tillage. The cooperating farmer implemented the tillage treatments when the corn was at the V6 growth stage. The tillage treatments were implemented in strips running the length of the field. The field was planting perpendicular to the sprinkler direction. In 2004, the cooperating farmer chose to use grow the corn crop using no-till and planted in a circular pattern. In-season tillage was was to be implemented, inter-row rip and basin tillage operations, it was prevented by wet weather in June.. Thus, the only tillage in 2004 was no-till. The cooperating farmer conducted all field operations (planting, fertilization, pest control, irrigation, etc.) during 2003 and 2004.

Runoff was measured on cultivation and basin tillage for 2 replications and both sprinkler heights in 2003. Four-inch, V-notch furrow weirs installed at the bottom of the 8-row plots. The runoff for two 30-inch rows for the entire length of the pivot span (plot) was directed into the weir by the tillage treatment and soil berms where needed. The water level height in the stilling-wells of the weirs was recorded using auto-logging pressure transducers. Because the cooperating farmer chose no-till for the 2004 season, two 10-foot by 38-foot runoff plots using landscape edging were installed. Furrow weirs were installed on the lower end of the plots to measure runoff.

The soil type at both sites was Kuma Silt Loam. The slope was approximately 1 to 1.5 percent and was fairly uniform across treatments. We measured soil moisture from mid-June through early September using a Troxler neutron probe at one-foot increments to five feet of soil depth. A neutron access tube was installed in each tillage and nozzle height treatment in 2003 and six access tubes were installed in each nozzle height treatment in 2004. The study was repeated in 2005 but the results are not published. Problems associated with the bowls created surging and resulted in sections of sprinklers not outputting water. These sprinklers were generally the above canopy sprinklers. In 2006, yields were taken from each sprinkler height. No soil moisture or runoff measurements were taken.

RESULTS

Grain Yield

Grain yields in 2003 were not significantly different for in-canopy and above canopy irrigation (Tables 1 and 2). Statistically significant difference between tillage treatments were not found. However the yields for above canopy irrigation were consistently 4 bushels per acre greater than in-canopy irrigation within each tillage treatment. This would indicate that moisture stress did not occur under either above canopy or in-canopy irrigation. Grain yields for above canopy sprinkler placement were not statistically greater than in-canopy placement in 2004 or 2006 as well. However, grain yields averaged over the three year period indicate a trend where above canopy placement of sprinklers has greater yields than that of in-canopy placement.

Soil Moisture

Soil moisture was measured for both above canopy and in-canopy sprinklers during the 2003 growing season. When comparing above canopy to in-canopy irrigation, changes in soil moisture were greater for in-canopy irrigation than above canopy (Figure 1). The depletion of soil moisture was significantly higher for the in-canopy sprinkler placement than with above canopy sprinklers. With similar yields, this would indicate that greater runoff losses occurred with in-canopy irrigation since soil moisture usage offset reduced infiltration. The greatest difference in change in soil moisture between above and in canopy irrigation occurred during early August when the difference was greater than 3 inches of soil moisture between the two sprinkler placements. Differences in soil moisture usage at physiological maturity were 1.7 inches greater for in-canopy irrigation than above canopy irrigation.

Changes in soil moisture between tillage treatments in 2003 were not significantly different from each other within a sprinkler height during the growing season. This would indicate that sprinkler height was the dominant factor in soil moisture content.

Contrary to 2003, soil moisture initially increased early in the 2004 growing season, declining after drier weather and higher ET rates began in July. Soil moisture content initially showed a greater increase for in-canopy placement as compared to above canopy placement (Figure 2). Much of this was due to the in-canopy placement being drier at the beginning of the season and above canopy placement reaching field capacity in mid-July. Most likely, deep percolation occurred in the above canopy placement while stored soil moisture increased for the in-canopy placement. Changes in soil moisture for both in-canopy and above canopy placement were similar after July 27. This was after the above canopy and in-canopy placement reached maximum stored soil moisture during the growing season.

Runoff

Due to inconsistent and unreliable readings from one replication of the data loggers installed on the weirs recording runoff, only one replication of the 2003 measurements was used for this paper. Runoff was greater with in-canopy irrigation than above canopy for the conventional cultivation and basin tillage treatments (Table 3). Changes in soil moisture between sprinkler placement treatments agree with runoff results collected for each placement. Greater amounts of runoff between sprinkler packages were offset by greater soil moisture loss. Runoff amounts were less for basin tillage as compared to cultivation. The reduction in runoff was due to the increase in surface storage created by the implanted basins. Although not measured, no or little runoff or signs of runoff was observed in the inter-row ripping tillage plots.

Only two significant runoff events due to irrigation, 1.1 and 0.89 inches of runoff, were recorded in 2004. This was due to management changes made by the producer. Irrigation depths in 2003 were 1.5 to 2 inches per application. In 2004, application amounts were reduced to 0.7 inches per application. This reduction in application depth reduced runoff in all but two irrigations where the producer applied higher amounts (at least 2 inches) per application.

Conclusions

Results from this study suggest that above canopy irrigation was more efficient at increasing stored soil moisture and reducing runoff as compared to in-canopy irrigation. Less runoff from above canopy irrigation in 2003 resulted in more stored soil moisture and similar to slightly more grain yield than in-canopy irrigation. In-season tillage such as basin tillage decreased runoff as compared to conventional cultivation. Yields between tillage treatments were not significantly different, but a trend of yield increases was observed when soil intake rates were modified by tillage.

No statistically significant yield differences were observed within a year when irrigation sprinkler nozzles were placed above the canopy and soil moisture differences between above canopy and in-canopy placement reflected the differences in runoff. The results of this project suggest that sprinkler placement above a corn canopy would be preferable to placing sprinklers in-canopy unless significant changes in irrigation management practices occur. However, when averaged over the three years of this study, sprinkler placement near truss level (above canopy) had significantly greater yields than compared to in-canopy placement.

References:

1995. Schneider, A. D. and Howell, T. A. Reducing sprinkler water losses. In Proc. 1995 Central Plains Irrigation Short Course & Equipment Exposition. Kansas Cooperative Extension Service, Manhattan, KS. pp. 60-63.

2000. Schneider, A. D. and Howell, T. A. Surface runoff due to LEPA and spray irrigation of a slowly permeable soil. Trans. ASAE 43(5):1089-1095.

Table 1. Average grain yields for sprinkler placement and tillage treatment (2003).

	Above Canopy		In-Canopy	
	Yield*	Moisture	Yield	Moisture
Tillage Treatment	(bu/acre)	(%)	(bu/acre)	(%)
Cultivation	187	15.2	182	17.5
Basin Tillage	188	14.5	184	18.1
Inter-row Rip	193	14.9	189	18.7
Average	189	14.9	185	18.1

*Grain yields adjusted to 15.5% grain moisture.

Table 2. Grain yields for sprinkler placement averaged across tillage treatments for 2003 and 2004.

	Grain Yield*		
	Above Canopy	In-Canopy	
Year	--------- bu/acre ---------		P>F
2003	189	185	0.33
2004	253	246	0.30
2006	267	250	0.39
Average	236	227	0.08

*Grain yields adjusted to 15.5% grain moisture.

Table 3. Estimated runoff from July 4 to August 30 for sprinkler nozzle placement and tillage treatment in 2003. Runoff represents 15 irrigation events.

	--- Nozzle Placement ---	
	Above Canopy	In-Canopy
Tillage Treatment	--------- Inches Runoff ---------	
Cultivation	5.8	9.3
Basin Tillage	0.0	2.0

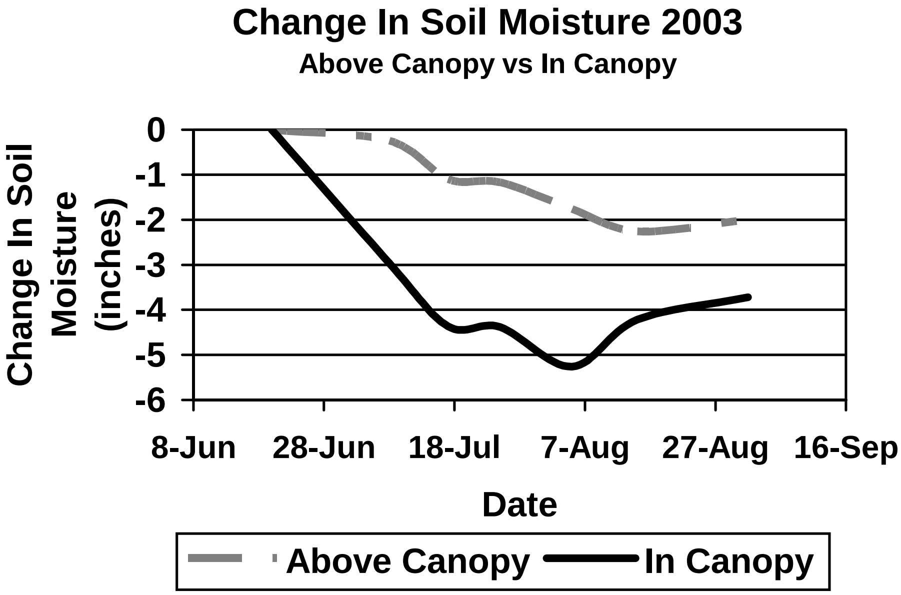

Figure 1. Change in soil moisture (from initial values) during the 2003 growing season for above canopy and in-canopy placement of sprinklers.

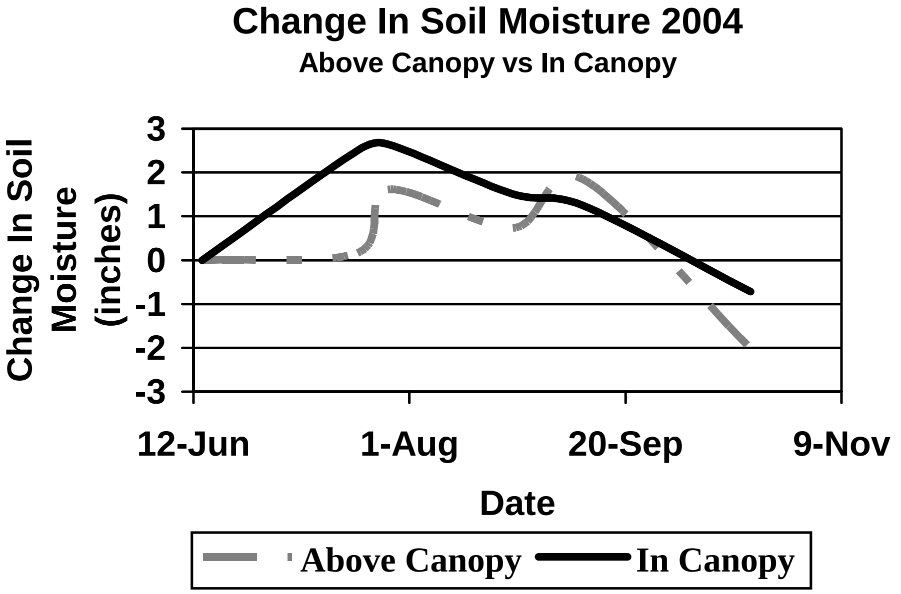

Figure 2. Change in soil moisture (from initial values) during the 2004 growing season for above canopy and in-canopy placement of sprinklers.

ECONOMICS OF IRRIGATION ENDING DATE FOR CORN: USING FIELD DEMONSTRATION RESULTS

Mahbub Alam,

Extension Irrigation Specialist, Kansas State University, SW Research-Extension Center, Garden City, KS. Phone: 620-275-9164, Fax: 620-276-6028. Email: malam@ ksu.edu

Troy J. Dumler, Danny H. Rogers, and Kent Shaw

Extension Agricultural Economist, SW Research-Extension Center, Garden City, KS; Professor, Kansas State University, Manhattan, KS; and Mobile Irrigation Lab Program coordinator, SWREC, Garden City, KS, respectively.

The results from a field study indicate that corn growers of western Kansas may cut back last one or two irrigation events of the season without appreciable loss in production. This will improve the economic return by reducing input cost from water. Recent increase in energy cost for pumping water has necessitated this study to compare the benefits of continuing irrigation until black layer formation. With the decline of Ogallala aquifer groundwater level and rising fuel cost, any reduction of pumping makes economic sense. The first irrigation ending date around August 10-15, corresponding to denting and starch layer formation of ¼ to ½ towards the germ layer resulted in an yield reduction of 17 bushels averaging for four years of data for a silty loam soil as compared to second ending date around August 21-22, which corresponded to starch layer at ½ to ¾ towards the germ layer. However, continuing irrigation until September 1, corresponding to the start of black layer formation, improved yield by only 2.5 bushels per acre. Economic sensitivity tests show that irrigating until the formation of starch layer at ½ to ¾ towards germ layer is feasible with a corn price of $2 per bushel and $8 per inch pumping costs. However, irrigating past this stage of grain development is not feasible even with $2.75 / bushel of corn and pumping costs as low as $4 / inch.

Introduction

Crop production in western Kansas is dependent on irrigation. The irrigation water source is groundwater from the Ogallala aquifer. The water level of the Ogallala aquifer is declining causing the depth of pumping to increase. The additional fuel consumption required for greater pumping depths and higher energy costs have resulted in higher pumping costs in recent years. Because of declining water levels and higher pumping costs, it is necessary to conserve water by adopting efficient water management practices. Irrigation scheduling is an important management tool. Farmers are interested in information on optimum timing for ending the irrigation season. There are some misconceptions regarding the optimum irrigation ending dates. Some farmers believe that the corn crop must continue to have water to avoid eardrop. Over application at the end of season based on this thought cause waste of water, increases cost of production, and may even cause degradation of quality of the grain due to high humidity or disease. Most of all, the excess use of water may reduce the useful life of the Ogallala aquifer which is a confined aquifer with little or no recharge. Depletion of the Ogallala aquifer will impact irrigated agriculture and the present economy of the area. The objective of the study was to determine the affect that irrigation ending date had on corn yield and economic return.

Procedures

A producer's center pivot sprinkler irrigated field was selected for the study. A silty loam soil of Ulysses series was selected and the study was conducted for four years (2000-2003). Two sets of six nozzles were shut progressively after the formation of starch layer in the corn grain. The first closure was done when the starch layer was ¼ to ½ to the germ. This corresponded to August 10th to 15th, depending on growing degree units. The second closure was done when the starch layer was ½ to ¾ to the corn germ. This corresponded to August 21 to 24. The third closure occurred when the producer ended irrigation for the year. This happened during the first week of September.

Four random plots of 30 ft. by 30 ft. were identified within the center pivot sprinkler circle over which the selected nozzles would pass during an irrigation event. Ridges were built around the plots to prevent entry of water from the adjacent areas. Gypsum block soil water sensors were buried in the plots at three different depths (1, 2, and 3 feet) below the soil surface. The soil of the test field is Ulysses silt loam series. It is relatively dark with a deep profile and good water holding capacity. The soil surface, however, cracks when dry.

Corn ears were hand harvested. Four contiguous rows measuring ten feet each were harvested at the middle of each plot to remove any border effect. Grain yields were adjusted to 15.5% moisture content.

In 2005, the study was moved to a field with loamy fine sand soil (Vona loamy fine sand series) to evaluate irrigation ending date for a light textured soil with lower water holding capacity. The hypothesis is that the sandy soil may require continuation of irrigation and irrigation ending date may be delayed compared to a silty loam soil with higher water holding capacity. The procedure followed was similar to the earlier study where two sets of six nozzles were closed progressively as the grain formed starch layer.

Results and Discussion

Continuation of irrigation from the first ending date in early August (August 10-15) to the second ending date in the beginning of the fourth week (August 21-22) gave an increase of average 19.5 bushels of grain per acre. The additional irrigation application amounted to 2.1 inches. The yield difference from the August 22 ending date to the first week of September ending date, as normally practiced, was only 2.5 bushels per acre on average for four years. The additional irrigation quantity for the period from the first ending to last irrigation date amounted to 4.6 inches (additional 2.1 inches from second ending date) as an average for four years. The yearly yields are shown in figure 1.

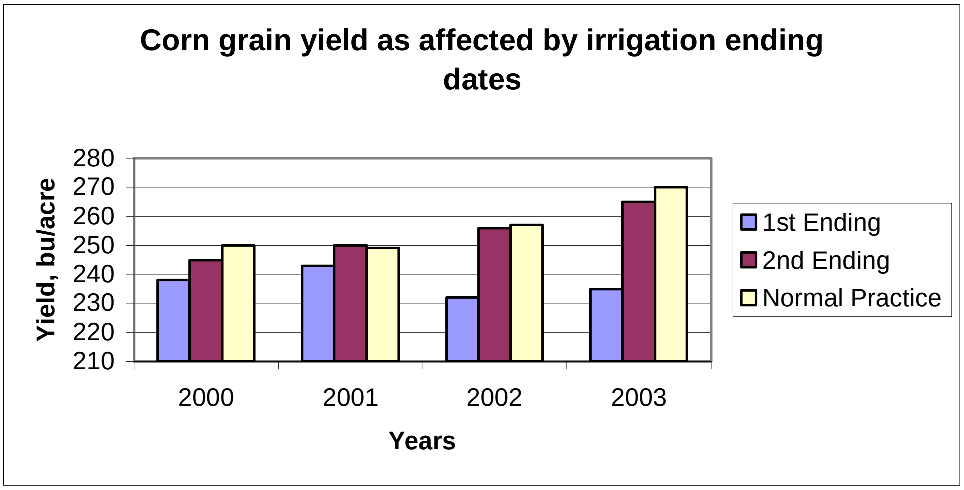

Figure 1: Yield of corn grain as affected by irrigation ending date at different growth stage on a silty loam soil, Stevens County, Kansas, 2000 -2003.

The tool used to determine the optimum irrigation ending date was the marginal value vs. marginal cost analysis. In this analysis corn price ranged from $2.00 to $2.75 per bushel, while pumping cost ranged from $3.00 to $8.00 per inch. Positive returns indicate that the marginal benefit of continuing irrigation was greater than the cost of applying water.

Figure 2 shows that under nearly all scenarios, irrigation remains profitable until the second ending date. However, irrigation past this growth stage may not be profitable (Figure 3). Return becomes negative at pumping cost of $4.00 per inch for corn even at $2.75.

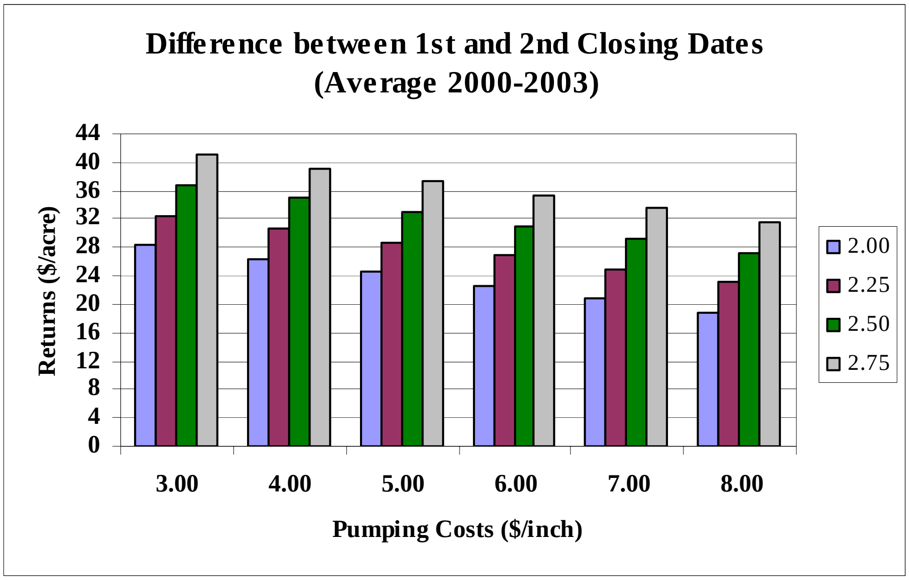

Figure 2: Returns at different levels of input cost and price of corn for difference between 1st and 2nd ending dates

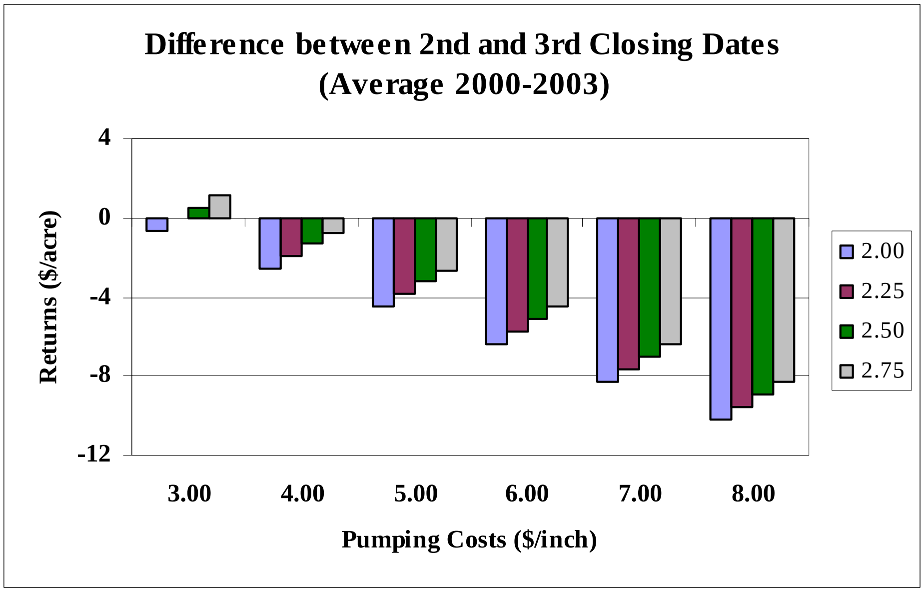

Figure 3: Returns at different levels of input cost and price of corn for difference between 2nd and 3rd ending dates

Kansas State University water management bulletin No. MF-2174 presents a table showing normal water requirements for corn between stages of growth and maturity. Corn grain, at full dent, will use 2.5 inches of water for the remaining 13 days before reaching physiological maturity.

The available water holding capacity of the soil in the study field is estimated to be approximately six inches or more per 3 feet of root zone. It is expected that at a 50 percent management allowable depletion level this soil will provide about 3 inches of water. This may be the reason that there was no appreciable benefit from continuing irrigation past August 21 or after the starch layer has moved past ½ to ¾ towards germ layer. The soil water sensors indicated that the soil water condition was adequate to carry the crop to full maturity. Soil water status monitored by gypsum block sensors is presented in Figure 4-6.

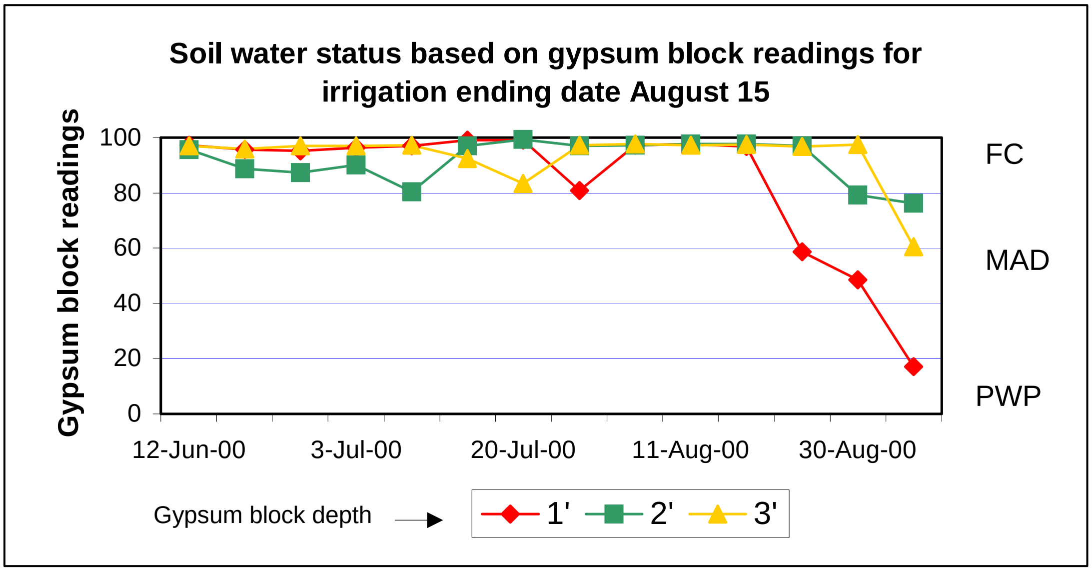

Figure 4: Soil water status for 1st irrigation ending date. (FC=field capacity, 100% available water holding capacity or AWHC, MAD=management allowable depletion, 50% AWHC, PWP=permanent wilting point, 0% AWHC)

Figure 4 shows that the soil water at first and third feet depths were falling below Management Allowable Depletion (MAD) level for the first ending date that caused reduction in yield. Figure 5 shows that soil water in first foot started to go down in the plots of second ending date, but there was enough in second and third foot to carry the crop to maturity. It is also seen that at this site for some reason the moisture level at 1-2' feet were at MAD level in the very beginning of the season. However, this changed as irrigation started.

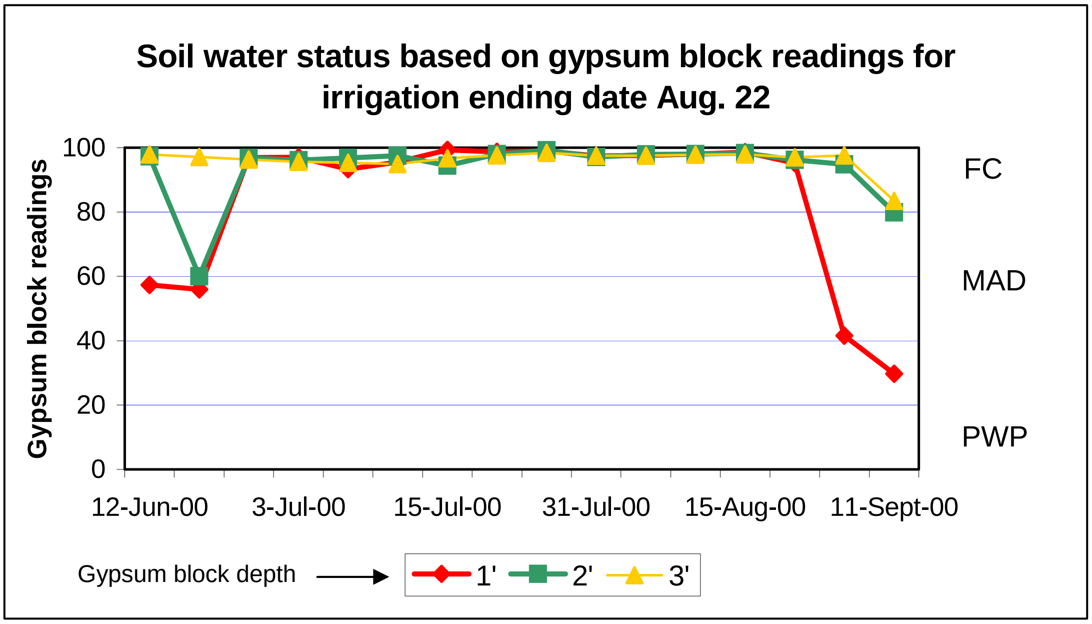

Figure 5: Soil water status for 2nd irrigation ending date. (FC = Field Capacity, MAD = Management Allowable Depletion, and PWP = Permanent Wilting Point)

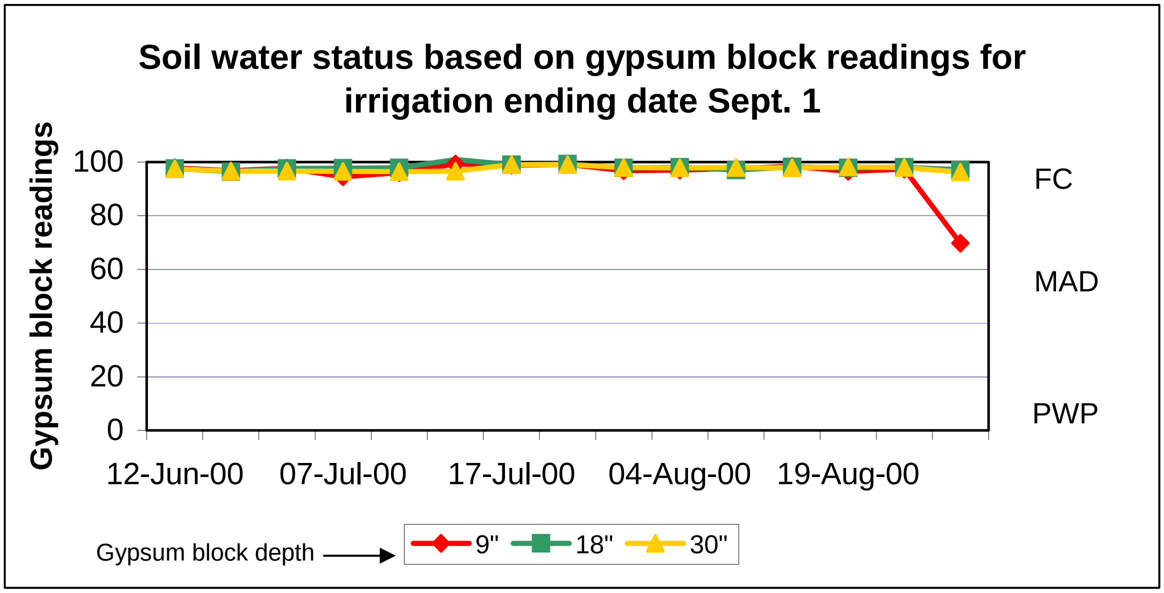

Figure 6: Soil water status on 3rd irrigation ending date. (FC = Field Capacity, MAD = Management Allowable Depletion, and PWP = Permanent Wilting Point)

Figure 6 shows soil water readings taken until September 11 at the area where irrigation continued until September 1 under producers practices, indicate that soil water was almost at Field Capacity, except for the first foot of the profile. The crop was already mature and there was no more water use. The profile was left with high water content over the winter. Most of the irrigated cornfields in western Kansas reflect this situation and have little room to store winter and early spring precipitation. This causes double loss from not taking advantage of natural precipitation and leaching of nutrient with the deep percolation of excess water. A three-year study by Rogers and Lamm (1994) also indicated that the irrigation practices of corn producers of western Kansas leave approximately 1.4 inches of available soil water per foot of soil profile.

Irrigated agricultural producers are continuously being educated on irrigation scheduling. Kansas State University Biological and Agricultural Engineering developed computer software called KanSched to provide the producers with an easy to use tool for irrigation scheduling. The irrigation events, rainfall, and crop water use (Evapotranspiration) data were entered to track soil water depletion pattern, which is presented in Figure 8. Tracking of crop water use and irrigation application show that the soil profile was pretty full at the end of the season when irrigation was continued until September 1.

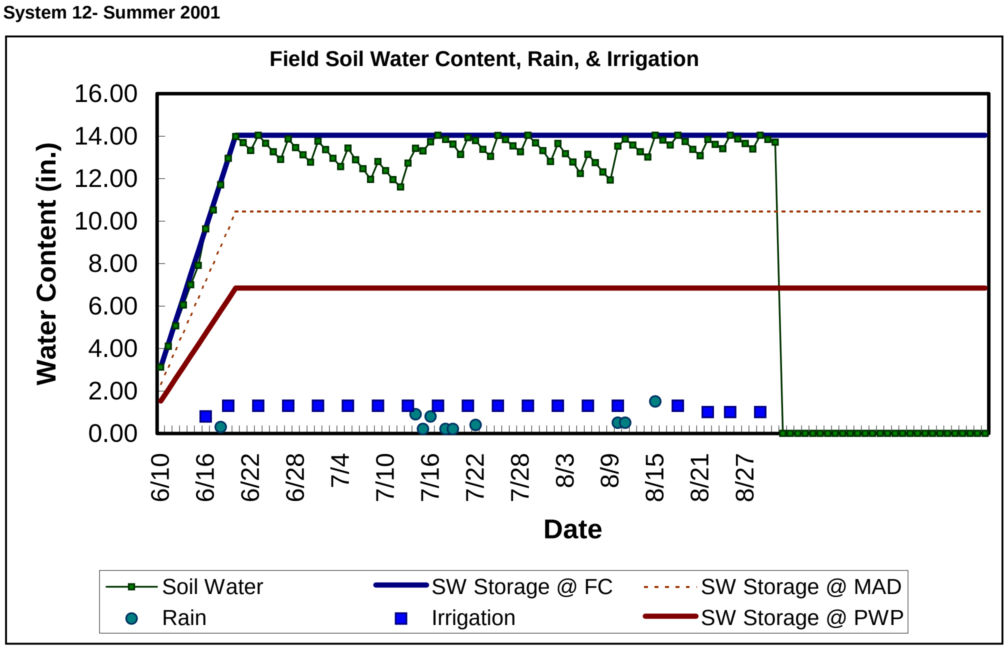

Figure 7: Chart showing water balance between soil water storage at field capacity and permanent wilting point. The dashed line in the middle represents management allowable depletion.

It would be worthwhile to mention that there was no appreciable eardrop observed in the field within the circular area with the first irrigation ending. However, the plants were dryer as compared to the rest of the field at the time of harvest.

Results of 2005 trial on Vona loamy fine sand needs to be continued to establish a trend. However, the first year results do indicate that the return remains in the positive at pumping cost of $5.00 per inch although the rate of return has been greatly reduced, Figure 9-10.

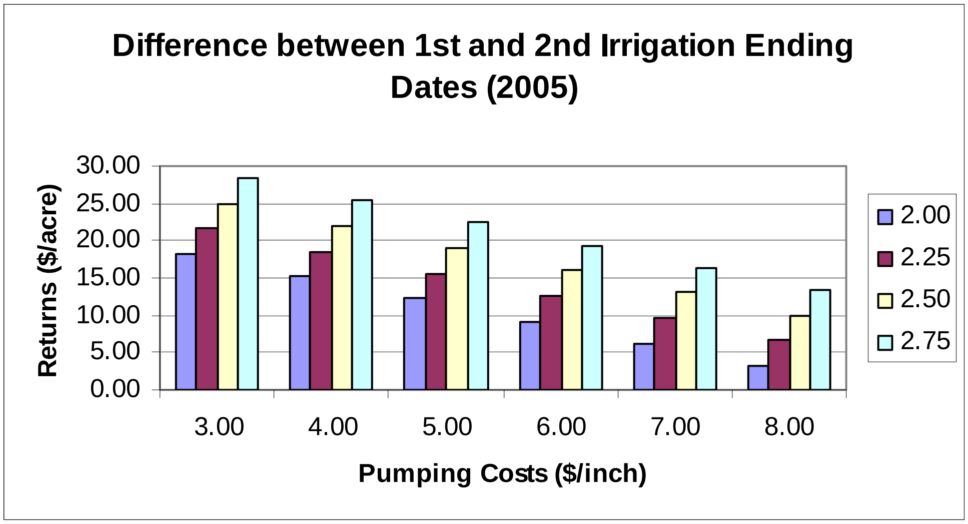

Figure 8: Returns at different levels of input cost and price of corn for difference between 1st and 2nd ending dates.

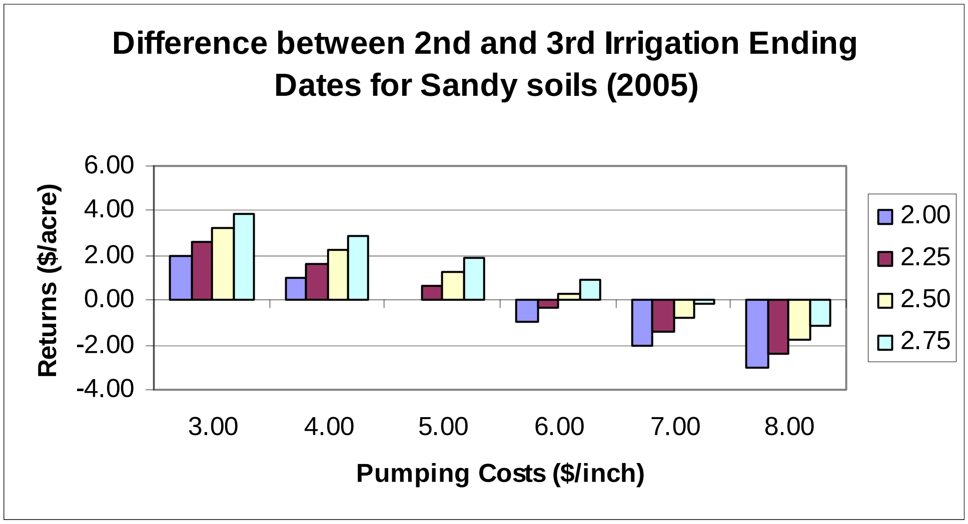

Figure 9: Returns at different levels of input cost and price of corn for difference between 2nd and 3rd ending dates

Conclusion

A four-year field study indicates that the present practice of irrigating until the formation of black layer in corn grain may not be economical. An earlier ending date for irrigation corresponding to the starch layer at ½ to ¾ of the grain may help improve the economic return and best utilize the soil profile water in a silt loam soil. Using KanSched or Soil water monitoring by other means may help in the decision process. However, this may require more cautious evaluation in a sandy soil for its low water holding capacity.

Acknowledgements

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CENTER PIVOT PRECISION MOBILE DRIP IRRIGATION

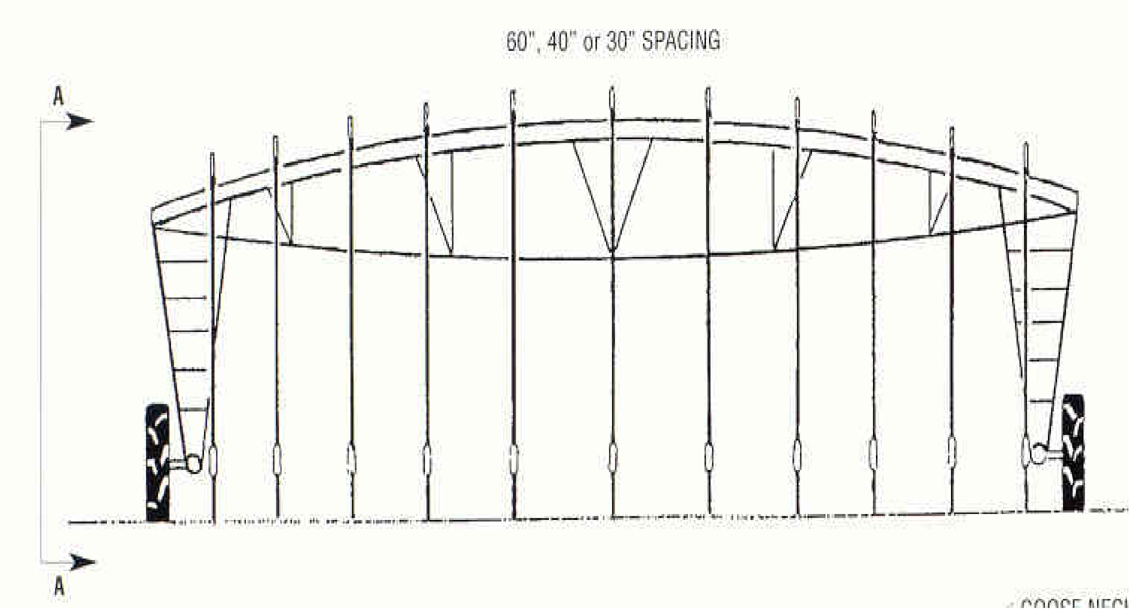
Brian L.S. Olson, Ph.D.
Kansas State University
105 Experiment Farm Rd.
Colby, KS 67701
Voice: 785-462-6281
bolson@oznet.ksu.edu

Dan Rogers, Ph. D.
Kansas State University
237 Seaton Hall, KSU
Manhattan, KS 66506
Voice: 785-539-2933
drogers@oznet.ksu.edu

INTRODUCTION

Precision mobile drip irrigation is an irrigation system where drip hoses are attached to a center pivot sprinkler and drug on top of the ground. The placement of water by the hoses on the ground could potentially increase irrigation efficiency over a standard drop nozzle system. In addition, problems associated with wet wheel tracks should be reduced. However, drag hoses lying on the ground could cause more management concerns for farmers. One example would be animal damage to the drip hoses which disrupts uniform water distribution. The objectives of this study were to compare yield from corn irrigated using precision mobile drip irrigation (PMDI) to sprinkler irrigation with drops (drop nozzle). The second objective was to discern if the emitters have a reduction in water flow over the season due to clogging. Figure 1 is a sprinkler with the drag hoses attached.

Figure 1



PROCEDURE

The study was initiated on a center pivot sprinkler located seven miles north and three miles west of Hoxie, KS. Cooperation from DLS Farms was very important to evaluating these two application methods. Three spans, spans 4, 5, and 7, of an eight span center pivot sprinkler were divided into two sections. Each section had either the PMDI system installed or the standard drop nozzle system. With this configuration, three replications of each method were achieved for a total of six plots. The center pivot sprinkler is nozzled to apply 300 gpm. Drag hose spacing on the PMDI system was 60 inches while the spacing on the drop nozzle system was 120 inches. The entire flow to the center pivot was screen filtered to 50 mesh.

For the 2004 growing season, the farmer strip-tilled the field the previous fall and applied 75 lbs/A of N as anhydrous ammonia and 7-25-0 lbs/A as 10-34-0. The field was planted on May 2, 2004 in circular rows with Mycogen 2E685 treated with Cruiser at 26,000 seeds/A with 50 lbs/A of N as 32% UAN applied in a 2x2. Appropriate pest management measures were taken to control weeds and insects.

For the 2005 growing season, manure was applied to the field, and then the field was strip-tilled in the fall. On April 28, 2005 Mycogen 2E762 treated with Cruiser was seeded in straight noncircular rows at 26,000 seeds/A with 50 lbs/A of N as 32% UAN applied in a 2x2. Appropriate pest management measures were taken to control weeds and insects.

Emitter water flow at the end emitter and then the 5, 10, and 15 emitter from the end of two drag hoses from each plot were captured for one minute on May 26, August 4, and September 13 in 2004 and May 27, July 29, and September 8 in 2005. Water flow for the entire drag hose was also collected for the two drag hoses along with the water flow from two drop nozzles on the same span.

Corn yield was collected in two ways. First, samples were hand harvested from forty feet of each plot. Samples were then dried, threshed, weighed, and yield was calculated on a bu/a basis. Yield was also collected at harvesting using a Green Star yield monitoring system for the entire field.

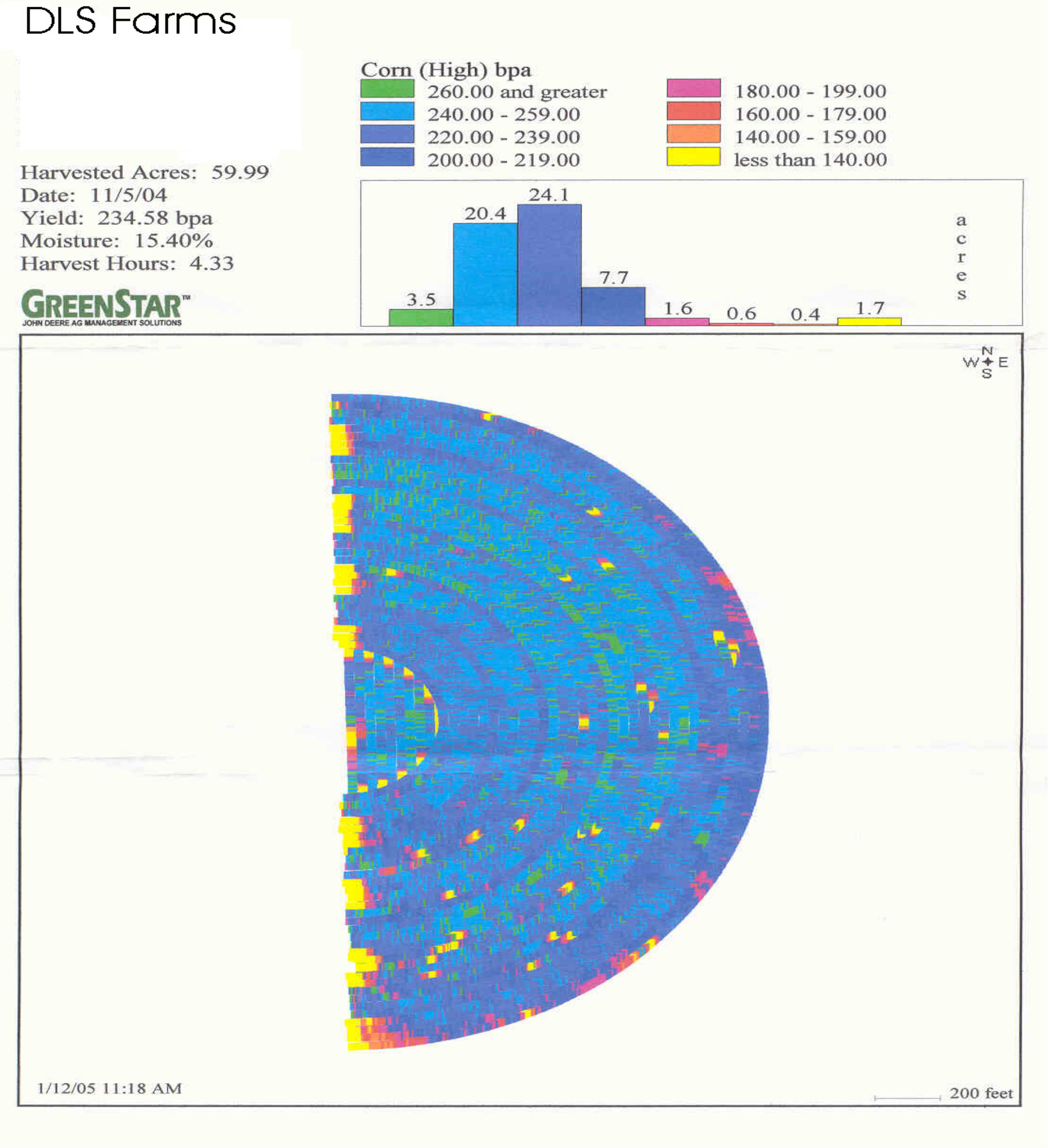
RESULTS

Weather conditions over the summer brought supplemental rainfall which allowed for respectable yields to be achieved at the site for both years. When comparing hand harvest yields, there was no significant difference between the PMDI treatment and the drop nozzle treatment in either year or when combined across years (Table 1). When looking at the 2004 field map (Fig. 2) or the 2005 field map (Fig. 3) generated by a yield monitor, no discernable pattern was evident between the two systems.

Table 1. Yield (bu/a) as influenced by irrigation treatment (Data from hand harvest)

Treatment	2004	2005	Combined Results
PMDI	233	239	236
Drop Nozzle	236	236	236
LSD (0.05)	NS	NS	NS

Fig. 2 – 2004 Field Map


DLS Farms

Harvested Acres: 59.99
Date: 11/5/04
Yield: 234.58 bpa
Moisture: 15.40%
Harvest Hours: 4.33

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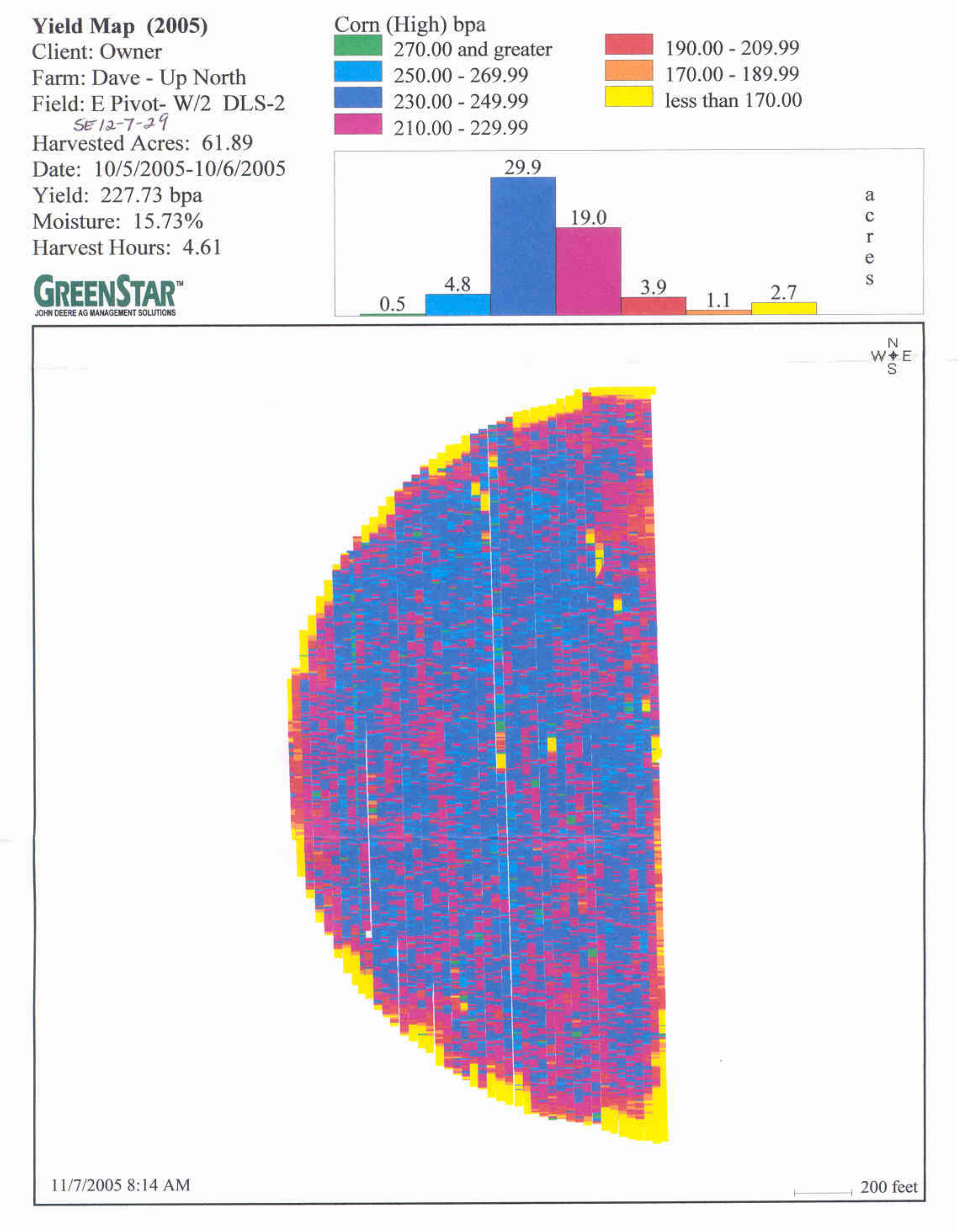
Fig. 3 – 2005 Field Map



Yield Map (2005)
Client: Owner
Farm: Dave - Up North
Field: E Pivot- W/2 DLS-2
SE 12-7-29
Harvested Acres: 61.89
Date: 10/5/2005-10/6/2005
Yield: 227.73 bpa
Moisture: 15.73%
Harvest Hours: 4.61

Corn (High) bpa
🟩 270.00 and greater
🟦 250.00 - 269.99
🟦 230.00 - 249.99
🟪 210.00 - 229.99
🟥 190.00 - 209.99
🟧 170.00 - 189.99
🟨 less than 170.00

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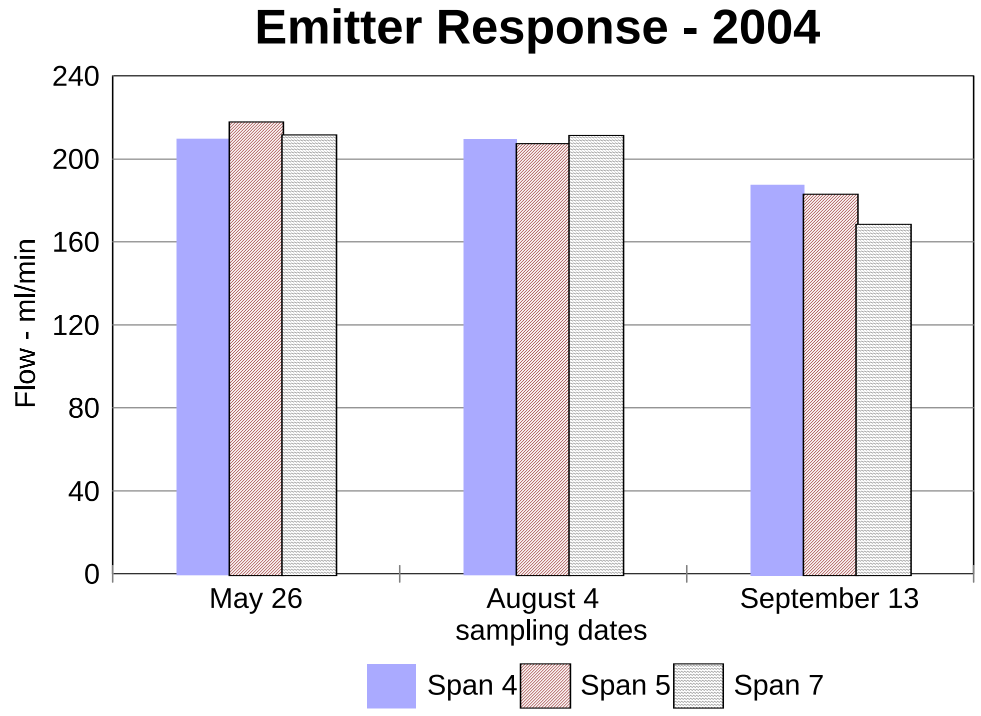
In 2004, the average emitter output over the summer declined from 214 ml/min. on May 24 to 209 ml/min on August 4 to 180 ml/min on September 13. Output from the emitters decreased by an average of 16% through the summer (Fig. 5). Output from the nozzles from span 4, 5, and 7 also decreased from an average of 2.51 gpm on May 26 to 2.48 gpm on August 4 to 2.28 gpm on September 13 (Fig. 4). The average reduction in flow was 9%. The 9% reduction in flow indicates that the overall pumping capacity of the well was reduced. However, the additional 7% reduction in flow rate from the emitters is likely due to emitter clogging.

In 2005, the average emitter output over the summer declined from 180 ml/min. on May 27 to 168 ml/min on July 29 to 158 ml/min on September 8. Output from the emitters decreased by an average of 14% through the summer (Fig. 5). Output from the nozzles from span 4, 5, and 7 actually increased from an average of 2.13 gpm on May 27 to 2.17 gpm on July 29 to 2.49 gpm on September 8. The average increase in flow was 17%. Why there was an increase in flow over this time is difficult to explain, but it may be related to a difference in field evaluation for the locations where the sampling was conducted. However, there was a greater difference in 2005 compared with 2004 in the flow between the average output of the emitters and the average output of the nozzles which implies increased clogging of the emitters.

Summary

In conclusion, as with any field evaluation, variability is inherently higher due to factors outside of the parameters that can be controlled by the investigators. However, there was no positive or negative impact on yield from those plots that were irrigated with the PMDI system versus a standard drop nozzle system. Emitter flow was decreased in both years when compared with nozzle flow which was likely due to emitter clogging. Clogging of the emitters over the life of the system along with puncturing of the hoses from wildlife appear to be two negatives of the system, while one benefit of the system was the reduced wheel pivot tracks when the PMDI system is used to water crops near the pivot wheel. The authors of this paper would again like to thank DLS farms for their cooperation on this project.

Fig. 5. Emitter response from 2004 and 2005



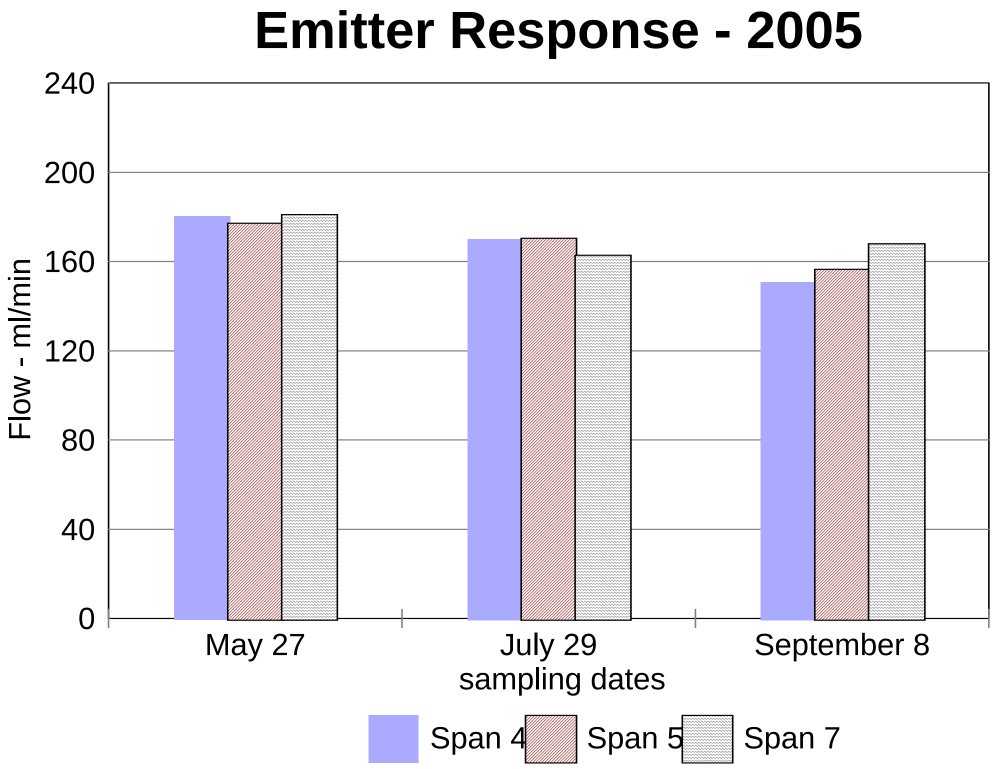
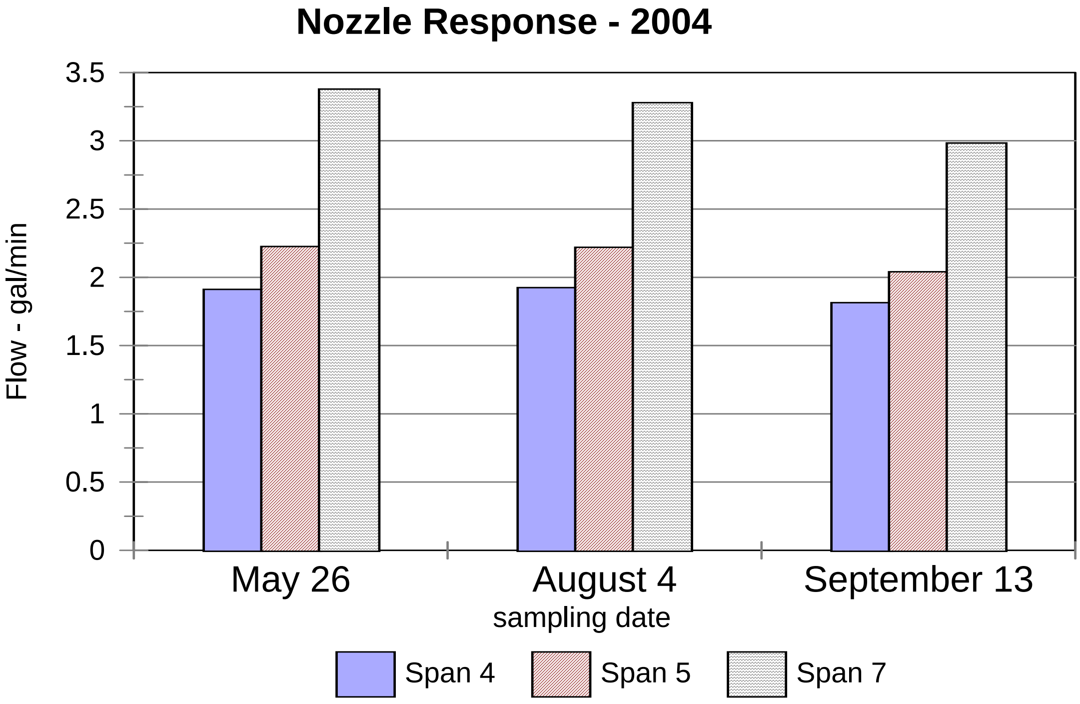
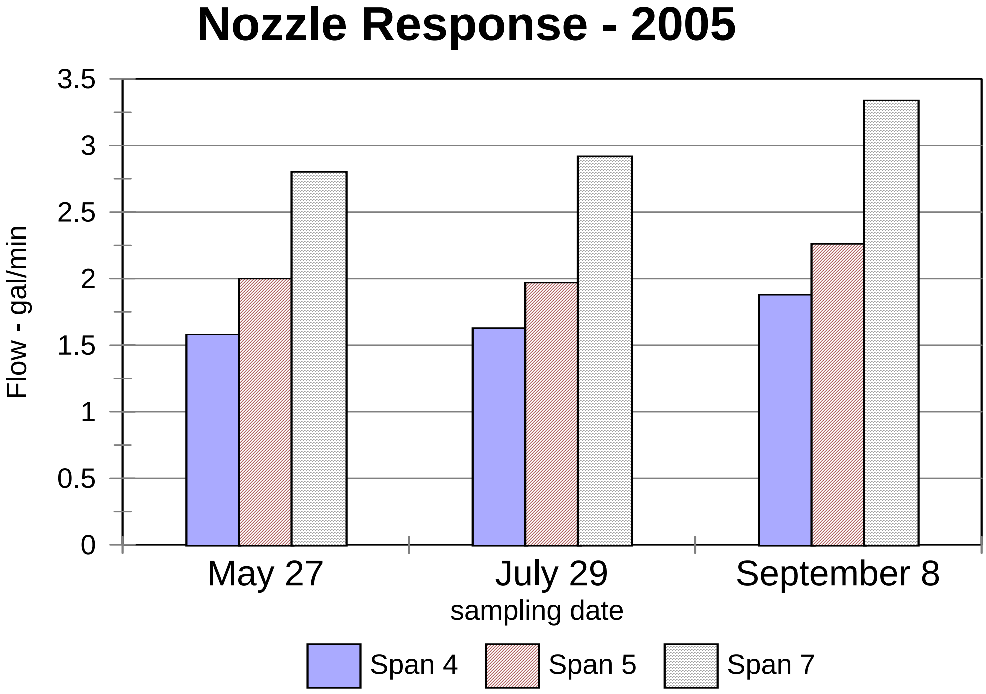


Fig. 6. Nozzle Response from 2004 and 2005





Using Your Records to Locate Inefficient Pumping Plants

Thomas W. Dorn
Extension Educator
University of Nebraska-Lincoln in Lancaster County
444 Cherrycreek Road, Lincoln, NE 68528
Voice: 402-441-7180 Fax: 402-441-7148
Email: tdorn1@unl.edu

Pumping Plant Performance

The Nebraska Pumping Plant Criteria

The University of Nebraska established a performance criteria for pumping plants, based on field tests of pumping plants, lab tests of engines and manufacturer data on three-phase electric motors. The criteria is commonly referred to as the Nebraska Pumping plant Criteria (NPC). A pumping plant meeting the NPC is delivering the expected amount of useful work, *measured as water horsepower hours (whp-h),* for the amount of energy consumed.

The NPC should be thought of as a reasonable target for every new pumping plant. It is possible for a well-designed pump coupled to an efficient power unit to exceed the NPC. In fact, large scale pump testing projects have found around 10% of pumping plants in the field that are performing over 100% of the NPC.

The NPC (Table 1) is stated in terms of horsepower-hours of work input into the pump shaft and in terms of the water horsepower hours (whp-h) produced per unit of energy consumed. Stating performance in these terms makes it possible to compare the performance of all pumping plants using a given energy source, regardless of pumping rate, lift, and system pressure.

Table 1. The Nebraska Pumping Plant Performance Criteria (NPC)

Energy Source	hp-h / energy unit[a]	whp-h/energy unit[b]	Energy units[c]
Diesel	16.66	12.5	Gallons
Gasoline	11.50	8.66	Gallons
Propane	9.20	6.89	Gallons
Natural gas (mcf)[d]	82.2	61.7	MCF
Natural gas (therm)	8.9	6.67	Therm (100,000 BTU)
Electricity[e]	1.18	0.885	kWh

The author personally conducted over 200 pumping plant tests in Kansas and Nebraska from 1978 to 1981. The most surprising finding was producers generally did not know when a pumping plant was inefficient until they received the test results, even when the pumping plant test showed it was using 30 to 50 percent more energy than expected by the NPC. The reason producers couldn't recognize poorly performing pumping plants is they almost never have two pumping plants operating under the same pumping conditions of volume, lift and system pressure. They therefore didn't have any way to judge the relative performance of a given pumping plant vs. others.

How to use long term records to locate inefficient pumping plants

Four large-scale pumping plant studies in the 1950s, 60s, 70s and 80s found fairly consistent results. The average performance rating was between 76% and 81% of the NPC. Discussing average performance ratings is useful when thinking about the energy wasted within the irrigation industry as a whole. But individual producers need to identify which specific pumping plants are highly efficient, average or poor. The primary purpose of this paper is to demonstrate how a producer can use existing records to identify pumping plants that should be tested by a professional so those with low performance ratings can be adjusted, repaired or replaced with a better design.

This involves a five step calculation procedure.

Step 1. Calculate the water horsepower output of the pumping plant.

whp-h = acre-inches[f] pumped x total head (ft) / 8.75 whp-h / ac-in x ft

Where:

- whp-h = water horsepower hours
- acre-inches = volume of water necessary to cover an acre one inch deep. 27,154 gallons.
- total head (ft) = lift (ft) + system pressure (ft)
  - lift = distance (feet) from the water level inside the well casing to the discharge head while pumping.
  - system pressure (ft) = psi x 2.31 ft/psi

Step 2. Performance = whp-h / fuel used for the test period

Step 3. Performance rating = (Performance / NPC for the energy source) x 100%

Step 4. Potential fuel savings = ((100% - %NPC) / 100) x fuel used for the test period

Step 5. Potential Dollar Savings = Fuel savings x Fuel price

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[f] Conversion to acre-inches

- If the water meter totalizer registers in gallons, divide gallons by 27,154.
- If the water meter totalizer registers in acre-feet, multiply acre-feet by 12.
- If the water meter totalizer registers in cubic feet, divide cubic feet by 3,630.

Example:

- Test period: Entire irrigation season
- System: Center pivot sprinkler system with a diesel engine.
- Pumping water level: 140 feet
- Pressure at the discharge head: 40 psi
- Ac-in of water pumped (from water meter)[f]: 1,415
- Total fuel used for test period = 3,571 gallons of diesel
- Diesel fuel price: $2.20 /gallon

Step 1. whp-h = acre-inches[f] pumped x total head (ft) / 8.75
= 1415 x (140 + (40 x 2.31)) / 8.75
= 1415 x (140 + 92.4) / 8.75
= 1415 x (232.4) / 8.75
= 37,518 whp-h

Step 2. Performance = whp-h for the test period / fuel used for the test period
= 37,518 whp-h / 3,571 gallons
= 10.5 whp-h / gallon

Step 3. Performance rating = (Performance/ NPC for the energy source) x 100%
= (10.5 whp-h / gallon / 12.5 whp-h / gallon of diesel) x 100%
= 84%

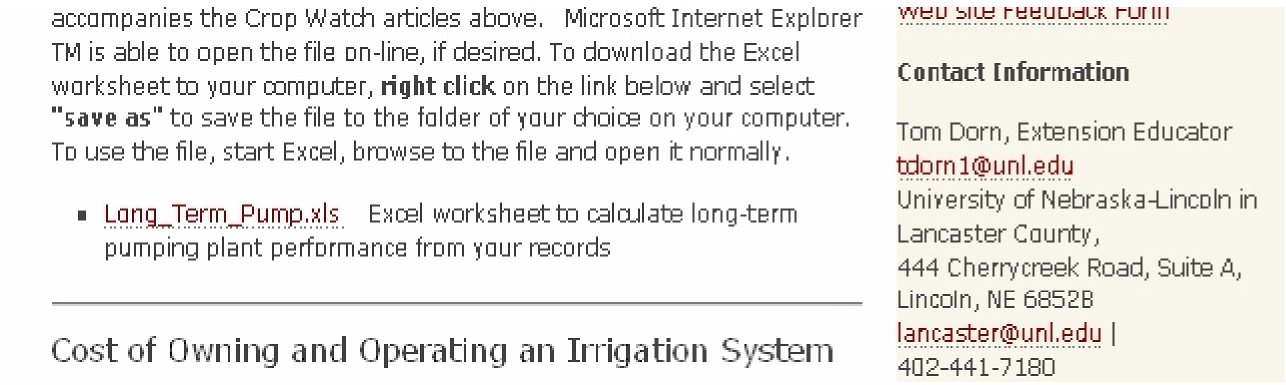
Step 4. Potential fuel savings = ((100% - %NPC) / 100) x fuel used for the test period
= ((100% - 84%) /100) x 3,571 gallons of diesel
= 0.16 x 3,571 gallons
= 571 gallons

Step 5. Potential Dollar Savings = Fuel savings x Fuel price
= 571 gallons x $2.20 per gallon
= $1256.20

For those with a computer and access to the internet, the author has created an Excel workbook to simplify the calculations. Results include: performance, performance rating, potential energy savings and potential dollar savings using records. The program can be run on-line in most popular internet browsers or it can be downloaded to the user's computer and opened in Excel.

The link to this workbook can be found on the Irrigation page of University of Nebraska in Lancaster County website http://lancaster.unl.edu/ag/crops/irrigate.shtml Click on Long Term Pump.xls as shown in the screen capture on the next page.
The workbook has a fill in the blanks worksheet plus three examples.

The Diesel Example worksheet is represented by the lower screen capture. Notice the tabs at the bottom of the worksheet. Click on the tabs to see examples or to open and use the Worksheet to calculate the performance of your pumping plants.



accompanies the Crop Watch articles above. Microsoft Internet Explorer TM is able to open the file on-line, if desired. To download the Excel worksheet to your computer, **right click** on the link below and select **"save as"** to save the file to the folder of your choice on your computer. To use the file, start Excel, browse to the file and open it normally.

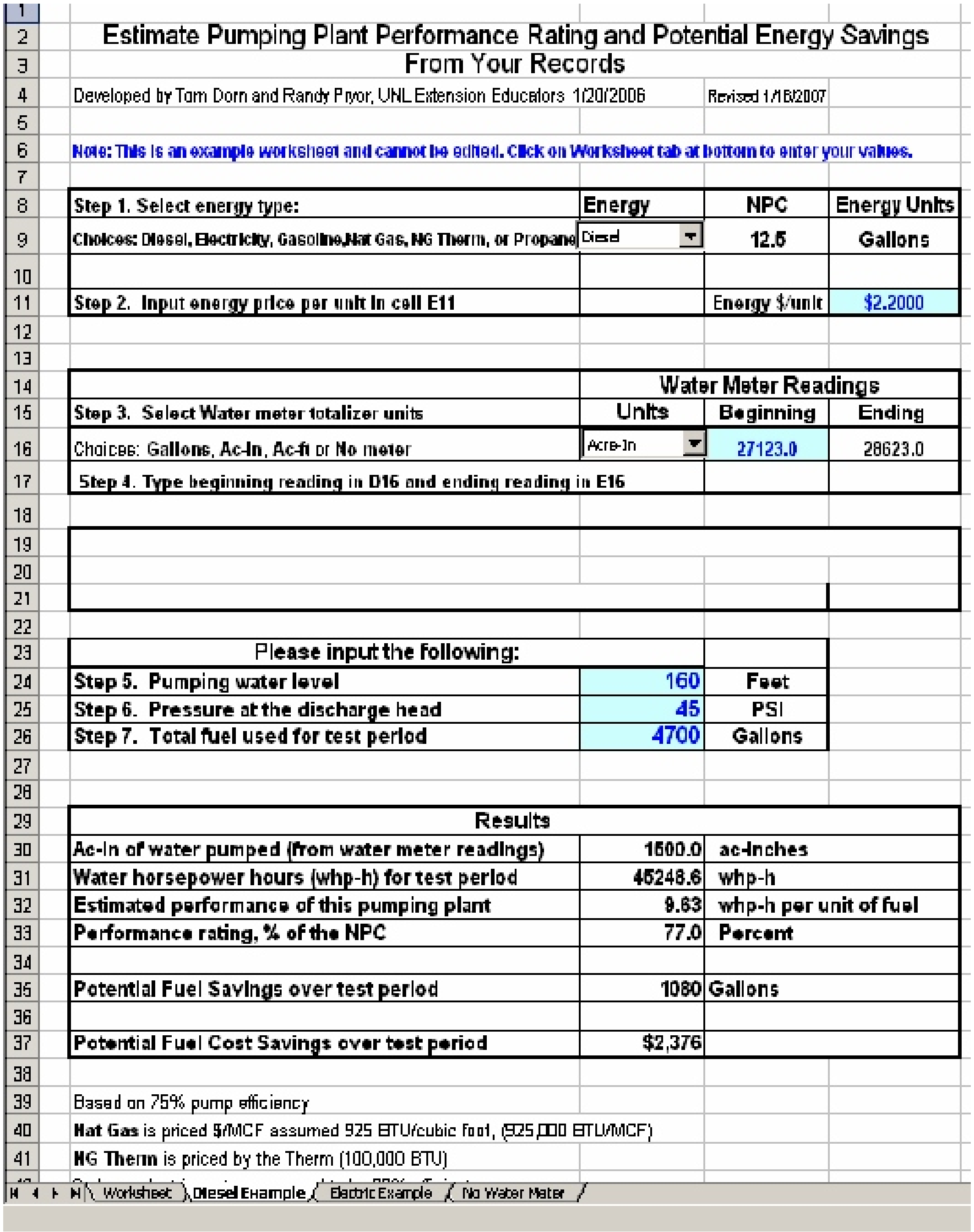
- Long_Term_Pump.xls Excel worksheet to calculate long-term pumping plant performance from your records

Cost of Owning and Operating an Irrigation System

Web Site Feedback Form

Contact Information

Tom Dorn, Extension Educator
tdorn1@unl.edu
University of Nebraska-Lincoln in Lancaster County,
444 Cherrycreek Road, Suite A,
Lincoln, NE 68528
lancaster@unl.edu |
402-441-7180



	B	C	D	E
1				
2	Estimate Pumping Plant Performance Rating and Potential Energy Savings			
3	From Your Records			
4	Developed by Tom Dorn and Randy Pryor, UNL Extension Educators 1/20/2006		Revised 1/16/2007	
5				
6	Note: This is an example worksheet and cannot be edited. Click on Worksheet tab at bottom to enter your values.			
7				
8	**Step 1. Select energy type:**	**Energy**	**NPC**	**Energy Units**
9	**Choices: Diesel, Electricity, Gasoline,Nat Gas, NG Therm, or Propane**	Diesel	**12.5**	**Gallons**
10				
11	**Step 2. Input energy price per unit in cell E11**		Energy $/unit	$2.2000
12				
13				
14		**Water Meter Readings**		
15	**Step 3. Select Water meter totalizer units**	**Units**	**Beginning**	**Ending**
16	Choices: **Gallons**, **Ac-In**, **Ac-ft** or **No meter**	Acre-In	27123.0	28623.0
17	**Step 4. Type beginning reading in D16 and ending reading in E16**			
18				
19				
20				
21				
22				
23	**Please input the following:**			
24	**Step 5. Pumping water level**	160	**Feet**	
25	**Step 6. Pressure at the discharge head**	45	**PSI**	
26	**Step 7. Total fuel used for test period**	4700	**Gallons**	
27				
28				
29	**Results**			
30	**Ac-In of water pumped (from water meter readings)**	**1500.0**	**ac-inches**	
31	**Water horsepower hours (whp-h) for test period**	**45248.6**	**whp-h**	
32	**Estimated performance of this pumping plant**	**9.63**	**whp-h per unit of fuel**	
33	**Performance rating, % of the NPC**	**77.0**	**Percent**	
34				
35	**Potential Fuel Savings over test period**	**1080**	**Gallons**	
36				
37	**Potential Fuel Cost Savings over test period**	**$2,376**		
38				
39	Based on 75% pump efficiency			
40	**Nat Gas** is priced $/MCF assumed 925 BTU/cubic foot, (925,000 BTU/MCF)			
41	**NG Therm** is priced by the Therm (100,000 BTU)			

Cost of Production and Equitable Leasing Arrangements for Center Pivot Irrigated Corn in Central Nebraska

Daniel M. O'Brien
Extension Agricultural Economist
K-State Research and Extension
Northwest Research Extension Center – Colby, Kansas
Voice: 785-462-6281   Fax: 785-462-2315
Email: dobrien@oznet.ksu.edu
Website: www.agmanager.info/

The focus of this paper is to provide an economic analysis of the profitability of center pivot irrigated corn enterprises in central Nebraska in 2007. An analysis of equitable crop share leasing arrangements and breakeven cash rental rates for irrigated corn producers follows from the estimates of irrigated corn enterprise profitability.

Currently (early February 2007) grain futures and expected 2007 harvest prices for U.S. corn are appreciably higher than at almost any other time since the early 1970s. The reasons for these high grain futures prices have to do with bioenergy-related market demand and other related factors affecting grain markets – but that is not the focus of this paper. Here, we are concerned about the impact of expected high corn prices upon not just the gross revenue but also the expected net profitability of the irrigated corn enterprise for 2007. This analysis is based on grain and fertilizer market prices and conditions as they existed in late January, early February, 2007.

With heightened expectations for corn prices in 2007and for gross/net revenues for irrigated corn enterprises, there is much interest on the part of both farm operator/tenants and landowners regarding the impact of these market factors upon cropland leasing arrangements. In this paper the equity and returns of irrigated crop share and cash rent leasing arrangements for landowners and tenants are examined for irrigated corn enterprises in central Nebraska.

2007 Irrigated Corn Production, Revenue and Cost Assumptions

Historically high expected corn prices for the 2007 crop have unquestionably raised expectations about the profitability of raising irrigated corn under center pivot sprinkler systems in central Nebraska (Tables 1 & 2). An expected harvest cash price of $3.50 per bushel for corn is used in this analysis. Other key assumptions and information sources used in this analysis are as follows:

Crop Yields and Direct Crop Production Costs: The UNL Extension publication "Nebraska Crop Budgets – 2006" (EC872), edited by UNL Extension Specialists Roger A. Selley and Robert N. Klein, was the primary source of yield and direct crop cost of production information used in these budgets (Tables 1 & 2). Three (3) alternative cost-return budgets are presented for irrigated corn in Nebraska:

A. Center pivot irrigated corn in a conventional-till continuous corn rotation: 175 bu/acre yield, 13 acre inches of irrigation water applied

B. Center pivot irrigated corn in a no-till continuous corn rotation: 180 bu/acre yield, 9 acre inches of irrigation water applied

C. Center pivot irrigated corn in a no-till corn-soybean rotation: 190 bu/acre yield, 9 acre inches of irrigation water applied

Assumptions about yield goals and actual yields, the amounts and costs of corn seed, herbicide and insecticide treatments, the amount of fertilizer applied, the number and types of field operations, and other management expenses are all taken from UNL Crop Production budgets. Drying, harvesting and hauling operation costs was also taken from this same source. Fertilizer prices are obtained from retail fertilizer sales contacts in Central Nebraska (Table 1).

Farm Program Payments: USDA farm program payments on irrigated cropland in central Nebraska are assumed to be $35 per acre (Source: Paul Burgener, UNL Extension) (Table 1).

Crop Revenue Coverage Insurance: Crop Revenue Coverage (CRC) insurance premium costs for irrigated corn in Buffalo County, Nebraska are estimated using the USDA Risk Management Agency online insurance premium calculator. Chicago Board of Trade December 2007 corn futures prices on January 31st were used in estimating the CRC insurance premiums (Table 1).

Custom Field Operation and Harvesting Costs: Expenses for field operations and harvesting are estimated using the most recent state-wide custom rate averages for Nebraska. This approach is a departure from field operation cost estimates in UNL Extension publication EC872, but consistent with the approach used in K-State Research and Extension crop budgets to estimate field crop cost of production. Labor cost estimates associated with field operation custom rates are calculated in the manner used in K-State budgets (Tables 1 & 2).

Irrigation Equipment and Pumping Costs: K-State Research and Extension estimates of irrigation equipment costs are used to represent the cost of the center pivot irrigation system (20 year life), power unit (7 year life), and well, pump and gearhead (25 year life). Straight-line (non-tax) depreciation methods are used to allocate the cost of the system over its lifespan. An interest rate of

Table 1. Irrigated Corn Cost Return Budget

Center Pivot Irrigated Corn Cost-Return Budget in Nebraska

Daniel O'Brien, Agricultural Economist - NW Kansas, K-State Research & Extension

Nebraska Crop Budgets for 2006 (Editors Roger Selley & Robert Klein), EC872

Tillage System:	Conv'l. Till	No-Till	No-Till
Crop Rotation:	Corn-Corn	Corn-Corn	Corn-Soyb.
INCOME PER ACRE		Yield Level, bu/ac	
A. Actual Yield - bushels per acre	175	180	190
Yield Goal - bushels per acre	*190*	*195*	*205*
B. Price per bushel	$3.50	$3.50	$3.50
C. Net government payment	$35.00	$35.00	$35.00
D. Indemnity payments	$0.00	$0.00	$0.00
E. Miscellaneous income	$0.00	$0.00	$0.00
F. Returns/acre ((A x B) + C + D + E)	$647.50	$665.00	$700.00
COSTS PER ACRE			
1. Seed	$58.90	$60.80	$63.65
2. Herbicide	27.03	27.59	38.45
3. Insecticide / Fungicide	4.65	4.64	1.86
4. Fertilizer and Lime	51.37	53.37	45.37
5. Crop Consulting	12.50	12.50	12.50
6. Crop Insurance	11.66	11.63	11.52
7. Drying	45.50	46.80	24.70
8. Miscellaneous	20.04	31.02	26.59
9. Custom Hire / Machinery Expense	119.33	85.80	88.29
10. Non-machinery Labor	13.48	9.70	9.98
11. Irrigation			
a. Labor	5.00	5.00	5.00
b. Fuel and Oil	64.61	44.73	44.73
c. Repairs and Maintenance	4.29	2.97	2.97
d. Depreciation on Equipment and Well	53.10	53.10	53.10
e. Interest on Equipment and Well	43.52	43.52	43.52
12. Land Charge / Rent	139.00	139.00	139.00
G. SUB TOTAL	$673.97	$632.17	$611.22
13. Interest on 1/2 Nonland Costs	17.68	15.74	15.79
H. TOTAL COSTS	$691.65	$647.91	$627.01
I. RETURNS OVER COSTS (F - H)	($44.15)	$17.09	$72.99
J. TOTAL COSTS/BUSHEL (H/A)	$3.95	$3.60	$3.30
K. RETURN TO ANNUAL COST (I+13)/G	-3.93%	5.19%	14.53%

TABLE 2. Production Inputs -- Center Pivot Irrigated Corn - Central NE

	Yield Level (bu)				
ITEM	175	180	190		
Seed, 1,000/acre* Bt Seed	31.0	32.0	33.5	$1.90	/1000
Fertilizer:					
N (anhydrous)	200	210	170	$0.20	/lb
N	7	7	7	$0.15	/lb
P	24	24	24	$0.43	/lb
Herbicide					
Bicep II Magnum	2.10	2.10	2.10	$11.25	/qt
Exceed	0.25	0.25	0.50	$12.40	/oz
+ Crop Oil Concentrate	0.50	0.50	0.50	$0.60	/pt
2,4-D Ester 4#	0.00	0.30	0.00	$1.88	/pt
Gramoxone Inteon	0.00	0.00	1.50	$5.03	/pt
NIS	0.00	0.00	6.00	$0.13	/oz
Insecticide / Fungicide					
Regent 4 SC	0.83	0.83	0.00	$3.46	/oz
Lorsban 15 G	0.10	0.10	0.10	$2.00	/lb
Capture 2 EC	0.51	0.51	0.51	$1.74	/oz
Mustang Max	0.40	0.40	0.40	$1.71	/oz
Capture 2 EC	0.00	0.00	0.05	$1.74	/oz
Irrigation water, inches	13	9	9	$4.97	/in

	Yield Level (bu)			Custom	
ITEM	175	180	190	Rate	
Tillage/Planting/Chemical Applications:					
Chopping stalks	1	0	0	$8.77	/ac
Disk	1	0	0	$9.28	/ac
Field cultivate	1	0	0	$7.97	/ac
Row crop cultivation	1.25	0	0	$7.59	/ac
Hoe	0	0	0.1	$5.00	/ac
Planting - conventional row crop	1	0	0	$12.65	/ac
Planting - no-till	0	1	1	$12.81	/ac
Anhydrous application	1	1	1	$8.53	/ac
Fertilizer application	0	0	0	$5.29	/ac
Herbicide application	1	1.2	1	$5.13	/ac
Insecticide - ground rig application	0.25	0.25	0.5	$5.12	/ac
Insecticide - airplane application	0.32	0.32	0.34	$6.59	/ac
Harvest					
Base charge	1	1	1	$26.12	/ac
Grain cart custom charge	175	180	190	$0.060	/bu
Hauling with truck	175	180	190	$0.100	/bu
Non-machinery labor	1.35	0.97	1.00		$10.00
Land charge/rent	$139.00	$139.00	$139.00		
Interest on capital					9.0%

Irrigation Equipment	Investment, $/ac	Years	Salvage value
Well, pump and gearhead value	$398.00	25	0%
Power unit and meter	$94.00	7	0%
Irrigation system	$475.00	20	0%

9% is used on the irrigation equipment to represent the economic cost of paying for and eventually replacing the irrigation equipment. Pumping cost acre inch of water applied are calculated using current diesel fuel prices and irrigation system assumptions relevant to central Nebraska (Tables 1 & 2).

Land Charge / Rent: An irrigated farmland rental rate of $139 per acre for central Nebraska is assumed in these cost-return budgets, as reported in the 2006 Nebraska survey of farmland and rental values (Bruce Johnson, UNL Agricultural Economist) (Table 1).

Interest on Operating Costs: A 9% interest rate on operating costs is used in these budgets, consistent with K-State cost of production budgets (Tables 1 & 2).

Expected Profitability of Center Pivot Irrigated Corn in 2007 in Central Nebraska

Expected net returns over all costs except management for the 175 bu., 180 bu. and 190 bu. per acre yield scenarios are ($44.15), $17.09, and $72.99 per acre, respectively (Table 1). As stated earlier, these budgets are based on expected harvest cash corn prices of $3.50 per bushel and cash rental rates of $139 per acre for irrigated corn in central Nebraska.

Equitable Crop Shares for Irrigated Corn Leases

An analysis of equitable crop share leasing arrangements for irrigated corn illustrates the marked impact of alternative irrigation equipment ownership situations. Specifically, equitable irrigated cropland leasing arrangements differ depending on whether farm operator/tenants or landowners own the center irrigation systems and power units involved (Table 3). Two irrigation equipment ownership scenarios are examined for each of the three corn yield/crop rotation regimes in this analysis.

Scenario #1: The first irrigate crop share lease scenario represents situations where the farm operator/tenant owns the center pivot sprinkler system and the power unit, pays 67% of herbicide, drying and crop insurance costs, and contributes 100% of all other crop inputs. In this scenario, the landowner contributes the land, well, pump and gearhead, and pays 33% of herbicide, drying and crop insurance costs.

Scenario #2: The second lease scenario represents situations in which the farm operator/tenant pays 67% of herbicide, drying and crop insurance costs, and contributes 100% of all other crop inputs. The landowner contributes the land, center pivot sprinkler system, power unit, well, pump and gearhead, and pays 33% of herbicide, drying and crop insurance costs.

Table 3. Equitable Crop Shares for Irrigated Corn Leases

		Conventional Tillage *Corn after Corn*	**No-Till** *Corn after Corn*	**No-Till** *Corn after Soybeans*
		Actual Yield: 175 bu./acre	**Actual Yield: 180 bu./acre**	**Actual Yield: 190 bu./acre**
Scenario #1: **Operator' Contribution**: Pivot System + Power Unit; 2/3 Herbicides, Drying & Crop Insurance **Landowner's Contribution**: Land; 1/3 Herbicides, Drying & Crop Insurance				
Expenses ($/acre)	Operator $	$475	$432	$438
	Landowner $	$210	$211	$209
Calculated Equitable Crop Shares (%)	Operator %	69%	67%	68%
	Landowner %	31%	33%	32%
Returns to Management @ $3.50/bu Corn$ ($/ac)	Operator $	($26)	$15	$36
	Landowner $	($12)	$7	$17
Scenario #2: **Operator's Contribution**: 2/3 Herbicides, Drying & Crop Insurance **Landowner's Contribution**: Land, Pivot System + Power Unit; 1/3 Herbicides, Drying & Crop Insurance				
Expenses ($/acre)	Operator $	$413	$370	$375
	Landowner $	$273	$274	$272
Calculated Equitable Crop Shares (%)	Operator %	60%	57%	58%
	Landowner %	40%	43%	42%
Returns to Management @ $3.50/bu Corn$ ($/ac)	Operator $	($23)	$12	$31
	Landowner $	($15)	$9	$22

Landowner's and tenant's total expenses, equitable shares, and profit/loss are reported for these two scenarios for each of the three yield/cropping system regimes (Table 3). Equitable share percentages (%s) for crop share leases are the focus of these analyses.

University of Nebraska-Lincoln Extension personnel indicate that the most common terms for irrigated crop share leasing arrangements in central Nebraska are 1/3-2/3 leases (i.e. 33% of returns for the landowner, 67% for the tenant) with herbicides, crop insurance and drying costs shared or paid for (i.e. 33% of these specific expenses) by the landowner (source: Paul Burgener, UNL Extension). Ownership of the center pivot systems and pumping plants will likely vary from farm to farm and may affect the proportional revenue shares between operator/tenants and landowners in irrigated crop share leasing arrangements.

Scenario #1 Results: Under Scenario #1 (ownership of the center pivot system and power unit by the operator/tenant) the calculated equitable crop shares for the tenant for the 175 bu., 180 bu. and 190 bu. scenarios are 69%, 67% and 68%, respectively. These calculated equitable crop share percentages are nearly identical to the most common 33%-67% landowner-tenant crop share arrangement for irrigated crop share leases in central Nebraska.

Scenario #2 Results: Under Scenario #2 (ownership of center pivot system and power unit by the landowner) the calculated equitable crop shares for the tenant for the 175 bu., 180 bu. and 190 bu. scenarios are 60%, 57% and 58%, respectively. These downward adjustments in equitable crop share percentages for the operator/tenant reflect greater contributions of financially valued resources by the landowner to the irrigated crop share leasing arrangement in the form of the center pivot irrigation system and power unit.

Cash Lease Equivalents and Breakevens

This part of the analysis is intended to address some of the current questions raised by farm operator/tenants and landowners about cash rental rates in the current environment for grain prices. Two measures of financial returns in cropland leasing arrangements are calculated (Table 4). The first measure is "risk adjusted crop share equivalent returns to landowners". The second is "tenant's breakeven returns to land and management".

Risk Adjusted Crop Equivalent Returns: The landowner's risk adjusted crop equivalent returns are calculated in the following manner. The returns per acre a landowner would receive with an equitably adjusted crop share lease arrangement are reduced by a risk adjustment or percentage. This risk adjustment is applied to account for the additional financial risk assumed by tenants in cash rental arrangements as opposed to crop share lease arrangements where tenants and landowners share more financial risk from the irrigated corn enterprise. A 3% risk adjustment factor is used in this analysis.

Breakeven Returns to Land: The farm operator/tenant's breakeven returns to land indicate the maximum amount that could be paid for irrigated cash rent under these corn production and irrigation equipment ownership scenarios before the operator/tenant begins losing money. Returns to management are not quantified or specifically accounted for in this crop budget analysis. If a tenant is paying the breakeven / maximum cash rent amount for irrigated cropland as indicated in this analysis, then they are not allowing for any return to management from this irrigated corn enterprise.

Two alternative corn prices ($3.00 and $3.50 per bushel) are used to illustrate the impact of higher grain price and revenue expectations for irrigated corn in 2007. The impact of alternative irrigation ownership scenarios (see the previous section) is also illustrated (Table 4).

Results - $3.00/bu. Corn / Tenant Owns Center Pivot and Power Unit: The landowner's equivalent risk adjusted financial returns under an equitable crop share rent arrangement is $131 /acre for the 175 bu/acre irrigated corn scenario, $146 /acre for the 180 bu/acre scenario, and $155 /acre for the 190 bu/acre scenario. The operator/tenant's breakeven returns to cover land and management are $48 /acre for the 175 bu/acre irrigated corn scenario, $105 /acre for the 180 bu/acre scenario, and $131 /acre for the 190 bu/acre scenario.

Results - $3.00/bu. Corn / Landowner Owns Center Pivot and Power Unit: The landowner's equivalent risk adjusted financial returns under an equitable crop share rent arrangement is $180 /acre for the 175 bu/acre irrigated corn scenario, $200 /acre for the 180 bu/acre scenario, and $211 /acre for the 190 bu/acre scenario. The operator/tenant's breakeven returns to cover land and management are $111 /acre for the 175 bu/acre irrigated corn scenario, $167 /acre for the 180 bu/acre scenario, and $194 /acre for the 190 bu/acre scenario.

Results - $3.50/bu. Corn / Tenant Owns Center Pivot and Power Unit: The landowner's equivalent risk adjusted financial returns under an equitable crop share rent arrangement is $156 /acre for the 175 bu/acre irrigated corn scenario, $175 /acre for the 180 bu/acre scenario, and $184 /acre for the 190 bu/acre scenario. The operator/tenant's breakeven returns to cover land and management are $135 /acre for the 175 bu/acre irrigated corn scenario, $195 /acre for the 180 bu/acre scenario, and $226 /acre for the 190 bu/acre scenario.

Results - $3.50/bu. Corn / Landowner Owns Center Pivot and Power Unit: The landowner's equivalent risk adjusted financial returns under an equitable crop share rent arrangement is $214 /acre for the 175 bu/acre irrigated corn scenario, $237 /acre for the 180 bu/acre scenario, and $250 /acre for the 190 bu/acre scenario. The operator/tenant's breakeven returns to cover land and management are $198 /acre for the 175 bu/acre irrigated corn scenario, $257 /acre for the 180 bu/acre scenario, and $289 /acre for the 190 bu/acre scenario.

Table 4. Cash Lease Equivalents & Breakeven Land Costs

	Conv. Tillage ***Corn-Corn***	**No-Till** ***Corn-Corn***	**No-Till** ***Corn-Soybeans***
	175 bu./acre	**180 bu./acre**	**190 bu./acre**
I. Cash Rent Equivalents & Breakevens @ $3.00 / bushel Corn Price:			
Scenario #1: Operator: Pivot System + Power Unit, Crop Expenses / **Landowner**: Land*			
Landowner's Equivalent Share Rent *(3% Risk Adj.)*	$131 /ac	$146 /ac	$155 /ac
Tenant's Breakeven Land Cost *(Less Mgmt Charge)*	$48 /ac	$105 /ac	$131 /ac
Scenario #2: Operator: Crop Expenses / **Landowner**: Land, Pivot System + Power Unit*			
Landowner's Equivalent Share Rent *(3% Risk Adj.)*	$180 /ac	$200 /ac	$211 /ac
Tenant's Breakeven Land Cost *(Less Mgmt Charge)*	$111 /ac	$167 /ac	$194 /ac
II. Cash Rent Equivalents & Breakevens @ $3.50 / bushel Corn Price:			
Scenario #1: Operator: Pivot System + Power Unit, Crop Expenses / **Landowner**: Land*			
Landowner's Equivalent Share Rent *(3% Risk Adj.)*	$156 /ac	$175 /ac	$184 /ac
Tenant's Breakeven Land Cost *(Less Mgmt Charge)*	$135 /ac	$195 /ac	$226 /ac
Scenario #2: Operator: Crop Expenses / **Landowner**: Land, Pivot System + Power Unit*			
Landowner's Equivalent Share Rent *(3% Risk Adj.)*	$214 /ac	$237 /ac	$250 /ac
Tenant's Breakeven Land Cost *(Less Mgmt Charge)*	$198 /ac	$257 /ac	$289 /ac

* Assume operator/tenant pays 67% fertilizer, drying and crop insurance expenses, 100% remaining crop costs.

Discussion of Results: For $3.00 /bushel corn, a landowner's equivalent risk adjusted financial returns under an equitable share rent arrangement are greater than operator/tenant's breakeven returns to cover land and management for all scenarios considered. For $3.50 /bushel corn, this remains true for the 175 bu/acre scenario, but not for the 180 bushel and 190 bushel per acre budgets, although the returns are similar. The tenant's breakeven returns to land and management in the $3.50 per bushel examples are markedly higher than the current or highest historic cash rental rates charged for irrigated cropland in the Nebraska-Kansas region. The comparable returns to landowners under equivalent equitable irrigation share leases with higher corn prices offer a reasonable alternative to cash rental arrangements in these examples.

Conclusions

The expected profitability of irrigated corn and the expected returns to operator/tenants and landowners in alternative crop leasing arrangements are markedly affected by expectations of higher corn prices for 2007. Whether all the adjustments in 2007 crop input prices for irrigated corn production have been fully realized to date is an open question. It is also unknown to what degree the higher selling price expectations for the 2007 corn crop will be actually realized at harvest time, although corn futures prices are other industry and governmental policy indicators are supportive of that perspective at the current time.

This analysis indicates that landowner's returns under risk adjusted crop share leasing arrangements are expected to be of similar to operator/tenant's breakeven cash rental rates for irrigated cropland in 2007. Given the uncertainty about both corn selling prices and the cost of production inputs for corn in 2007, it may be advisable for farm operator/tenants and landowners to consider equitably designed crop share leasing arrangements as opposed to cash rent leases for irrigated cropland in the coming year. Alternatively, existing cash rental arrangements could be adjusted to include both fixed (with a cash rent base payment) and flexible (with crop share adjustment for higher realized net revenues) components to share higher crop revenues should historically high actual 2007 harvest prices for corn and expected crop yields (or better) actually come to fruition in fall 2007.

A focus on grain prices in this analysis and these decisions is only partially adequate. Instead, the focus of local crop leasing arrangements for any particular farm operation or piece of irrigated farmland would more appropriately placed on net crop enterprise revenues instead of on crop prices alone. In the risky, uncertain environment for irrigated corn production in 2007, crop share leasing arrangements are a viable and reasonable option to cash lease arrangements. They are a mechanism that may help farm operator/tenants manage their financial risk in high cost irrigated corn enterprises while allowing landowners to means to participate is potentially 2007 higher crop revenues.