Proceedings of the 24th Annual Central Plains Irrigation Conference, Colby, Kansas, February 21-22, 2012
Available from CPIA, 760 N. Thompson, Colby, Kansas

ERRATICITY OF SPRINKLER IRRIGATED CORN IN 2011

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INTRODUCTION

A definition:

> erraticity (ĭr·ə·tĭs'·ĭ·tē) *n.* The quality or state of being erratic, characterized by the lack of consistency, regularity or uniformity.

That's correct, there is no such word, but you sure know it when you see it. Unfortunately, we saw a lot of it this past season in sprinkler irrigated corn.

Figure 1. Nonuniformity of sprinkler irrigated corn under extreme drought conditions in southwest Kansas in 2011.

These instances of erraticity resulted in low quality, low- or non-yielding corn production. Crop water stress caused by the extreme drought in portions of the central and southern Great Plains is ultimately responsible for the erraticity. However, there may be ways to reduce erraticity and its harmful effects by improvements in design and management of center pivot sprinklers for corn production that can minimize water losses.

SPRINKLER PACKAGE EFFECTS ON WATER LOSSES

Center pivot sprinkler management techniques to avoid water losses begin at the design and installation stages with selection of an appropriate sprinkler package. Typical sprinkler packages in use to today are medium and high pressure impacts which are located on top of the sprinkler span (approximately 12 to 15 ft height above soil surface), low pressure rotating spray nozzles which are typically located on the span or at least above the crop canopy, low pressure fixed spray applicators that are located above and within the crop canopy and LEPA (low energy precision application) that are located near the ground surface (usually 1 to 2 ft maximum height above soil surface). Commercial LEPA applicators often can apply water in multiple modes (e.g., bubble mode with little or no wetting of the canopy, fixed spray mode, and chemigation mode that sprays the undersides of the leaves). The popular low pressure fixed spray applicators have also been categorized by their location with respect to the canopy with the terms LESA (low elevation spray application, 1 to 2 ft maximum height) and MESA (mid elevation spray application, 5 to 10 ft maximum height) (Howell, 1997). Application with MESA is typically above the crop canopy for all or most of the crop season depending on the crop (e.g., MESA application occurs within top portions of corn canopy in last 30 to 40 days of irrigation season). There are numerous water loss pathways using center pivot sprinklers and each type of sprinkler package has advantages and disadvantages as outlined by Howell (2006) that must be balanced against the water loss hazards (Table 1).

Table 1. Water loss components associated with various sprinkler packages. Adapted from Howell (2006).

<table>
<tr><th rowspan="2">Water Loss Component</th><th colspan="4">Sprinkler Package</th></tr>
<tr><th>Overhead
(Impact sprinklers, rotating or fixed spray applicators)</th><th>MESA</th><th>LESA</th><th>LEPA</th></tr>
<tr><td>Droplet evaporation</td><td rowspan="3">Yes</td><td rowspan="5">Yes</td><td>Yes</td><td rowspan="2">No</td></tr>
<tr><td>Droplet drift</td><td>No</td></tr>
<tr><td>Canopy evaporation</td><td>Yes
(not major)</td><td>No
(chemigation mode only)</td></tr>
<tr><td>Impounded water evaporation</td><td>No</td><td>Yes</td><td>Yes
(major)</td></tr>
<tr><td>Wetted soil evaporation</td><td>Yes</td><td>Yes</td><td>Yes
(limited)</td></tr>
<tr><td>Surface water redistribution</td><td rowspan="2">No,
(but possible)</td><td>Yes,
(not major)</td><td>Yes</td><td rowspan="2">Yes
(not major unless surface storage is not used)</td></tr>
<tr><td>Runoff</td><td>Yes</td><td>Yes</td></tr>
<tr><td>Percolation</td><td>No</td><td>No</td><td>No</td><td>No</td></tr>
</table>

Windy and hot conditions during the growing season affect center pivot sprinkler irrigation uniformity and evaporative losses. As a result many producers in the southern and central Great Plains have adopted sprinkler packages and methods that apply the water at a lower height within or near the crop canopy height, thus avoiding some application nonuniformity caused by wind and also droplet evaporative losses.

In-canopy and near-canopy sprinkler application can reduce evaporative losses by nearly 15% (Table 2), but introduce a much greater potential for irrigation nonuniformity. These sprinkler package systems are often adopted without appropriate understanding of the requirements for proper water management, and thus, other problems such as runoff and poor soil water redistribution occur.

Table 2. Partitioning of sprinkler irrigation evaporation losses with a typical 1 inch application for various sprinkler packages. (Adapted from Howell et al., 1991; Schneider and Howell, 1993).

Sprinkler package	Air loss, %	Canopy loss, %	Ground loss, %	Total loss,%	Application efficiency, %*
Impact sprinkler ≈ 14 ft height	3	12	--	15	85
MESA ≈ 5 ft height	1	7	--	8	92
LEPA ≈ 1 ft height	--	--	2	2	98

* Ground runoff and deep percolation are considered negligible in these data.

Traditionally, center pivot sprinkler irrigation systems have been designed to uniformly apply water to the soil at a rate less than the soil intake rate to prevent runoff from occurring (Heermann and Kohl, 1983). These design guidelines need to be either followed or intentionally circumvented with appropriate design criteria when designing and managing an irrigation system that applies water within the canopy or near the canopy height where the full sprinkler wetted radius is not developed. Peak application rates for in-canopy sprinklers such as LESA (low elevation spray application) and LEPA (low energy precision application) might easily be 5 to 30 times greater than above-canopy sprinklers (Figure 2).

Runoff from LEPA sprinklers was negligible on 1% sloping silt loam soils in eastern Colorado but exceeded 30% when slopes increased to 3% (Buchleiter, 1991). Runoff from LEPA with basin tillage was approximately 22% of the total applied water and twice as great as MESA (mid elevation spray application at 5 foot applicator height) for grain sorghum production on a clay loam in Texas (Schneider and Howell, 2000). Basin tillage created by periodic diking of crop furrow (2 to 4 m spacing), rather than reservoir tillage created by pitting or digging small depressions (0.5 to 1 m), is often more effective at time averaging of LEPA application rates, and thus, preventing runoff (Schneider, 2000).

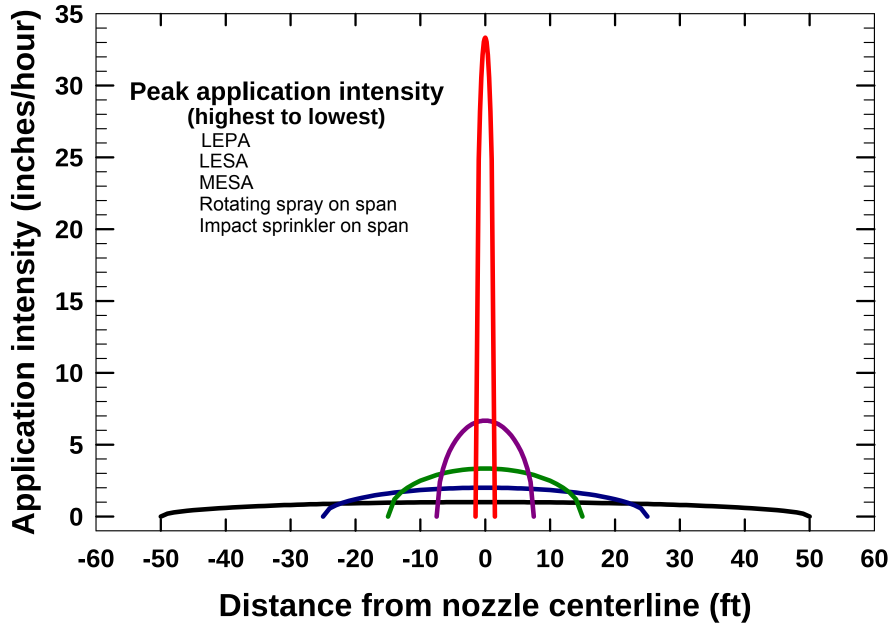

Figure 2. Application intensities for LEPA, LESA, MESA, rotating sprays on span and impact sprinklers on the span as related to the typical size of their wetting pattern.

Decreasing the application intensity is the most effective way to prevent irrigation field runoff losses and surface redistribution within the field (Figure 3.) When runoff and surface redistribution occurs using in-canopy sprinklers because of a reduced wetting pattern, one solution would be to raise the sprinkler height.

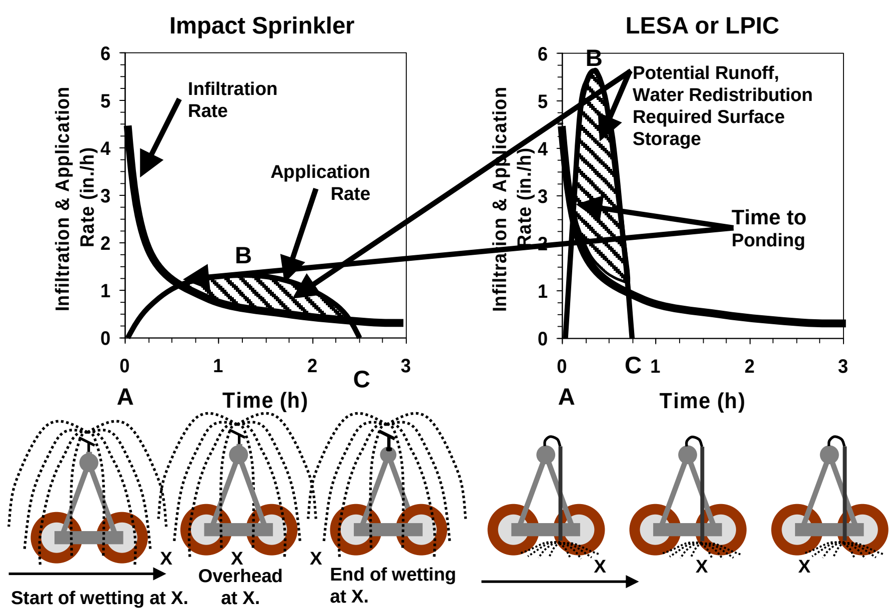

Figure. 3. Illustration of runoff or surface water redistribution potential for impact and LESA sprinkler application packages for an example soil. After Howell (2006).

One might assume that the erraticity observed in sprinkler irrigated fields in 2011 was primarily associated with the evaporative water loss components shown in Table 1, but that is probably not the case. When using fixed plate applicators near or within the canopy (MESA, LESA and LEPA), the magnitude of field runoff and particularly surface redistribution within the field may overwhelm the evaporative loss reductions possible with these packages. Surveys conducted by Kansas State University have indicated that approximately 90% of the center pivot sprinkler systems in western Kansas use fixed plate applicators and nearly 60% have sprinkler nozzle height less than 4 ft above the soil surface (Rogers et al. 2009). The erraticity can be caused by failure to follow appropriate guidelines for irrigation with near- and in-canopy sprinklers.

SOME GUIDING PRINCIPLES FOR IN-CANOPY APPLICATION

A prototype of the LEPA system was developed as early as 1976 by Bill Lyle with Texas A&M University. Jim Bordovsky joined the development effort in 1978 (McAlavy and Dillard, 2003) and the first scientific publication of their work was in 1981 (Lyle and Bordovsky, 1981). Although, originally LEPA was used in every furrow, subsequent research (Lyle and Bordovsky, 1983) demonstrated the superiority for alternate furrow LEPA. The reasons are not always evident, but they may result from the deeper irrigation penetration (twice the volume of water per unit wetted area compared with every furrow LEPA), possible improved crop rooting and deeper nutrient uptake, and less surface water evaporation (~30-40% of the soil is wetted). The seven guiding principles of LEPA were given by Lyle (1992) as:

1) *Use of a moving overhead tower supported pipe system (linear or center pivotal travel)*
2) *Capable of conveying and discharging water into a single crop furrow*
3) *Water discharge very near the soil surface to negate evaporation in the air*
4) *Operation with lateral end pressure no greater than 10 psi when the end tower is at the highest field elevation*
5) *Applicator devices are located so that each plant has equal opportunity to the water with the only acceptable deviation being where nonuniformity is caused by nozzle sizing and topographic changes*
6) *Zero runoff from the water application point*
7) *Rainfall retention which is demonstrably greater than conventionally tilled and managed systems.*

The other types of in-canopy and near-canopy sprinkler irrigation do not necessarily require adherence to all of these seven guidelines. However, it is unfortunate that there has been a lack of knowledge or lack of understanding of the importance of these principles because many of the problems associated with in-canopy and near-canopy sprinkler irrigation can be traced back to a failure to follow or effectively “work around” one of these principles. In-canopy and near-canopy application systems can definitely reduce evaporative losses

(Table 2), but these water savings must be balanced against runoff and within field water redistribution, deep percolation and other soil water nonuniformity problems that can occur when the systems are improperly designed and managed.

PROVIDING PLANTS EQUAL OPPORTUNITY TO ROOT-ZONE SOIL WATER

The No. 5 LEPA guiding principle listed earlier emphasizes the importance of plants having equal opportunity to root-zone soil water. Ensuring this equal opportunity requires sufficient uniformity of water application and/or soil water infiltration. Key issues that must be addressed are irrigation application symmetry, Crop row orientation with respect to center pivot sprinkler direction of travel, and the seasonal longevity of the sprinkler pattern distortion caused by crop canopy interference.

SYMMETRY OF SPRINKLER APPLICATION

Increased sprinkler application uniformity will often result in increased yields, decreased runoff, and decreased percolation (Seginer,1979). Improved sprinkler uniformity can be desirable from both economic and environmental standpoints (Duke et al., 1991). Their study indicated irrigation nonuniformity can result in nutrient leaching from over-irrigation and water stress from under-irrigation. Both problems can cause significant economic reductions.

Sprinkler irrigation does not necessarily have to be a uniform broadcast application to result in each plant having equal opportunity to the irrigation water. Equal opportunity can still be ensured using a LEPA nozzle in the furrow between adjacent pairs of crop rows provided runoff is controlled (Figure 4).

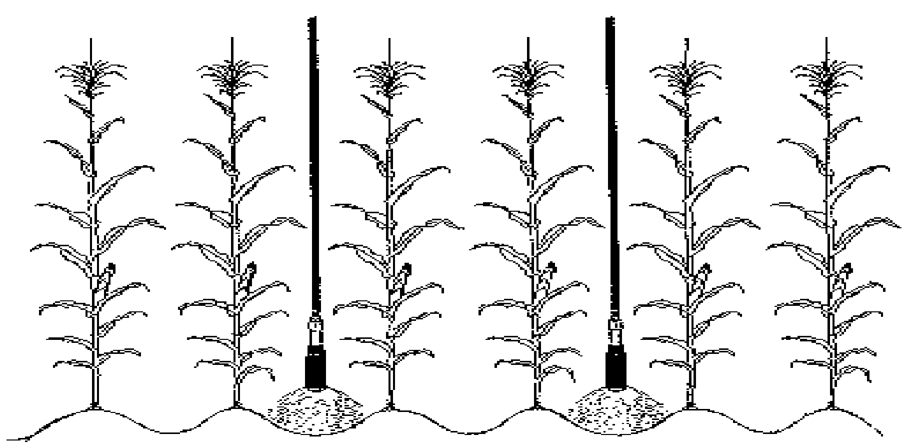

Figure 4. LEPA concept of equal opportunity of plants to applied water. LEPA heads are centered between adjacent pairs of corn rows. Using a 5–ft nozzle spacing with 30-inch spaced crop rows planted circularly results in plants being approximately 15 inches from the nearest sprinkler. After Lamm (1998).

Some sprinkler application nonuniformity can also be tolerated when the crop has an intensive root system (Seginer, 1979). When the crop has an extensive root system, the effective uniformity experienced by the crop can be high even though the actual resulting irrigation system uniformity within the soil may be quite low. Additionally, when irrigation is deficit or limited, a lower value of application uniformity can be acceptable in some cases (von Bernuth, 1983) as long as the crop economic yield threshold is met.

Many irrigators in the U.S. Great Plains are using wider in-canopy sprinkler spacings (e.g., 7.5, 10, 12.5, and even 15 ft) in an attempt to reduce investment costs (Yonts et al., 2005). Surveys from western Kansas in 2005 and 2006 indicated only 34% of all sprinkler systems with nozzle height of less than 4 ft had consistent nozzle spacing less than 8 ft (Rogers et al. 2009). Sprinkler nozzles operating within a fully developed corn canopy experience considerable pattern distortion and the uniformity is severely reduced as nozzle spacing increases (Figure 5).

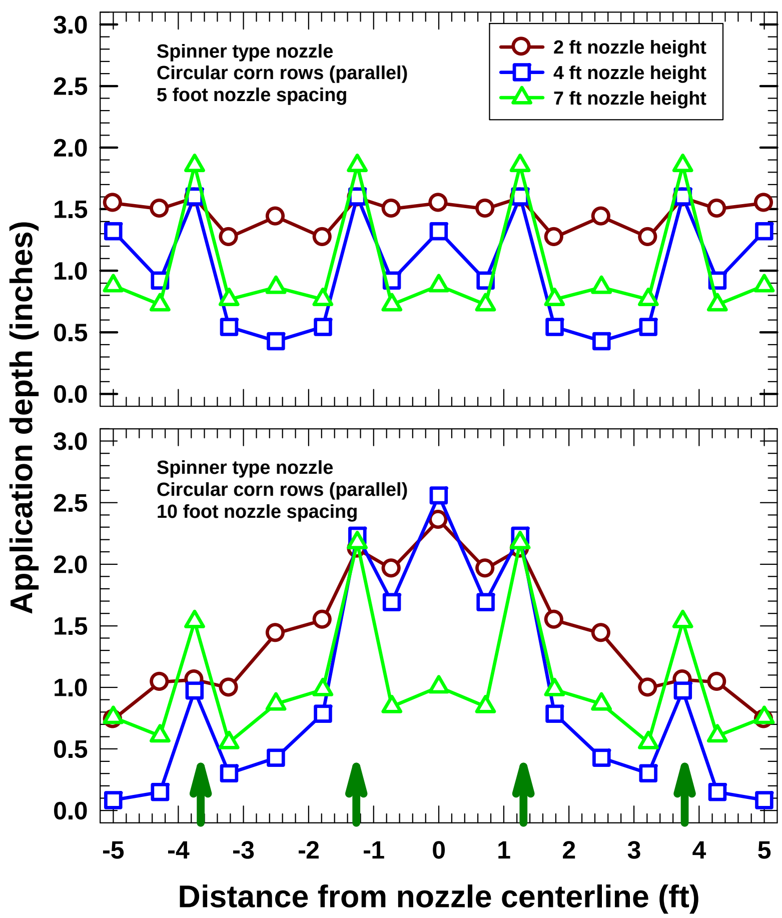

Figure 5. Differences in application amounts and application patterns as affected by sprinkler nozzle height and spacing. Center pivot sprinkler lateral is traversing parallel to the circular corn rows. Data are from a fully developed corn canopy, July 1996, KSU Northwest Research-Extension Center, Colby, Kansas. Data are mirrored about the nozzle centerline for display purposes. Arrows on X-axis represent location of corn rows and thus the location for higher stemflow amounts.

Although Figure 5 indicates large application nonuniformity, these differences may or may not always result in crop yield differences. Hart (1972) concluded from computer simulations that differences in irrigation water distribution occurring over a distance of approximately 3 ft were probably of little overall consequence and would be evened out through soil water redistribution.

Some irrigators in the Central Great Plains contend that their low capacity systems on nearly level fields restrict runoff to the general area of application. However, nearly every field has small changes in land slope and field depressions which do cause field runoff, in-field redistribution or deep percolation in ponded areas when the irrigation application rate exceeds the soil infiltration rate. In the extreme drought years of 2000 to 2003 that occurred in the U. S. Central Great Plains, even small amounts of surface water movement affected sprinkler-irrigated corn production (Figure 6). Similarly some of the worst erraticity in sprinkler-irrigated corn observed in the summer of 2011 was for sprinklers with 10 ft spaced in-canopy sprinkler packages (Figure 7).

Figure 6. Large differences in corn plant height and ear size for in-canopy sprinkler application over a short 10-ft. distance (4 crop rows) as caused by small field microrelief differences and the resulting surface water movement during an extreme drought year, Colby, Kansas, 2002. The upper stalk and leaves have been removed to emphasize the ear height and size differences.

Figure 7. Erraticity of sprinkler irrigated corn in southwest Kansas in 2011 under extreme drought conditions thought to be related to a nozzle spacing too wide (10 ft) for in-canopy application (2 ft nozzle height).

CROP ROW ORIENTATION
WITH RESPECT TO DIRECTION OF SPRINKLER TRAVEL

When using in-canopy sprinkler application, it has been recommended that crop rows be planted circularly so that the crop rows are always perpendicular to the center pivot sprinkler lateral. Matching the direction of sprinkler travel to the row orientation satisfies the important LEPA Principles 2 and 5 noted by Lyle (1992) concerning water delivery to one individual crop furrow and equal opportunity to water by for all plants. Producers are often reluctant to plant row crops in circular rows because of the cultivation and harvesting difficulties of narrow or wide "guess" rows. However, using in-canopy application for center pivot sprinkler systems in non-circular crop rows can pose two additional problems (Figure 8). In cases where the CP lateral is perpendicular to the crop rows and the sprinkler spacing exceeds twice the crop row spacing, there will be nonuniform water distribution because of pattern distortion. When the CP lateral is parallel to the crop rows there may be excessive runoff due to the great amount of water being applied in just one or a few crop furrows. There can be great differences in in-canopy application amounts and patterns between the two crop row orientations (Figure 9).

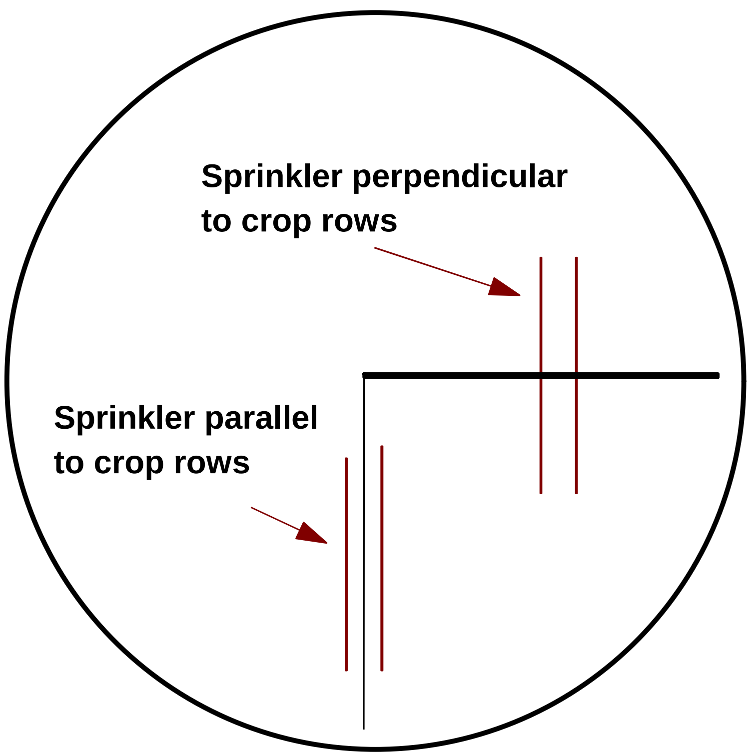

Figure 8. Two problematic orientations for in-canopy sprinklers when crops are not planted in circular rows.

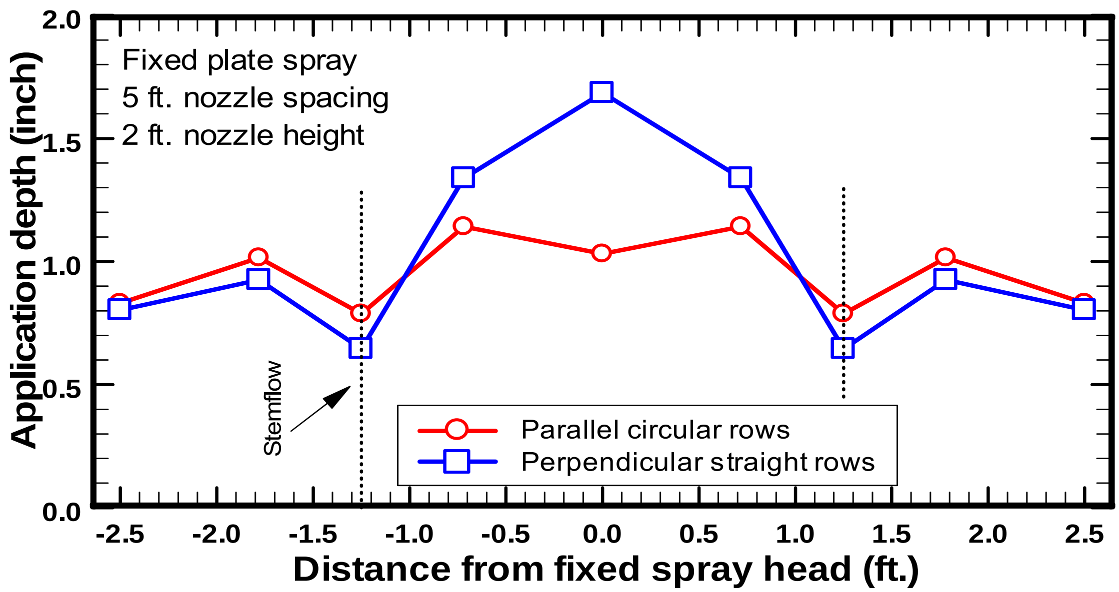

Figure 9. Differences in application amounts and application patterns as affected by corn row orientation with respect to the center pivot sprinkler lateral travel direction. Dotted lines indicate location of corn rows and stemflow measurements. Data are from a fully developed corn canopy, July 23-24, 1998, KSU Northwest Research-Extension Center, Colby, KS. Data are mirrored about the centerline of the nozzle.

PATTERN DISTORTION AND TIME OF SEASON

Drop spray nozzles just below the center pivot sprinkler lateral truss rods (approximately 7-10 ft height above the ground) have been used for over 30 years in northwest Kansas. This configuration rarely has had negative effects on corn yields although the irrigation pattern is distorted after corn tasseling. The reasons are that there is only a small amount of pattern distortion by the smaller upper leaves and tassels and this distortion only occurs during the last 30 to 40 days of the irrigation season. In essence, the irrigation season ends before a severe soil water deficit occurs. Compare this situation with spray heads at a height of 1 to 2 ft that may experience pattern distortion for more than 60 days of the irrigation season. Under dry and elevated evapotranspiration conditions in 1996, row-to-row corn height differences developed rapidly for 10-ft spaced sprinkler nozzles at a 4 ft nozzle height following a single one-inch irrigation event at the KSU Northwest Research-Extension Center, Colby Kansas (Figure 10). A long term study (1996-2001) at the same location on a deep silt loam soil found that lowering an acceptably spaced (10 ft) spinner head from 7 ft further into the crop canopy (e.g., 4 or 2 ft) caused significant row-to-row differences in corn yields (Figure 11).

Figure 10. Crop height difference that developed rapidly under a widely spaced (10 ft) in-canopy sprinkler (4 ft height) following a single 1 inch irrigation event at the KSU Northwest Research-Extension Center, Colby, Kansas. Photo taken on July 6, 1996.

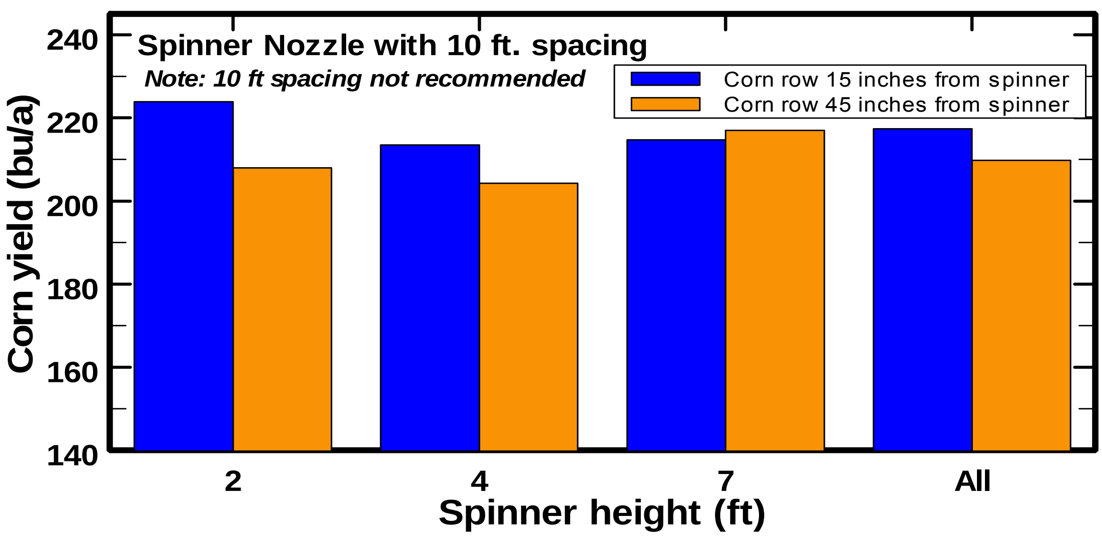

Figure 11. Row-to-row variations in corn yields as affected by sprinkler height for 10 ft. spaced in-canopy sprinklers. Sprinkler lateral travel direction was parallel to crop rows. Data was averaged from four irrigation levels for 1996 to 2001, KSU Northwest Research-Extension Center, Colby, Kansas.

COMBINATION OF EFFECTS CAN CAUSE ERRATICITY

Sometimes poor design, installation or maintenance problems can exist for years before they are visually observed as sprinkler irrigation erraticity. It may take severe drought conditions for some of these subtle effects to combine to such an extent to be noticeable erraticity. In addition, smaller row-to-row differences in crop yield cannot be measured with yield monitors on commercial-sized harvesters. An example of a combination several of these subtle effects was observed during the severe drought of 2002 in northwest Kansas (Figure 12). The small nozzle height difference on this sprinkler allowed at least three small effects to combine negatively to cause the sprinkler erraticity:

1. *Since there are no pressure regulators, the small height difference results in unequal flow rates for these low pressure spray nozzles.*
2. *There is a incorrect overlap of the sprinkler pattern due to the height difference with one sprinkler within the canopy while the other two nozzles are above the canopy.*
3. *Evaporative losses would be greater for the nozzles above the crop canopy.*

Figure 12. Erraticity of sprinkler-irrigated corn near Colby, Kansas during the extreme drought year of 2002.

CONCLUSIONS

The drought that southwest Kansas experienced in 2011 was devastating to production on many sprinkler irrigated corn fields, but the erraticity did highlight some design and management issues that producer might address before the next irrigation season:

1. *Does the selected sprinkler package strike the correct balance in reducing evaporative losses without increasing irrigation runoff or in-field water redistribution?*
2. *Does the sprinkler package and its installation characteristics provide the crop with equal opportunity to applied or infiltrated water?*
3. *Are the sprinkler nozzle heights and spacings appropriate for the intended cropping?*
4. *Should planting of taller row crops such as corn be in circular patterns if in-canopy sprinklers are used?*
5. *Are there subtle irrigation system characteristics (design, installation, or maintenance) that might combine negatively to reduce crop yields?*

These design and management improvements won't change the weather conditions, but they might change how the crop weathers future droughts.

ACKNOWLEDGEMENTS

This paper is the result of cooperative efforts of the authors through the Ogallala Aquifer Program, a consortium between USDA Agricultural Research Service, Kansas State University, Texas AgriLife Research, Texas AgriLife Extension Service, Texas Tech University, and West Texas A&M University.

This is a joint contribution from Kansas State University, USDA Agricultural Research Service and Texas A&M University. Contribution no. 12-309-A from the Kansas Agricultural Experiment Station.

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This paper was first presented at the Central Plains Irrigation Conference, February 21-22, 2012, Colby, Kansas. It can be cited as

Lamm, F.R., T.A Howell, and J.P. Bordovsky. 2012. Erraticity of sprinkler irrigated corn in 2011. In: Proc. 24th annual Central Plains Irrigation Conference Feb. 21-22, 2012, Colby, Kansas. Available from CPIA, 760 N. Thompson, Colby, Kansas. pp. 88-101.