CONCEPTS OF IN-CANOPY AND NEAR-CANOPY SPRINKLER IRRIGATION

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ABSTRACT

The use of in-canopy and near-canopy sprinkler application from mechanical move systems is prevalent in the U. S. Great Plains. These systems can reduce evaporative by nearly 15%, but introduce a much greater potential for irrigation non-uniformity. Close attention to the design, installation and operational guidelines for these systems can prevent many non-uniformity problems from becoming unmanageable.

INTRODUCTION

In the U. S. Great Plains, center pivot sprinkler irrigation (CP) is the dominant irrigation method. There are far few linear lateral-move sprinkler irrigation systems (LL) and together with CP systems they are jointly termed as mechanical-move sprinkler irrigation systems (MM). Windy and hot conditions during the growing season affect MM irrigation uniformity and evaporative losses. As a result many producers have adopted MM sprinkler packages and methods that apply the water at a lower height within or near the crop canopy height, thus avoiding some application non-uniformity caused by wind and also droplet evaporative losses. However, often these sprinkler package systems are adopted without appropriate understanding of the requirements for proper water management, and thus, other problems such as runoff and poor soil water redistribution occur. This paper will discuss in-canopy and near-canopy MM sprinkler irrigation from a conceptual standpoint with supporting data from research studies that have been conducted in the U.S. Great Plains region.

GUIDELINES, DEFINITIONS AND DESCRIPTIONS

Traditionally, MM 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 a MM 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 might easily be 5 to 30 times greater than above canopy sprinklers.

A number of sprinkler package systems have been developed that apply water in-canopy or near the crop canopy height. They should be and are classified as systems because they not only involve sprinkler irrigation hardware but also installation and management guidelines (Tab. 1 and Fig. 1).

Table 1. Near canopy and in-canopy sprinkler package systems and their general installation and management guidelines. (Adapted from Howell, 2006)

Sprinkler package system & *hardware type*	**Tillage and crop row orientation**	**Typical applicator height**
MESA (Mid elevation spray application) *180 or 360° Spray head Stationary, rotating or oscillating plates*	Any tillage system and row orientation. Controlled traffic desired. Basin tillage with ridge-till or reservoir tillage desirable with or without beds. No-till, ridge-till, or conservation tillage compatible.	1.2 to 2.5 m. Above the crop canopy for most of season.
LESA (Low elevation spray application) *180 or 360° Spray head Stationary, rotating or oscillating plates*	Any tillage system with circular crop rows desired for CP systems. Controlled traffic desired. Basin tillage with ridge-till or reservoir tillage desirable with or without beds. No-till, ridge-till, or conservation tillage compatible.	0.15 to 0.6 m Within the crop canopy for most of season.
LPIC (Low pressure in-canopy) *180 or 360° Spray head Stationary, rotating or oscillating plates*	Any tillage system and row orientation. Controlled traffic desired. Basin tillage with ridge-till or reservoir tillage desirable, with or without beds. No-till, ridge-till, or conservation tillage compatible.	0.15 to 2.5 m
LEPA (Low energy precision application) *Bubbler nozzle*	Circular rows required with CP systems. Controlled traffic desired. Basin tillage with ridge-till or reservoir tillage required with beds. Some adjustment of irrigation interval is allowable to prevent runoff.	0.15 to 0.6 m Within the crop canopy for most of season.
LEPA (Low energy precision application) *Any nozzle within drag sock*	Circular rows required with CP systems. Controlled traffic desired. Basin tillage with ridge-till or reservoir tillage required with beds (basin tillage is more effective). Some adjustment of irrigation interval is allowable to prevent runoff.	0 m Within the crop canopy all season.

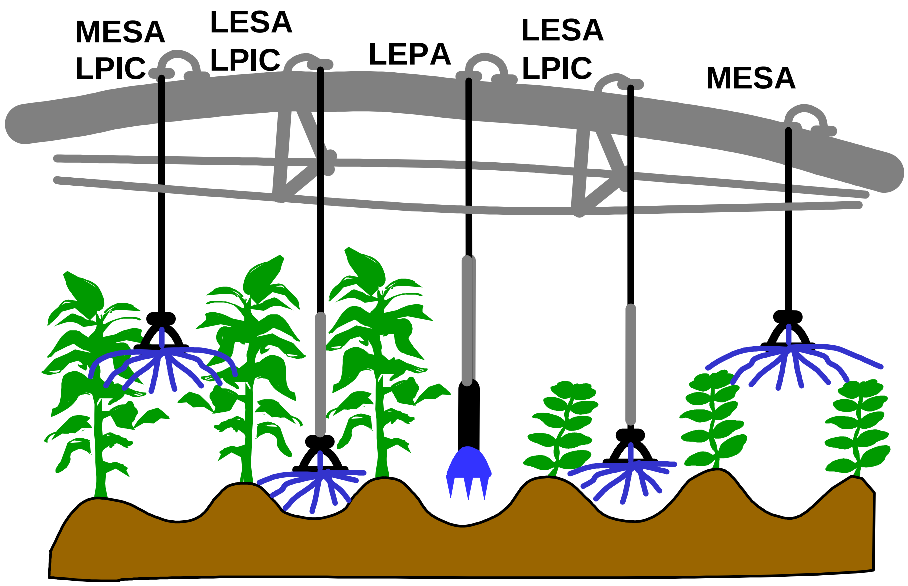

Figure 1. Illustration of the relative heights of MESA, LESA, LPIC, and LEPA concepts in tall and short crops. Note their can be overlapping definitions. (Adapted from Howell, 2006)

The low energy precision application (LEPA) system was the earliest in-canopy sprinkler application system for MM systems although there had been earlier attempts with traveling drip irrigation systems (Rawlins, 1974, Phene et al., 1985). 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 aren't 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 70 kPa 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 non-uniformity 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 (Tab. 2.), but these water savings must be balanced against runoff, deep percolation and other soil water non-uniformity problems that can occur when the systems are improperly designed and managed.

Table 2. Partitioning of sprinkler irrigation evaporation losses with a typical 25 mm 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 ≈ 4.3 m height	3	12	--	15	85
MESA ≈ 1.5 m height	1	7	--	8	92
LEPA ≈ 0.3 m height	--	--	2	2	98

* Ground runoff and deep percolation are considered negligible.

There are overlaps in definitions among the in-canopy and near-canopy sprinkler irrigation systems, while at the same time differences in their focused scope (Tab. 1 and Fig.1). LEPA and LPIC were both initially developed when there was an intense focus on irrigation energy costs so it can be understood why they both emphasize aspects of energy within their name. LPIC was partially developed as an alternative to LEPA for tighter soils and steeper topography where preventing runoff was difficult with LEPA. Buchleiter (1991) reported that LEPA on 1% sloping silt loam soils had no runoff while runoff exceeded 30% on a slope of 3%. Runoff from LEPA with basin tillage was approximately 22% of the total applied water and twice as great as MESA (1.5 m 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). Increasing the irrigation frequency, and thus lowering the irrigation event amount, is also used to reduce LEPA runoff and deterioration of furrow dikes. Often LPIC systems will have difficulties strictly adhering to the LEPA Principles 2, 3, 5 and 6, but still many irrigators believe they are obtaining most of the benefits of LEPA. In fact, many LPIC systems with their spray application are inaccurately called LEPA in the U. S. Great Plains. In a worthwhile attempt to clarify and prevent misuse of the in-canopy and near-canopy irrigation technologies, USDA-ARS at Bushland, Texas developed the new terms MESA and LESA which can essentially replace LPIC. (Howell, 1997). These terms (MESA and LESA) both emphasize a spray application at a relative height above the ground but not necessarily relative to the crop or to the MM lateral. Although the terms do not emphasize it in their name, both MESA and LESA can similar operating pressure requirements to LPIC or LEPA.

LEPA is often used in the Texas High Plains for low capacity wells and on relatively level fields, whereas LESA and MESA are predominately used in Kansas and Colorado High Plains region. The worldwide annual benefit of LEPA has been estimated to be $US 1.1 billion with a $US 0.477 billion benefit to consumers in the United States (Lacewell, 1998).

SYMMETRY OF SPRINKLER APPLICATION

The importance of uniform water application and/or infiltration has been documented by numerous workers (Zaslavsky and Buras, 1967; Seginer 1978; Seginer 1979, von Bernuth, 1983; Feinerman et al., 1983; Letey, 1985; Duke et al., 1991).

An increase in uniformity can increase yields and decrease percolation (Seginer,1979. Improving the uniformity of CP systems would be highly desirable from both an economic and environmental standpoint (Duke et al., 1991). Their results show irrigation non-uniformity such as over-irrigation resulting in nutrient leaching or under-irrigation resulting in water stress can cause significant economic reductions.

In some cases where irrigation is deficit or limited, a lower value of application uniformity can be acceptable (von Bernuth, 1983). For example, when the maximum water application amount still falls upon the upward sloping line of the yield production function, a crop area deficient of water will be compensated for by an area receiving a larger amount of water (Fig. 2). Overall production for uniform and non-uniform irrigation would be identical because the production function is linear over the range of water applications**.**

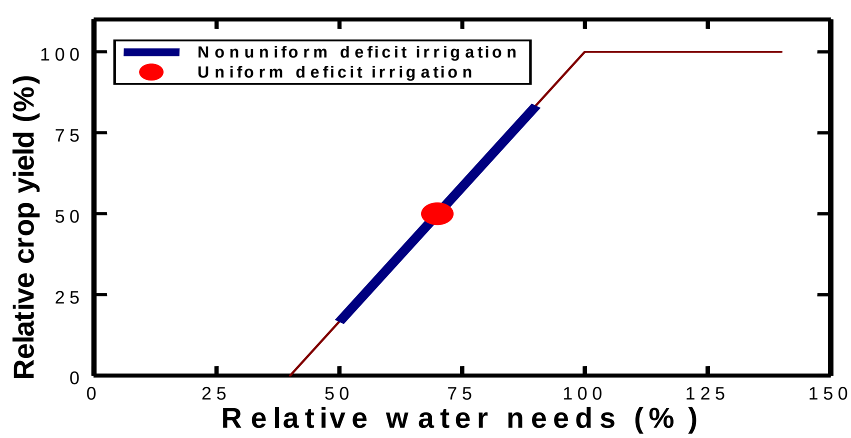

Figure 2. Hypothetical relationship of relative crop yield and relative water needs for non uniform deficit irrigation (bold range bar) and for uniform deficit irrigation (large dot). Average relative water need is the same for both irrigation schemes and consequently the average relative yield would also be the same. (After Lamm, 1998)

An excellent conceptual discussion of the need to consider the extent of crop rooting in irrigation design is presented by 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.

In-canopy and near canopy sprinkler irrigation does not necessarily result in nonuniform application. Using a LEPA nozzle in the furrow between adjacent pairs of crop rows obeys LEPA Principle 5 (Lyle, 1992) of each plant having equal opportunity to water (Fig. 3).

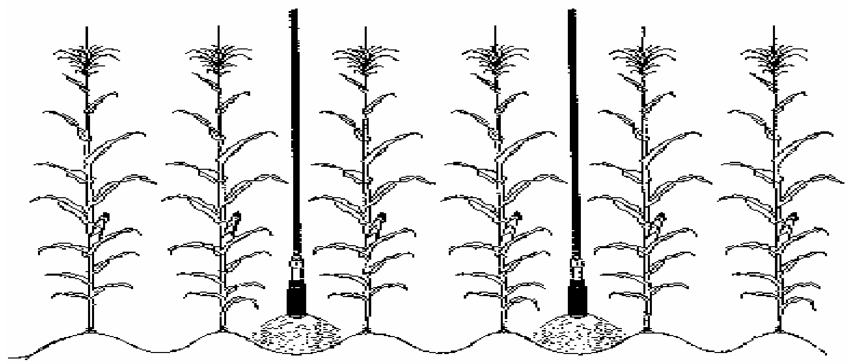

Figure 3. LEPA concept of equal opportunity of plants to applied water. LEPA heads are centered between adjacent pairs of corn rows. Using a 1.5 m nozzle spacing with 0.75 m spaced crop rows planted circularly results in plants being approximately 0.38 m from the nearest sprinkler. After Lamm (1998).

Some irrigators in the U. S. Great Plains, are experimenting with wider in-canopy sprinkler spacing (e.g., 2.3, 3.0, 4.6, and even 5.5 m) in an attempt to reduce investment costs (Yonts et al., 2005). Spray heads which perform adequately at these intervals above bare ground have a severely distorted pattern when operated within the canopy (Fig. 4).

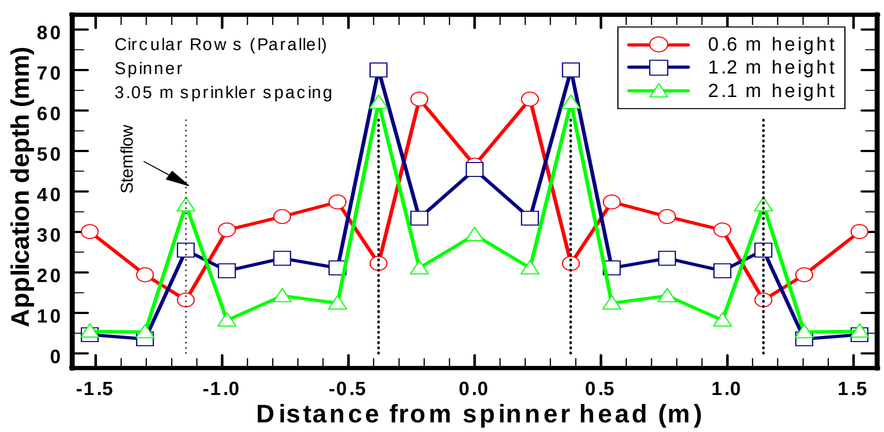

Figure 4. Differences in application amounts and application patterns as affected by sprinkler height that can occur when sprinkler spacing is too wide (3.05 m) for in-canopy application. CP lateral is traversing parallel to circular rows. Dotted lines indicate corn rows and stemflow values. Data from fully developed corn canopy, July 23-24, 1998, KSU Northwest Research-Extension Center, Colby, KS. Data is mirrored about the centerline.

Hart (1972) concluded from computer simulations that differences in irrigation water distribution occurring over a distance of approximately 1 m were probably of little consequence and would be evened out through soil water redistribution. Seginer (1979) noted that the overall effect on production of irrigation non-uniformity is related to the horizontal root zone of the crop. Although Fig.4 shows large application non-uniformity, these differences may or may not always result in yield differences, but they should be considered in design. Pattern distortion will result in over-irrigation in some areas which may cause runoff or deep percolation and under-irrigation in other areas which may cause crop yield reductions. 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. If this is so, using the concepts expressed by von Bernuth (1983), this non-uniformity is probably acceptable. However, nearly every field has small changes in land slope and field depressions which do cause field runoff if the irrigation application rate exceeds the soil infiltration rate. In the extreme drought years of 2000 to 2003 in the U. S. Central Great Plains, even small amounts of surface water movement affected sprinkler-irrigated corn production (Fig. 5).

Figure 5. Large differences in corn plant height and ear size for in-canopy sprinkler application over a short 3-m distance 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 differences.

PARTITIONING OF THE APPLIED SPRINKLER IRRIGATION AMOUNT

The sprinkler application amount that reaches the crop canopy is partitioned into three major components: stemflow, throughfall, and interception storage (Lamm and Manges 2000. Stemflow is the amount of irrigation water that flows down the leaves to the leaf-stalk node and then down the stem to the soil surface. Lamm and Manges, 2000). Throughfall represents any irrigation water that reaches the soil surface by directly or indirectly falling through the plant leaf structure. Interception storage is the amount of water temporarily remaining on the plant after irrigation, including both water on leaf and stem surfaces and water trapped in the leaf-sheath area. Although interception storage is eventually lost as evaporation, crop transpiration is temporarily suppressed during the evaporative process (Tolk et al.,1995).

Stemflow is the predominant flow path to the soil after the corn canopy is fully developed, averaging 55% of the total irrigation amount for corn with a within-row plant spacing of 0.18 m (Fig. 6). Thoroughfall averages approximately 42% for the same plant spacing and interception storage is approximately 2 mm for each irrigation event (Lamm and Manges, 2000). When averaged over the entire field there are very little differences in the partitioning process between above-canopy impact sprinklers and MESA at a height of 2.2 m. However, because of MESA pattern distortion by the crop canopy, there are large partitioning differences between corn rows nearer and further from the applicator head (Fig. 6). The ratio of stemflow to throughfall also increases with increased in-canopy applicator height, effectively allowing the corn plant to serve as a larger funnel (Fig. 4).

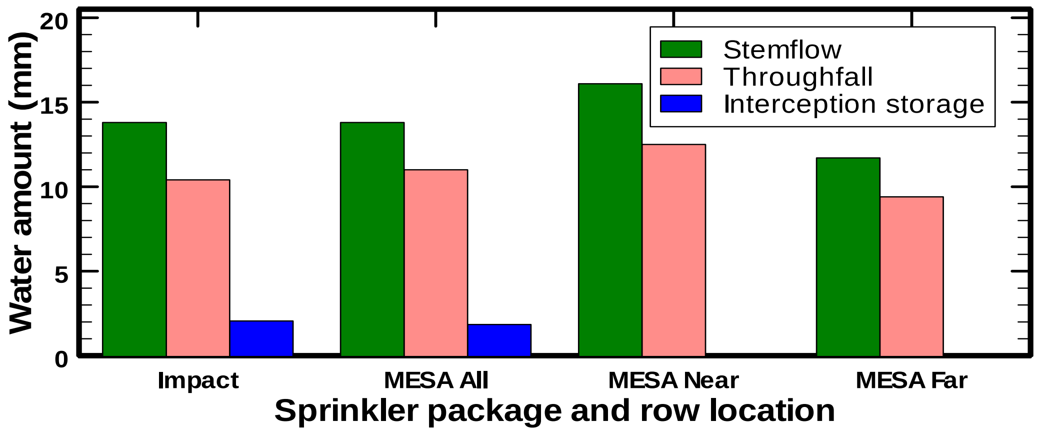

Figure 6. Partitioning of a 25 mm applied sprinkler irrigation amount by a fully developed corn canopy (circular rows) as affected by CP sprinkler package and row location. The impact sprinklers spaced at 12 m are at a height of 4.1 m and the MESA nozzles spaced at 3 m are at a 2.2-m height within the 0.76-m spaced corn rows with 0.18-m plant spacing. MESA pattern distortion results in different stemflow and throughfall calculated values for rows 0.38 and 1.14 m way from the nozzle (Near and Far rows, respectively). Fixed interception storage estimates are provided only for the two major packages. (Calculated values using equations from Lamm and Manges, 2000).

SPATIAL ORIENTATION

The direction of travel of the MM lateral with respect to crop row direction has added importance when in-canopy application is used. It has been recommended for CP systems that crop rows be planted circularly so that the rows are perpendicular to the sprinkler lateral. Matching the MM direction of travel to the row orientation satisfies the important LEPA Principles 2 and 5 noted by Lyle (1992).

Some producers have been 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 CP systems in non-circular crop rows can pose two additional problems. 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 non-uniform 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 between the two crop row orientations (Fig. 7).

PATTERN DISTORTION AND TIME OF SEASON

Drop spray heads just below the CP lateral truss rods (MESA) have frequently been used for over 25 years in northwest Kansas. This has had relatively little negative effects on crop yields although the MESA pattern is distorted after corn tasseling. The reasons are that there is only a small amount of pattern distortion by the tassels and because the distortion only occurs during the last 30 to 40 days of growth. In essence, the irrigation season ends before a severe soil water deficit occurs. Compare this situation with LESA at a height of 0.30 to 0.60 m that may experience pattern distortion for more than 60 days of the irrigation season. Yield reductions might be expected for some corn rows in the latter case because of the extended duration of the pattern distortion. Lowering an acceptably spaced (3.05 m) MESA spinner head from 2.1 m to 1.2 m or to a LESA height 0.6 can cause significant row-to-row differences in corn yields (Fig. 8).

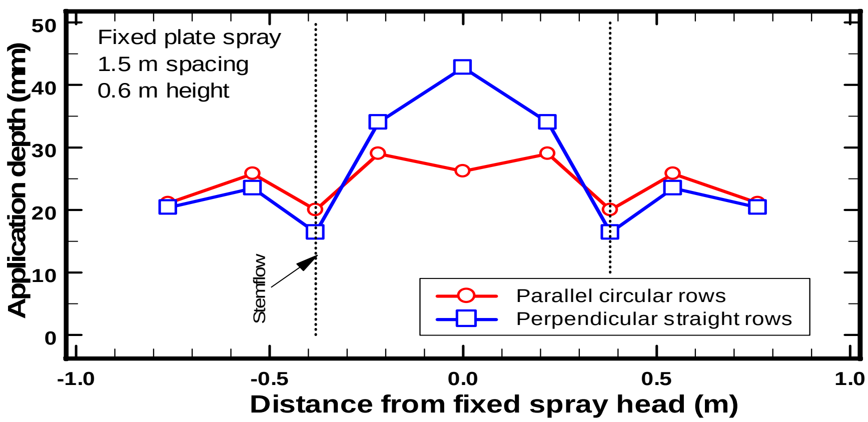

Figure 7. Differences in application amounts and application patterns as affected by corn row orientation to the CP lateral travel direction. Dotted lines indicate corn rows and stemflow values. Data from fully developed corn canopy, July 23-24, 1998, KSU Northwest Research-Extension Center, Colby, KS. Data is mirrored about the centerline.

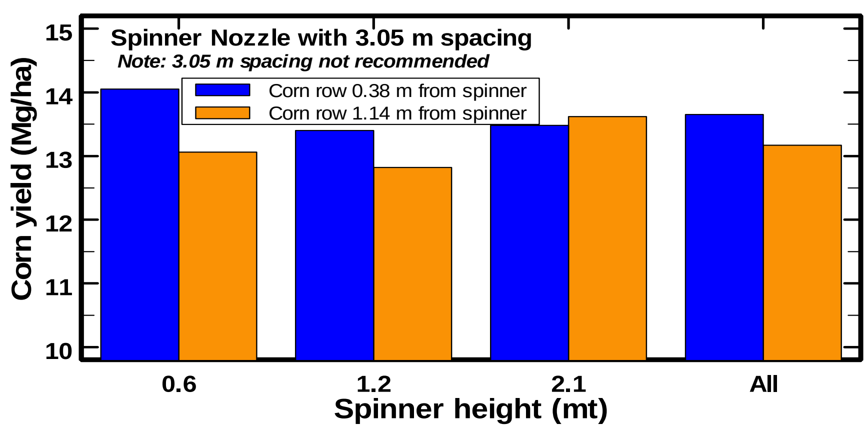

Figure 8. Row-to-row variations in corn yields as affected by sprinkler height for 3.0 m spaced in-canopy sprinklers. Data averaged from four irrigation levels for 1996 to 2001, KSU Northwest Research-Extension Center, Colby, KS.

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