UNIFORMITY OF IN-CANOPY CENTER PIVOT SPRINKLER APPLICATION IN FULLY DEVELOPED CORN CANOPIES[1]

Freddie R. Lamm
Associate Professor
Research Agricultural Engineer
KSU Northwest Research-Extension Center
Colby, Kansas

INTRODUCTION

In-canopy sprinkler irrigation is rapidly becoming the norm rather than the exception for center pivot sprinkler systems in northwest Kansas. However, there are additional management and system design considerations whenever the sprinkler application pattern no longer results in a relatively uniform broadcast application.

This paper will show results from uniformity studies using in-canopy sprinklers on fully developed corn canopies. The effect of nozzle spacing, nozzle height, and corn-plant spacing will be discussed with reference to their effect on partitioning of the in-canopy irrigation amount as expressed by throughfall and stemflow measurements.

PROCEDURES

The study was conducted on a fully developed corn canopy from July 19-21, 1994 at the KSU Northwest Research-Extension Center at Colby, Kansas. Corn was planted in 30 inch rows at a plant population of 33,600 plants/acre (6.5-in spacing) in both circular and straight rows under a center pivot sprinkler irrigation system. This resulted in separate plot areas with rows parallel or perpendicular to the center pivot travel direction. The plot areas were centered at a radius of 317 ft on a two tower center pivot.

The center pivot was equipped with Senninger[2] LDN 360-degree spray nozzles attached to drop hoses with a resulting height of 12.5 inches above the base of the corn plants. Randomly selected LDN sprinklers using 6 psi regulators were fitted with 17/64" ID nozzles (Dark Green). Dual-stage pads were used on the LDN nozzles to disperse the irrigation flow. The upper stage pad was a 33 groove concave pad (Blue CC-33) and the lower stage pad was a 33 groove flat pad (Black FL-33). The design flowrate for this nozzle at this pressure is 5.03 gpm. The center pivot was equipped with an electronic automated control panel which gave excellent repeatability of travel speeds among trials. Repeated trials were conducted on the same plot areas with either nozzle spacing or nozzle height changed between trials. The timer setting was set at 12% which resulted for this system in gross application amounts of 0.60, 0.40, 0.30, 0.24, 0.20, and 0.15 inches for 5-, 7.5-, 10-, 12.5-, 15-, and 20-ft nozzle spacings, respectively. Three replicated trials were conducted for the 5 and 10-ft nozzle spacings. The remaining nozzle spacings did not have replicated trials.

Water distribution at the soil surface was measured with throughfall pans (26 inches wide x 16 inches long x 4.5 inches deep) placed between adjacent corn rows. For the circular rows (rows parallel to center pivot system travel), pans were placed parallel to the center pivot lateral with measurements made beneath the nozzle and also in the interrows without nozzles. A similar arrangement was employed for the straight rows (rows perpendicular to center pivot travel) with the exception that the pans were alternated between two interrows. Sprinklers sometimes hung up in the perpendicular corn rows, and when they finally released might swing through only briefly watering some rows. The alternating pattern for the pans allowed for a truer representation of average water distribution but also showed the distortion caused by the corn plant interference with sprinkler movement. The sprinkler nozzles were centered between the circular rows, and as a result, did not hang up in the plant canopy. Pans were centered 30 inches apart, both left and right, from a central sprinkler nozzle for a distance equal to 1/2 the nozzle spacing or the whole nozzle spacing, depending upon the number of pans available to cover the spacing. The throughfall percentage was calculated as the percentage of the applied irrigation amount that was collected from the pans. Data was averaged from the various pan distances from the sprinkler nozzles to graph the water distribution. However, individual pan data were used to compute the Christiansen (1942) uniformity coefficient (CU),

$$\mathrm{CU} = 100[1-(\mathrm{SUM}(\mathrm{ABS}(X-\mathrm{MEAN}(X)))/\mathrm{SUM}(X))] \qquad (1)$$

where X is the volume caught in equally spaced pans. Because the plots are only a small portion of the center pivot length, the CUs were not adjusted using the technique for computing CUs for center pivot sprinklers developed by Heerman and Hein (1968). Individual pan results were also used to compute the coefficient of variation (CV) between throughfall amounts for the various spacings,

$$\mathrm{CV} = 100[\mathrm{STDEV}(X)/\mathrm{MEAN}(X)] \qquad (2)$$

where X is the volume caught in equally spaced pans.

A separate set of trials was conducted to examine the effect of sprinkler nozzle height on penetration of the irrigation amount through the crop canopy. Trials were conducted using a single central sprinkler at heights of 12, 24, 48, 66, and 94 inches above the base of the corn plants. The full height of the corn including the tassel was approximately 100 inches, and the height of the ear was approximately 48 inches. The measurements from these trials were left as raw volumes because only one nozzle was used and because stemflow was the predominant flow path at some of the heights. Stemflow was not measured in these trials.

Stemflow results from a 1987-1988 study will also be discussed. The experimental procedure for this study is thoroughly described in Lamm and Manges (1990), however, a brief description is in order. Stemflow, or the amount of water reaching the soil surface by traveling down the outside of the plant stem, was measured on fully developed corn plants for a total of nearly 3000 measurements during the course of 23 different irrigation/precipitation events using 240 different plants. Tests were conducted on both impact sprinklers above the canopy and spray nozzles within the canopy at a height of 84 inches. Plant spacing was an experimental variable being either 8, 12, or 16 inches.

RESULTS

Effect of Sprinkler Nozzle Spacing and Row Orientation

The throughfall distribution patterns were greatly affected by sprinkler nozzle spacing and row orientation (Figure 1 and 2). Throughfall percentages varied less than 15% for the 5-ft sprinkler spacing on parallel circular rows, which would be acceptable as long as runoff is controlled because each plant is equidistant from a sprinkler nozzle. The throughfall variation for the 5-ft spacing increased to approximately 33% when the rows were perpendicular to center pivot travel. This variation was similar to the variation for the 7.5-ft sprinkler spacing with parallel circular corn rows. The problem of the sprinkler nozzles hanging up in the perpendicular rows is compounded by wider sprinkler spacings as there are less sprinklers (and they are further apart) that could possibly correct a poor distribution from an adjacent nozzle. This is evidenced by the differences in throughfall distribution between even the 5- and 7.5-ft spacings on perpendicular rows. The throughfall percentage occurring near the nozzle can be quite variable depending upon where the center pivot system or individual sprinkler starts and stops in relation to the pan. Some of this randomness would average out in repeated trials as evidenced by the repeated trials for the 5 and 10-ft spacing. However, the magnitude of the variations is probably unacceptable for the wider sprinkler spacings or for the perpendicular rows.

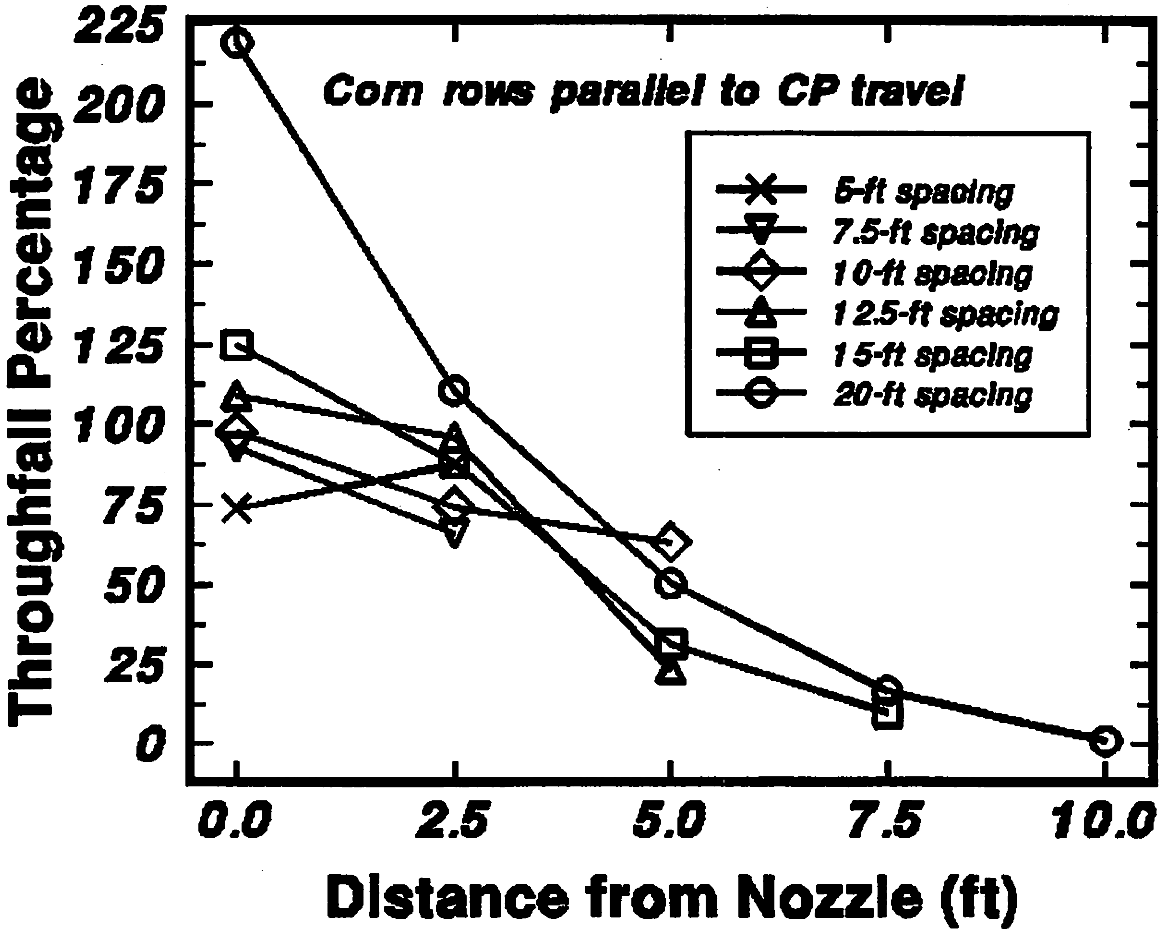

Figure 1. Throughfall percentage as related to distance from sprinkler nozzle for various sprinkler spacings with corn rows parallel to direction of center pivot sprinkler travel.

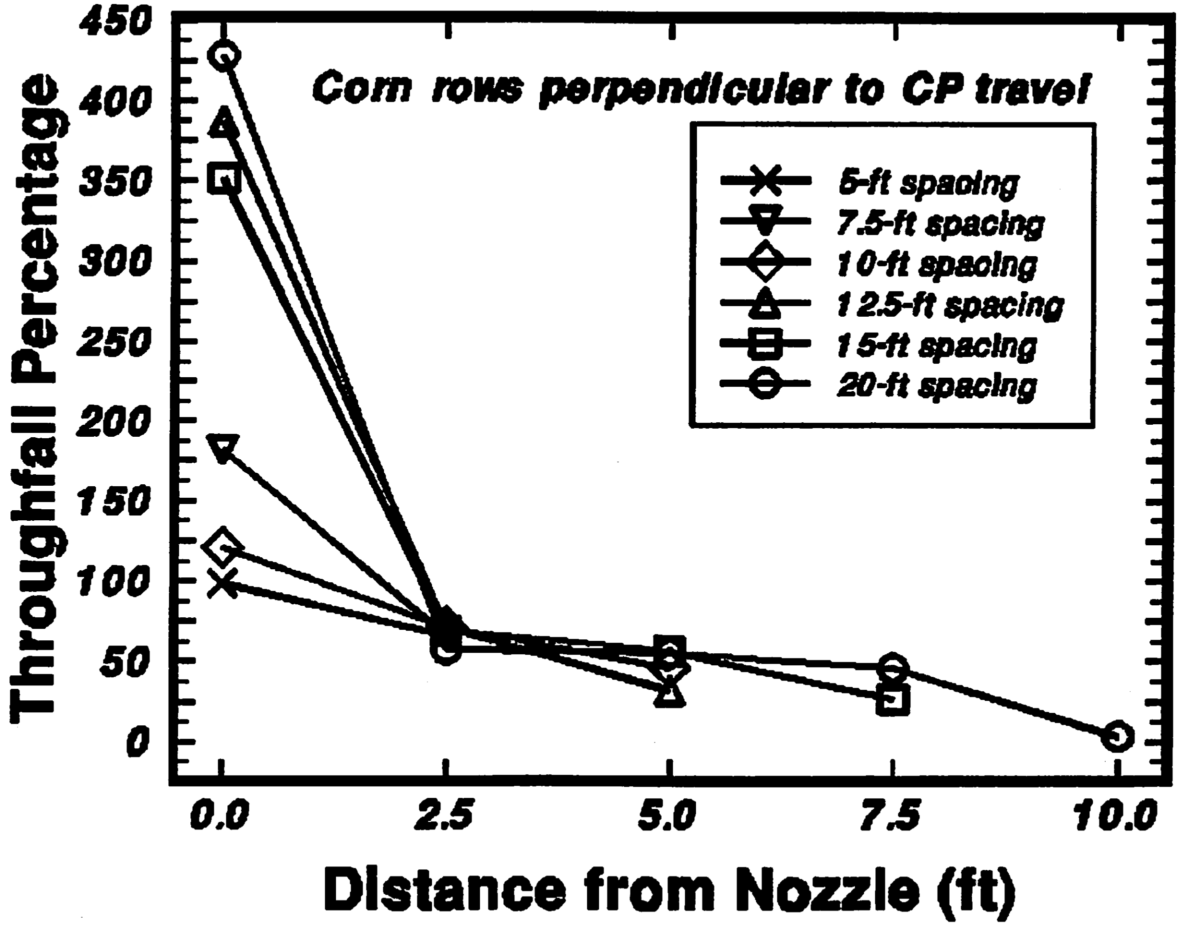

Figure 2. Throughfall percentage as related to distance from sprinkler nozzle for various sprinkler spacings with corn rows perpendicular to direction of center pivot sprinkler travel.

The Christiansen uniformity coefficient (CU) for the 5-ft spacing was 86.2 and 72.4 for the parallel and perpendicular rows, respectively (Figure 3). A CU of 86.2 for the parallel circular rows with the 5-ft spacing would probably be acceptable for most types of chemigation because of the equidistant relationship between plants and sprinkler nozzles. CUs for the other sprinkler spacings are fairly poor given the state-of-the-art in current systems. Corn row orientation generally decreased the CU by about 15-20% with the exception of the very wide 15 and 20 ft spacings where CUs were extremely low at both row orientations.

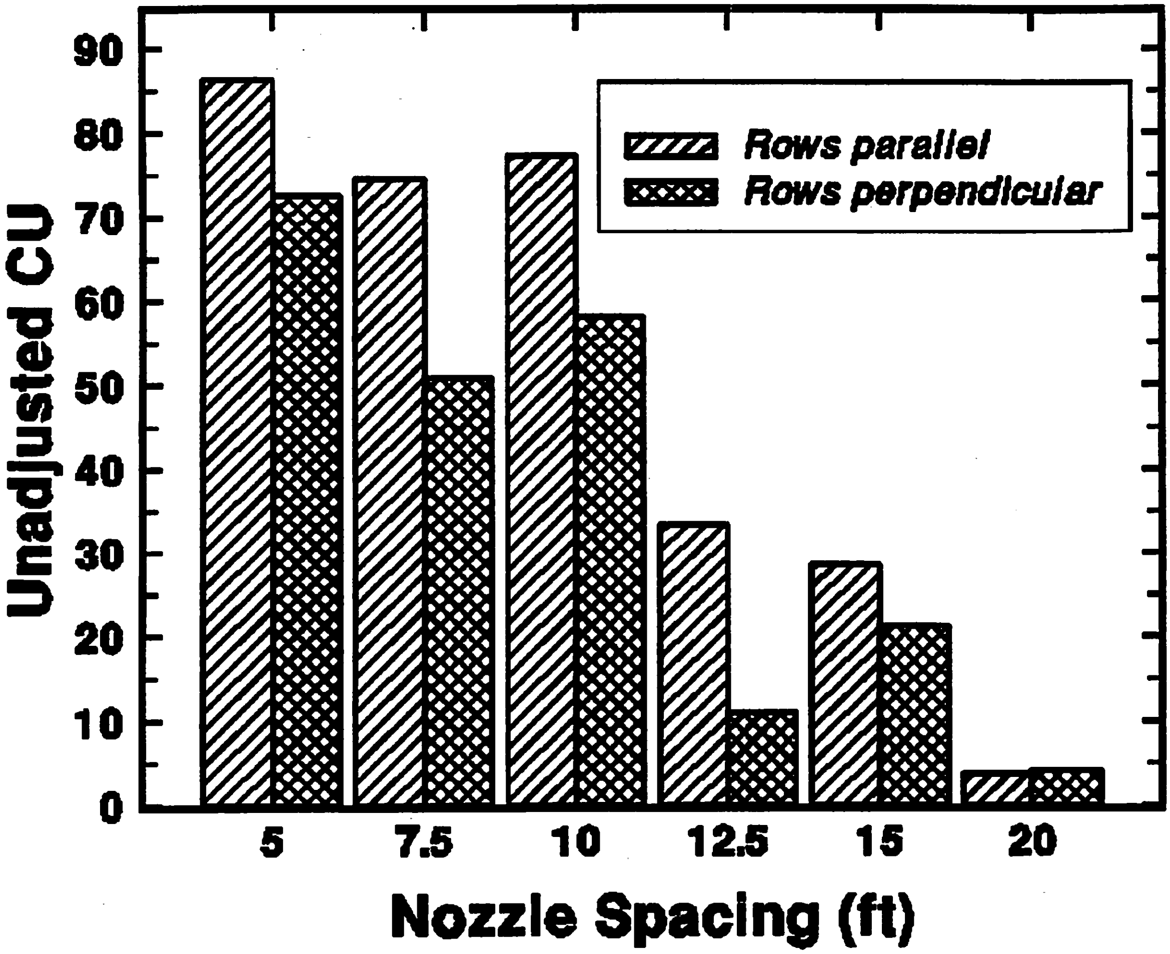

Figure 3. Unadjusted Christiansen uniformity coefficient (CU) for throughfall amounts as related to sprinkler spacing with corn rows parallel and perpendicular to direction of center pivot sprinkler travel.

The coefficient of variation (CV) is presented for those individuals more familiar with using CV as a indicator of statistical dispersion about the mean (Figure 4). The perpendicular row orientation approximately doubled the CV for the 5-, 7.5-, 10- and 12.5-ft sprinkler spacings as compared to the parallel row orientation. Only the 5-ft spacing with parallel row orientation had a CV of less than 20%.

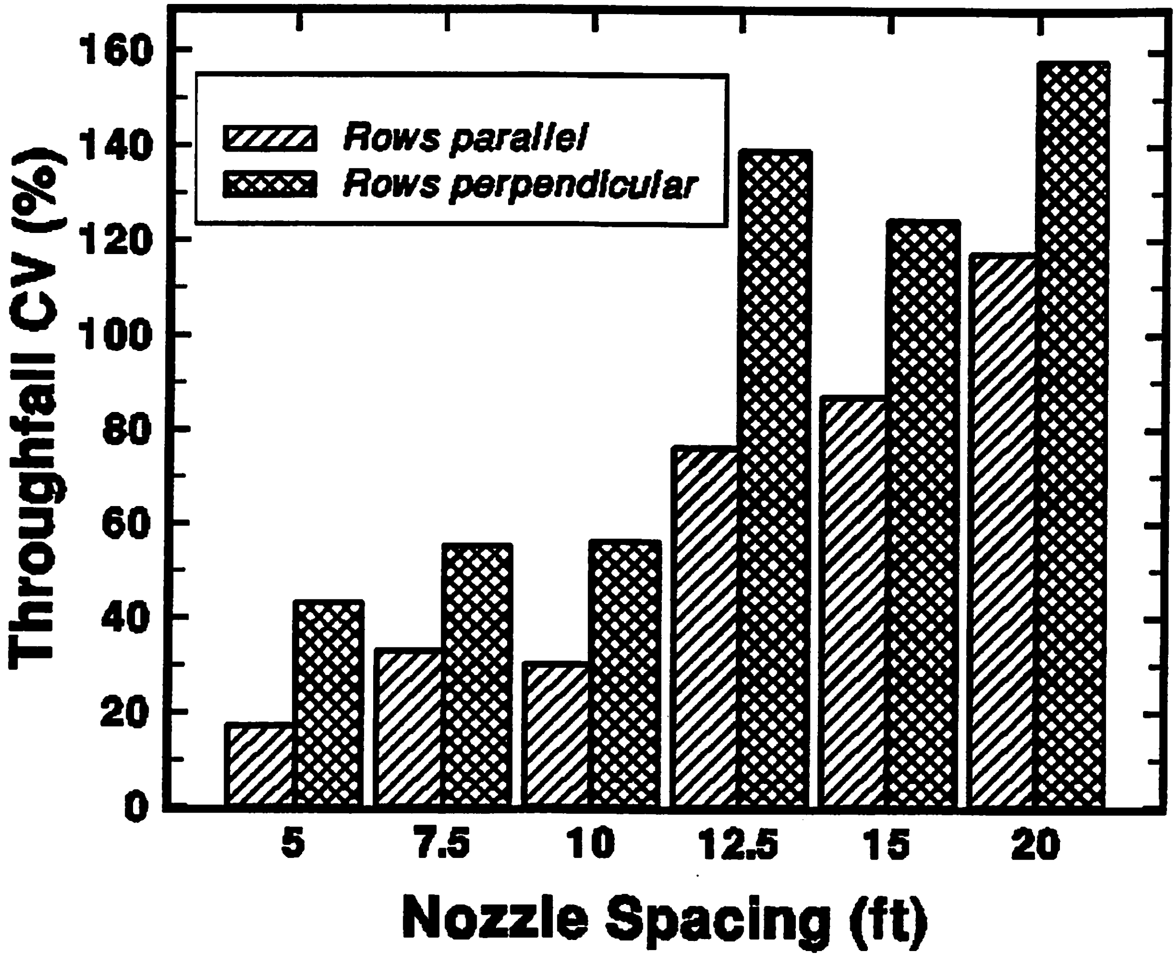

Figure 4. Coefficient of variation (CV) for throughfall amounts as related to sprinkler spacing with corn rows parallel and perpendicular to direction of center pivot sprinkler travel.

Effect of Sprinkler Height

The effect of sprinkler height is shown in Figure 5. It should be noted that this is data from a single nozzle. The actual throughfall distribution would improve if additional nozzles were added through superposition. However, for the purposes of this discussion, this data will suffice. All heights had at least some penetration a distance of 7.5 ft with the exception of 48 inches. It is instructive to note that this is the ear height which also has the highest concentration of large leaves at this time of the season. Obviously, there must be a clear pathway for lateral penetration. The 12 and 24-inch heights had the most quantity of water penetrating as throughfall to a distance of 5 ft. However, this is only part of the story. As the water strikes plant leaves, a significant fraction is converted to stemflow (water running down the outside of the plant stem). If no stemflow was occurring, the area under each curve would be the same although distribution could be different. Obviously, stemflow became the predominate pathway as the sprinkler height was increased. Stemflow was not measured in 1994 so it is not possible, with this data, to accurately describe the effect of nozzle height on the total distribution of irrigation water. However, a previous study by the author can give some insights.

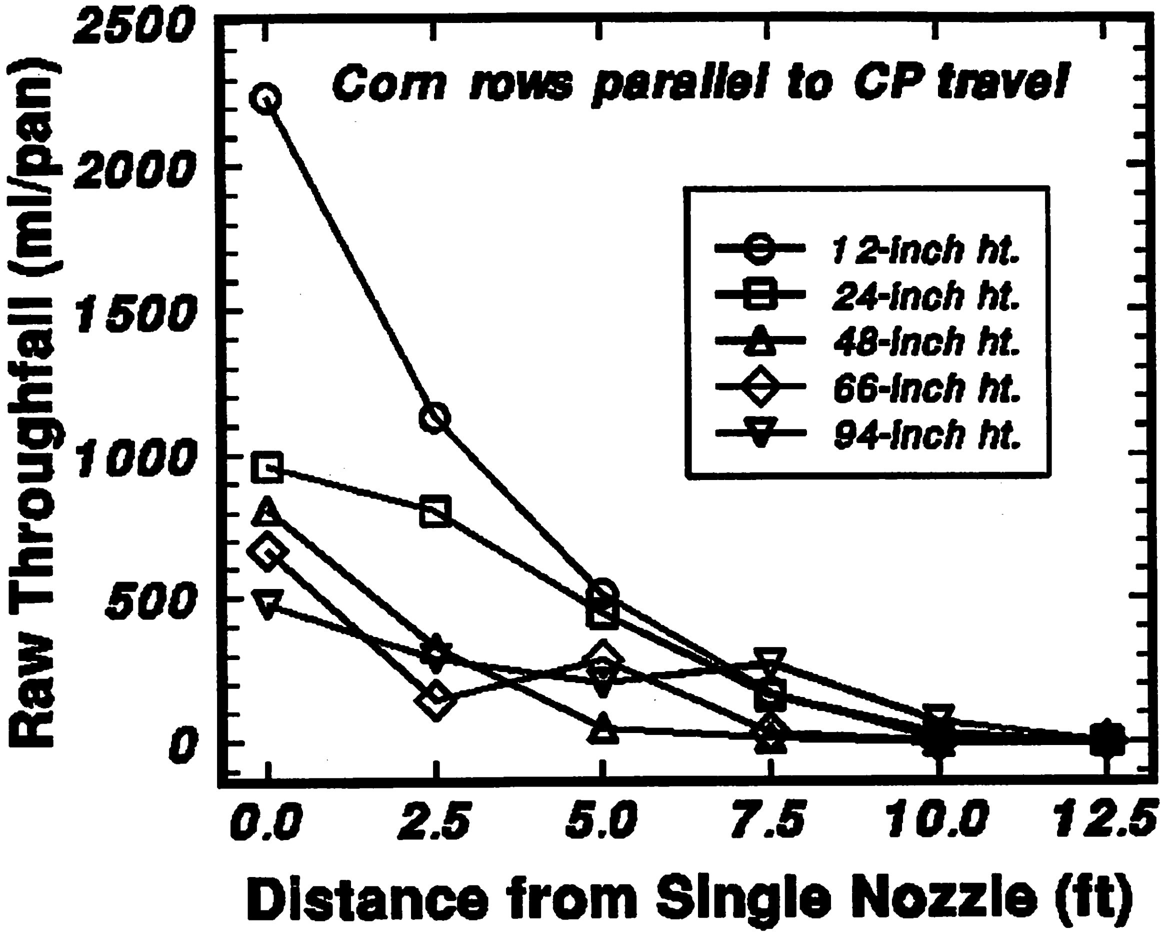

Figure 5. Throughfall amounts from a single sprinkler as related to sprinkler height with corn rows parallel to direction of center pivot sprinkler travel.

Empirical equations from Lamm and Manges (1990) are used to show the effect of corn plant spacing, sprinkler type, and location on the Stemflow Percentage (Figure 6). As plant spacing decreases, stemflow increases as the predominate flow path. This concept would be similar in effect to increased leaf density at the ear height physically reducing throughfall. The stemflow percentage on the average was less for overhead impact sprinklers than for spray nozzles. This is thought to be because of the nearly perpendicular incidence angle of the water hitting the leaves and possibly because of larger droplet size resulting in more throughfall due to heavier leaf loading. When spray nozzles (10-ft spacing) were used down in the top of the plant canopy (86-in ht.) stemflow was considerably higher for the corn row closest to the sprinkler as compared to the next adjacent corn row, 45 inches away. At a plant spacing of 6 inches, this difference was approximately 20%. From these concepts, it would be reasonable to assume that stemflow would be most greatly affected at the heights of highest leaf density and would be most concentrated in the rows closest to the sprinkler.

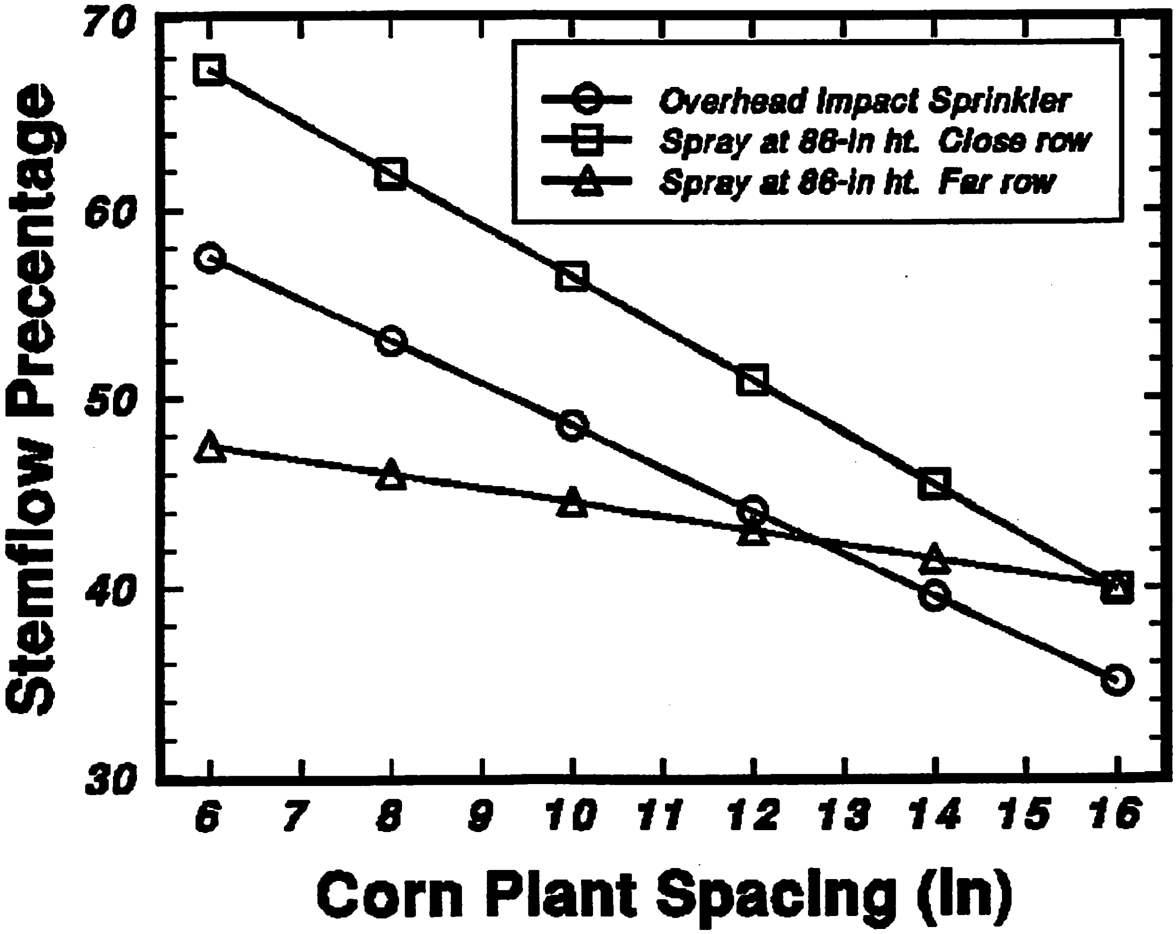

Figure 6. Stemflow amounts as related to corn plant spacing, sprinkler type and location. Calculated from equations from Lamm and Manges (1990).

CONCLUSIONS

In-canopy sprinklers at a height of 12 inches at spacings wider than 5 ft have significant water distribution problems in fully developed corn.

Corn row orientations perpendicular to the direction of center pivot travel increase the variation in in-canopy water distribution to a much greater extent than circular parallel rows. If chemigation is a desired option, sprinkler spacing and row orientation must be carefully considered.

It is reasonable to assume that there are particular heights in the corn canopy where water distribution problems would be magnified, namely around the ear height.

[1] *This information was first presented at the 15th International Irrigation Association Exposition and Technical Conference, Atlanta, Georgia, November 5-8, 1994. It is reprinted here with permission of the author and the Irrigation Association, Fairfax Virginia.*

[2] *The mention of trade names or commercial products does not constitute their endorsement or recommendation by the authors or by the Kansas Agricultural Experiment Station.*

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