IN-CANOPY SPRINKLER APPLICATION FOR CORN: WHAT WORKS AND WHAT DOESN'T

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SUMMARY

In-canopy sprinkler application in fully developed corn after tasseling is affected by nozzle spacing, nozzle height, row orientation with respect to center pivot travel, and nozzle type. Incorrect combinations can lead to poor in-canopy uniformity. In general, as nozzle spacing increased from 5 to 10 ft, in-canopy uniformity decreased. The 4 ft nozzle height was worse than the 2 and 7 ft nozzle heights in terms of in-canopy uniformity. Circular (parallel to sprinkler travel) rows almost always have better in-canopy uniformity than straight (perpendicular to sprinkler travel) rows. Spinner nozzles had better in-canopy uniformity than plate nozzles at the 2 and 7 ft heights.

INTRODUCTION

In-canopy center pivot sprinkler irrigation is gaining popularity in much of the Great Plains region. However, uniformity of applied irrigation can be greatly affected by canopy distortion of the sprinkler pattern. Some irrigators are experimenting with wide-spaced in-canopy sprinklers for irrigation of corn as a means of reducing investment costs. However, there is little research information available on the effectiveness of this strategy. The height of the sprinklers also has a direct bearing on the magnitude of the distortion. Redistribution of the applied water within the crop canopy is also affected by the orientation of the corn rows with respect to the center pivot sprinkler travel direction. Nozzle type (static plate vs. rotating plate) may also influence distribution of in-canopy sprinkler application. This report summarizes the 1996 in-canopy sprinkler application research conducted at the KSU Northwest Research Extension Center at Colby, Kansas. The results are from fully developed corn plants after tasseling. It should be noted that the canopy conditions roughly represent the last 30-40 days of the irrigation season. The results do not represent the whole corn growing season, but do represent a time when irrigation needs are critical.

PROCEDURES

The study was conducted on a fully developed corn canopy from August 1-3, 1996 at Colby, Kansas. Corn was planted in 30 inch rows at a plant population of 33,100 plants/acre (6.32-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 radii of 277, 327 and 377 ft on a two tower center pivot.

Throughfall is water that reaches the soil surface by *falling through* the leaves of the plant canopy. Stemflow is water that reaches the soil surface by *flowing* down the plant *stem*. Both components must be measured to get estimates of water distribution at the soil surface. Throughfall was measured in pans 16 inches long by 26 inches wide (30 inches between corn rows) and 4.5 inches in height. Throughfall was converted to an equivalent depth by dividing the measured amount by the pan area with appropriate conversion factors. Stemflow was measured with special collection units made from a 6 inch section of split 2 inch PVC pipe taped around the base of the corn stalks. Stemflow was converted to an equivalent depth by relating the measured amount to the land area represented by an individual plant (30 inch row spacing x plant spacing of 6.32 inches).

Trials were replicated at three radii (277, 327, or 377 ft) with a single nozzle at each location. Flowrates at the three radii were 5.08, 5.80 and 6.85 gpm using #30, #32 and #35 Nelson[1] nozzles with 10 psi pressure regulators. Treatments variables were nozzle height (2, 4 or 7 ft) and nozzle type (S-3000 spinner with purple D6-20 plates or D-3000 spray nozzle with blue deflection plate). Each height and nozzle type combination was replicated at each radii. The location of the throughfall and stemflow collection units are fixed at the three radii, so the replication is made by repeating irrigation events. The six events (2 plates and 3 heights) were conducted over a three day period. Stemflow and throughfall was also measured for a coincidental 1.2 inch rainfall event that occurred the evening of July, 31, 1996. Stemflow and throughfall was measured from a single nozzle at each of the three radii for the left half of each pattern for both parallel and perpendicular rows. Preliminary tests indicated a potential in-canopy wetted radius of 20 ft for the highest sprinkler height. Collection units were dispersed over the 20 ft distance with one throughfall pan for each interrow and one stemflow collection unit for each row. This translates into 54 stemflow and throughfall collection units each (3 radii x 2 row orientations x 9 row/interrow locations). Each throughfall pan was further divided into three equal size compartments (8.67 inches by 16 inches) to give better breakdown of water distribution. A single event could potentially consist of 162 measurements of throughfall and 54 measurements of stemflow, although distorted sprinkler patterns reduced some of the amounts to be measured to zero. The single nozzle arrangement was used to facilitate the use of superpositioning to "mirror" the amounts catched. This allowed the simulation of various nozzle spacings (i.e. 5, 7.5, and 10 ft). The center pivot sprinkler for these trials was operated at a speed that would apply 1.5 inches if all nozzles were operating on a 5-ft spacing. For this system, it is operating at a linear speed of 0.88 ft/minute for 3% of the 1 minute cycle at the 377 ft radius. This slow speed allows for larger measured sample and therefore more accuracy as measurement errors would constitute a smaller fraction of the sample. The applied amount does not affect the relative sprinkler water distribution pattern, only the magnitude of the amounts. The collected data was analyzed using appropriate statistical procedures. The under-canopy water distribution was calculated for various simulated nozzle spacings. The unadjusted Christiansen Uniformity Coefficient was calculated for each treatment and row orientation as a index of performance. These are not truly the CU for these in-canopy systems because they are using "mirrored" data, but these values do serve as a relative index between the comparisons in this study.

RESULTS

Water application pattern as affected by row orientation and nozzle spacing

As outlined in the procedures, the concept of superposition was used to *mirror* the application from the single nozzle to get the resultant water pattern for nozzle spacings of 5, 7.5 and 10 ft. Figure 1 shows the water application patterns at the ground surface from the Nelson Spinner nozzle applying water from a height of 2 ft for both the circular corn rows (parallel to center pivot sprinkler travel) and the straight corn rows (perpendicular to sprinkler travel). It is helpful to remember in interpreting the data, that a flatter pattern for a given nozzle spacing represents the best water distribution. For example, in Figure 1, the circular rows with the 5 ft nozzle spacing *(open circles in Fig 1.)* have a better water distribution pattern than the perpendicular rows with the 5 ft nozzle spacing *(open squares).*Application variation [A_{var} = 100 x ((Maximum amount -Minimum amount)/ Maximum amount)] was 20% for the circular parallel rows and 54% for the straight perpendicular rows. This is a considerable difference between the two row orientations. Normally for sprinkler applications on bare soils, it is considered desirable to limit the variation to less than 10% along the sprinkler lateral. However, there are other factors affecting distribution for in-canopy application and the 10% rule is probably not acceptable.

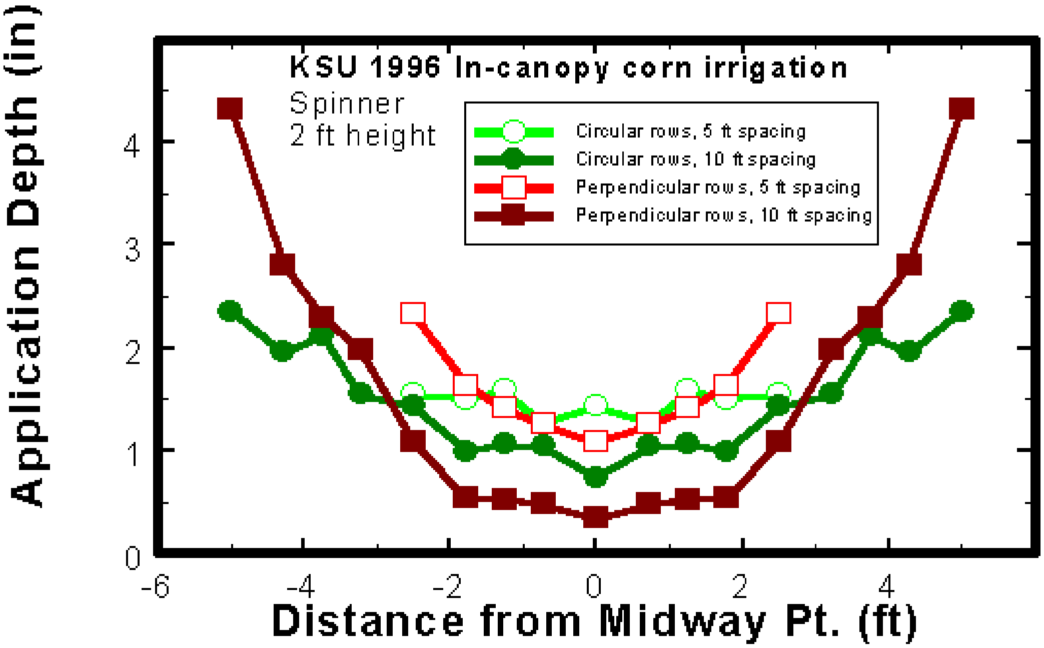

Figure 1. Water application pattern as affected by row orientation and nozzle spacing for spinner nozzles at the 2 ft height in a fully developed corn canopy after tasseling.

The differences in A_{var} for the two orientations with the 5 ft nozzle spacing is considerable, but it should be noted that it occurs over a distance less than 2.5 ft. In some cases, depending on field slope, soil type, tillage practices and residue levels, soil water infiltration differences may buffer out the water application differences over this short distance. Hart (1972) concluded from computer simulations that differences in irrigation water distribution occurring over a distance of approximately 3 ft were probably of little consequence and would be evened out through soil water redistribution. However, if chemigation (foliar or soil-applied chemicals) is a consideration, these differences might be very significant. If field characteristics encourage runoff or ponding in low areas, these differences would probably be unacceptable. Perfectly perpendicular rows only exist for two locations in a center pivot sprinkler field with straight rows, so for straight rows the application varies from parallel to perpendicular. In ridge-till situations when the rows are perpendicular, a large percentage of the center pivot capacity (GPM) is being applied to just a very few furrows in in-canopy application.

Figure 1 also shows the effect of wider nozzle spacings on the water distribution pattern. It is helpful to remember in interpreting this aspect of the data, that even if the magnitude of the variation in application amounts are similar that the shorter the trend line the better the potential distribution. For example, the circular rows with the 10 ft nozzle spacing has a somewhat similar A_{var} to the perpendicular rows with the 5 ft nozzle spacing (54% vs. 69%, respectively). However, for the 10 ft spacing, there is a trend of decreasing water application over a much longer distance, and so potentially larger areas would have incorrect application amounts (over or under application). The differences between A_{var} for the circular parallel and perpendicular rows for the 10 ft. nozzle spacing are 69 and 92%, respectively. It is highly probable that these amounts of application variation over the distance of 5 ft would lead to runoff or ponding in the locations with over application and crop water stress in the locations with under application.

Figures 2 and 3 show the water application patterns for circular parallel and straight perpendicular rows for all three simulated nozzle spacings**,** 5, 7.5 and 10 ft for the spinner nozzle at the 2 ft height. Acceptable nozzle spacings/row orientation combinations for the spinner nozzle at 2 ft height are probably limited to 5 and 7.5 ft spacings with circular rows and to the 5 ft nozzle spacing with perpendicular rows. A_{var} for these combinations were 20, 44 and 54%, respectively. This conclusion assumes chemigation is not being used (applies only to 7.5 ft spacing or perpendicular rows) and that runoff is controlled to a small (2-10 ft radius) localized area with tillage management (furrow dams or implanted reservoirs) or by residue management.

In-canopy uniformity as affected by sprinkler height and nozzle type

Another way of characterizing the performance of in-canopy sprinkler distribution would be to calculate the Christiansen Uniformity Coefficient, CU. For those familiar with CU values, it should be re-noted that the in-canopy uniformity values expressed in this paper are not true CU values because they are using "mirrored" data, but they do serve as a relative index between the comparisons in this study. In addition, these values are not adjusted (using the techniques of Heermann and Hein, 1968) for the center pivot radius since they are over a very short distance. For these reasons, the values in this paper are referred to as in-canopy uniformity, to distinguish them from true CUs.

Figure 4 shows the in-canopy uniformity for spinner nozzles at heights of 2, 4 or 7 ft at nozzle spacings of 5, 7.5 or 10 ft for both circular parallel and straight perpendicular rows. It can be seen that the 4 ft height is always the worst height for a given nozzle spacing and row orientation. This may not be surprising since this is about the corn ear height, an area of high leaf density at this portion of the season. Distortion of the sprinkler pattern is very high at the 4 ft height. For the circular parallel rows, the 2 ft height is better than the 7 ft height, but the opposite is true for the straight perpendicular rows. This may seem confusing. However, some previously unmentioned factors are beginning to have an influence. As the nozzle is raised in the canopy, the flowpath to the soil surface changes from almost equal amounts of stemflow and throughfall to larger amounts of stemflow. This is indicated by the *"spikes"* in the 4 and 7 ft height lines in Figure 5. The spikes correspond to the locations of the corn rows and are stemflow amounts. Because these spikes affect the in-canopy uniformity, the 7 ft height is worse than the 2 ft height for the circular rows. For the perpendicular rows, there are some spots in the center pivot travel that give a relatively straight path of throughfall that is not heavily distorted by the nearby plant row. The in-canopy uniformity at 7 ft can be better than at the 2 ft level for the straight perpendicular rows because of less distortion.

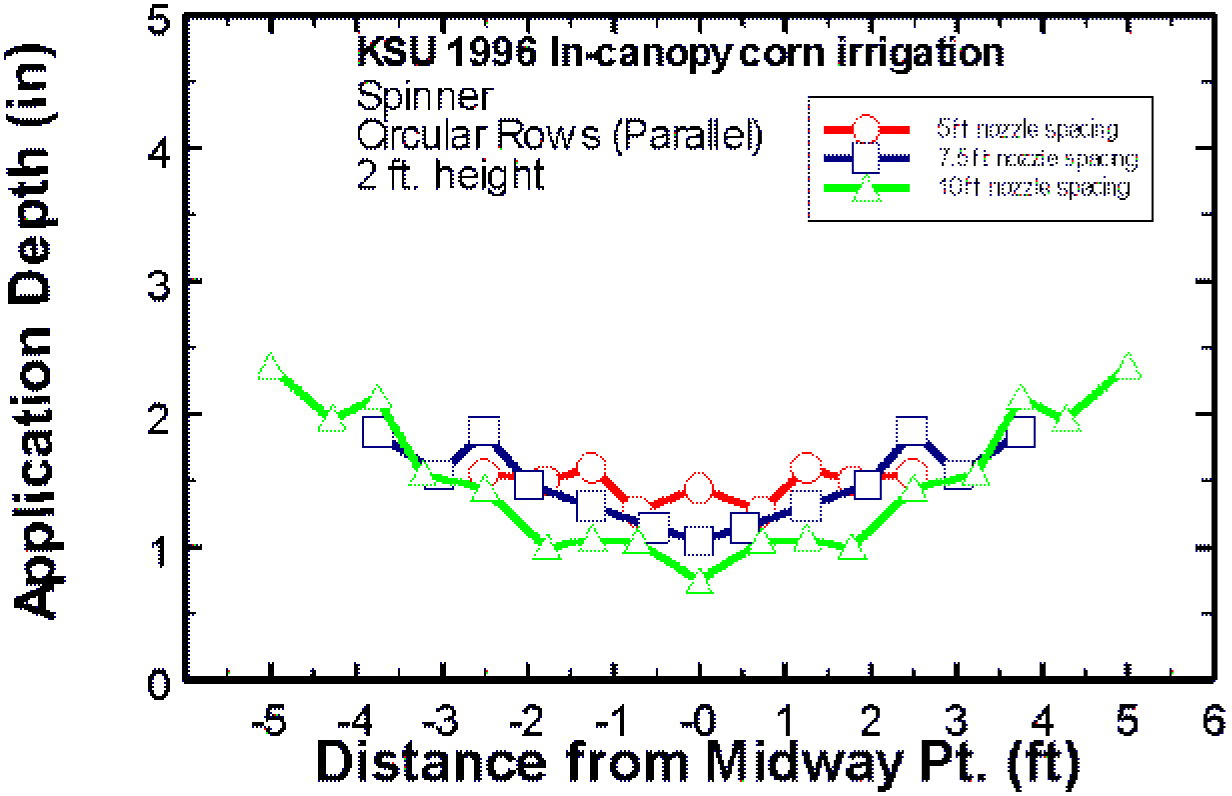

Figure 2. Water application pattern for circular parallel rows at various nozzle spacings for spinner nozzles at the 2 ft height in a fully developed corn canopy after tasseling.

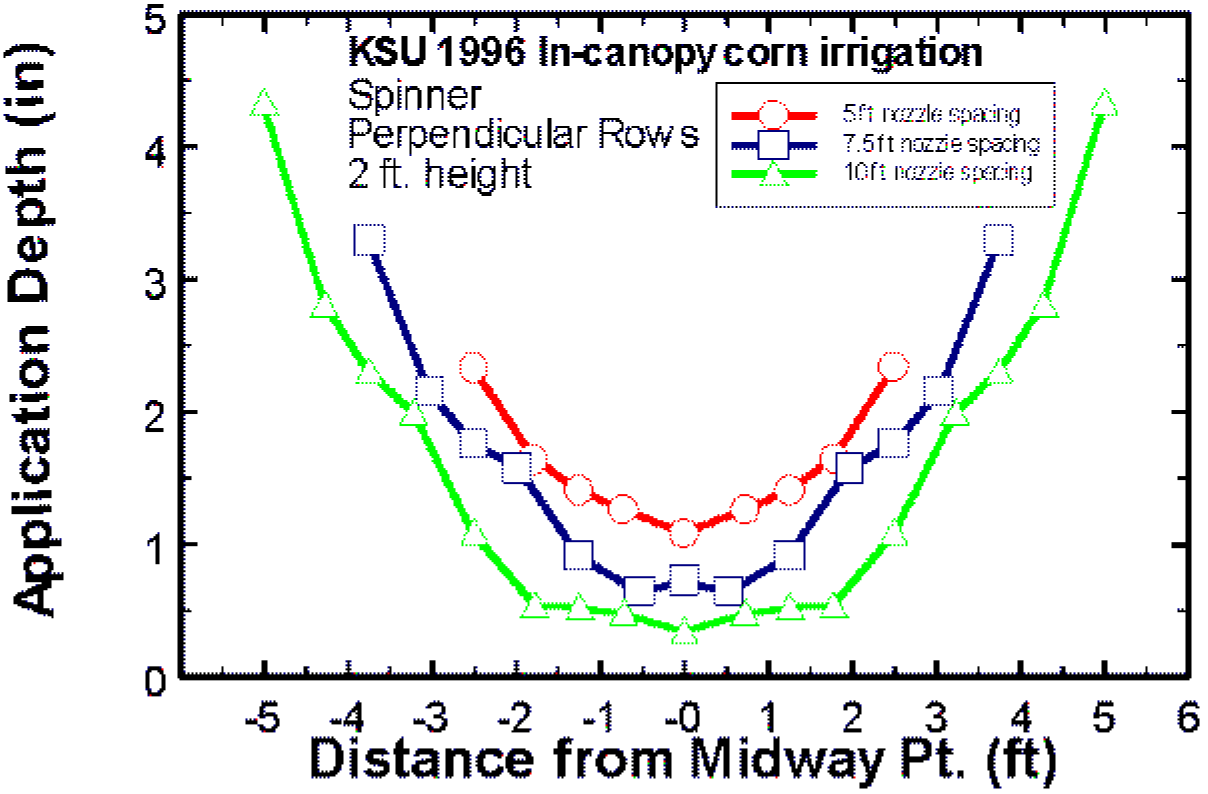

Figure 3. Water application pattern for straight perpendicular rows at various nozzle spacings for spinner nozzles at the 2 ft height in a fully developed corn canopy after tasseling.

Spinners had considerably better in-canopy uniformity than plates at the 2 ft height (Figure 6.) This may not be surprising since the spinner has a rotating water impingement plate that has multiple angles for the diffused water. Conversely, the plate nozzle is static and has only one angle of water diffusion. In essence, the spinner nozzle allows searching of the crop canopy for holes to better diffuse the water. At the 4 ft level, the plate nozzle showed better in-canopy uniformity than the spinner nozzle. One possible reason is that the plate nozzle may be diffusing water at a higher kinetic energy which may allow better penetration. Another possibility may be that the multiple diffusion angles of the spinner may be causing more partitioning of the sprinkler application into stemflow as the height is raised in the canopy (IE the spiking mentioned in the previous section). At the 7 ft height there was not great differences in in-canopy uniformity as affected by nozzle type but the spinner did have higher values.

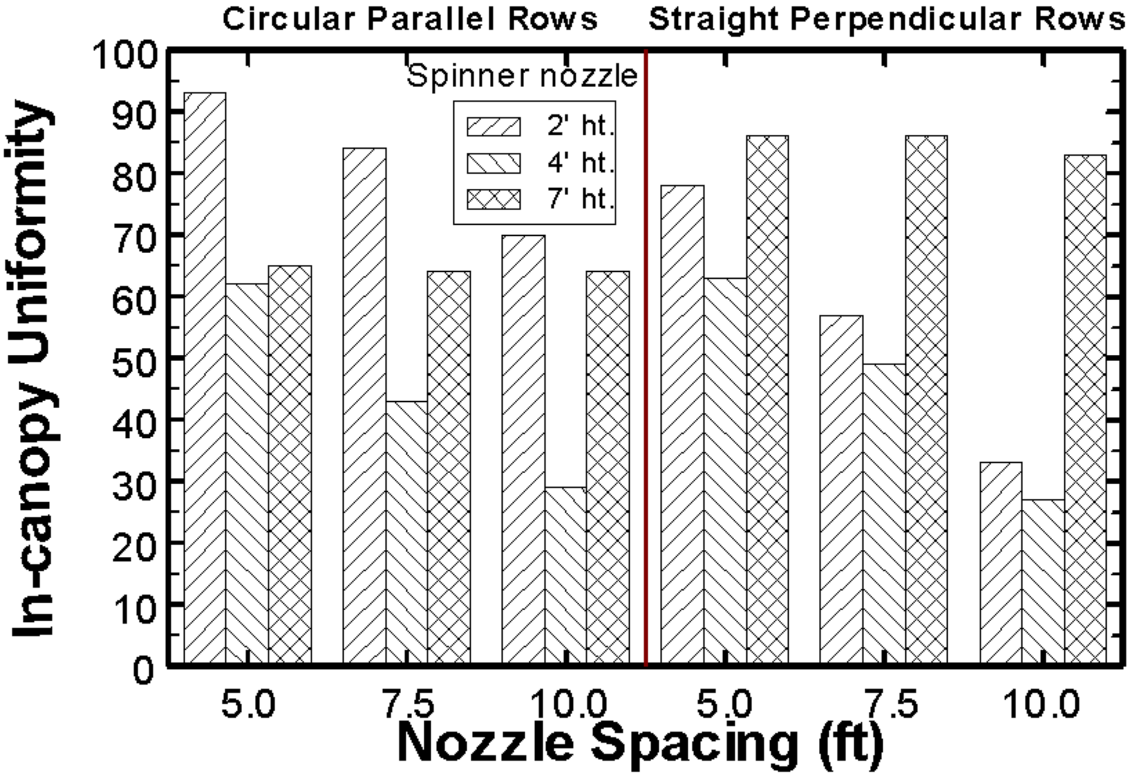

Figure4. In-canopy uniformity as affected by nozzle spacing and row orientation for spinner nozzles at various heights in a fully developed corn canopy after tasseling. The uniformity between corn rows was calculated from closely spaced containers.

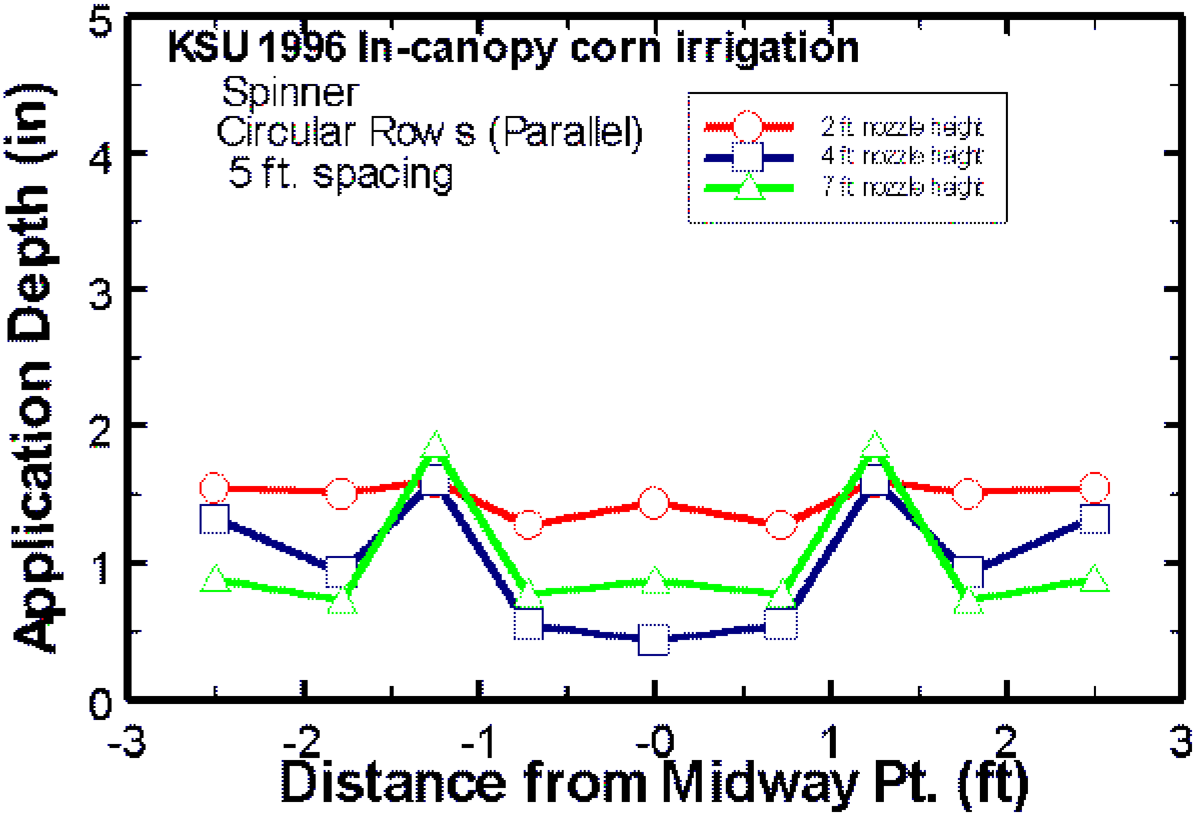

Figure 5. Water application patterns showing evidence of spiking due to stemflow increases as nozzle height increased from 2 to 4 to 7 ft in a fully developed corn canopy.

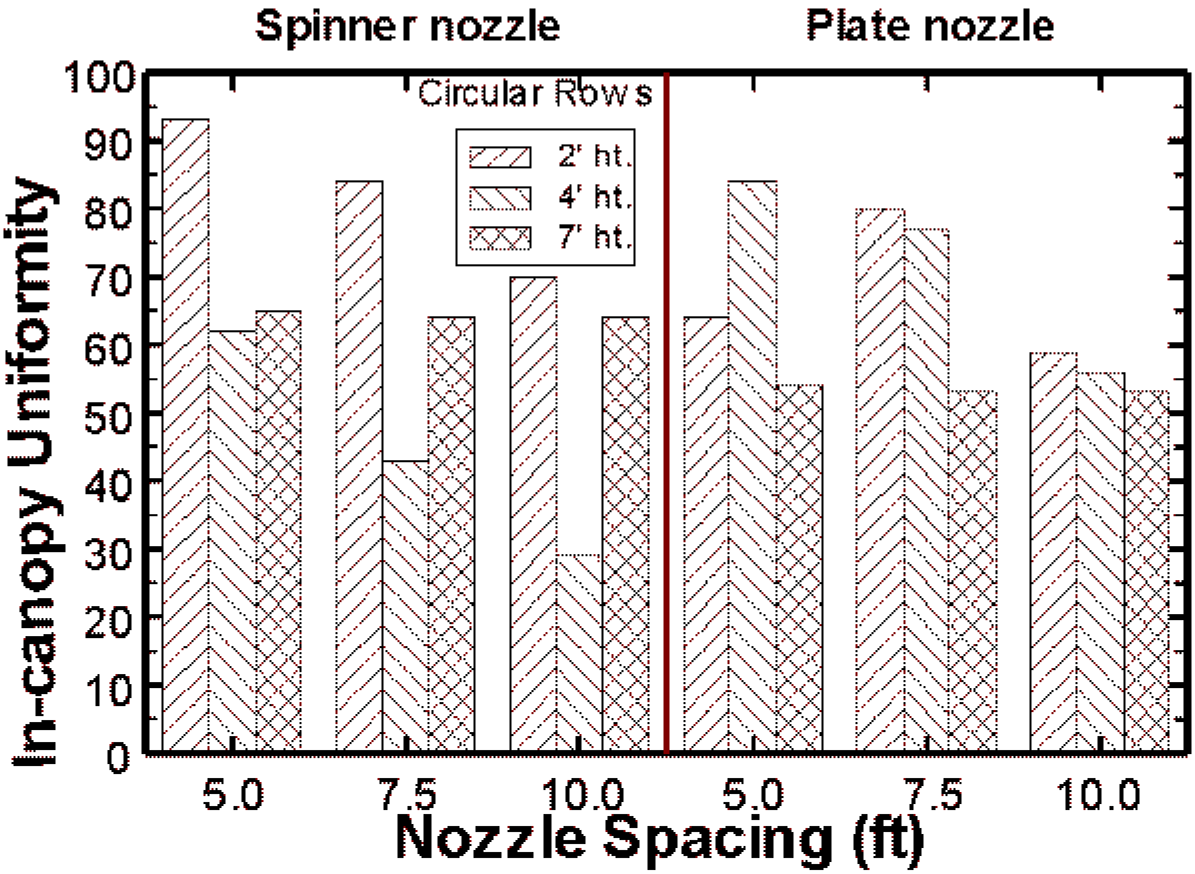

Figure 6. In-canopy uniformity as affected by nozzle spacing and nozzle type for circular parallel rows at various heights in a fully developed corn canopy after tasseling. The uniformity between corn rows was calculated from closely spaced containers.

Table 1 shows the some of the application characteristics for all the comparisons in this study. Examining the rainfall event shows that even Mother Nature can present uniformity differences. The rain storm in this case was driven by a 17 mph (hourly average) wind from the East-Northeast. This resulted in nearly perpendicular application for the circular rows and nearly parallel application for the straight rows, resulting in in-canopy uniformities of 65 and 86%, respectively. In reviewing of this table and additional water application patterns not shown, it is the author’s belief that in-canopy uniformities can be characterized by the following categories:

Good to Excellent 80-100% Fine for most application scenarios

Fair to Good 70-80% Chemigation may require symmetry

Marginal to Fair 60-70% Probably will cause some problems

Unacceptable < 60% There are better methods

Summarizing this section, the worst height in terms of in-canopy uniformity for a spinner nozzle is at 4 ft in a fully developed corn canopy. Row orientation makes a large difference in in-canopy uniformity at the 2 and 7 ft height. Spinners performed better than plates at the 2 and 7 ft heights. In-canopy uniformities as high as 93% are possible with circular rows using spinners with a 5 ft spacing.

References

Hart, W. E. 1972. Subsurface distribution of nonuniformity applied surface waters. Trans. ASAE 15(4):656-661, 666.

Heermann D.F. and P.R. Hein. 1968. Performance characteristics of self-propelled center-pivot sprinkler irrigation systems. Trans. ASAE, 11(1):11-15.

Table 1. Water pattern application characteristics for several in-canopy sprinkler comparisons.

Row Orientation	Nozzle type	Nozzle height (ft)	Nozzle spacing (ft)	Maximum amount (in)	Minimum amount (in)	Mean amount (in)	Standard Deviation (in)	Coefficient of Variation	In-canopy Uniformity	Avar
Parallel (C)	Rain	-	-	0.86	0.26	0.46	0.20	43	65	70
Perpendicular (S)	Rain	-	-	0.81	0.35	0.57	0.11	19	86	57
Parallel (C)	Spinner	2	5.0	1.59	1.27	1.47	0.12	8	93	20
Parallel (C)	Spinner	2	7.5	1.86	1.05	1.50	0.30	20	84	44
Parallel (C)	Spinner	2	10.0	2.36	0.74	1.52	0.53	35	70	69
Parallel (C)	Spinner	4	5.0	1.60	0.43	1.02	0.46	45	62	73
Parallel (C)	Spinner	4	7.5	1.92	0.30	1.06	0.68	65	43	84
Parallel (C)	Spinner	4	10.0	2.56	0.08	1.08	0.89	83	29	97
Parallel (C)	Spinner	7	5.0	1.86	0.73	1.04	0.47	45	65	61
Parallel (C)	Spinner	7	7.5	2.17	0.60	1.04	0.52	50	64	72
Parallel (C)	Spinner	7	10.0	2.18	0.55	1.05	0.51	48	64	75
Perpendicular (S)	Spinner	2	5.0	2.33	1.08	1.60	0.45	28	78	54
Perpendicular (S)	Spinner	2	7.5	3.30	0.64	1.64	0.91	55	57	81
Perpendicular (S)	Spinner	2	10.0	4.33	0.34	1.67	1.33	79	33	92
Perpendicular (S)	Spinner	4	5.0	2.41	0.76	1.36	0.65	47	63	69
Perpendicular (S)	Spinner	4	7.5	3.06	0.47	1.41	0.91	65	49	85
Perpendicular (S)	Spinner	4	10.0	4.07	0.10	1.44	1.29	90	27	98
Perpendicular (S)	Spinner	7	5.0	1.35	0.83	1.04	0.19	18	86	38
Perpendicular (S)	Spinner	7	7.5	1.37	0.75	1.04	0.20	19	86	46
Perpendicular (S)	Spinner	7	10.0	1.51	0.68	1.05	0.24	23	83	55
Parallel (C)	Plate	2	5.0	2.03	0.79	1.28	0.52	41	64	61
Parallel (C)	Plate	2	7.5	1.97	0.68	1.25	0.37	29	80	66
Parallel (C)	Plate	2	10.0	2.49	0.59	1.30	0.65	50	59	76
Parallel (C)	Plate	4	5.0	1.44	0.61	1.10	0.25	23	84	58
Parallel (C)	Plate	4	7.5	1.55	0.55	1.13	0.33	29	77	64
Parallel (C)	Plate	4	10.0	1.99	0.29	1.15	0.57	50	56	85
Parallel (C)	Plate	7	5.0	1.95	0.45	0.96	0.58	60	54	77
Parallel (C)	Plate	7	7.5	2.07	0.57	0.96	0.57	59	53	72
Parallel (C)	Plate	7	10.0	2.06	0.33	0.98	0.59	60	53	84
Perpendicular (S)	Plate	2	5.0	2.22	0.71	1.31	0.56	43	69	68
Perpendicular (S)	Plate	2	7.5	2.88	0.61	1.33	0.78	58	56	79
Perpendicular (S)	Plate	2	10.0	3.74	0.64	1.35	1.00	74	44	83
Perpendicular (S)	Plate	4	5.0	2.79	0.46	1.27	0.92	73	45	83
Perpendicular (S)	Plate	4	7.5	3.69	0.42	1.30	1.16	89	32	89
Perpendicular (S)	Plate	4	10.0	4.68	0.29	1.32	1.41	107	23	94
Perpendicular (S)	Plate	7	5.0	1.58	0.82	1.13	0.31	27	77	48
Perpendicular (S)	Plate	7	7.5	1.75	0.83	1.13	0.31	27	80	52
Perpendicular (S)	Plate	7	10.0	1.82	0.81	1.15	0.34	29	76	56