Measured and Simulated Uniformity of Low Drift Nozzle Sprinklers

G. A. Clark, K. Srinivas, D. H. Rogers, R. Stratton, V. L. Martin

Abstract. *Field measurements conducted on large–scale irrigation systems with fixed–plate, low drift nozzle (LDN) sprinklers showed that coefficient of uniformity (CU) values ranged from 70 to over 90. Measured CU values were typically lower in value for the lower operating pressure systems and for sprinkler packages with wider spacings. Measured single–sprinkler distribution patterns were then used in an overlapping sequence with specific sprinkler spacing scenarios to simulate multiple–sprinkler distribution patterns for moving systems. Scenarios included sprinkler operating pressures of 41, 69, 104, and 138 kPa; sprinkler spacings of 1.83, 2.44, 3.05, and 3.66 m; and nozzle orifice sizes of 4.76 to 7.94 mm with a flow range of 0.16 to 0.77 L/s.*

Simulated patterns and CU values compared well with field–measured patterns and CU values for the respective sprinkler size, spacing, and operating pressure combinations. CU values from simulated patterns were highest for closer sprinkler spacing scenarios (<2.4 m) and higher operating pressures (104 and 138 kPa; still in the low range for sprinkler systems). However, evaporative and wind losses could be higher than with the lower operating pressures, thus reducing the overall application efficiency. Based on the spacing, nozzle size, and operating pressure scenarios tested in this research, sprinkler spacing to wetted diameter ratios should not exceed 0.20 in order to achieve coefficients of uniformity in excess of 90 under no–wind conditions with fixed–plate, LDN–type sprinklers.

Keywords. *Center pivot, Irrigation, Low pressure, Sprinkler, Uniformity.*

Center–pivot irrigation systems account for over half of the irrigation systems on the High Plains of the U.S. While high–pressure sprinklers (300 to 600 kPa) typically have improved droplet breakup, along with more uniform and lower intensities of applied water (Bilanski and Kidder, 1958), energy costs are higher than those associated with the lower pressure (40 to 200 kPa) spray sprinklers that are commonly used on center–pivot irrigation systems on the High Plains. Low–pressure sprinklers typically include fixed–plate spray, grooved–plate spray, and rotating–plate types of diffusers that result in very different droplet size distributions and water application patterns (Kincaid et al., 1996). Wind and evaporation based spray losses are also reduced with lower operating pressures (Howell and Phene, 1983; Vories and von Bernuth, 1986); however, surface runoff may increase due to reductions in wetted diameters (DeBoer et al., 1992).

Article was submitted for review in June 2002; approved for publication by the Soil & Water Division of ASAE in January 2003. ASAE Annual Meeting Paper No. 002021. Contribution of the Kansas State University Agricultural Experiment Station Journal Series No. 02–51–J.

Mention of specific products, trade names, or manufacturers does not imply endorsement by the authors or Kansas State University.

The authors are **Gary A. Clark, ASAE Member Engineer,** Professor, **Kasukurti Srinivas,** Former Graduate Student, **Danny H. Rogers, ASAE Member Engineer,** Professor, and **Robert H. Stratton,** Extension Assistant, Department of Biological and Agricultural Engineering; Kansas State University, Manhattan, Kansas; and **Victor L. Martin,** Associate Professor of Agronomy, Sandyland Experimental Farm, Kansas State University, St. John, Kansas. **Corresponding author:** Dr. Gary A. Clark, Department of Biological and Agricultural Engineering, 147 Seaton Hall, Kansas State University, Manhattan, KS 66506–2906; phone: 785–532–2909; fax: 785–532–5825; e–mail: gac@ksu.edu.

Typical performance characteristics of center–pivot systems include rate of water application, depth of water application with respect to system rotational speed, and system pressure distribution, in addition to the droplet size, trajectory, and distribution characteristics of the sprinkler package. The Christiansen (1942) uniformity coefficient (CU) has been extensively used as a means to assess irrigation system performance by characterizing the distribution of water from sprinklers. Because the area of influence associated with individual sprinklers and locations along a center pivot varies with radial position, the Christiansen (1942) CU relationship was modified for use on center–pivot irrigation systems (Heermann and Hein, 1968; *ASAE Standards*, 2000). Catch depths associated with increasing radial position locations from the pivot point were provided with an increased weighting factor to account for the associated increased area of influence related to that position. Because environmental factors (wind, temperature, vapor pressure deficit) that influence sprinkler system distribution patterns (Bilanski and Kidder, 1958; Edling, 1985; DeBoer et al., 1992; Thompson et al., 1997; Tarjuelo et al., 1999) vary from day to day, composite uniformities (from several irrigation events) can provide an improved indication of system performance and should range from 90 to 94 for well–designed systems (Keller and Bliesner, 1990).

Edling (1985) reported that droplet evaporation rapidly decreased when droplet diameter increased from 0.3 mm to 0.6 mm. Evaporation for 0.3 mm diameter droplets was reduced from in excess of 80% to less than 30% as nozzle elevation was reduced from 3.66 to 1.22 m. However, evaporation rates for 0.6 mm diameter droplets only ranged from 11% to 4% over the same elevation changes. At an operating pressure of 69 kPa, droplet diameters of #8

 © 2003 American Society of Agricultural Engineers ISSN 0001–2351

(3.18 mm), #16 (6.35 mm), and #20 (7.94 mm) Senninger LDN nozzle sizes averaged 1.19, 1.68, and 2.34 mm, respectively, for grooved–plate sprinklers (Kincaid et al., 1996). As pressure was increased to 206 kPa, droplet diameters averaged 1.09, 1.98, and 2.03 mm, respectively, for the same three nozzles. Only 1.4% to 4.2% of the droplets were less than 0.5 mm in diameter, and less than 8.8% were smaller than 1.0 mm for all pressure and nozzle size combinations other than #8 (3.18 mm) at 206 kPa, which had 17.2% of the droplets less than 1.0 mm. Therefore, total droplet evaporation losses from these types of sprinklers would be expected to be close to the 0.4% to 0.6% evaporation loss values (based on total sprinkler output) for the coarse–serrated, fixed–plate, low–pressure sprinklers as reported by Kohl et al. (1987). Thompson et al. (1997) reported droplet evaporation losses of less than 1% each for both impact sprinkler and grooved–plate spray nozzles. However, due to greater areas of wetted coverage, canopy and soil evaporation losses were greater from impact sprinkler water applications than for the spray nozzle applications.

Hanson and Orloff (1996) measured field–based application uniformities of rotator and fixed–plate, spray–type sprinklers from two center–pivot irrigation systems under wind and no–wind field conditions. The fixed–plate sprinkler had a grooved–disk diffuser with measured CU values that ranged from 74 to 87 under no–wind and windy conditions, while CU values of rotator sprinklers ranged from 90 to 97. Wind increased the uniformity of the fixed–plate sprinklers and decreased the uniformity of the rotator sprinklers. Similarly, Schneider (2000) reported that the average uniformities (CU) for spray–type sprinklers used on mechanical–move irrigation systems ranges from 75 to 85 along the mainline and 75 to 90 in the direction of travel.

In 1996, the sprinkler package on a four–span linear–move irrigation system at Kansas State University's Sandyland Experimental Farm, St. John, Kansas, was changed from medium pressure (276 kPa), low angle impact sprinklers to low pressure (41 kPa), grooved–plate, low drift nozzle (LDN) sprinklers. Each span of the linear system had 16 sprinkler drops on flexible hoses at a height of approximately 2 m. The LDN sprinklers were placed on a spacing of 3.05 m and resulted in a substantial overlap of the 8.1 m radius of the wetted pattern from the sprinklers. Sprinkler nozzles on two of the spans were modified to apply a "medium" water application rate that would be used in an irrigation scheduling study. Sprinkler nozzles on the other two spans were designed to apply a "low" application rate and a "high" application rate.

Wind drift losses of applied irrigation water appeared to be visually less than those from a higher–pressure impact sprinkler system that was 150 m to the west. Clark et al. (1999) reported measured uniformities of 71 to 79 for that system. Furthermore, the application patterns had a very sinusoidal shape with minimum and maximum application depths ranging from 50% to 150% of the mean catch depth. Higher application depth locations have the potential to leach crop nutrients or other soluble elements from the soil profile (Brito and Willardson, 1982), while reduced depth zones may leave undesirable salts in the profile. The system was later modified to improve uniformity by increasing the nozzle pressure to 104 kPa and reducing the nozzle size to maintain the similar discharge rates. While resulting application patterns were still periodic, maximum and minimum application depths ranged from –15% to +15% of the mean, and uniformities ranged from 92 to 95 (Clark et al., 2000). However, reductions in droplet size due to increased nozzle pressure may result in higher evaporation losses (Steiner et al., 1983; Edling, 1985; DeBoer et al., 1992; Kincaid et al., 1996; Thompson et al., 1997).

In general, grooved–plate spray nozzles have performance characteristics of relatively large droplets, medium areas of application coverage, minimal wind distortion, and low energy requirements. These are desirable sprinkler package characteristics for use with center–pivot irrigation systems in the windy, semi–arid field conditions of the High Plains. However, water application uniformities may be low, even when good design procedures are followed. Therefore, a study was designed to simulate water applications patterns for various sprinkler spacing and operating pressure combinations from grooved–plate, low drift nozzle (LDN) sprinklers. Specific objectives were:

- To compare and validate simulated LDN sprinkler distribution patterns based on single–sprinkler characteristic data with field–measured LDN distribution data.
- To use simulated multiple–sprinkler application distribution results to evaluate optimal spacing and pressure combinations for LDN type sprinklers.

METHODS AND MATERIALS

FIELD TESTS

Catch pan tests were conducted in south central Kansas on four traveling irrigation systems with grooved–plate, low–pressure sprinkler packages. Tested systems are described in table 1 and included a linear–move system and three center pivots. The linear system was used for multiple nozzle orifice size and pressure combination measurements. All systems had drops at the truss height (2.1 to 2.4 m high), and all systems were pressure regulated with individual regulators for each sprinkler. Wind during each of the tests ranged from 2 to 4 m/s. Catch containers were 430 mm diameter pans that were 100 mm deep (fig. 1). These "large" pans were used because the application characteristics of the grooved–plate sprinklers result in discrete streams of water (fig. 2) rather than a randomly distributed droplet pattern. The pans were placed on either a 1.2 or 1.5 m spacing, depending on the sprinkler spacing of the measured system, to avoid lining up with every sprinkler. The 1.5 m spacing was used on system ED08 (table 1), and the 1.2 m spacing was used on the other systems. These field test procedures varied from the outlined procedures in ASAE Standard S436.1 (*ASAE Standards*, 2000). While only one row of collectors was used, collectors were spaced closer than the recommended 3 m for spray

Table 1. Characteristics of the field–scale irrigation systems.

System	Total System Length (m) / No. of Spans	Sprinkler Package	Sprinkler Spacing (m)	Operating Pressure (kPa)
Linear	195 / 4	Senninger LDN	3.1	42 – 10 4
Pivot I	404 / 6	Senninger LDN	1.5	69
Pivot II	395 / 8	Nelson D3000	2.4	69
Pivot III	396 / 10	Nelson D3000	3.1	104

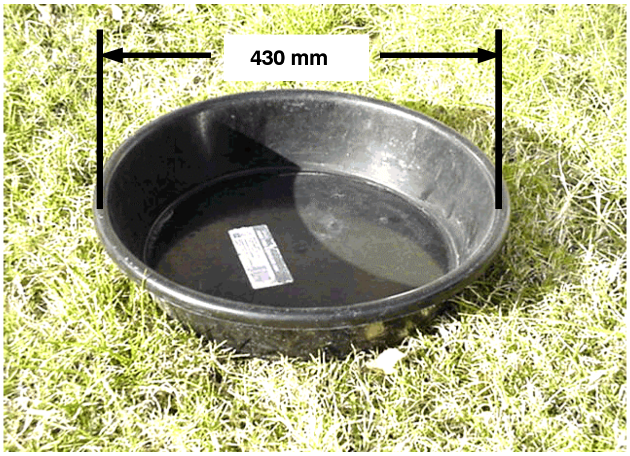

Figure 1. Catch pan used for sprinkler application measurements. Pans were 100 mm deep.

Figure 2. Example of a grooved–plate sprinkler with discrete water streams as tested in this study.

devices, and the opening of the collectors provided 51 times the surface area of the recommended minimum diameter of 60 mm.

The catch pan tests were conducted on the outer half of the center–pivot systems, which represents about 75% of the total irrigated area. Tests were conducted early in the growing season (June) on the access roads or in a location that would not have any plant interference of applied water. Pans were collected and weighed as soon as the sprinkler water pattern passed over and was no longer adding water to the pans. A team of four to five persons was involved to collect the pans and minimize any evaporative influences. The linear system was used to evaluate several nozzle orifice size and pressure combinations as part of a separate field experiment. Resultant distribution depth field data were normalized with respect to the average depth for comparison purposes.

Collected data were entered into a spreadsheet program for graphical display and analysis using the Christiansen Coefficient of Uniformity (CUC) or the Heermann and Hein (CUH) modification for center pivots, as appropriate (*ASAE Standards*, 2000). All coefficient of uniformity data were reported using the CU notation.

Laboratory Tests

Single–sprinkler distribution patterns were measured at the Department of Biological and Agricultural Engineering at Kansas State University during the spring and summer of 1999 using the 430 mm diameter pans described above. Sprinklers were mounted on an elevated lateral pipe with hose drops for the sprinklers so that the sprinkler diffuser plates were approximately 2 m above the ground. Each sprinkler was individually pressure regulated to the desired test pressure. Sprinkler flow rates and pressures were measured to verify intended performance. Catch pans for initial sprinkler tests were positioned in rows using a rectangular grid pattern on a concrete pad. The test area was surrounded on three sides by 3–story buildings that helped to minimize any wind distortion effects. Pan rows were 0.6 m apart, and pans within rows were touching each other (fig. 3a). Measured water applications were summed by rows to simulate the water accumulation from a linearly moving sprinkler. Subsequent single–sprinkler tests used a radial orientation catch pan pattern (fig. 3b). Four rows of touching catch pans extended outward from the center point of the

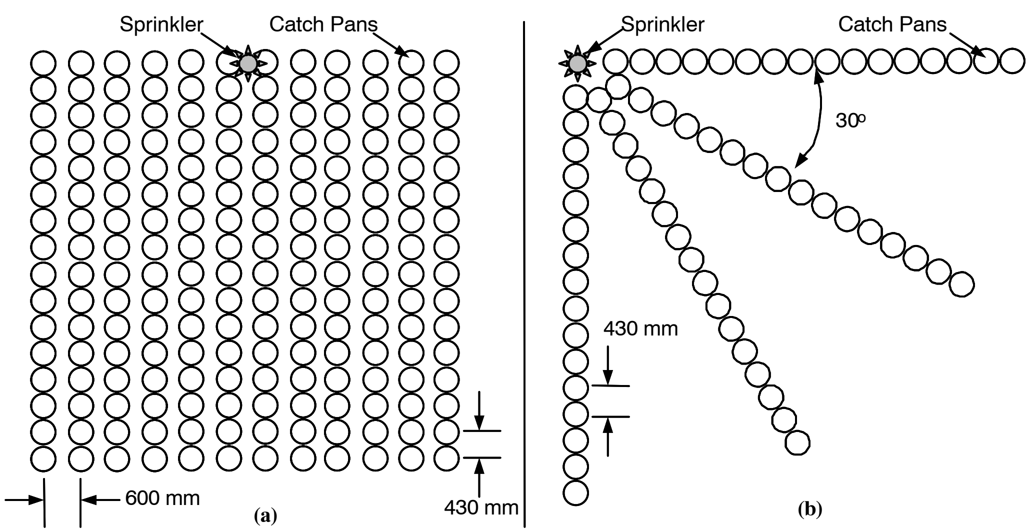

Figure 3. Catch pan configurations for the laboratory tests on sprinkler distribution patterns: (a) initial full grid pattern design, and (b) subsequent radial pan design.

Table 2. Low drift nozzle (LDN) sprinkler discharge rates (L/s) based on orifice size (number and diameter in mm) and operating pressure (kPa) combinations for the single–sprinkler tests. Diameters of coverage ranged from 8.0 to 16.0 m.

Orifice No.	Orifice Size (mm)	Operating Pressure (kPa)			
		41	69	104	138
12	4.76	0.16	0.20	0.24	0.28
13	5.16	—	—	0.28	—
14	5.56	0.22	0.28	0.33	0.39
16	6.35	0.28	0.37	0.44	0.51
18	7.14	0.36	0.46	0.55	0.63
20	7.94	0.43	0.56	0.66	0.77

distribution pattern. An average radial distribution pattern was then generated and used to model and simulate the accumulated application of water from a linear movement of the sprinkler.

Individual sprinklers were operated for 30 min during each test. Pans were individually weighed to measure applied water. Data were then adjusted to depths based upon the surface area of the catch pans. For replication purposes, three different sprinkler nozzle, grooved diffuser, and regulator assemblies were tested and measured for each orifice size and pressure combination (table 2). Measured patterns of similar–size sprinkler combinations were then averaged. Orifice size and pressure combinations resulted in sprinkler discharge rates from 0.16 to 0.77 L/s and diameters of coverage from 8.0 to 16.0 m. Sprinkler combinations were coded according to the orifice number (size in 64th of an inch) and operating pressure (psi). For example, a No. 14 orifice (14/64th in., or 5.56 mm) operated at 69 kPa (10 psi) was coded as "14S10." The "S" represented the manufacturer of the sprinkler as Senninger Irrigation, Inc. Four of the combinations (table 2) were selected to evaluate the effect of operating pressure with respect to spacing by providing the same flow rate of water (0.28 L/s) at the four different operating test pressures (41, 69, 104, and 138 kPa).

Distribution Simulations

A computer simulation of water application distribution patterns for linear–move irrigation systems was conducted by overlapping measured single–sprinkler water application patterns based on the desired device spacing. Each orifice and pressure combination was used to simulate sprinkler spacing scenarios of 1.83, 2.44, 3.05, and 3.66 m. Thus, all spacing scenarios ranged from 10% to 46% of the range of wetted diameters. An additional designation was added to the sprinkler combination code to designate the simulated spacing (ft), such that "14S10–08" represented the 14S10 orifice and pressure combination on 2.44 m (8 ft) spacing. Simulated distribution depths and patterns were normalized for comparison purposes using the average depth. Resultant water application patterns were then analyzed to determine the associated CU value using the CUC procedure for linear–move systems.

Results and Discussion

Figures 4 through 7 show irrigation distribution results from the linear and center–pivot irrigation systems with the grooved–plate, low drift nozzle packages, as described in table 1. Calculated uniformities (CU values) ranged from 78 to 90 and were lower than expected, but were consistent with values reported by Hanson and Orloff (1996). The linear system (fig. 4) had the lowest CU value and had the lowest sprinkler operating pressure (41 kPa). The pivot I system, which had the closest spaced (1.5 m) sprinklers, had the highest uniformity (fig. 5). However, such a design results in more sprinklers and a higher initial system cost. The relative application depths of that system ranged from 0.7 to 1.3, while the relative depths of the other three systems (linear, pivot II, and pivot III) ranged from 0.6 to 1.4. This range of application depths was also greater than expected, but was similar to those observed on the linear system (fig. 4) with similar sprinkler packages (Clark et al., 1999).

Examples of the single–sprinkler cumulative depth patterns are shown in figures 8 and 9. These figures show the cumulative depth pattern from a linearly moving single sprinkler. Figure 8 shows the effect of increasing pressure with a fixed orifice size. Slight increases in radial distance occurred with increased pressure. Similarly, a slight increase in orifice size from 6.35 mm (16S10) to 7.14 mm (18S10) had the same effect (fig. 9). These patterns were then overlapped according to the desired spacing and summed to create the simulated distribution patterns.

A comparison between measured (linear system) and simulated distribution patterns is shown in figures 10 and 11 for the 16S10 and 18S06 combinations, respectively, on 3.05 m spacing. While the discharge rates of these sprinklers were similar at 0.37 and 0.36 L/s (table 2), resultant application patterns and CU values were very different. The lower operating pressure scenario (18S06) had lower field–measured and simulated CU values than the 16S10 scenario.

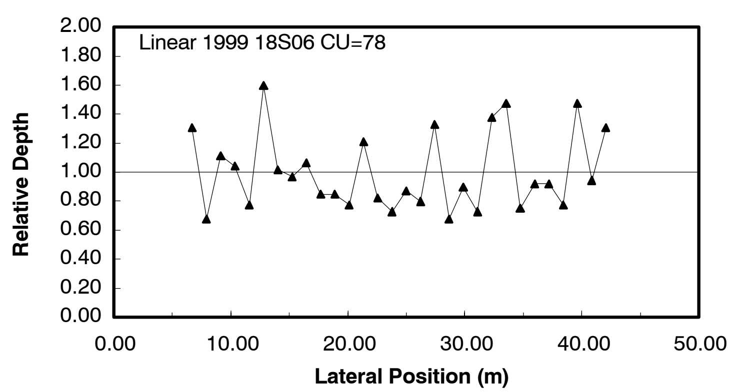

Figure 4. Relative depths of measured water applications from the linear system with 18S06 sprinklers on 3.1 m spacing. The coefficient of uniformity (CU) was 78.

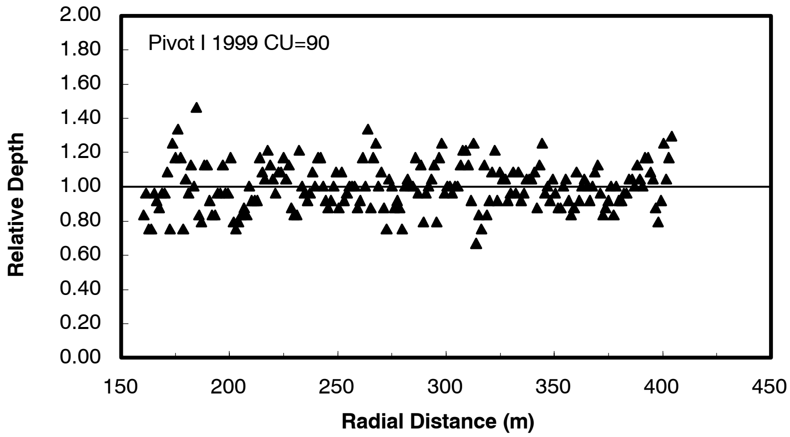

Figure 5. Relative depths of measured water applications from the pivot I system with 1.5 m sprinkler spacing. The coefficient of uniformity (CU) was 90.

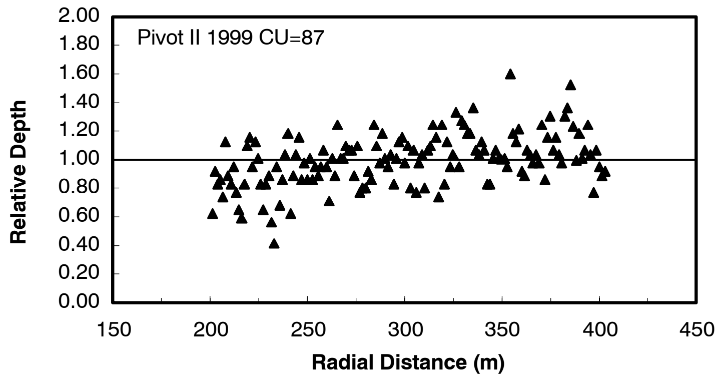

Figure 6. Relative depths of measured water applications from the pivot II system with 2.4 m sprinkler spacing. The coefficient of uniformity (CU) was 87.

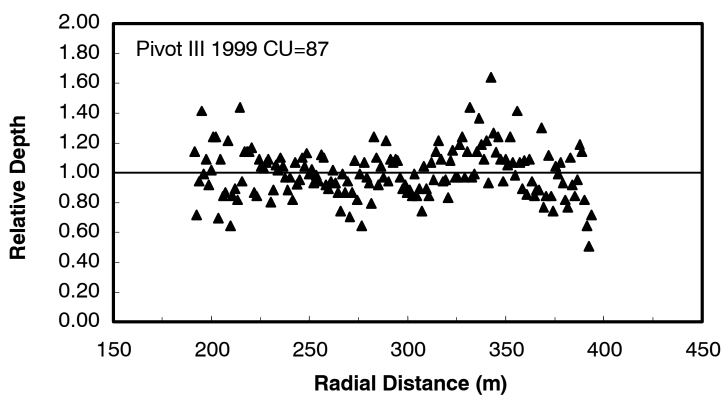

Figure 7. Relative depths of measured water applications from the pivot III system with 3.1 m sprinkler spacing. The coefficient of uniformity (CU) was 87.

Simulated patterns tended to mimic measured patterns and resulted in similar CU values. In a comparison between measured and simulated CU values for six field–measured sprinkler combinations over three pressure ranges (table 3 and fig. 12), differences were small. In a paired value t–test, the average difference was zero ($p = 0.038$), and a linear regression of simulated versus measured CU values (fig. 12) had a slope of 0.98 with an R^2 of 0.80 ($p = 0.016$). Thus, it was believed that the simulation procedures were valid for other scenarios and compared well with field–measured data.

Relative water distribution patterns for the 16S10 sprinkler combination spaced at 1.83, 2.44, 3.05, and 3.66 m (16S10–06, 16S10–08, 16S10–10, and 16S10–12) are shown in figures 13, 14, 15, and 16, respectively. The diamond symbols used in these figures are on a 0.61 m spacing. Therefore, depending on plant spacing and populations, some plants on the lower CU packages could receive substantially less (fig. 15) or more (fig. 14) water. Depending on local rainfall, crop rooting characteristics, and soil hydraulic characteristics, crop yields could be influenced due to water stress or leaching (non–beneficial or inadequate).

Table 4 summarizes resultant CU values from all simulated scenarios. While simulated CU values tended to decrease with increased spacing, some nozzle combination

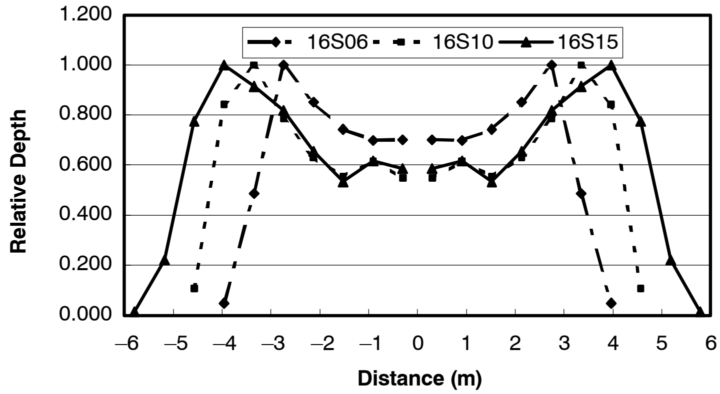

Figure 8. Cumulative depth (relative) patterns for single–sprinkler combinations 16S06, 16S10, and 16S15.

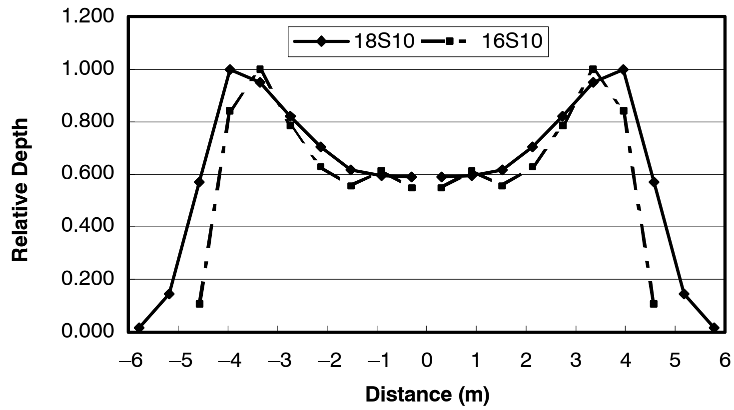

Figure 9. Cumulative depth (relative) patterns for single–sprinkler combinations 18S10 and 16S10.

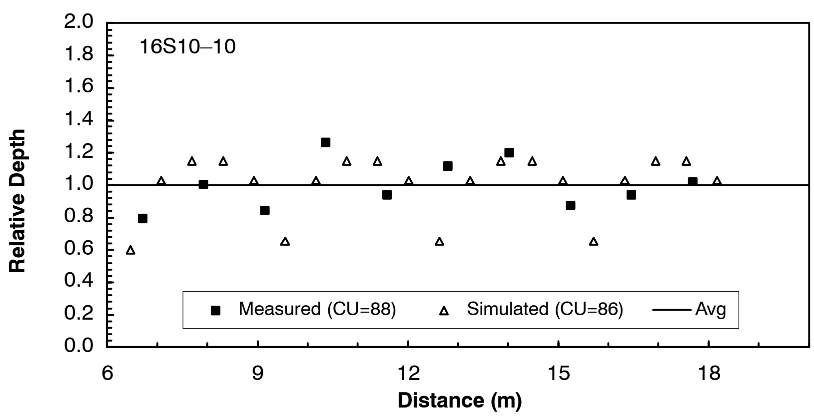

Figure 10. Comparison of the simulated nozzle pattern (CU = 86) to field–measured data (CU = 88) for a 16S10 sprinkler on 3.05 m spacing.

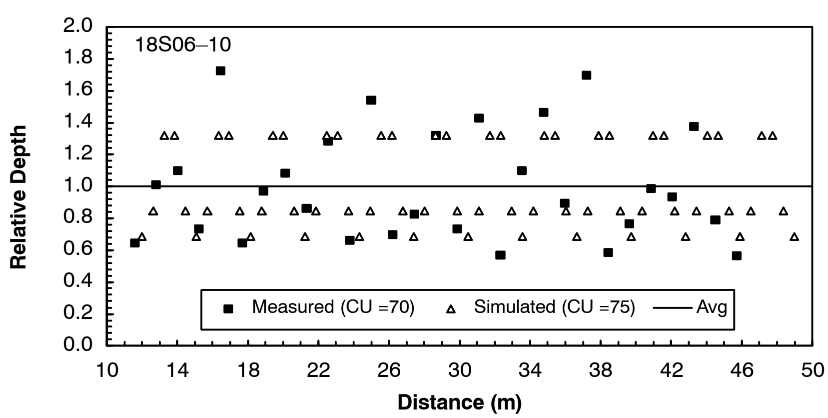

Figure 11. Comparison of the simulated nozzle pattern (CU = 75) to field–measured data (CU = 70) for an 18S06 sprinkler on 3.05 m spacing.

Table 3. Comparison of measured and simulated CU values for six sprinkler orifice size and pressure scenarios with 3.05 m spacing.

Nozzle Code	Measured	Simulated	Difference
16S06	82.2	83.4	–1.2
18S06	78.0	75.0	3.0
20S06	79.5	82.0	–2.5
16S10	88.0	86.0	2.0
13S15	93.8	90.4	3.4
16S15	91.5	95.9	–4.4
Average	85.5	85.5	0.0
Significance	—	—	p = 0.038

and spacing scenarios had mixed results (e.g., 14S06, 16S10, and 20S10). The simulated relative water distribution pattern for the 18S10 sprinkler combination on 3.05 m spacing resulted in a CU of 99. This was substantially higher than that of the 18S06 combination or the 16S10 combination with the same sprinkler spacing (CU = 75 and 86, respectively). Thus, a slight increase in pressure and/or orifice size that results in an increase in the size of the distribution pattern (figs. 8 and 9) could subsequently have a substantial effect on the resultant application pattern and associated CU value. The 16S15 single–sprinkler pattern (fig. 8) and the 18S10 pattern

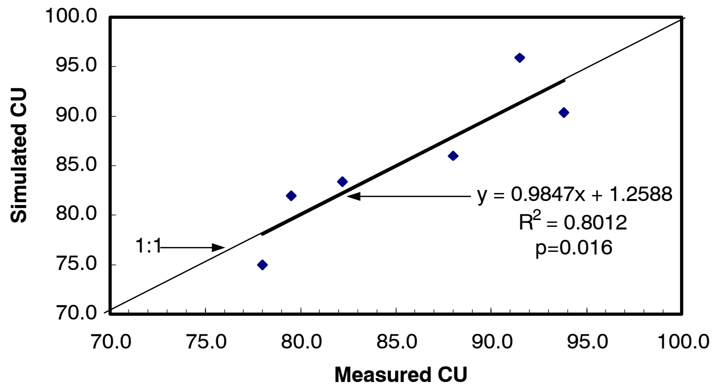

Figure 12. Graphical distribution of simulated and measured CU values from systems with 3.05 m sprinkler spacing.

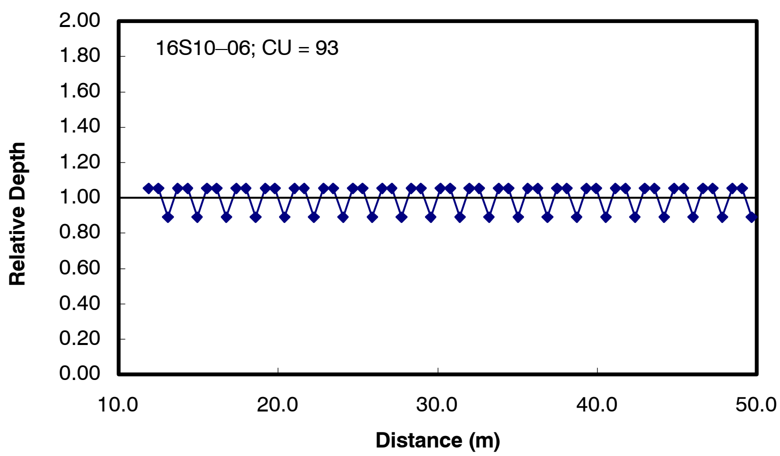

Figure 13. Simulated relative distribution pattern for a 16S10–06 sprinkler (6.35 mm orifice, 69 kPa, and a 1.83 m spacing) with a CU of 93.

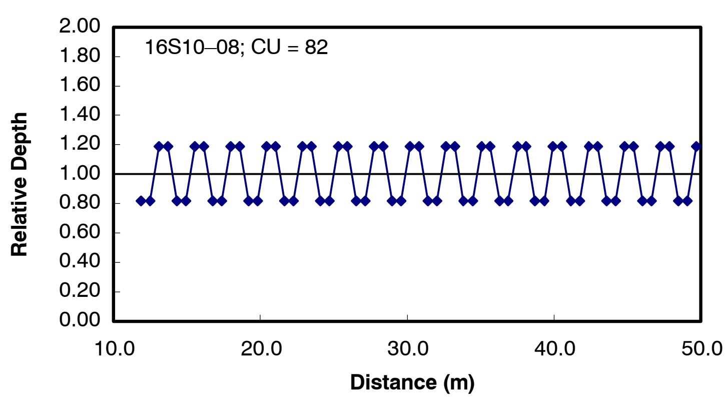

Figure 14. Simulated relative distribution pattern for a 16S10–08 sprinkler (6.35 mm orifice, 69 kPa, and a 2.44 m spacing) with a CU of 82.

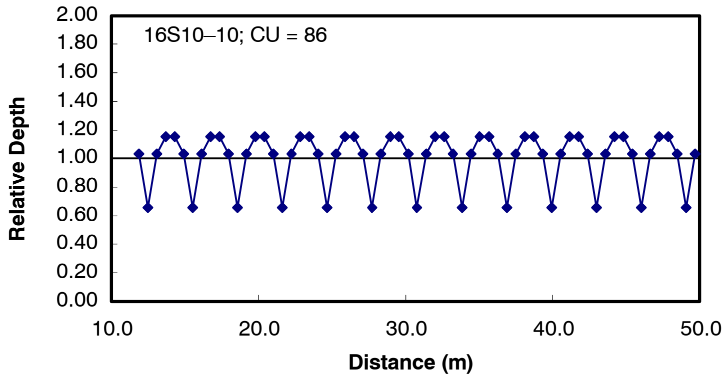

Figure 15. Simulated relative distribution pattern for a 16S10–10 sprinkler (6.35 mm orifice, 69 kPa, and a 3.05 m spacing) with a CU of 86.

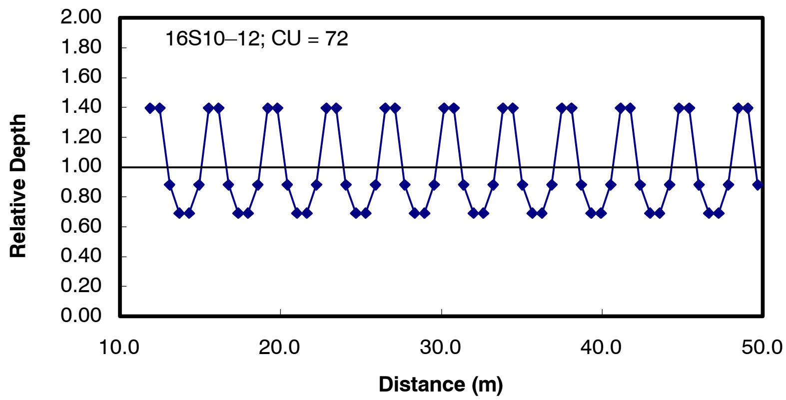

Figure 16. Simulated relative distribution pattern for a 16S10–12 sprinkler (6.35 mm orifice, 69 kPa, and a 3.66 m spacing) with a CU of 72.

Table 4. Coefficient of uniformity (CU) values of the various simulated water distribution patterns for all LDN nozzle size, operating pressure, and spacing scenarios.

Nozzle Combination	Sprinkler Spacing (m)			
	1.83	2.45	3.05	3.66
12S06 (1)	95	90	85	82
12S10 (1)	95	93	90	89
12S15 (1)	>99	97	91	96
12S20 (1)[a]	96	92	88	89
13S15 (1)[a]	96	92	90	84
14S06 (1)	93	83	93	72
14S10 (1)[a]	>99	90	86	98
14S15 (1)	96	91	88	85
14S20 (1)	97	97	91	96
16S06 (2)[a]	92	88	83	88
16S10 (2)	93	82	87	72
16S15 (2)	95	>99	96	80
16S20 (2)	98	97	94	94
18S06 (2)	95	88	75	94
18S10 (2)	>99	94	99	82
18S15 (2)	97	91	88	97
18S20 (2)	99	>99	99	90
20S06 (3)	93	86	87	84
20S10 (3)	>99	98	83	93
20S15 (3)	>99	95	98	85
20S20 (3)	>99	>99	96	95

[a] These four sprinklers had the same discharge rate (0.28 L/s).

(fig. 9) have similar shapes in comparison to the 16S10 pattern shown in both figures. As would be expected, the resultant CU values (table 3) are very similar for the four spacing combinations with those nozzle combinations (16S15 and 18S10). Yet many of these single–sprinkler patterns are unique and difficult to predict, requiring individual measurement and characterization.

Table 5. Average coefficient of uniformity values for the various simulated operating pressure and sprinkler spacing combinations and the analysis of variance results.

Operating Pressure (kPa)	Sprinkler Spacing (m)				Significance[a]
	1.83	2.45	3.05	3.66	
41	93	87	84	84	**
69	97	91	89	87	NS
104	97	94	92	88	**
138	98	97	94	93	*
Significance[a]	**	***	*	NS	

[a] Significance is expressed as $p < 0.10$ (*), $p < 0.05$ (**), $p < 0.001$ (***), or not significant (NS) using analysis of variance procedures.

Analysis of variance (ANOVA) results of the data in table 4 are summarized in table 5, showing the data grouped according to sprinkler spacing and operating pressure. Coefficient of uniformity (CU) values from simulated patterns significantly increased with operating pressure for the 1.83, 2.45, and 3.05 m spacing scenarios. The CU values for the widest spacing (3.66 m) were more varied, but still showed an increasing trend with operating pressure. While only the highest operating pressure (138 kPa) resulted in consistently acceptable uniformity values (CU > 90) for all spacing scenarios, closer sprinkler spacing is required with lower operating pressures to maintain CU > 90. Four of the scenarios identified in table 4 had the same discharge rate (0.28 L/s). Simulated CU values tended to decline for most

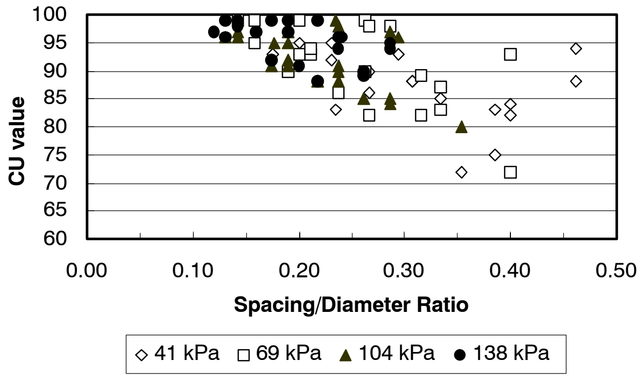

Figure 17. Relationship between simulated coefficient of uniformity (CU) and the ratio of sprinkler spacing to wetted diameter. Simulated scenarios are plotted with respect to operating pressure.

combinations with a wider spacing (3.05 and 3.66 m). This is consistent with fixed–plate spray sprinkler spacing recommendations of 1.5 to 2.4 m for operating pressures of 10 to 20 psi, respectively (Keller and Bliesner, 1990; Scherer et al., 1999).

Figure 17 shows the relationship between CU value and the ratio of sprinkler spacing to wetted diameter for all simulated scenarios. In general, for design CU values of 90 or more, sprinkler spacing to wetted diameter ratios should be maintained at 0.20 or less. Lower operating pressures (41 and 69 kPa) had more varied CU values than the higher pressures (104 and 138 kPa). If wind is a problem and larger droplets (and coarser patterns) are needed, then the lower pressures should be used (Howell and Phene, 1983; Edling, 1985; Vories and von Bernuth, 1986; Kincaid et al., 1996). However, associated sprinkler wetted diameters should be assessed to determine an acceptable spacing. While this study did not evaluate spacing scenarios closer than 1.83 m, closer spacing criteria may be desired for smaller nozzle sizes with lower pressures that have wetted diameters less than 8 m. However, application rates should be closely monitored.

Summary and Conclusions

Field and laboratory studies were conducted to evaluate the uniformity of applied water from fixed–plate, low drift nozzle (LDN) sprinklers as used on center–pivot and linear–move irrigation machines. Field measurements of water application patterns were conducted on three center–pivot systems and one linear–move irrigation system in south central Kansas. Catch pan results showed that coefficient of uniformity (CU) values ranged from 70 to over 90, but were typically lower in value for lower operating pressure systems and wider sprinkler spacings.

Distribution patterns from single fixed–plate sprinklers were measured and summed to approximate the cumulative pattern from a single moving sprinkler. Those patterns were then used in an overlapping sequence with specific sprinkler spacing scenarios to simulate the resultant multiple–sprinkler distribution patterns. Coefficient of uniformity (CU) values were calculated for the resultant patterns. Simulated application patterns and CU values compared well with field–measured patterns and CU values for the respective sprinkler sizes, spacing, and operating pressures.

Simulated spacing scenarios ranged from 10% to 46% of the wetted diameters of the sprinklers. Resultant simulated spacing CU values ranged from 72 to 99 and tended to decrease with increased sprinkler spacing and/or decreased operating pressure. However, some lower pressure and wide spacing scenarios resulted in CU values in excess of 90. Manufacturers of these types of sprinklers recommend spacing sprinklers between 1.2 to 3.1 m and operating at the lower pressure ranges of 40 to 70 kPa. However, this research has shown that fixed–plate sprinkler package designs that use the higher end of that spacing range and/or the lower end of that pressure range may result in lower than acceptable uniformities (<<90). In general, if design CU values of 90 or greater are desired, then fixed–plate sprinkler spacing should probably not exceed 20% to 25% of the wetted diameter of the sprinkler, and under low pressure (40 kPa), sprinkler spacing should probably not exceed 1.8 m. Fixed–plate, spray sprinklers may be spaced at 2.5 to 3.0 m with operating pressures that exceed 70 kPa, but evaporative and wind losses could be higher than with the lower pressure systems, thus reducing application efficiency.

Acknowledgements

The authors wish to express their appreciation and gratitude to Senninger Irrigation, Inc., and Nelson Irrigation Corporation for their support of this work through product donations. This work was supported in part by the State Water Plan funds from the Kansas Water Office and by the Kansas Corn Commission.

References

ASAE Standards. 2000. ANSI/ASAE Standard S436.1 OCT97: Test procedure for determining the uniformity of water distribution of center pivot and lateral move irrigation machines equipped with spray or sprinkler nozzles. St. Joseph, Mich.: ASAE.

Bilanski, W. K., and E. H. Kidder. 1958. Factors that affect the distribution of water from a medium–pressure rotary irrigation sprinkler. *Trans. ASAE* 1(1): 19–23, 28.

Brito, R. A. L., and L. S. Willardson. 1982. Sprinkler irrigation uniformity requirements for the elimination of leaching. *Trans. ASAE* 25(5): 1258–1261.

Christiansen, J. E. 1942. Irrigation by sprinkling. Bulletin No. 670. Berkeley, Cal.: University of California, Agricultural Experiment Station.

Clark, G. A., D. H. Rogers, V. L. Martin, R. Stratton, and D. L. Fjell. 1999. Uniformity of low drift nozzle irrigation. In *Field Research, 1999*, 116–119. Report of Progress No. 835. Manhattan, Kansas: Kansas State University, Agricultural Experiment Station and Cooperative Extension Service.

Clark, G. A., E. Dogan, V. L. Martin, D. H. Rogers, and R. Stratton. 2000. Uniformity of low drift nozzle irrigation. In Field Research, 2000, 114–118. Report of Progress No. 854. Manhattan, Kansas: Kansas State University, Agricultural Experiment Station and Cooperative Extension Service.

DeBoer, D. W., D. L. Beck, and A. R. Bender. 1992. A field evaluation of low, medium, and high pressure sprinklers. *Trans. ASAE* 35(4): 1185–1189.

Edling, R. J. 1985. Kinetic energy, evaporation, and wind drift of droplets from low–pressure irrigation nozzles. *Trans. ASAE* 28(5): 1543–1550.

Hanson, B. R., and S. B. Orloff. 1996. Rotator nozzles more uniform than spray nozzles on center–pivot sprinklers. *California Agric*. 50(1): 32–35.

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

Howell, T. A., and C. J. Phene. 1983. Distribution of irrigation water from a low pressure, lateral–moving irrigation system. *Trans. ASAE* 26(5): 1422–1429, 1434.

Keller, J., and R. D. Bliesner. 1990. *Sprinkle and Trickle Irrigation*. New York, N.Y.: Van Nostrand Reinhold.

Kincaid, D. C., K. H. Solomon, and J. C. Oliphant. 1996. Droplet size distributions for irrigation sprinklers. *Trans. ASAE* 39(3): 839–845.

Kohl, K. D., R. A. Kohl, and D. W. BeBoer. 1987. Measurement of low–pressure sprinkler evaporation loss. *Trans. ASAE* 30(4): 1071–1074.

Scherer, T. F., W. Kranz, D. Pfost, H. Werner, J. A. Wright, and C. D. Yonts. 1999. *Sprinkler Irrigation Systems*. 1st ed. MWPS–30. Ames, Iowa: Iowa State University, Midwest Plan Service.

Schneider, A. D. 2000. Efficiency and uniformity of the LEPA and spray sprinkler methods: A review. *Trans. ASAE* 43(4): 937–944.

Steiner, J. L., E. T. Kanemasu, and R. N. Clark. 1983. Spray losses and partitioning of water under a center–pivot sprinkler system. *Trans. ASAE* 26(4): 1128–1134.

Tarjuelo, J. M., J. Montero, P. A. Carrion, F. T. Honrubia, and M. A. Calvo. 1999. Irrigation uniformity with medium size sprinklers: Part II. Influence of wind and other factors on water distribution. *Trans. ASAE* 42(3): 677–689.

Thompson, A. L., D. L. Martin, J. M. Norman, J. A. Tolk, T. A. Howell, J. R. Gilley, and A. D. Schneider. 1997. Testing of a water loss distribution model for moving sprinkler systems. *Trans. ASAE* 40(1): 81–88.

Vories, E. D., and R. D. von Bernuth. 1986. Single nozzle sprinkler performance in wind. *Trans. ASAE* 35(4): 1185–1189.