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Tillage and Low-Pressure Center-Pivot Irrigation Effects on Corn Yield¹

W. W. Wilhelm, L. N. Mielke, and J. R. Gilley²

ABSTRACT

Low-pressure sprinkler irrigation systems have the potential to save energy, but also may aggravate soil- and water-management problems. The objective of this research was to determine the influence of center-pivot sprinkler irrigation method in combination with various tillage practices on corn (*Zea mays* L.) yield and yield components. A center-pivot irrigation machine was redesigned to apply water by high-pressure-impact (HPI), low-pressure-impact (LPI), and low-pressure-spray (LPS) nozzles. Nozzles were sized and spaced to apply three different amounts of water: 100% (full irrigation), 75 and 50%. Three tillage treatments were used—till-plant (T), disk (D), and till-plant with chisel after last cultivation (C)—for each method and amount of water applied. The field study was conducted over a 4-year period (1978 to 1981) on a Sharpsburg silty clay loam (fine, montmorillonitic, mesic Typic Argiudolls). Yields were influenced by the seasonal distribution and amount of precipitation, irrigation water applied, tillage, and the combined management inputs. The method of water application (HPI, LPI, and LPS nozzles) did not significantly ($P > 0.10$) influence grain yield. In 1979, the chisel tillage treatment produced significantly less grain than other treatments because severe root pruning limited stored water uptake during an extremely stressful period immediately following the chisel operation. No inherent differences in productivity were associated with low-pressure center-pivot-sprinkler irrigation, or with various conservation-tillage practices used in combination with reduced-pressure-sprinkler irrigation. Therefore, use of these practices can reduce production costs without reducing yield.

Additional index words: *Zea mays* L., Reduced tillage, Conservation tillage.

Two of the most important problems facing ground-water-supplied, irrigated agriculture are energy consumption and limited water supplies. In Nebraska, over 40% of the energy consumed by irrigated agriculture is used in pumping water from wells (Gilley and Watts, 1977). In addition, water shortages are becoming commonplace, and limited water supplies are a reality in many areas of the USA.

Much of the future irrigation development in the USA will occur on lands not suited to surface (furrow) irrigation methods. Sprinkler irrigation, probably in the form of center-pivot systems, will be the primary method used in most future irrigation development.

Center-pivot systems have the capability of applying controlled amounts of water within relatively short periods of time. Therefore, operators of center-pivot systems can utilize more of the irrigation-scheduling procedures than irrigators using surface methods (Kincaid et al., 1969). Irrigation-scheduling practices can

reduce the amount of water used, resulting in savings of both water and energy.

Center-pivot systems with high pressure nozzles require relatively large amounts of energy to develop 410- to 590-kPa pressure required for proper sprinkler operation and uniform water distribution throughout the length of the system. A significant savings in energy would result with lower pressure requirements (Gilley and Mielke, 1980).

Center-pivot manufacturers offer reduced-pressure systems (140 to 210 kPa) that use either low-pressure-impact sprinklers or spray nozzles for distribution of the water. There are several types of spray nozzles available for use on center-pivot systems; however, these reduced-pressure systems have the disadvantage of increased water application rates or application intensities. The high rate of water application increases the potential runoff of water applied. This may restrict their use to certain topography, soil types, or tillage- and crop-management systems. Depending on slope and type of soil, runoff water may cause soil erosion and increase soil loss.

There is need to develop and use tillage systems compatible with irrigated agriculture that maintain plant residues on the soil surface, thus providing soil erosion protection (Mannering and Meyer, 1963), reducing evaporation losses (Bond and Willis, 1969; Greb et al., 1967), increasing surface water-holding capacity (McCalla and Army, 1961), and increasing infiltration of water into soil (Mielke et al., 1984). By using reduced-tillage systems, fewer energy-intensive tillage operations are used, and soil, water, and energy are conserved. The purpose of this experiment was to compare effects of tillage and type of sprinkler used to apply water with a center-pivot system on corn (*Zea mays* L.) yield.

MATERIALS AND METHODS

A 54-ha center-pivot system located at the Univ. of Nebraska-Lincoln field laboratory near Mead, NE, was modified to include each of the following: (i) a high-pressure-impact-nozzle (HPI, conventional) system, (ii) a low-pressure-impact-nozzle (LPI) system, and (iii) a low-pressure-spray-nozzle (LPS) system. The pressure at the end of the line for the HPI system was approximately 410 kPa, corresponding to a pivot pressure of about 480 kPa, which is typical of a conventional center pivot. The pressure at the end of the line for the LPI and LPS systems was about 140 kPa, corresponding to a pivot pressure of 210 kPa. The nozzle system and pressure were automatically changed at specific locations in the field by electric and hydraulic apparatus on the center-pivot machine (Gilley et al., 1983), which resulted in "pie-shaped" experimental units (Fig. 1).

Amount of water applied during any given irrigation was a function of location along the pivot lateral. Sprinklers and spray nozzles toward the outer end of the machine, circular area I in Fig. 1, were sized to supply a discharge rate ($0.90 \text{ L s}^{-1} \text{ ha}^{-1}$) that would meet the crop evapotranspiration requirements for eastern Nebraska. The procedure of Heermann et al. (1974) was used to select this discharge requirement. Circular area I is designated as 100%. The sprinklers and spray nozzles within circular area II in Fig. 1 were sized

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to supply 75% of the depth applied in area I ($0.68 \text{ L s}^{-1} \text{ ha}^{-1}$) and is designated 75%. For circular area III, designated the 50% treatment, the sprinklers were sized to supply $0.45 \text{ L s}^{-1} \text{ ha}^{-1}$. For a given circular area, III for example, the system was designed to apply the same depth of water under all three methods of applications: HPI, LPI, and LPS. Of course, depth of water applied per irrigation was dependent on speed of rotation of the machine. As speed of rotation increased, depth of water applied decreased. Additional details of the center-pivot design and operational characteristics were discussed by Gilley et al. (1983).

IRRIGATE, the irrigation scheduling model developed by Tscheshke et al. (1978) using a soil water balance was em-

ployed to determine irrigation dates for the system. The system was managed to maintain relatively small water depletion in area I (Fig. 1). All areas (I, II, and III) were irrigated at the same time.

Amount of irrigation water applied at each irrigation was measured with rain gauges within each irrigation method and amount treatment combination. Because of the variation in application associated with wind and system rotation, the gauges were constructed with $0.015 \times 1.520\text{-m}$ openings. They were supported above the corn canopy at a slight angle from the horizontal to allow rapid drainage into a collection vessel with a small opening to reduce evaporation. Gauges were positioned on radii of the center pivot.

Fig. 1. Physical arrangement of irrigation method (high-pressure impact, low-pressure impact, and low-pressure spray), irrigation amount (I = 100%, II = 75%, and III = 50%), and tillage (T = till plant, D = disk, and C = chisel) treatments.

Table 1. Precipitation summary for 1978 through 1981 at Univ. of Nebraska-Lincoln Field Laboratory, Mead, NE.

Month	1978		1979		1980		1981	
	Rainfall†	Deviation from normal‡	Rainfall†	Deviation from normal‡	Rainfall†	Deviation from normal‡	Rainfall†	Deviation from normal‡
	mm							
May	88	-10	77	-21	45	-53	110	+12
June	88	-43	62	-69	91	-39	14	-116
July	101	+13	72	-16	44	-44	84	-4
August	41	-51	69	-23	173	+81	191	+99
September	139	+61	19	-59	4	-74	59	-19
Total	457	-30	299	-188	357	-127	458	-28

† NOAA, Mead Agronomy Lab, 6 km east of field site.

‡ Calculated from the normal for NOAA East District for year preceding 1976.

The experiment was conducted over a 4-year period (1978 to 1981) on a Sharpsburg silty clay loam (fine, montmorillonitic, mesic Typic Argiudolls). The three tillage systems were: shred stalks in the spring, plant, and cultivate (till-plant - T); tandem disk twice, plant, and cultivate (disk - D); and shred stalks in the spring, plant, cultivate, and chisel (chisel - C). Corn was planted on all plots with a six-row till planter equipped to meet Nebraska till-plant criteria (Wittmuss et al., 1971) with 0.76-m rows in 1978 and 0.91-m rows in 1979 to 1981. For the C treatment, a five-shank chisel (Sub-Mulcher, B-C Mfg. Co.¹) was used to open a 25-mm wide slot in the soil to a depth of 350 mm on the center of each interrow after the last cultivation (corn in the six- to eight-leaf stage). A 457-mm-diam straight coulter mounted in line with each shank cut through plant residues that remained between the rows. Tillage plots were 22 m wide (24 rows) by 23 m long.

In 1978 and 1981, a late-season corn hybrid, 'Prairie Valley 76S', was planted at 53 900 and 64 200 kernels/ha, respectively. In 1979 and 1980, 'B73xMo17' was planted at 74 100 and 64 100 kernels/ha, respectively. All treatments were planted within 3 days during each year of the study. Starter fertilizer was banded at 5.6 and 10.6 kg/ha N and P, respectively. The corn was side-dressed at the six-leaf stage with 170 kg N/ha as a 28% N (w/w) solution. Required herbicides and insecticides were applied at labeled rates uniformly across treatments.

The experimental design was a randomized, complete block with a split-split-plot arrangement of treatments in three replications. Whole-plot treatments were method of water application (HPI, LPI, and LPS); subplot treatments were amount of water applied (100, 75, and 50%); and sub-subplot treatments were tillage (D, C, and T). Water-application method treatments were randomized within blocks and tillage treatments within subplots. However, because of the physical constraints of the center-pivot system, randomization was not possible for the subplot treatments (amount of water applied), which limited the statistical support given the conclusions about the effect of the amount of water applied (Hanks et al., 1980).

After physiological maturity, two sets of adjacent row segments 7.62 m in length were identified. Number of plants and ears were recorded for each of the four-row segments. Ears were hand-harvested and grain removed with a tractor-powered sheller. Total grain weight was recorded and subsampled for water content and seed weight determination. Ears/plant and kernels/ear were calculated. Means of grain yield (adjusted to 15.5% water) and yield components for the four-row segments were analyzed by standard analysis of variance (ANOVA) procedures.

RESULTS AND DISCUSSION

During 1978, precipitation and temperature were below normal and greatly delayed planting. Precipitation in June and July was slightly below normal and

Table 2. Irrigation water applied for 1978 through 1981 at Univ. of Nebraska-Lincoln Field Laboratory, Mead, NE.

Year and Date	Area I (100% ET)	Area II (75% ET)	Area III (50% ET)
	mm		
1978			
10-11 July	20	20	20
27-31 July	38	26	17
5-11 August	34	23	15
17-22 August	34	24	15
24 August†	31	24	14
Total‡	141	105	74
1979			
28 July-3 August	36	26	18
3-10 August	30	23	14
11-24 August	31	23	14
24 August-20 September	30	22	14
Total	128	94	60
1980			
28 June-3 July	34	25	18
7-15 July	37	27	17
17-22 July	35	26	20
28 July-2 August	34	27	21
7-14 August	31	22	14
Total	171	127	90
1981			
2-7 July	39	28	20
9-14 July	37	28	19
23-28 July	42	28	21
19-31 August	42	30	20
Total	160	114	80

† Partial irrigation on one-half of field.

‡ Used one-half of total irrigation for 24 August.

greatly below normal in August (Table 1); however, plant water stress symptoms did not appear in the 50% treatment either on infrared aerial photographs or by visual inspection of the field. September was wetter than usual. The crop used some of the September precipitation because of the late date of maturity resulting from the late planting date. Irrigation water requirements during 1978 were relatively low due to the ET pattern. The 1978 fertilizer N was applied with a uniform 20-mm irrigation (nozzles changed to give equal water application) on 10 and 11 July over all treatments. All other irrigations were applied according to treatment specifications (Table 2). Measured total water application for the 1978 irrigation season was 100, 71, and 46% for the 100, 75, and 50% treatments, respectively.

The 1979 growing season was extremely dry. The months of May through September had below-normal rainfall totaling only 299 mm compared to normal precipitation of 487 mm. Although below normal, the

Table 3. Mean yield components and yield of corn grown under three methods of water application and three tillage practices from 1978 through 1981 near Mead, NE.

Year	Tillage												$\bar{X}$
	Till plant				Chisel				Disk				
	Method of application†												
	HPI	LPI	LPS	$\bar{x}$	HPI	LPI	LPS	$\bar{x}$	HPI	LPI	LPS	$\bar{x}$	
Population (plants/m ²)													
1978	6.73	6.10	6.73	6.52	6.99	6.02	5.99	6.34	8.28	7.30	8.74	8.11	6.99
1979	5.72	5.20	6.11	5.68	5.56	6.71	5.80	6.02	6.11	6.22	6.23	6.19	5.96
1980	5.64	5.40	5.85	5.63	5.72	5.89	5.57	5.73	5.78	5.96	5.67	5.80	5.72
1981	5.78	5.71	5.91	5.80	5.61	5.88	5.65	5.71	5.65	5.96	5.97	5.86	5.79
$\bar{x}$	5.97	5.60	6.15	5.91	5.97	6.13	5.75	5.95	6.46	6.36	6.65	6.49	6.12
Ears/plant													
1978	0.94	0.93	0.95	0.94	0.95	0.94	0.94	0.94	0.88	0.87	0.90	0.88	0.92
1979	0.88	0.84	0.86	0.86	0.87	0.75	0.80	0.81	0.89	0.87	0.88	0.88	0.85
1980	0.88	0.92	0.91	0.90	0.91	0.92	0.90	0.91	0.88	0.90	0.90	0.89	0.90
1981	0.96	0.95	0.95	0.96	0.96	0.93	0.95	0.95	0.94	0.93	0.91	0.93	0.94
$\bar{x}$	0.92	0.91	0.92	0.91	0.92	0.89	0.90	0.90	0.90	0.89	0.90	0.90	0.90
Kernels/ear													
1978	646	638	637	640	602	638	676	639	559	591	564	571	617
1979	656	676	648	660	674	551	618	614	645	587	616	616	630
1980	552	549	474	525	526	517	517	520	533	503	514	517	520
1981	669	716	672	686	628	666	692	662	667	649	629	648	666
$\bar{x}$	631	645	608	628	608	593	626	609	601	582	581	588	608
Seed weight (mg/kernel)													
1978	266	279	271	272	276	286	274	279	264	276	260	267	272
1979	269	271	270	270	263	257	265	262	267	263	267	266	266
1980	263	257	254	258	260	251	252	254	259	256	259	258	257
1981	242	231	240	238	236	224	231	231	240	232	237	236	235
$\bar{x}$	260	260	259	259	259	254	256	256	258	257	256	257	257
Yield (Mg/ha)													
1978	10.62	9.88	10.67	10.39	10.56	10.12	10.25	10.31	9.94	9.89	10.56	10.13	10.28
1979	8.71	7.83	9.19	8.57	8.53	7.40	7.62	7.85	8.79	8.29	8.89	8.66	8.36
1980	7.06	6.89	6.39	6.78	7.08	6.88	6.52	6.83	7.03	6.81	6.76	6.87	6.82
1981	8.90	8.85	8.97	8.91	7.98	8.10	8.47	8.18	8.43	8.29	8.04	8.25	8.45
$\bar{x}$	8.82	8.36	8.80	8.66	8.54	8.13	8.22	8.29	8.55	8.32	8.56	8.48	8.48

† HPI = High pressure impact, LPI = Low pressure impact; LPS = Low pressure spray.

precipitation distribution throughout the season was excellent, which resulted in less total irrigation water required than in 1978. Irrigation amounts in the 75 and 50% treatment were 73 and 47% of the 100% treatment, respectively.

During 1980, average temperature for June through September was greater than 1°C above normal. This season was also dry, with precipitation being 129 mm below normal for the months of May through September. Seasonal irrigation was highest during 1980, reflecting the greater evaporative demand caused by the combination of high temperature and low rainfall.

Mean air temperatures in 1981 were near normal for July and August, below normal in May and August, and above normal in June. Rainfall for the season was near normal; however, it was substantially below normal in June and above normal in August. Irrigation water application reflected the rainfall pattern, with most of the irrigation applied during July and very little during August, normally a high irrigation month.

Yields and yield components for 1978 to 1981 are presented in Table 3 for treatment combinations of tillage and irrigation method. Results of ANOVA (Table 4) indicate method of water application (HPI, LPI, or LPS) did not significantly ($P > 0.10$) influence grain yield during the study. Grain yields, over the duration of the experiment, averaged 8.97, 8.51, and 7.96 Mg/ha for the 100, 75, and 50% treatments, respectively.

Table 4. Analysis of variance table with mean squares for yield and yield components of corn grown under three methods and amounts of water application and three tillage practices from 1978 to 1981 near Mead, NE.

Sources	Degree of freedom	Mean squares					
		Popula- tion	Ears/ plant $\times 10^{-2}$	Kernel/ ear $\times 10^3$	Seed weight	Yield	
Blocks	2	13.23	0.26	34.70	822	11.24	
Method (M)	2	0.66	0.66	2.16	144	3.82	
Error a	4	1.48	0.89	16.38	895	4.23	
Amount (A)	2	0.10 NV†	2.36 NV	67.35 NV	1 425 NV	27.84 NV	
A $\times$ M	4	1.90	1.37*	7.90	637	4.31	
Error b	12	1.21	0.29	12.26	392	2.77	
Tillage (T)	2	11.36†	0.97	42.90†	316*	3.72*	
T $\times$ M	4	2.10*	0.37	12.31*	40	0.48	
T $\times$ A	4	1.02	0.69	12.48*	130	2.51	
T $\times$ A $\times$ M	8	0.51	0.51	5.42	40	1.86	
Error c	36	0.67	0.74	3.72	91	0.96	
Years (Y)	3	28.30†	13.01†	311.35†	21 605†	161.59†	
Y $\times$ M	6	1.91	0.93	11.29	763**	1.87	
Y $\times$ A	6	0.32	0.76	57.02†	180	12.91†	
Y $\times$ T	6	5.50**	2.10**	9.32	527*	2.17	
Residual§	60	0.85	0.48	5.14	86	1.23	
Error d	162	1.19	0.47	7.73	205	1.70	
Total	323	1.53	0.69	11.69	412	3.59	

*,** Mean squares significant at $P < 0.05$ and 0.01 , respectively.

† Mean squares significant at $P < 0.001$.

‡ Test of significance not valid because treatments were not randomized.

§ Residual includes all three- and four-way interactions involving the year main effect. None of these were significantly different.

The small yield differences over the irrigation amount treatments were due to i) system management to maintain small soil water depletion in the 100% area with frequent irrigations, ii) relatively high soil water-holding capacity, and iii) substantial precipitation during critical portions of the growing season (Table 1). The combination of these factors resulted in relatively small reductions in crop evapotranspiration and thus yield. The two-way interaction of method by amount was significant during 1978 and 1979, when grain yield was least with the 75% application for the LPS method, while yields were not significantly different for the 75 and 100% amounts for the HPI and LPI methods of application. The tillage effect was significant ($P < 0.05$) for yield, with T treatment producing more grain than the C treatment (8.66 and 8.29 Mg/ha, respectively). With irrigation in eastern Nebraska, effects of differences in conservation of soil water among tillage treatments are unlikely to be reflected in crop yield. The tillage treatments were selected to maximize infiltration of irrigation water, thereby decreasing runoff, rather than to conserve soil water by evaporation during the nongrowing season.

The C tillage treatment significantly reduced yields in 1979, producing 89% of the mean yield, while the D and T treatments produced 103 and 104% of the mean yield, respectively (Table 3). This resulted from greater water stress on the plants immediately following the chisel operation. As used in this study (after cultivation), chiseling severely pruned plant roots, effectively isolating each row of plants into a block of soil 0.91 m wide and to a depth of 0.35 m. Any roots extending beyond these dimensions were severed, limiting immediate water uptake capabilities. DeBoer and Beck (1982) also reported inconsistent yield responses to chisel treatments applied at the six- to eight-leaf stage. In paired-plots in farmer-operated, sprinkler-irrigated fields, a 2-year average yield increase of 0.8 Mg/ha was reported for the C treatment; however, in a more controlled experiment, no difference was found between chisel and nonchisel treatments. In our experiment, a significant tillage effect was noted during 1981, in which the T treatment produced 105% of the average grain yield, while the C and D treatments produced 97 and 98%, respectively (Table 3). A significant tillage-x-amount interaction existed in 1978. The C treatment produced equal yields at all levels of irrigation, while the D and T treatments produced greater yields with greater irrigation.

The lack of grain yield response due to method of water application was supported by data on yield components. None of the yield components measured—plant population at harvest, ears per plant, kernels per ear, or seed weight—displayed a significant response to method of water application. These results strongly support the conclusion that none of the nozzle systems investigated have an inherent advantage or disadvantage in terms of corn grain production capability.

Similarly, the significant effect of tillage on grain yield was confirmed by corresponding differences in yield components. Significantly more plants were present in D than T or C treatments (Table 3). During 1979, significantly more plants survived until harvest in D compared to the T treatment. The higher plant population in the D treatment may have been asso-

ciated with greater numbers of volunteer plants surviving because seedbed conditions in the D treatment were more conducive to volunteer plant survival than in T and C treatments. When plant population was used as a covariant, the three-way interaction (tillage $\times$ method $\times$ amount) for grain yield in 1979 was no longer significant, suggesting that differences in grain yield were directly related to differences in plant stand.

Number of ears produced per plant (Table 3) showed a significant year-x-tillage response (Table 4). During 1979, fewer ears were produced per plant with the C treatment than with D or T treatments. This was a logical result of the higher plant population with the C treatment that year. Fewer ears per plant were produced with the D treatment than with the T or C treatment during 1981; however, the magnitude of the differences was not great and probably of little practical importance.

For the experiment, the average number of kernels per ear was just over 600 (Table 3). Irrigation method and amount-x-method interaction effects were not significant (Table 4). Tillage effect was significant in all years except 1980, which was the most stressful year for corn production. Below-normal rainfall (Table 1) and high number of hot days (maximum air temperature $\geq 35^{\circ}\text{C}$ during 47 days from June through September) resulted in lower yields and a reduced number of kernels per ear. Coefficient of variation for these data in 1980 (45%) was four to six times the coefficient for the other 3 years. Stress conditions during the 1980 growing season resulted in greater variation and less precision in detection of treatment differences. Over the entire experiment, more kernels per ear were produced with T (628) than with the other treatments (598). This may have been a compensating response of the corn to the somewhat lower plant population for the T treatment. A significant tillage-x-amount interaction also occurred.

Although the overall analysis showed no significant response of seed weight to method of irrigation, individual year analysis (analysis not shown) indicated a significant response to irrigation method during 1981. The HPI treatment resulted in larger seeds (240 mg/seed) than the LPS treatment (232 mg/seed). The tillage effect for seed weight was also significant during 1978, 1979, and 1981. During these years, T treatment resulted in slightly greater seed weight (260 mg/seed) than C (257 mg/seed) or D (256 mg/seed) treatments. Again, this may reflect the lower plant population with T treatment. Alternatively, greater water conservation would be expected with till planting and may have resulted in larger seeds with that treatment. Visual inspection of seed weights over the three amounts of water applied would tend to suggest that, with additional available water, seed size increased.

The year effect was significant for all measured parameters and was not unexpected. Only seed weight was significantly affected by the year-by-method interaction. The significant year-by-amount and year-by-tillage effects on several parameters were logical, considering the variation in amount and timing of rainfall and the influence the C treatment had on plants, especially during 1979. None of the three- and four-way interactions with years was significant and was therefore pooled and reported as residual in Table 5.

The use of low-pressure irrigation machines will increase with future developments in irrigated agriculture. Lowering nozzle pressure increases peak application intensity because a smaller land area is covered. Soil-management methods are needed to increase soil water infiltration or provide temporary surface storage of water for the successful use of low-pressure nozzles on some soils. Corn grain yield was not influenced by method of applying water. Tillage methods may influence yield if not applied at the proper time (e.g., 1979 C treatment decreased yield). The use of low-pressure-sprinkler irrigation systems on lands that are not subject to runoff problems, or in combination with soil-management and tillage practices, which reduce potential for runoff, can reduce production costs and save energy.

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