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LOW PRESSURE CENTER PIVOT AND SOIL MANAGEMENT EFFECTS ON RUNOFF

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ABSTRACT

The objective of this research was to determine the influence center-pivot sprinkler irrigation methods in combination with tillage practices for corn (*Zea mays* L.) have on surface runoff of irrigation and rainfall. 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. The center-pivot was a standard 10-tower machine, 395 meters in length and 38.4 meters tower spacing. Three tillage systems were used -- till-plant (T), disk (D), and subtill (S) which was till-plant with subsoiling between rows with straight single shanks, 360 mm deep, after last cultivation. The soil was a Sharpsburg silty clay loam (fine, montmorillonitic, mesic Typic Argiudolls). Runoff was measured from two plots representing each tillage system under the span between towers 9 and 10 for HPI, LPI, and LPS. Hand samples of water were taken at specific time intervals during runoff events for sediment and nutrient analysis. The greatest average annual sediment yield within each irrigation system was for D tillage treatment (148 kg ha^{-1}) and smallest was for S tillage treatment (2 kg ha^{-1}). Total nitrogen in runoff followed a pattern similar to sediment with a range from 0.86 to 0.01 kg ha^{-1} for D and S tillage, respectively. Runoff as a percentage of irrigation water applied for irrigation systems ranked LPS > LPI > HPI. Tractor wheel trafficked rows accounted for majority of the runoff.

1. INTRODUCTION

As competition between users increases for existing water supplies both within and outside of agriculture, it will be necessary to improve efficiency of the design and management of irrigation systems. Center-pivot irrigation systems account for about 50 percent of sprinkler irrigated land in United States. A large portion of future irrigation development in United States will be on land not well adapted to surface irrigation methods. Thus, as new lands are developed for irrigation, sprinklers most likely in the form of center-pivot systems will be the primary method used.

Center-pivot systems have the capability of applying controlled amounts of water within relatively short time. Operators of center-pivots systems also have irrigation scheduling options not available to operators of surface irrigation systems. However, relatively large amounts of energy are required to develop the pressure necessary for effective operation of conventional high pressure (480 to 580 kPa) center-pivot systems.

Significant energy savings would be realized if the pressure requirement were lowered. However, lowering the pressure on center-pivot systems can create water application intensity problems. When pressures are decreased, the radius of water application of individual sprinklers are reduced, thereby decreasing the effective area over which the water is applied. These changes cause an increase in the water application intensity. If the application rate exceeds the soil infiltration rate, runoff of irrigation water occurs. Good soil management as well as good irrigation water management, is required for efficient operation of an irrigation system.

There is a need to improve soil management that will increase infiltration or surface retention thus providing runoff control when reduced pressure center-pivot systems are used. Plant residues on the soil surface are effective in reducing runoff and erosion on most soils and landscapes. Systems of tillage that maintain plant residues on the surface or increase soil surface water storage provide the best potential to reduce runoff under high intensity irrigation. Thus, specific tillage systems may allow use of reduced pressure systems on a greater variety of soil types and landscapes.

The objective of this paper is to present the results of the runoff portion of a four-year study comparing different tillage systems under both high- and low-pressure sprinkler nozzles.

2. MATERIALS AND METHODS

2.1. Experimental Irrigation System

The field work was located at the University of Nebraska Agricultural Research and Development Center located near Mead, Nebraska, about 50 km northeast of Lincoln. The center-pivot system consisted of a Valley Model 4071, ten tower electric drive system 395 m in length with a tower spacing of 38.4 m. The system was modified to include each of the following; 1) a high pressure impact sprinkler head (HPI) conventional system, 2) a low-pressure impact sprinkler head (LPI) with low vertical angle nozzle system, and 3) a low-pressure spray nozzle (LPS) with 80 degree nozzle directional system. The pressure at the end of the center-pivot lateral for the HPI system was approximately 410 kPa, corresponding to a pivot pressure of approximately 480 kPa (this is within the range of operation of a high pressure system). The pressure at the end of the center-pivot for both the LPI and LPS systems was approximately 140 kPa, corresponding to a pivot pressure of approximately 210 kPa. The nozzle system in operation and the system pressure were automatically changed at specific locations in the field using electric and hydraulic apparatus located on the center-pivot system. Details describing the operation of the system are given by Gilley et al. (1983). The experimental layout of the entire study is shown in Figure 1.

The amount of water applied during any given irrigation event was a function of the location along the pivot lateral. The irrigation nozzles towards the outer end of the machine, circular area I in Figure 1, were sized to supply a discharge rate of (0.90 L s^{-1} ha^{-1}) that would meet the crop evapotranspiration requirements on an approximate 90 percent probability using the procedures of Heermann et al. (1974). The irrigation nozzles in area II of Figure 1 were sized to supply 75% (0.68 L s^{-1} ha^{-1}) of the depth applied in area I. In circular area III, the design application rate was 0.45 L s^{-1} ha^{-1}. For a given circular area, I for example, the system was designed to apply the same gross depth of water under all three methods of application; HPI, LPI, and LPS. The depth of water applied per application was dependent on the ground speed of the machine. Details of the sprinkler spacing, flow rates and operational characteristics were discussed by Gilley et al. (1983).

A soil water balance model was used to schedule the irrigation dates for the system (Tscheschke et al., 1978). The system was managed to maintain a relatively small water depletion of 50% in area I.

2.2. Field Experiment

The soil was a Sharpsburg silty clay loam (fine, montmorillonitic Typic Argiudoll). The three tillage systems evaluated were: 1) till plant (T) consisting of shredding stalks in the spring, plant, and cultivate, 2) disk (D) consisting of tandem disk twice in the spring, plant, and cultivate; and 3) subtill (S) consisting of shredding stalks in the spring, plant, and cultivate, followed by single shank, 300 to 360 mm deep between the rows after cultivation. The subtill treatment was applied at six- to eight-leaf stage of corn growth with a five shank, Sub-Mulcher, B-C Mfg. Co. machine. Corn was planted with a six-row till planter with 0.91 m wide rows.

In 1st and 4th year, a full season corn hybrid, "Prairie Valley 76S", was planted at 53,900 and 64,200 kernels/ha, respectively. In

2nd and 3rd year, a full season corn hybrid, "B73 x Mo17" was planted at 74,100 and 64,100 kernels/ha, respectively. All treatments were planted within three days each year. Starter fertilized was banded at rates of 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 label rates uniformly across treatments.

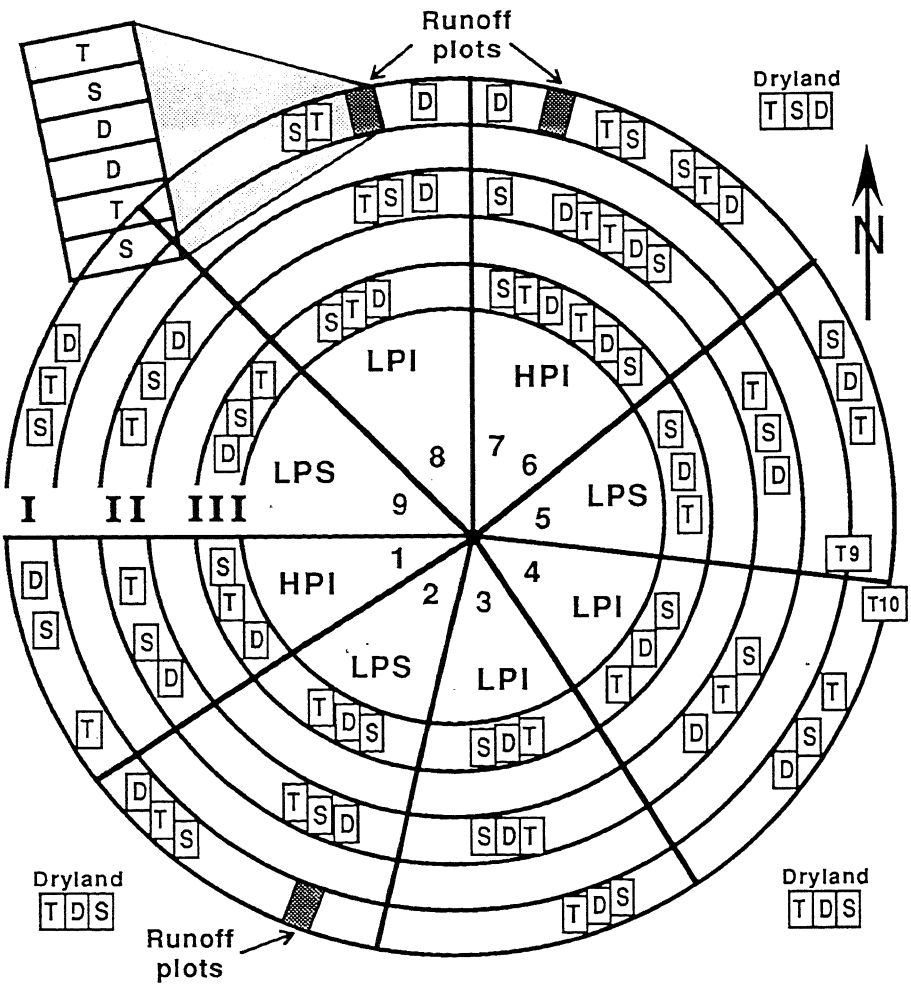

Figure 1. Experimental center-pivot layout with type of irrigation and tillage treatments.

Special test areas were established between towers 9 and 10 to measure infiltration and runoff characteristics for sprinkler nozzles packages and tillage treatments. They are shown as runoff plots in northeast, northwest, and southwest areas of circular area I in Figure 1. These plots were used to monitor runoff for four years and sediment and nutrients in runoff were sampled for three years with rows parallel to the slope. The plots were established the first year with randomly assigned tillage treatments that remained in the same position thereafter. The flumes, recorders, and soil dikes to isolate runoff to the plot area were installed after the last cultivation in late June each year. Thus runoff measurements for rainfall and water samples and runoff measurements for irrigation were available for July and August, and some years in early September. Plots were 4.6 m wide and 30.5 m long. Runoff was measured using trapezoidal vee flumes with continuous stage recorders. There were two replications of each tillage treatment under each method of water application. Data from continuous recorders were used to calculate peak discharge and total runoff volume. Water samples were collected during the irrigation runoff events and analyzed for total sediment, NO_3-N, NH_4-N, total N, and soluble phosphorus in the water.

At the end of the 4th year, wheel track and non-wheel track runoff was measured for T and D tillage systems using LPS. Infiltration was determined for wheel track and non-wheel track conditions the 3rd year with a standard double ring method.

Plant residue weight was determined in the surface 100 mm of soil from 10 samples of equal soil volume from each tillage system. Samples were obtained in early June, July, and late August.

3. RESULTS AND DISCUSSION

3.1. Runoff Analysis

The runoff from the irrigation and rainfall events was determined from the first part of July through August most years. Runoff from irrigation events for all years of the study are summarized in Table I. Runoff the first year from HPI and LPI sprinkler systems was relatively small for all tillage treatments. The LPS system generated the greatest runoff. The till-plant system produced the greatest average runoff. The subtill treatment reduced runoff from the LPS to a value similar to that for HPI and LPI systems.

During the 2nd year, runoff from irrigation occurred only from the LPS system (Table I). The runoff was the greatest for the disk tillage (average 6.7%) and ranged between 1.9 and 12.8% of irrigation depth applied. The runoff from the T and S tillage systems ranged from 2.6 to 5.1% and from 0.4 to 1.2%, respectively. Annual average runoff was 4.3% for T and 0.7% for S.

The irrigation runoff during the third year was low for HPI and LPI and ranged from 0 to 4.8% with an average annual runoff less than 1%. The D tillage produced the greatest runoff with a range of 4.4 to 10.0%. The S tillage resulted in the lowest values between 0.3 and 0.7%.

During the 4th year, runoff was greater for the HPI and LPI than for the other years as shown in Table I. However, there was only one irrigation event for HPI and LPI and that event was larger by 33 and 13%, respectively than the average rainfall for those irrigation systems the previous years. The runoff patterns relative to tillage systems showed that D and T were about the same and S was much less. The disk tillage with the LPS system produced the most runoff with an average of 8.8% and a range from 0.4 to 28.8% of applied

TABLE I. Average runoff as a percent of amount applied from irrigation for each irrigation system and tillage method.

System Type[1]	Plot Slope	Till Trt[2]	1st Year Irri. No.	1st Year Total Amt	1st Year Avg runoff	2nd Year Irri. No	2nd Year Total Amt	2nd Year Avg runoff
	%			mm	%		mm	%
HPI	3.0	T	4	33.9	0.4	4	32.7	0.0
		D			0.4			0.0
		S			0.0			0.0
LPI	3.5	T	3	33.9	0.6	4	32.7	0.0
		D			0.4			0.0
		S			0.2			0.0
LPS	3.3	T	3	35.4	7.9	4	32.7	4.3
		D			4.6			6.7
		S			0.9			0.7
			3rd Year			4th Year		
HPI	3.0	T	4	38.3	0.5	1	46.5	6.7
		D			1.3			5.5
		S			0.0			0.4
LPI	3.5	T	4	33.9	0.0	1	37.8	3.5
		D			0.2			6.7
		S			0.1			2.0
LPS	3.3	T	4	33.4	5.6	8	39.0	4.5
		D			6.3			8.8
		S			0.5			0.5

1 HPI = High pressure impact sprinkler head; LPI = Low pressure impact sprinkler head; and LPS = Low pressure spray nozzles.
2 T = Till-plant; D = Disk; and S = Subtill between rows.

depth for eight events. The S tillage system produced the smallest runoff of the tillage treatments for the LPS irrigation system.

A summary of the four year average irrigation and runoff events is given in Table II. The runoff from the various T, D, and S. tillage treatments under HPI and LPI was nearly the same. Regardless of tillage system, LPS resulted in six to seven times more runoff than HPI or LPI irrigation system. Runoff from the D tillage system was the greatest and averaged about 6.6% for all years. The S tillage system resulted in the least runoff of all tillage systems regardless of the irrigation system used.rates of 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 label rates uniformly across treatments.

Runoff from rainfall was less than 2% for all the events the first two years. In the third year there were only three runoff producing events, all with low runoff except one 74 mm event following an irrigation on the LPS area that produced 5.5, 5.2 and 0.1% runoff on T, D and S, respectively. Runoff percentage from rainfall events during August and September of the last year are shown in Table III. The runoff trends show similarity in runoff patterns as effected by tillage treatments and suggest the tillage effects were the same in all portions of the field.

Table II. Four-year average irrigation and runoff from irrigation for each irrigation method and tillage treatment.

System Type[1]	Plot Slope	Till Trt[2]	Irrigation Avg	Irrigation sd.	Runoff Avg	Runoff sd.
	%		mm	mm	%	%
HPI	3.0	T	36.2	4.3	1.0	1.7
		D	36.2	4.3	1.1	1.8
		S	36.2	4.3	0.1	0.8
LPI	3.5	T	34.8	3.5	0.9	1.4
		D	34.8	3.5	1.6	2.5
		S	34.8	3.5	0.3	0.5
LPS	3.3	T	35.6	3.2	5.8	2.9
		D	35.6	3.2	8.2	5.8
		S	35.6	3.2	0.7	0.5

[1] HPI = High pressure impact sprinkler head; LPI = Low pressure impact sprinkler head; and LPS = Low pressure spray nozzles.
[2] T = Till-plant; D = Disk; and S = Subtill between rows.

Runoff from wheel track and non-wheel track of D and T tillage system was measured at the end of 4th year. Earlier observations showed a major portion of runoff was coming from wheel track rows. Runoff measurements from D tillage showed about three times more runoff from wheel track rows than non-wheel track rows. The ratio was 6 to 1, wheel track to non-wheel track, for T tillage systems. Subtill treatment was not evaluated because of the very low amount of runoff and because the wheel track effects were minimized by the shank between the rows.

3.2. Sediment and Nutrient Losses

A summary of annual mean sediment and total nitrogen in runoff from irrigation for LPS for 2nd, 3rd, and 4th year are in Table IV. The amount of runoff during years 1 through 4 was very small from HPI and LPI irrigation systems (Table II) thus no sediment and nutrient analysis were preformed. The annual losses of sediment and nutrients provided a consistent pattern the second and third years of study. The increase in sediment yield in the 4th year was possibly the result of a 6 mm increase in average irrigation amount. However, the relative magnitude of sediment from each tillage method maintained the same ranking as previous years.

TABLE III. Mean runoff from rainfall for each event and average for the 4th year for each irrigation each irrigation method and tillage treatment.

System Type[1]	Plot Slope	Till Trt[2]	Date Aug 1	Aug 5	Aug 23	Sept 7	Mean
	%				%		
HPI	3.0	T[3]	5.6	9.3	4.2	1.0	5.0
		D	7.1	13.6	5.0	5.1	7.7
		S	2.2	3.0	0.2	0.4	1.4
LPI	3.5	T	5.7	9.3	3.2	2.5	5.2
		D	11.6	15.5	5.1	RF[4]	10.6
		S	2.7	4.5	1.3	1.0	2.4
LPS	3.3	T	2.3	9.6	2.8	4.2	4.7
		D	5.3	12.5	3.2	8.6	7.4
		S	0.0	1.0	0.1	0.0	0.3
Rainfall Amt. (mm)			65.3	55.9	31.8	28.5	

[1] HPI = High pressure impact sprinkler head; LPI = Low pressure impact sprinkler head; and LPS = Low pressure spray nozzles.
[2] T = Till-plant; D = Disk; and S = Subtill between rows.
[3] Mean for two plots.
[4] Recorder failed.

Total N in runoff was very small for all tillage treatments and only approached 1 kg ha^{-1} with D the 4th year. Phosphorus was measured and was zero for about 60% of the plot-irrigation events.

Soil physical characteristics and plant residue were determined for each tillage treatment for use in interpreting runoff patterns. Crop residue on the surface and within the top 100 mm of soil depth was about 20% greater for the T treatment than for D and S in early June. Residue decreased about 20% for S and almost 50% for D and T tillage systems from early June to late August. Water infiltration was measured on the tillage runoff plots for both tractor wheel track and non-wheel track conditions. The results showed that the infiltration rate for the non-wheel track soil was about two times greater than that for wheel track soil. The infiltration rate for wheel track was very similar for all tillage treatments.

Table IV. Mean irrigation amount, sediment, total N, and percent of runoff from LPS[1] irrigation for T, D, and S tillage treatments 2nd, 3rd, and 4th year.

Year	Till Trt[2]	Irri. Mean	Sediment	Total N	Runoff Mean
	%	mm	kg ha^{-1}	kg ha^{-1}	%
2nd	T	32.7	22	0.13	4.3
	D		34	0.17	6.7
	S		5	0.01	0.7
3rd	T	33.5	25	0.21	5.6
	D		39	0.28	6.3
	S		3	0.02	0.5
4th	T	39.0	49	0.31	4.5
	D		148	0.76	8.8
	S		13	0.05	0.5

[1] LPS = Low pressure spray nozzles.
[2] T = Till-plant; D = Disk; and S = Subtill between rows.

4. SUMMARY

An experimental center-pivot irrigation system was developed to evaluate effects of tillage and irrigation systems on quantity and quality of runoff water. Only small amounts of irrigation runoff were measured from HPI and LPI irrigation systems. Low pressure spray systems had the greatest percentage of runoff, approaching 28% in the worst case. Runoff from irrigation was less than 1% for LPS where shanks were used between the rows after cultivation (S tillage).

Analysis of runoff from irrigation from the LPS system shows soil erosion from disk tillage treatment produced the greatest loss of sediment and total N each year. However, the amounts were very small, <150 kg ha^{-1} for sediment and <1 kg ha^{-1} total N.

Reducing the pressure of center-pivot irrigation systems can save energy and can provide economic benefits to producers. However, using low pressure irrigation systems may create water management problems of increased runoff and nonuniformity of water application. Modification of tillage systems can be effective in reducing runoff.

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