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COMPARISON OF SPRAY AND IMPACT SPRINKLER PERFORMANCE

by

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SUMMARY:

Secondary tillage management may be critical in successful operation of a spray system with high application rates. Furrow diking controlled runoff and increased corn yields on a spray system but had little effect on an impact system. Stemflow represented a large fraction of the total applied water and appeared to differ between irrigation systems.

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ABSTRACT

One year's data suggest secondary tillage management may be critical in successful operation of a low pressure spray nozzle system with high application rates. Furrow diking controlled runoff and increased corn yields on a spray nozzle system but had little effect on a high pressure impact system. Stemflow represented a large fraction of the total applied water and appeared to differ between spray and impact systems.

INTRODUCTION

Nearly all center pivot systems currently being placed on Northwest Kansas farms are classified as low pressure systems. Energy savings are the primary reason low pressure systems are being selected instead of high pressure systems. Low pressure systems are not without their problems. Generally, the peak application rate is significantly higher than on high pressure systems. In some cases this will result in excess runoff and in less water for actual crop use. Irrigators may try to compensate for this by speeding up the system. This will not solve the peak application problem, although there may be some reduction in total runoff. When the system is speeded up, less water will be applied per revolution. Since a certain amount of evaporative losses occur before any water enters the soil, this speeding up will increase the fraction, that evaporative losses represent of the total water applied. Irrigators may also try to compensate by running low pressure systems more hours during the season to apply more water. This is undesirable in a time of declining water supplies. Research in Nebraska by one center pivot manufacturer (Irrigation Age, February, 1982) found that, although total energy costs were less for the low pressure system, savings did not make up the differences in yields between high and low pressure systems. The reduction in yields was attributable to more runoff on low pressure systems and thus less water entering the silt loam soil.

There are some possible solutions to the runoff problems sometimes associated with low pressure systems. Minimum tillage, which leaves more residue on the soil surface, often reduces runoff. In some areas, furrow diking is used to trap runoff and to give it more time to infiltrate into the soil. DeBoer and Beck (1983) reported secondary tillage at the 6-8 leaf stage reduced surface runoff and increased soil water content.

Some irrigators in Northwest Kansas are already experiencing runoff problems. As more of these systems are being sold, there will probably be more. A study was initiated to evaluate present tradeoffs between low pressure and high pressure systems and to determine management techniques that might optimize each system.

Objectives:

1. To compare corn production under these types of systems in terms of yields, energy use, water use, soil moisture status, runoff and economics.

2. To compare tillage management of the two systems.

PROCEDURE

The project was initiated in 1983 on the Colby Branch Experiment Station at Colby, Kansas, on a deep, well drained, loessial Keith silt loam soil. This medium-textured soil, typical of many western Kansas soils, is described in more detail by Bidwell et al. (1980). The 1.5 m (5-ft.) soil profile will hold approximately 25 cm (10 in.) of available water at field capacity. This corresponds to a volumetric soil moisture content of approximately 0.30 and a profile bulk density of approximately 1.3 gm/cm^3.

The climate can be described as semi-arid, with an average annual precipitation of 46.9 cm (18.5 in.).

A three tower 5 ha (12.3 acres) high pressure (410 Kpa) (60 psi) center pivot system was converted to a system capable of both a high pressure impact nozzle system and a low pressure (140 Kpa) (20 psi) spray nozzle system. The low pressure system was equipped with drops leaving the nozzle approximately 2.1 m (7 ft) above the ground surface. As a result, the nozzle was within the corn canopy after tasseling . The system was purposely designed with application rates similar to a full size system to allow for studies simulating full size systems. The nominal design flow rate was 660 L/min (175 gpm). However, actual flow rates measured were 620 L/min (164 gpm) and 700 L/min (184 gpm) for the high and low pressure systems respectively. Pressure to the spray nozzles was reduced from the high pressure system by pressure regulators. Pressure regulators, as well as the sprinkler packages, were provided by Senninger Irrigation Inc. Switching between sprinkler packages was done manually by opening and closing full port ball valves.

The treatments consisted of two irrigation treatments and three tillage sub-treatments, with the main treatment replicated three times in a complete randomized design.

Irrigation treatments:

1. High pressure impact sprinklers
2. Low pressure spray nozzles with drops

Tillage systems:

A. Conventional (chisel fall, disk spring)
B. Conventional with corrugation at 6-8 leaf stage
C. Conventional with furrow diking at 6-8 leaf stage

A fourth tillage treatment, minimum tillage, was excluded from analysis as it was identical to conventional tillage in 1983.

Each irrigation main plot was 12 x 27 m (40 ft. x 90 ft.) randomly arranged around the radius of the circle as shown in Figure I. Appropriate buffer zones were provided to allow for the wetted diameter range of the sprinklers. Each main plot was divided into tillage sub-plots, 6 x 12 m (20 ft. x 40 ft.), randomly arranged. Borders were provided between adjacent plots to prevent runoff from one plot influencing the other.

Each sub-plot was instrumented with an access tube for neutron probe measurements of soil moisture. Soil moisture measurements were made on approximately a weekly basis in increments of 30 cm (1-foot) to a depth of 1.5 m (5-foot). Each sub-plot was instrumented with a rain gage at ground level in an alleyway near the plot to determine irrigation amount.

Near the end of the season, application rates with and without the crop canopy were measured at a radius of 103 m (338 ft.) from the pivot point. The application amounts were measured with 4 digital recording rain gages (Rainwise gages, resolution 0.25mm [.01 in]) arranged together. The data was manually recorded at periodic time intervals. The mean amount of the four gages was used in all calculations. An attempt to measure stemflow under the two irrigation systems was made. Stemflow from individual corn plants was measured by collecting water in five cm diameter (2 inch) PVC tubes placed around the stem. The tubes were sealed on the bottom and sides with duct tape. Water was funneled away by means of a flexible tube to storage containers for later measurement.

The area was prepared in the spring (4-25-83) by disking twice, followed by a rod weeder to level and firm up the seed zone. The area was fertilized with 210 kg/ha (188 lbs./a) of nitrogen applied preplant in the form of ammonium nitrate. The corn (Pioneer 3183) was planted in 76 cm (30 in.) rows at a rate of 67,600 plants/ha (27,350 plants/a) on April 26, 1983.

The post-plant secondary tillage for tillage treatments B and C was performed on June 27, 1983, when the corn was approximately 0.6 m (2 feet) tall.

Irrigation was scheduled using a water budget with water use values calculated from a modified Penman method.

The corn was hand harvested for yield component analysis on September 23, 1983.

RESULTS AND DISCUSSION

Water Use

Irrigation requirements for corn were high in 1983 due to high ET and low precipitation. The corn was irrigated 13 times during the summer with a nominal design application amount of 38 mm (1.5 in.). The actual amounts applied were measured in rain gages at ground level placed in a bare alleyway near each plot. Analysis of this data showed this technique was unacceptable for the spray nozzle plots. It is believed this is because the width of the alleyway was not sufficient to receive the total spray pattern. As a result of the lack of confidence in this data, nominal application values of 40.6 and 45.7 mm (1.60 and 1.80 in.) were used in water use calculations. These values were based on measured flowrates and rotation speed of the pivot.

Cumulative water use for successive dates during the season are shown in Table 1. Water use was the sum of precipitation, irrigation,and soil moisture depletion. As a result any runoff would inadvertently be included in water use data. The low pressure system would have received 66 mm (2.6 in.) more irrigation during the season due to differences in application amounts. Figures 2 and 3 graphically represent the water use patterns for the two systems. It can be seen that tillage had little effect on water use for the high pressure system, which experienced negligible runoff. However under the low pressure system, runoff was significant and the furrow diking resulted in a more favorable soil moisture condition.

Yields

Analysis of the yields (Table 2) showed some important trends. Taking into account experimental variation, there were little differences in corn yields for the impact system attributable to tillage. This tends to indicate that, if runoff is not a problem, secondary tillage isn't necessary to achieve maximum yields. The low pressure system had a higher average yield. This may be attributable to differences in evaporative losses or to the differences in total applied water. Unfortunately, it can't be determined from the available data. There were appreciable differences in yields due to tillage for the low pressure system. Secondary tillage was critical in attaining high yields, with furrow diking giving the top yield of the test. Conversely, conventional tillage gave the lowest yield of the test (Figure 4). An analysis of the yield components showed furrow diking to have the highest number of ears/plant, seeds/ear and the highest seed weight of all treatments. A sensitivity analysis showed that the furrow diking treatment's increase in the number of harvestable ears/plant had the most weight in achieving its high yield.

Tillage had little effect on water use efficiency (WUE) for the high pressure system but did have appreciable effects on the low pressure system. The furrow diking on the low pressure system having a high yield and relatively low water use gave the top WUE (Table 2 and Figure 5). Likewise, the conventional tillage treatment on the spray system, with the lowest yield and highest water use gave a poor WUE compared to the other treatments.

Irrigation Application Rates

Inspection of the field in early September revealed some striking differences between irrigation treatments. Near the base of the plants (Corrugation and Furrow Diking treatments) there was significant erosion for the low pressure system. The apparent reason for the erosion was stemflow down the corn plant. It appeared that there might be large differences in stemflow between the impact and the spray sprinklers. Although it was late in the season, an attempt was made to quantify these differences. Irrigation amounts as a function of time were measured with and without the corn canopy present for the two irrigation systems. Results were obtained at a fixed radius from the pivot point but the location and dates varied. Results for the two irrigation systems are shown in Figures 6 and 7. There were appreciable differences in application amounts and time periods for the two systems. The low pressure system applied a measured amount of approximately 45.2 mm compared to it,s calculated design value of 45.7 mm. However the measured amount for the high pressure system was only 30.1 mm compared to its calculated design value of 40.6 mm. Part of this discrepancy may be due to the higher evaporative losses for the high pressure system but this can't be determined from the data. We might look at the canopy and no canopy data as being estimates of throughfall (T) and the above canopy amount (A). The ratio T/A for the impact sprinklers is much greater than for the spray nozzle system. If we average across irrigation dates, the ratio T/A for the impact sprinklers is 0.62 compared to 0.27 for the low pressure systems. Functionally the above canopy rate, A, is equal to the sum of throughfall (T), stemflow (S), and interception (I):

$$A = T + S + I \qquad (1)$$

It seems legitimate to assume I would be nearly equal for the two sprinkler systems once stemflow appears. However Kelso and Gilley (1983) reported indirect measurements of interception to be slightly higher for impact sprinklers as compared to spray nozzles. Assuming I to be nearly equal, the above equation and the preceding discussion would indicate the ratio S/A is much greater for the low pressure system. This would support the conjecture that the erosion at the base of the plants for the spray nozzle system was indeed caused by increased stemflow.

Stemflow of individual corn plants was measured once for each irrigation system. A problem arose on the first system evaluated (Impact) in that the catch containers for stemflow were not large enough. Three of fourteen containers overflowed. The container size was increased before the spray system was evaluated. In this case eight of sixteen would have overflowed if the small containers had been used. The overflowed containers for the impact sprinklers were added in at there full amount so that a crude estimate of the mean stemflow could be made. During these two tests, throughfall and the no canopy rate were also measured. The results are presented in Table 3. There is surprisingly good agreement between the sum of stemflow and throughfall and the total amount, even though there were problems with some of the data. Interception for these two tests would be less than 2.5 mm (0.10 in). Granted, there are problems in this analysis but the agreement shown may indicate measuring throughfall in the described manner can be used to estimate stemflow. Earlier it was noted that for all the data sets where the no-canopy amount A and the throughfall T were measured, the T/A ratio for the impact and spray systems were 0.62 and 0.27 respectively. If so, stemflow would be considerably higher than shown in Table 3. Recent work by Quinn and Laflen (1983) and Steiner (et al., 1983) reported stemflow for corn of 49 and 47% of above canopy amounts respectively. It appears the stemflows presented in this study are feasible. If there are large differences in stemflow between systems, perhaps these differences can be exploited in designing more efficient systems.

CONCLUSIONS

Trends in the data would indicate that secondary tillage may be a good management tool for high application rates. A decrease in total water use reflecting decreased runoff was noted for the furrow diking treatment under the spray nozzle.

One year's data would indicate good yields can be attained with a low pressure spray nozzle system if furrow diking is performed. Conversely, if no secondary tillage is performed a high pressure impact system may give better yields.

Modes of water travel to the soil, namely throughfall and stemflow, appear to represent appreciably different proportions of the total applied amount. More work is needed to verify if these differences exist, and to quantify their magnitude. Perhaps system differences in stemflow could be exploited to enhance water infiltration.

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Table 1. Cumulative water use in mm from June 23, 1983 for corn in a center pivot performance study. KSU Colby Branch Experiment Station.

To Date	High Pressure Impact			Low Pressure Spray		
	A	B	C	A	B	C
Jul 14	150	158	150	161	157	154
Jul 19	200	213	220	231	224	213
Jul 25	294	299	296	325	316	304
Jul 29	340	340	332	372	364	344
Aug 08	417	401	400	453	434	421
Aug 11	455	446	442	497	493	464
Aug 17	518	509	505	567	557	532
Aug 25	576	566	561	629	620	601
Sep 06	672	662	662	740	729	694
Sep 24	752	741	743	836	822	774

A. Conventional Tillage
B. Corrugation (6-8 Leaf)
C. Furrow Diking (6-8 Leaf)

Table 2. Corn yield component analysis for a center pivot performance study. KSU Colby Branch Experiment Station 1983.

IRRIGATION SYSTEM	TILLAGE SYSTEM	EARS /PLANT	SEEDS /EAR	SEED WT. Gm/100	YIELD Kg/Ha	WATER USE mm	WUE Kg/Ha-mm
IMPACT	A. CONVENTIONAL	0.93	694	27.2	9227	752	12.3
	B. CORRUGATION	0.96	698	29.7	9039	741	12.2
	C. DIKING	0.96	681	30.0	9576	743	12.9
	MEAN	0.95	691	29.0	9281	745	12.4
SPRAY	A. CONVENTIONAL	0.95	663	28.6	8769	836	10.5
	B. CORRUGATION	0.96	705	29.6	10487	822	12.8
	C. DIKING	1.05	724	30.1	11074	774	14.3
	MEAN	0.99	697	29.4	10110	811	12.5
TILLAGE MEANS	A.	0.94	679	27.9	8998	794	11.4
	B.	0.96	702	29.7	9763	782	12.5
	C.	1.01	703	30.1	10325	759	13.6

Table 3. Partition of irrigation amounts in mm. within the canopy for an impact and spray nozzle system. KSU Colby Branch Experiment Station 1983.

IRRIGATION SYSTEM	NO CANOPY AMOUNT	THROUGHFALL		STEMFLOW	
		AMT.	%	AMT.	%
Impact*	35.6	23.1	65.0	11.7	32.9
Spray (360)	37.1	17.3	46.6	17.5	47.3

* Three of fourteen containers overflowed for Stemflow, so mean stemflow amount would be some higher than shown.

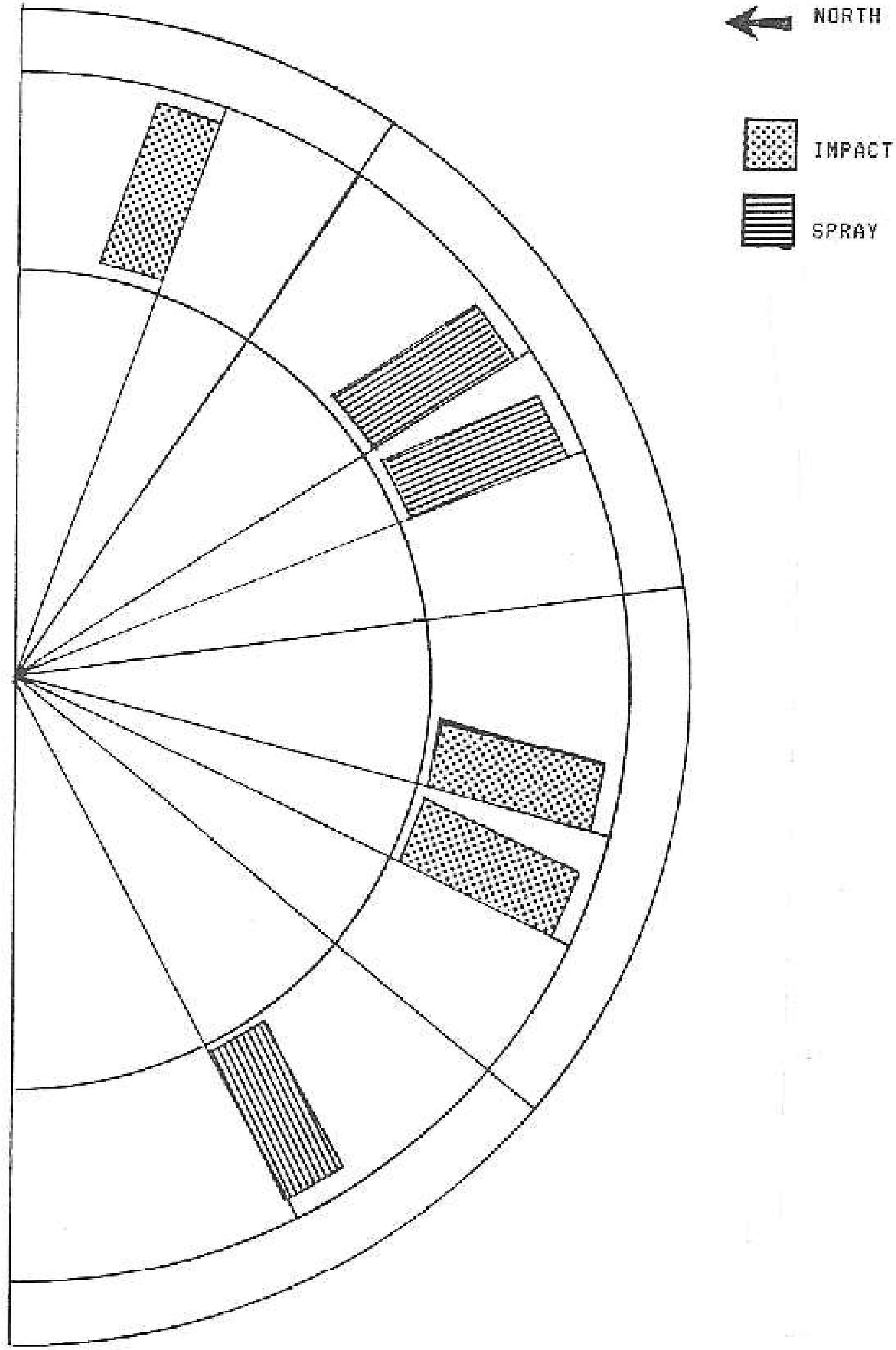

Figure 1. Configuration of irrigation plots in a sprinkler performance study. KSU Colby Branch Experiment Station.

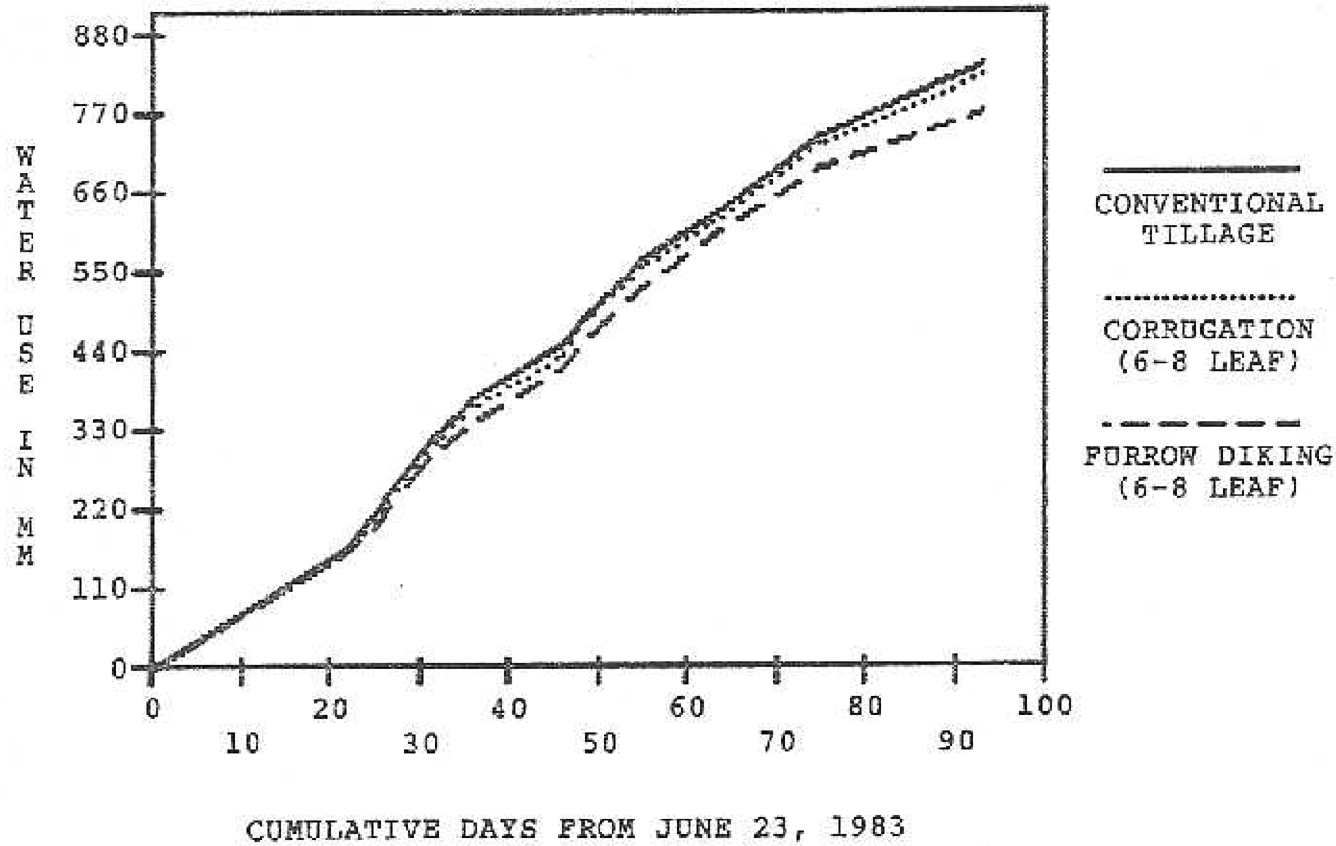

Figure 2. Cumulative water use of corn from June 23, 1983 for a low pressure spray nozzle irrigation system. KSU Colby Branch Experiment Station.

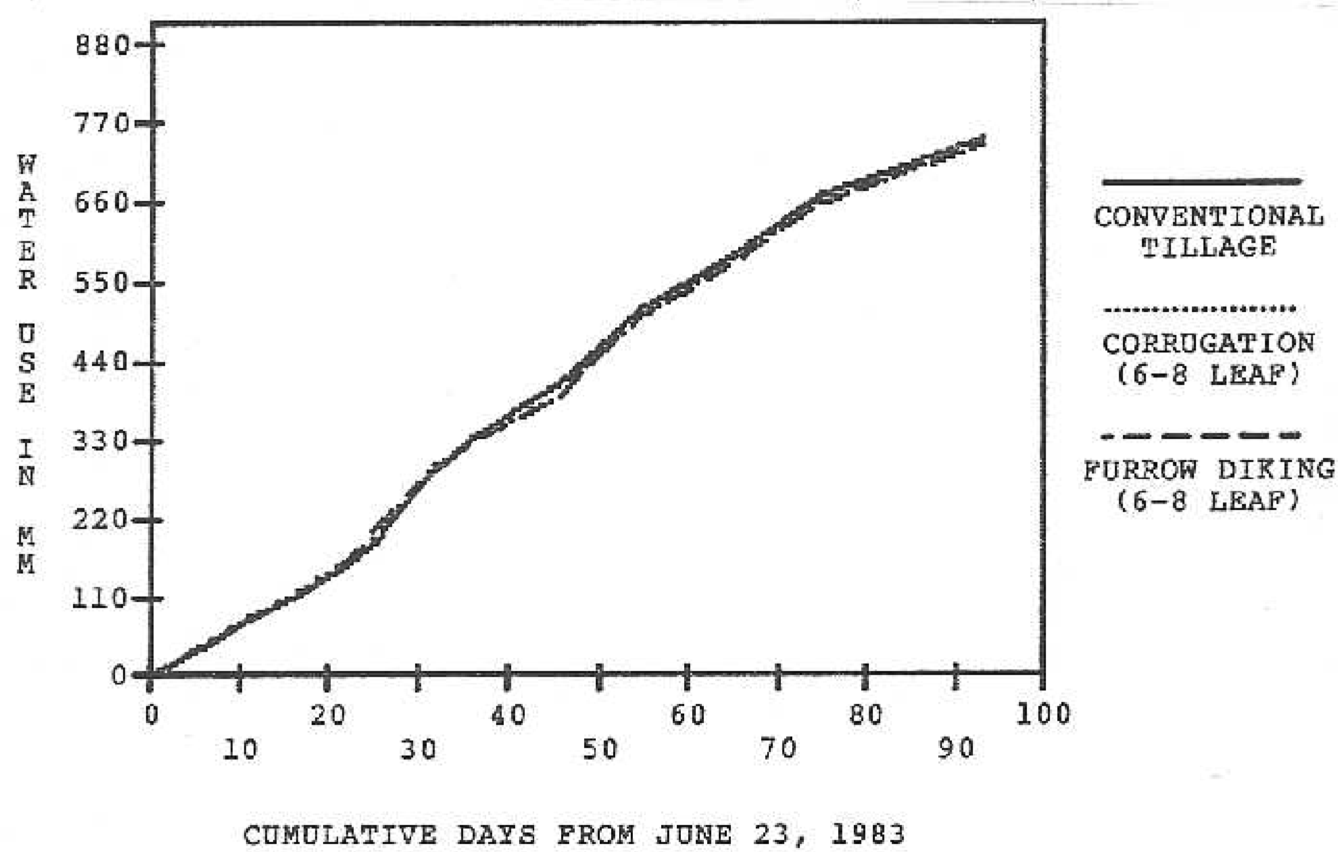

Figure 3. Cumulative water use of corn from June 23, 1983 for a high pressure impact sprinkler system. KSU Colby Branch Experiment Station.

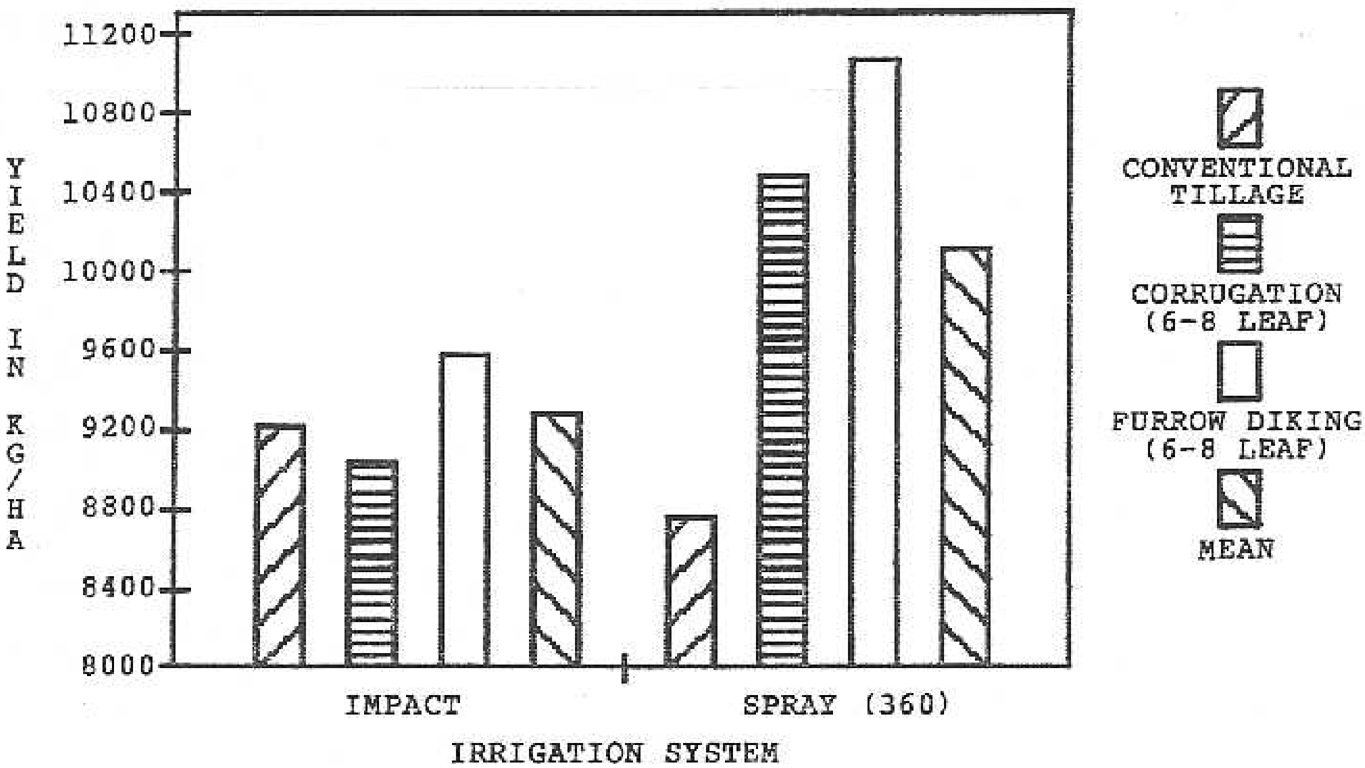

Figure 4. Corn yields as affected by tillage and irrigation system. KSU Colby Branch Experiment Station. 1983

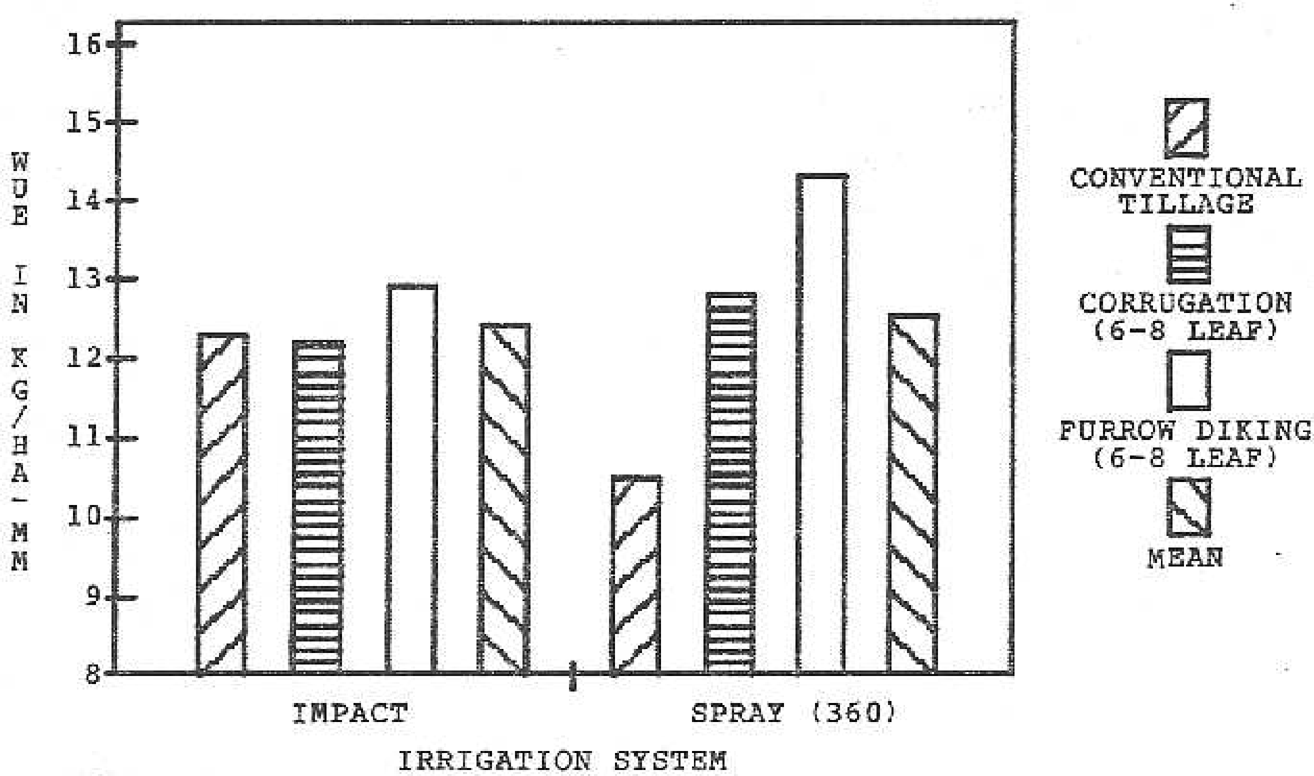

Figure 5. Corn water use efficiency (WUE) as affected by tillage and irrigation system. KSU Colby Branch Experiment Station. 1983

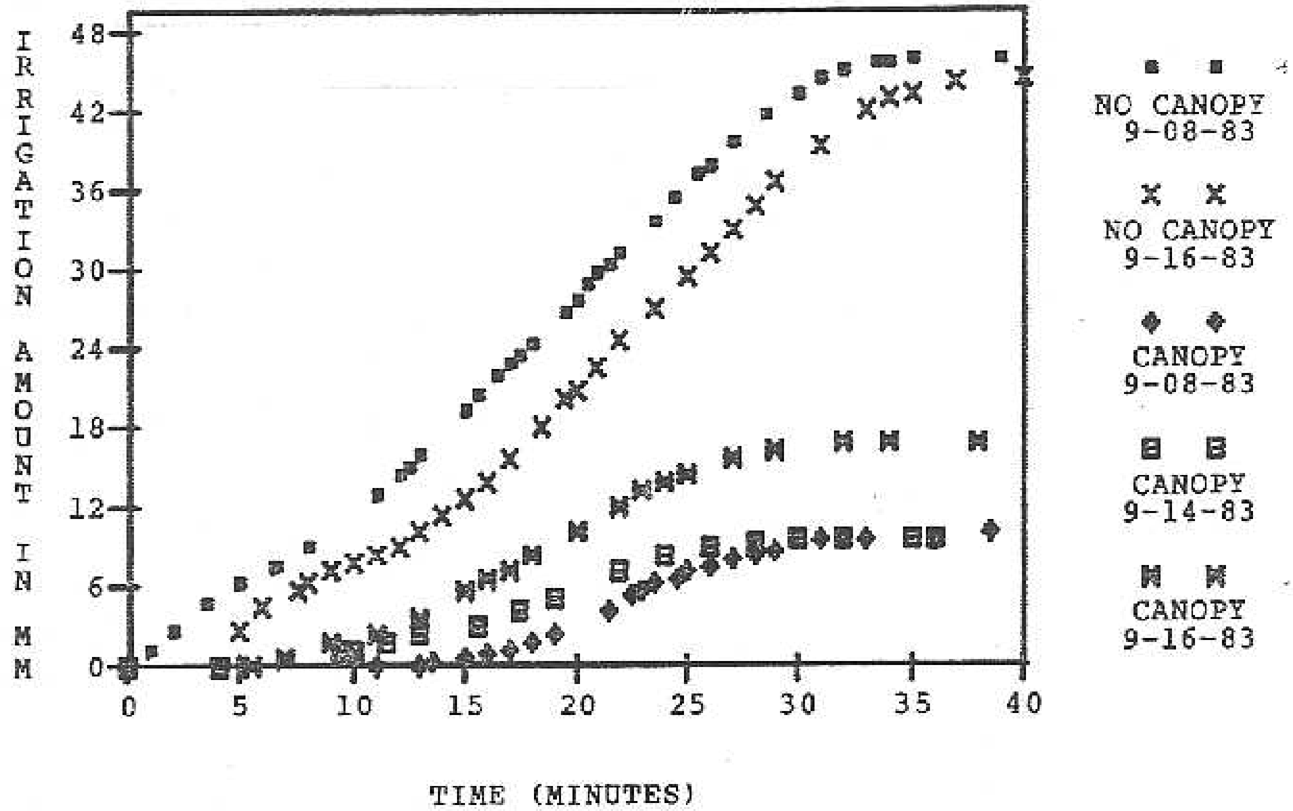

Figure 6. Irrigation amounts as a function of time for a low pressure spray nozzle irrigation system. KSU Colby Branch Experiment Station. 1983

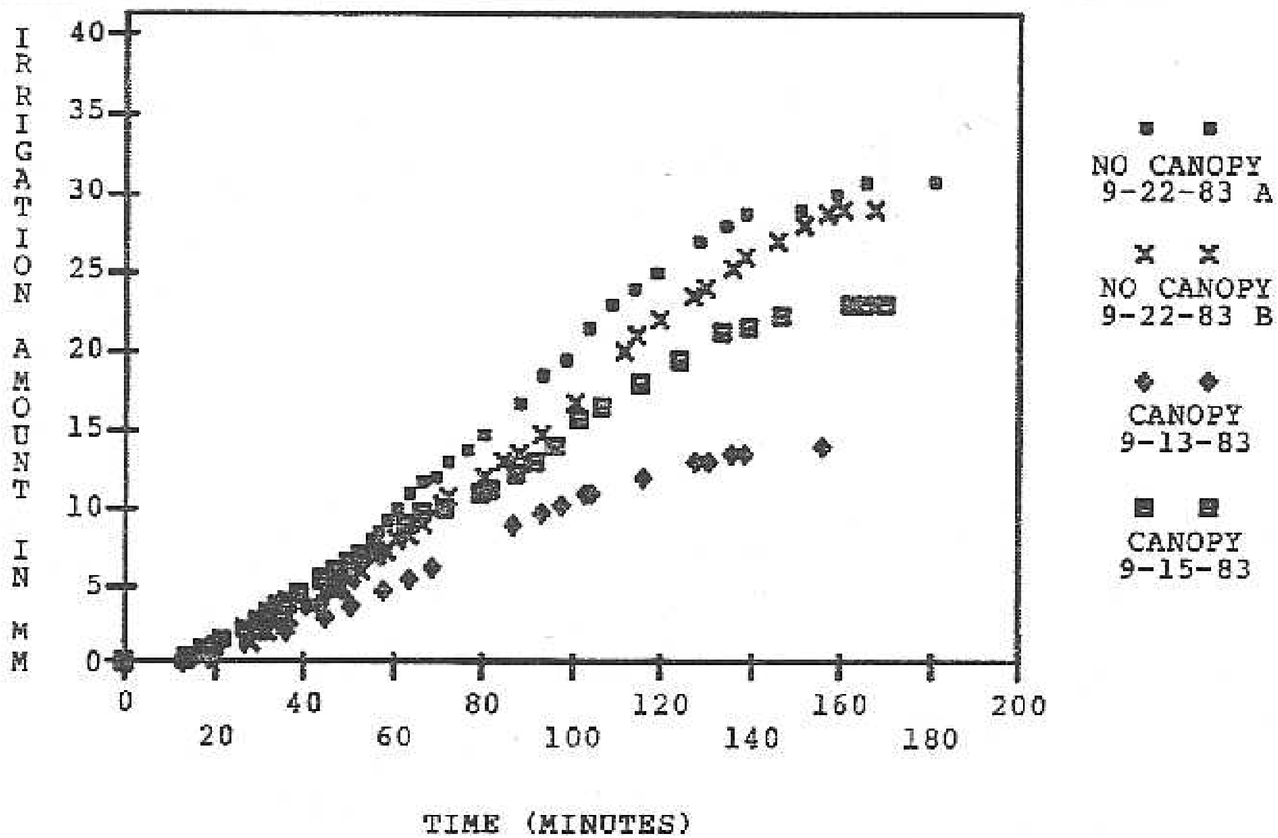

Figure 7. Irrigation amounts as a function of time for a high pressure impact sprinkler system. KSU Colby Branch Experiment Station. 1983