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WATER AND NITROGEN MANAGEMENT USING A SITE-SPECIFIC CENTER PIVOT

by

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Summary:

Corn and soybean were grown in a two-year experiment with crop rotation, irrigation, deep tillage, and N fertilizer treatments under a center pivot irrigation system that had been modified to allow variable-rate water and nutrient applications to fixed-boundary plots within the system. Measured water distribution uniformity and border effects met design criteria, and reliability of the control system improved during the period. Irrigation increased corn yield both years and soybean one year.

Keywords:

Corn, Soybean, Precision Agriculture, Spatial variability

INTRODUCTION

Many soils in the southeastern Coastal Plain have compacted soil horizons that severely restrict root development and extraction of water and nutrients from deeper soil layers. Consequently, in-row subsoiling prior to planting each year is a common cultural practice for many agronomic crops, especially corn and soybean. Rainfall during the growing season normally exceeds crop evapotranspiration but is poorly distributed. Consequently, corn grain yield increases with irrigation have been reported for the southeastern Coastal Plain (Camp et al., 1985; Cassel et al., 1985; Hook et al., 1984). In some cases, additive yield increases were reported for deep tillage and irrigation on these soils (Camp et al., 1988; Cassel et al., 1985). High population soybean planted in narrow ($\leq$0.25 m) rows has received increased interest in the region because of increased yield and easier weed management. A question remains regarding irrigation water requirements for soybean in high-population configurations, especially during drought periods. For corn, incremental sidedress N applications should reduce the potential for nitrate loss in rainfall-induced runoff and leaching and could improve N use efficiency. Incremental N applications are not used in many cases because of the additional operational expense using ground equipment; however, these applications can be accomplished easily and at little additional cost using a center pivot irrigation system.

Within-field variability of the coarse-textured soils of the southeastern Coastal Plain is high, even for small fields or small center pivot irrigation systems. Based on observations of spatial patterns in crop growth, especially during periods of plant water stress, the major factor contributing to yield variability for soils in the Coastal Plain appears to be plant-available soil water (Sadler et al., 1995). Results from an ongoing study that investigated yield for 14 crops during an 11-year period found no useful correlation between yield and several patterns of variation, including soil mapping unit and fertility. The combined effects of climate and soil variability and the uniform application rates of most center pivot irrigation systems make it almost impossible to optimally manage irrigation and nutrients using a conventional irrigation system (Camp et al., 1988).

Beginning in 1991, a center pivot irrigation system was developed at USDA-ARS, Florence, SC, to provide variable-rate application of water and nutrients to discrete elements within the total system. A commercial center pivot system was modified by adding a variable-rate water delivery system (Omary et al., 1997) and by adding and integrating a computer-based control system that provides spatial control of individual elements in the total system (Camp et al., 1994; 1996). This modified system was used to apply water and nitrogen fertilizer to fixed-boundary plots of a replicated experiment to determine the effects of irrigation, N fertilizer, and deep tillage for corn and soybean grown in rotation under conservation tillage.

The objectives of this paper are to describe the operation of the site-specific center pivot irrigation system developed at Florence, to report two-year results from an experiment to determine crop rotation, irrigation, and deep tillage effects with conservation tillage, and to illustrate the system capabilities for application in site-specific management of water and chemicals.

MATERIALS AND METHODS

The study was conducted on a relatively uniform, 6-ha site of Norfolk loamy sand (Typic Hapludults) near Florence, South Carolina, where the control system for a modified center pivot irrigation system was being developed and evaluated. There were three crop rotations (corn-corn, corn-soybean, and soybean-corn), two tillage practices (subsoiled and not subsoiled), two water managements (rainfed and tensiometer-controlled irrigation), two nitrogen fertilizer regimes (single sidedress application (STD) and multiple, incremental sidedress applications (INC)), and four replications, which provided a total of 144 plots. The deep tillage treatments remained in the same location both years, but irrigation and N sidedress treatments were randomized each year. No surface tillage was performed during the experiment. Soybean yield data for N fertilizer treatments were combined because they were not different and N fertilizer was not applied to that crop.

The center pivot irrigation system had been modified to provide 13 segments along its length, each 9.1 m long. The variable-rate water delivery system for each segment consisted of three manifolds to deliver 1x, 2x, or 4x of a base application depth at that specific location along the truss. All combinations of the three manifolds provided 0x, 1x, 2x, ..., 7x the base depth. The 7x depth was designed for 12.7 mm when the outer tower was operated at 50% duty cycle. The variable-rate water delivery system was under the overall control of an 80386 PC (Horner Electric, Indianapolis, IN[1]) with hard drive, floppy drive, serial ports, and peripheral connectors, which was mounted on the programmable logic controller (PLC) backplane (GE Fanuc model 90-30, Charlottesville, VA) and connected via the system buss. The PLC was mounted on the mobile portion of the system, from which it controlled all manifold solenoids. Angular location of the truss was determined from the C:A:M:S ™ (Valmont Industries, Inc., Valley, NE) management system via a radio communication link between the mobile PC and the stationary management system.

Software written in Visual Basic for DOS (Microsoft Corp., Redmond, Wash.) converted a set of control values to on-off settings in the directly-addressable control registers of the PLC. The on-board computer determined angular position of the truss by repeated interrogation of the stationary computer. Position, together with the fixed radius of each segment along the truss allowed determination of segment location at that time, expressed in polar coordinates. Appropriate manifold solenoids were switched on or off according to the

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[1] Mention of trade mark, proprietary product, or vendor is for information only and does not constitute a guarantee or warranty of the product by the U.S. Department of Agriculture and does not imply its approval to the exclusion of other products or vendors that may also be suitable.

current angular position, based upon user-supplied data. More detailed descriptions of the water delivery system may be found in Omary et al. (1997) and of the control system, in Camp et al. (1996).

The nutrient injection system installed on the modified center pivot system is based on the principle of maintaining a constant nutrient concentration in the water supply line. Variable nutrient amounts were applied to each segment by varying water application depth. Because the water flow rate varies frequently depending upon the number of solenoids switched on at any time, the nutrient injection rate must also vary in proportion to water flow rate at that time. This was achieved with a variable-rate injection pump (Ozawa R & D, Inc. model 40320, Ontario, Oreg.) that had four heads and operated on 24 VDC. The pump injected nutrient solution (UAN 24S in this case) into the water supply pipe at the pivot center. Pump injection rate was varied by the number of heads used and the pump speed, which was controlled by adjusting the 0-5 VDC signal sent to the pump controller. To keep the nutrient injection rate proportional to the water flow rate, the on-board computer calculated the water flow rate, the required nutrient injection rate, and the appropriate control voltage setting; it then set the appropriate control voltage for the pump controller via the PLC control system. All sidedress nitrogen fertilizer for corn (UAN 24S) was applied via the nutrient injection system using the 2x manifold, which delivered 3.6 mm of water at 50% duty cycle and 1.8 mm at 100%. Water was supplied by a pressure-regulated pipe distribution system from a lined reservoir, which was filled by a float-controlled pump delivering 1,500 L/min open discharge from a well. The system flow rate was 0 to 3,000 L/min at 275 kPa pressure. Additional details are included in Camp et al. (1996).

Individual plots were established in a regular 7.5° by 9.1-m pattern, which made the minimum plot length 10 m in segment 8 and 17 m in segment 13. All experimental plots were sited on the outer six of 13 segments of the center pivot system, on the most uniform soil areas (fig. 1). All rows were planted and all subsequent operations were performed in a circular pattern that coincided with the travel pattern of the center pivot system. Each of the four replicates were located in angular sectors of the circle (fig. 1).

Subsoiling to a depth of 0.40 m in the appropriate plots was the only tillage operation performed during the experiment. For both corn and soybean, subsoilers were spaced 0.76 m apart, which coincided with the row in corn. Soybean was planted with a grain drill in rows spaced 0.19 m apart and parallel to the subsoiler path. Fertilizer application was based on soil test results and pesticides were applied as recommended by the Clemson University Cooperative Extension Service. Corn received 45 kg/ha N, 19 kg/ha P, and 112 kg/ha K preplant broadcast fertilizer with micronutrients both years. Sidedress N was applied either 134 kg/ha within one week (STD) or the same amount in six equal increments (INC) starting at the same time as in the STD treatment. Sidedress N application dates and amounts are shown in table 1 for both years. Soybean received 24 kg/ha P and 46 kg/ha K preplant broadcast fertilizer in 1995 only. Corn (cv. Pioneer 3163) was planted at the rate of 74,000 seeds/ha both years (12 April 1995 (DOY 102) and 26 March 1996 (DOY 86)) using a

Case/IH model 800 planter. Soybean (cv. Hagood) was planted at the rate of 95 kg/ha both years (22 May 1995 (DOY 142), 22 May 1996 (DOY 143)) using a John Deere model 750 drill. In 1995, 37-m^2 areas of the center eight rows of each corn plot were harvested 5-20 September (DOY 248-263) using an Almaco plot combine with corn header. Because of lodging caused by Hurricane Fran, 9-m^2 areas of the center four rows of each corn plot were hand harvested 10-19 September 1996 (DOY 254-263). All corn yields were corrected to 15.5% grain moisture. Areas of varying size were harvested from the center of each soybean plot, 14-20 m^2 on 28 November 1995 and 18-39 m^2 on 10 December 1996 using an Almaco plot combine with a small grain header. All soybean yields were corrected to 12.5% moisture content. The experimental design was a split-split randomized complete block design with crop rotation and deep tillage as splits, and irrigation and N-application treatment combinations in a completely randomized block. Yield data were analyzed using analysis of variance (ANOVA) and means were separated by calculating a least significant difference (LSD) (SAS, 1990).

Tensiometers were installed at depths of 0.30 m and 0.60 m in both the subsoiled and non-subsoiled treatments, irrigated treatment only, for all four replicates. Tensiometer readings were usually recorded three times each week and were serviced as required. Irrigation was applied to corn when the mean tensiometer value at the 0.30-m depth exceeded 25 kPa or at lower values if the value at 0.60 m continued to increase, and to soybean when the mean value at the 0.30-m depth exceeded 35 kPa. Irrigation application depths were equal for all irrigated treatments; either 12 mm/day or 25 mm/day depending upon soil water potential and crop growth stage.

RESULTS AND DISCUSSION

Daily and seasonal rainfall and irrigation amounts for corn and soybean during 1995 and 1996 are shown in figures 2 and 3. Daily values are shown as individual lines at the top of each graph and seasonal totals are annotated in the data area. Seasonal rainfall was less in 1995 than in 1996 for both corn (407 mm vs 659 mm) and soybean (659 mm vs 835 mm). For corn, irrigation was applied most of the growing season in 1995 except for a period about mid-season, but was applied primarily during the latter half of the season in 1996. Seasonal irrigation amounts were usually greater in 1995 than in 1996 (221 mm vs 178 mm), as indicated by seasonal rainfall totals. However, irrigation was applied primarily during drought periods between large rainfall events. In the case of soybean, all irrigation in 1995 was applied during the first half of the season, when soybean traditionally does not consistently respond to irrigation (pre-bloom). The irrigation pattern for soybean in 1996 was similar to that of the previous year except that less irrigation was applied (114 mm vs. 178 mm).

Soil water potential (SWP) values for corn were greater than -30 kPa at the 0.30-m depth most of the season in both years. SWP values at the 0.60-m depth were slightly lower than those at the 0.30-m depth both years, especially in the latter part of the growing season.

This trend indicates that irrigation amounts were not sufficient to replace water extracted from the subsoil during the growing season. Past observations indicate that large rainfall amounts are required to replace subsoil water during the growing season for corn. This was evident by the SWP values at about DOY 208 in 1996 when rainfall was 111 mm. In the case of soybean, SWP values at the 0.30-m depth were greater than -50 kPa most of the 1995 season and greater than -30 kPa most of the 1996 season because of rainfall. In 1995, rainfall near the end of the season (DOY 230) caused much greater SWP values than for the remainder of the season. SWP values at the 0.60-m depth were less than for the 0.30-m depth most of the time both years, especially during the middle and latter portions of the seasons. Overall, SWP values were maintained within the desired range of values for both crops in both years.

Crop rotation effects were not significant either year. Corn grain yields averaged over rotations for both years are reported in table 2. Corn grain yields were greater for irrigated treatments in both years, and the differences were numerically greater in 1995 than in 1996. All yields were slightly greater in 1996. There was no difference in yield between the two N sidedress treatments or between the two deep tillage treatments in either year. Analyses indicate interaction between tillage and irrigation-N application combinations ($P \geq 0.076$ in 1995 and $P \geq 0.037$ in 1996), which was probably caused by the differential response to deep tillage for the irrigated and rainfed treatments. With irrigation, subsoiling increased yields both years, but without irrigation yields were not affected by subsoiling. Inconclusive statistical results and small yield differences suggest that this phenomenon cannot be explained until the final two years of results are obtained.

Irrigated soybean yields were greater than non-irrigated yields in 1995 but not in 1996 (table 3). Because crop rotation effects were not significant, means of crop rotation treatments are reported for 1996 (only one soybean crop treatment in 1995). Yields for the subsoiled treatment were greater ($P \geq 0.076$) than for non-subsoiled in 1995 but were not different in 1996. There was no interaction between tillage and irrigation for soybean.

The control system software for the site-specific irrigation system evolved during the 1995 growing season through experience and modification so that by the end of season, the system operated unattended most of the time. Improvement in communication reliability between the fixed and movable components improved during the 1996 growing season but more improvement is still needed. Acceptable distribution uniformity within control elements and expected border effects between elements with different application depths were measured and reported previously (Omary et al., 1997). Observations during the 1995 and 1996 seasons presented no evidence that border width was different. Concern about water ponding and surface redistribution during design, because of relatively high instantaneous application rates caused by small wetted diameters, proved not to be a problem even when nozzle discharge was collected in a 37-mm diameter flexible hose used during nutrient application and discharged near the soil surface. Satisfactory water distribution uniformity values were measured both along the radius and parallel to the travel path (Camp et al., 1997). Infrared thermometers

(IRT) for each element have been installed on the system and will be used to measure crop canopy temperature and soil surface temperature for each 9.1-m segment.

SUMMARY AND CONCLUSIONS

Preliminary results (two years) from a corn-soybean rotation experiment where conservation tillage was used indicate no difference between crop rotation or nitrogen side dress treatments. Irrigated corn yield was greater both years but irrigated soybean yield was greater only in 1995. Corn yield for deep tillage treatments were not different either year but soybean yield was higher with subsoiling in 1995. Subsoiling increased corn grain yield with irrigation but yields were equal or less without irrigation.

Water and N fertilizer were applied to individual fixed-boundary plots in the experiment using a site-specific center pivot irrigation system that had been modified to apply variable-rate water depths to individual elements within the system. N fertilizer was injected into the water supply to maintain a constant concentration although water flow rate varied with time, and variable N-fertilizer rates were accomplished by applying different water depths. Reliability of the control system hardware and software improved during the two years of this experiment until it could operate unattended much of the time. Preliminary water distribution data indicate acceptable water distribution uniformity with expected border effects when two adjacent elements apply different water depths. Further evaluation of water and nutrient distribution uniformity will be performed in the future.

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Table 1. Nitrogen fertilizer applications to corn in an irrigation and tillage experiment in Florence, SC, during 1995-1996.

N Fertilizer Treatment	1995		1996	
	Application Dates* (DOY)	Total Amount (kg/ha)	Application Dates (DOY)	Total Amount (kg/ha)
INC	152, 159, 163, 165, 170, 172	134	136, 145, 155, 162, 165, 169	134
STD	152, 158†	134	136, 144†	134

* Nitrogen fertilizer source was urea ammonium nitrate (UAN) 24% with sulfur. All application rates are 22 kg/ha N via the irrigation system except where noted.

† Application rate was 112 kg/ha N from UAN 24S.

Table 2. Corn grain yield for irrigation, nitrogen, and conservation tillage experiment in Florence, SC, during 1995-1996.

Treatment		Tillage Treatment		
Irrigation	N Fertilizer	Subsoiled	Non-subsoiled	Mean
		---------- Mg/ha ----------		
1995				
IRR	INC	11.00	10.55	10.75 a*
IRR	STD	11.55	10.40	11.00 a
NI	INC	9.70	9.80	9.75 b
NI	STD	9.60	10.15	9.90 b
Mean		10.70 a	10.30 a	
1996				
IRR	INC	12.25	11.60	11.90 a
IRR	STD	12.30	11.45	11.90 a
NI	INC	10.95	11.40	11.20 b
NI	STD	11.20	11.15	11.20 b
Mean		11.90 a	11.45 a	

*Means followed by the same letters are not different according to LSD at P≤ 0.05.

Table 3. Soybean yield for irrigation and conservation tillage experiment in Florence, SC, during 1995-1996.

Irrigation Treatment	Tillage Treatment		
	Subsoiled	Non-subsoiled	Mean
	---------- Mg/ha ----------		
1995			
IRR	1.92	1.80	1.86 a*
NI	1.52	1.42	1.47 b
Mean	1.79 a	1.68 a	
1996			
IRR	2.26	2.26	2.24 a
NI	2.22	2.23	2.22 a
Mean	2.24 a	2.22 a	

*Means followed by the same letters are not different according to LSD at P≤ 0.05.

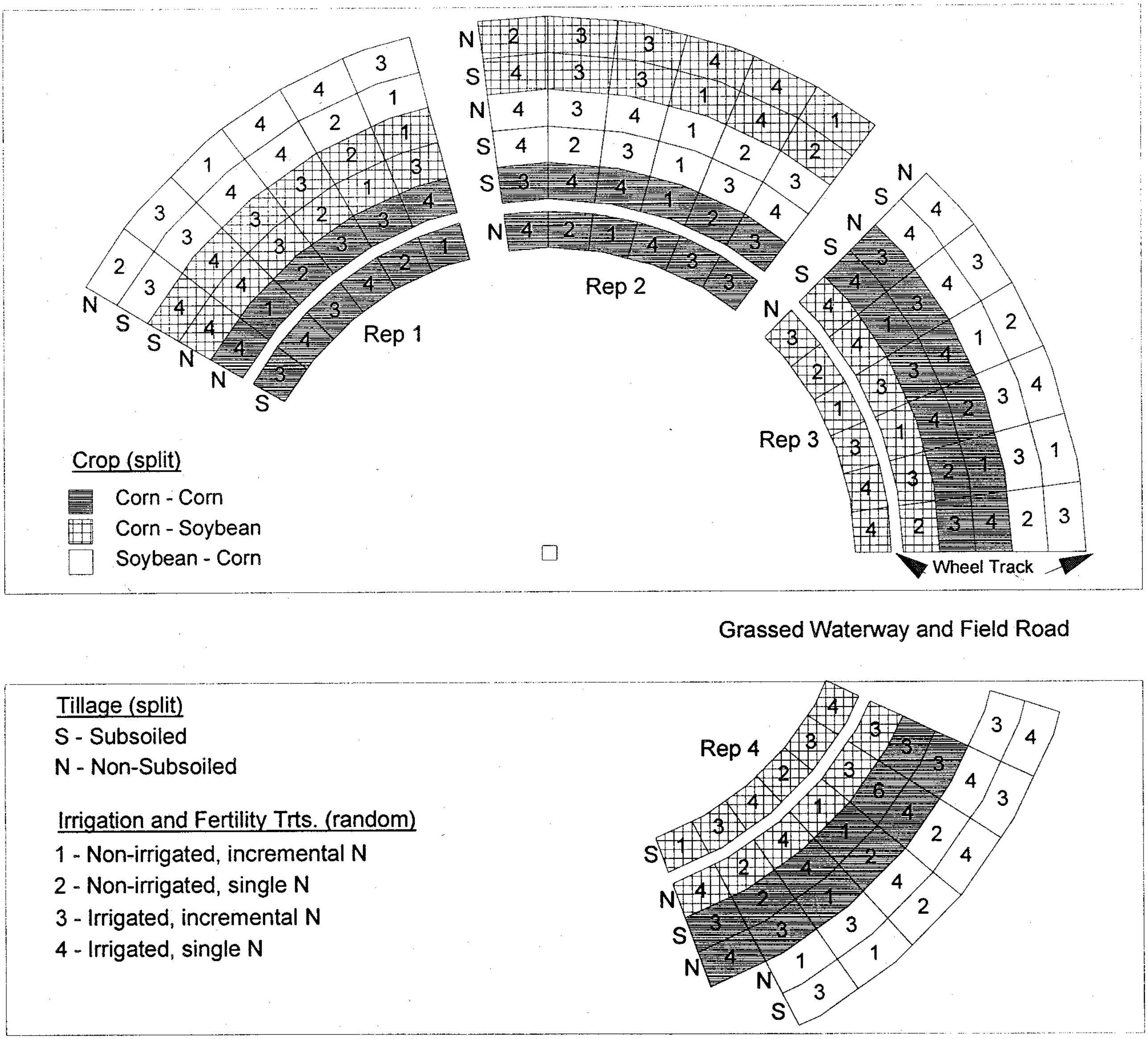

Figure 1. Schematic diagram of treatments in a corn-soybean rotation experiment under a site-specific center pivot irrigation system with irrigation, tillage, and N-fertilizer sidedress treatments, all on conservation tillage, in the southeastern Coastal Plain.

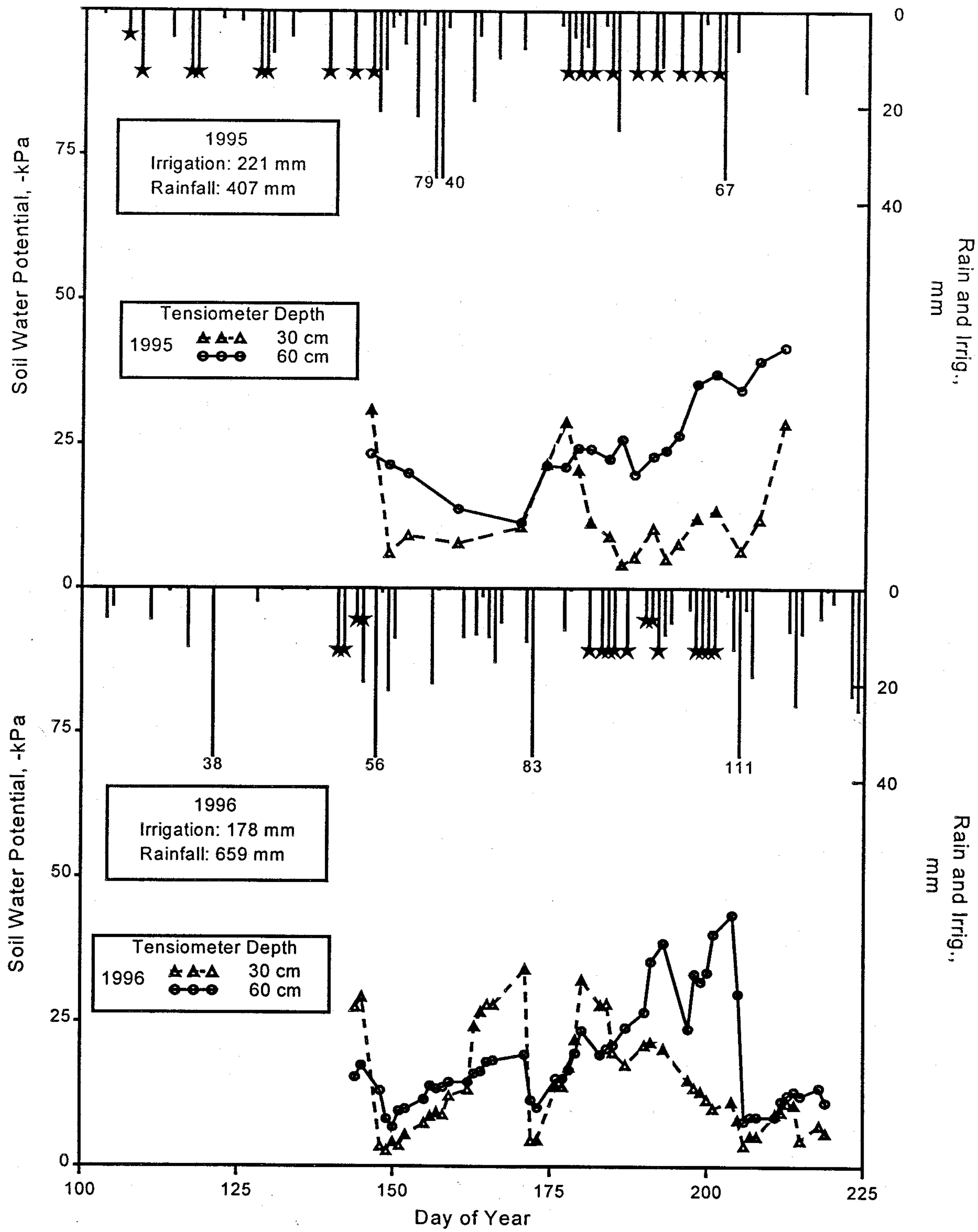

Figure 2. Daily rainfall and irrigation and soil water potential at two depths for corn irrigated with a site-specific center pivot irrigation system in 1995 and 1996. Soil water potential data points are means of tensiometers located in two tillage treatments and two N-fertilizer treatments. Numbers by truncated rainfall lines are rainfall amounts in mm.

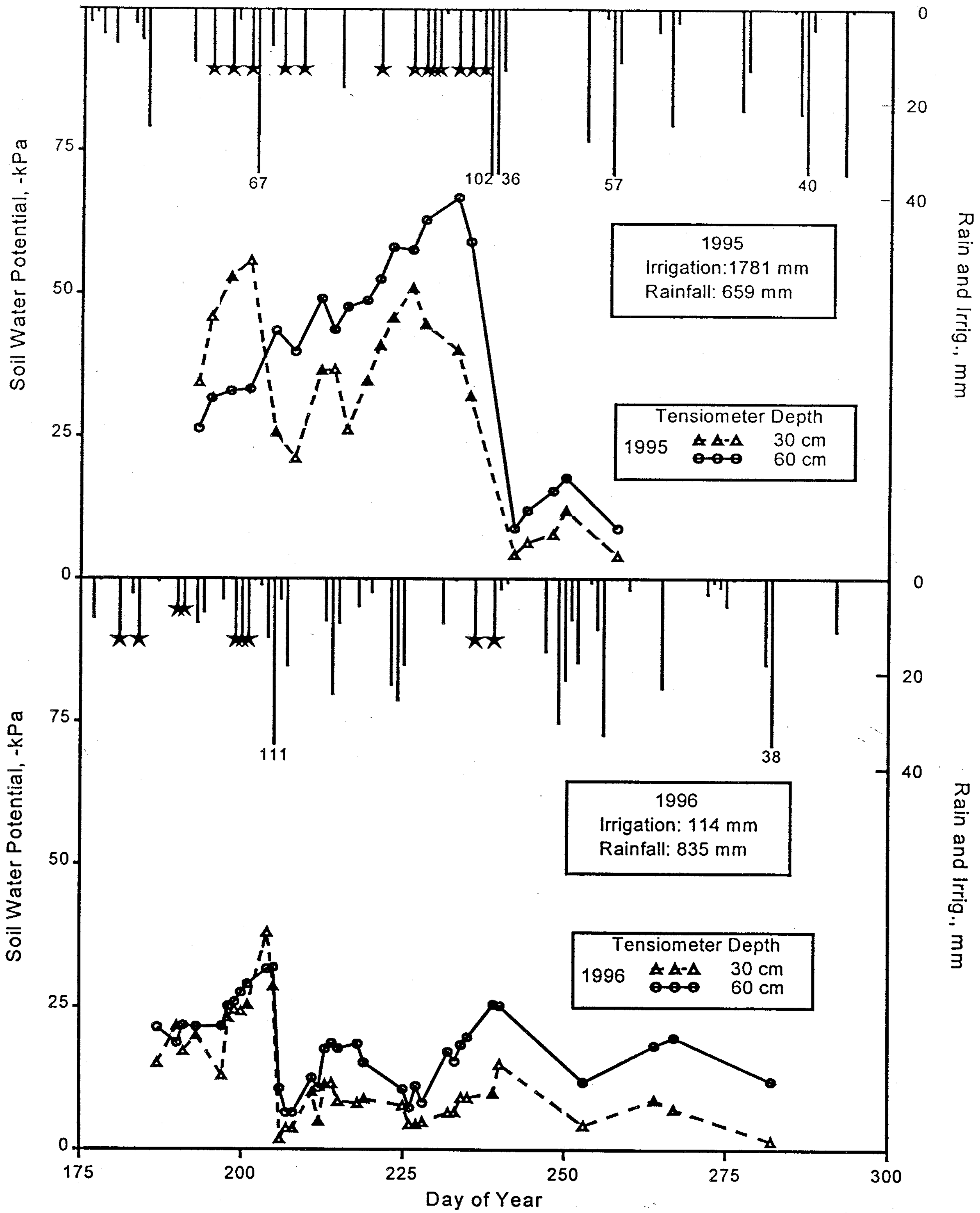

Figure 3. Daily rainfall and irrigation and soil water potential at two depths for soybean irrigated with a site-specific center pivot irrigation system in 1995 and 1996. Soil water potential data points are means of tensiometers located in two tillage treatments and two N-fertilizer treatments. Numbers by truncated rainfall lines are rainfall amounts in mm.