IRRIGATION AND N-FERTILIZER COMBINATIONS FOR SITE-SPECIFIC MANAGEMENT OF CORN

J. A. Millen, C. R. Camp, E. J. Sadler, and D. E. Evans*

ABSTRACT

Efficient management of irrigation and N-fertilizer requires knowledge of soil variability and crop response to these inputs. Automated measurements can be used to indicate plant stress throughout the growing season and may help indicate timing and amount needed of these inputs. In 1999, a 6-ha center pivot, modified to provide site-specific irrigation, was used to impose irrigation and N-fertilizer treatments on 396 separate corn (Zea mays) plots (9 m by 9 m) on highly variable soils. Treated plots were arranged in randomized complete blocks where space allowed and incomplete blocks where space was limited. Two N-fertilizer rates (135 and 225 kgN/ha) and four irrigation rates (0%, 50%, 100%, and 150% of a base rate) were applied within each of twelve soil mapping units representative of the southeastern Coastal Plain. The four irrigation treatments, averaged across N-fertilizer and soils, produced corn grain yields of 6.4, 8.8, 10.1, and 10.7 Mg/ha. Canopy temperatures were measured on eight separate days using non-contact infrared thermometers (IRTs). Soil moisture of the surface 6 cm was measured on two days when canopy temperatures were measured. Preliminary analysis suggests this information will be useful to researchers and precision farming innovators interested in managing spatial variation, especially within the southeastern Coastal Plain and similar sandy areas.

Keywords. Center pivot, Canopy temperature, Soil moisture, Variable rate application

INTRODUCTION

The climate in the southeastern Coastal Plain is humid, subtropical, with a growing season of approximately 250 frost-free days. Annual rainfall of 1100 mm normally exceeds crop requirements but is often distributed poorly throughout the growing season and year. Highly variable soils with nearly level sandy surfaces and sandy clay subsoils are common in the region and are characterized by a low water holding capacity. Many of the soils also have compacted layers near the surface that restrict crop-rooting depths. Shallow depressions of various sizes (Carolina bays) are found throughout the region. These depressions often have a finer-textured surface soil and sandy inclusions. The combination of poorly distributed rainfall and highly variable soils with low water holding capacities causes frequent yield reductions in areas within a field (Sadler et al., 1995).

Most center pivots are designed to apply uniform water rates along the length of the pivot. With the soil variability of the Coastal Plains, these center pivots often cannot provide optimum applications of water and/or nutrients to all parts of a field (Camp et al., 1988). Because of this limitation, a team at the USDA-ARS in Florence, SC, developed specifications for a variable rate computer-controlled center pivot (Camp and Sadler, 1994). In 1993, two small, commercial, three span pivots were purchased (Valmont Industries Inc., Valley, NE†). Center pivot 1 (CP1) was modified in 1995 to provide variable-rate water applications (Omary et al., 1997). After testing and refining was

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completed on CP1, Center pivot 2 (CP2) was modified in 1998 for variable-rate water and nutrient application.

Our objectives are to summarize first-year effects of water and N-fertilizer rates on corn yield, describe a canopy temperature measurement system, and evaluate the spatial accuracy of water delivery for a 1999 experiment on CP2.

MATERIALS AND METHODS

Irrigation system - CP2 has an irrigated area of 5.8 ha, is 137 m long, and has three drive towers. The inner two towers maintain alignment automatically via their position relative to the outer drive tower. The system can be controlled at the pivot or from a remote base station through a computer interface.

To provide variable rate irrigation over the entire span of the pivot, both systems were divided into 13 segments, each 9.1 m long. Three parallel manifolds, each with six spray nozzles spaced 1.5 m apart and 3 m above the ground, were added to each segment. Water was supplied to each segment by a 5-cm diameter port. The supply port for each segment led to a distribution manifold and drop hoses to each of the parallel manifolds. Solenoid valves controlled flow to the parallel manifolds. Each parallel manifold had a pressure regulator, a vacuum breaker, and a low-pressure drain. The three parallel manifolds and their nozzles were sized to provide 1/7, 2/7, and 4/7 of a base application depth, which was 12.7 mm with the pivot running at 50% speed. All combinations of the manifolds provided application rates of 0, 1/7, 2/7, ... and 7/7 of the base application depth.

A PLC switch (programmable logic controller) (GE Fanuc model 90-30, Charlottesville, VA) was mounted on the moveable portion of the pivot about 5 m from the center. The PLC received angular position data from the center pivot C:A:M:S^{TM} controller (Valmont Industries, Inc., Valley, NE)through an RS232 link. Using the angular position, data stored on the computer, and software developed at USDA-ARS in Florence, the PLC switched on solenoids in various combinations to provide the appropriate water depth to each plot. Camp et al. (1998) and Omary et al. (1997) describe the water control and application system in more detail.

Nutrient Application – Variable-rate nutrients can be applied by injection into the water distribution system. To accomplish this, nutrients are maintained at a constant concentration in the supply water, and a nominal VRT water application then controls nutrient application. Nutrients were injected into the supply line with a variable-speed, four-head injection pump (Ozawa R & D, Inc., model 40320, Ontario, OR) located at the center of the pivot. The injection pump received a control signal from the PC on the pivot, which calculated injection amounts based on the water flow though the pivot. By changing the depth of water application, variable-rate nutrient applications were achieved analogous to the variable-rate water applications.

IRT System - Two small infrared thermometers (IRTs) were placed in each of the 13 segments of CP2 (26 total units) on aluminum masts and booms that extended approximately 3 m in front of the water application manifolds. The IRTs used were Exergen Irt/c .3X with a 3:1 field of view and type K thermocouple leads (Exergen Corp., Newton, MA). The IRTs were directed toward an area approximately 3 m inside the edges of each segment. The masts allowed the height of the IRTs to be adjusted to 1.5 m above or below the water application manifolds. Thermal (canopy temperature from IRT), time, and positional data (from C:A:M:S^{TM}) were collected using a CR21x data logger (Campbell Scientific Inc., Logan, UT) and the PC mounted on the pivot.

Experimental Design - In 1999, CP2 applied variable water and N-fertilizer rates to grain corn on 12 soil mapping units based on a local 1:1200 scale soil survey. The experiment was designed to determine crop yield responses to water and nutrient applications for these soils. Water treatments included 0, 50, 100, and 150 % of a base irrigation rate with timing of irrigation applications determined by tensiometers placed in several plots. N-fertilizer rates were 135 and 225 kgN/ha, which respectively represent the recommended fertilizer rates for non-irrigated and irrigated corn production in South Carolina. Plots were approximately 9 m by 9 m containing 12 rows of corn. The center 6-m by 6-m area of the plots was considered to be the control area. The outer 1.5 m area was used as a buffer because of overspray from surrounding plots. The number of replications and treatments was determined by the available area within each soil mapping unit. If area permitted, randomized complete blocks were used; where space was limited, incomplete blocks were used. This resulted in a total of 396 plots. Areas that fell on soil boundaries were not included as treatment plots but received treatment 1 (no irrigation and lower N-fertilizer rate). The treatments and soil mapping units are shown in Fig. 1. Yield data were analyzed using the general linear models procedure and the Waller - Duncan K-ratio T test (SAS, 1990).

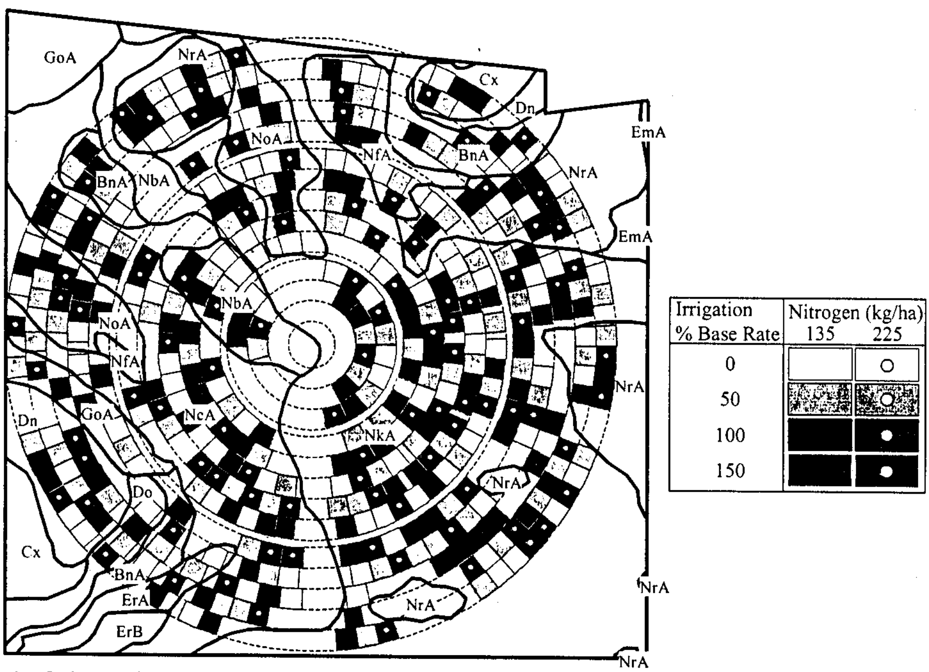

Figure 1. Schematic of Treatments and Soil Mapping Units Under a Variable Rate Center Pivot in Florence, SC.

Management and Data Collection – Wheat had been harvested from CP2 in the spring of 1998, followed by a soybean crop in the fall of 1998. On Feb 17, Mar 19, and Mar 20, 1999, the field was disked. On Mar 23, pre-plant fertilizer with an analysis of 11-19-19 was applied to CP2 at a rate of 280 kg/ha (35 kgN/ha) using a drop spreader. On Apr 3, Pioneer 3163 corn was planted at a rate of 71,500 seeds/ha using a 6-row planter with sub-soilers. Final population was 64,200 plants/ha. Between Aug 31 and Sep 19, corn was harvested using both a plot combine in stop and weigh mode and a combine equipped with a yield monitor.

Irrigation was managed with tensiometers placed at depths of 0.3 and 0.6 m. Irrigation was initiated in the 100% base rate when the average tensiometer reading in this treatment was -30 kPa. Irrigation was applied to the other treatments at the same time at appropriate rates. The base rate depth varied throughout the season (4 – 13 mm) depending upon crop growth stage and climate conditions. Total irrigation for the 100% base rate treatment was 218 mm, applied in 26 irrigation events.

On June 2 and 3, Urea Ammonium Nitrate (UAN) 24% was applied to the all plots at a rate of 50 kg N/ha. On June 4, an additional application of 90 kg N/ha was applied to the high N-fertilizer plots. With pre-plant fertilizer, 135 kg N/ha was applied on the low N-fertilizer plots, and 225 kg N/ha was applied on the high N-fertilizer plots. The amount of supply water was kept at a minimum to prevent wetting the non-irrigated treatments any more than necessary for the nutrient application (4.6 and 7.4 mm for the low and high N-fertilizer treatments respectively).

On eight separate days during grain fill, IRT readings were taken at 15-s time increments using the pivot operating at 100% speed with no irrigation. The readings were then corrected for individual IRT calibrations, cloud cover, and temporal changes during the 3.5-hour period required for a complete revolution.

On two days when IRT readings were taken (July 9 and 20), soil water content measurements in the surface 6 cm of soil were made using a frequency domain reflectometry device (Delta-T Theta Probe, Delta-T Devices Ltd., Cambridge, U. K.). The measurements were made at 0.3-m intervals along the corn row (pivot travel direction) on several selected plots to determine water application uniformity within control zones and soil water content changes across zone borders. In both cases, irrigation was applied the day before the probe measurements were made.

RESULTS

Yield Response - Corn yield was significantly different (P = 0.05) for irrigation amounts of 0, 50, and 100% of the base rate but not between 100 and 150% of base rate for the Dunbar loamy sand (Dn) (16 total plots) and Norfolk loamy sand (NkA) (168 total plots) soils. There was no significant difference in corn yield among irrigation amounts in the Bonneau loamy sand (BnA) (18 total plots) soil. An unusually low yield (4.72 Mg/ha) in the single 100% base rate-high N-fertilizer plot on the BnA soil caused a very high standard deviation (3.3 Mg/ha) which probably caused the lack of significance difference for this soil. Yields were not statistically different for the two N-fertilizer treatments on any of the three soils. The yield responses for these soils are shown in Fig. 2.

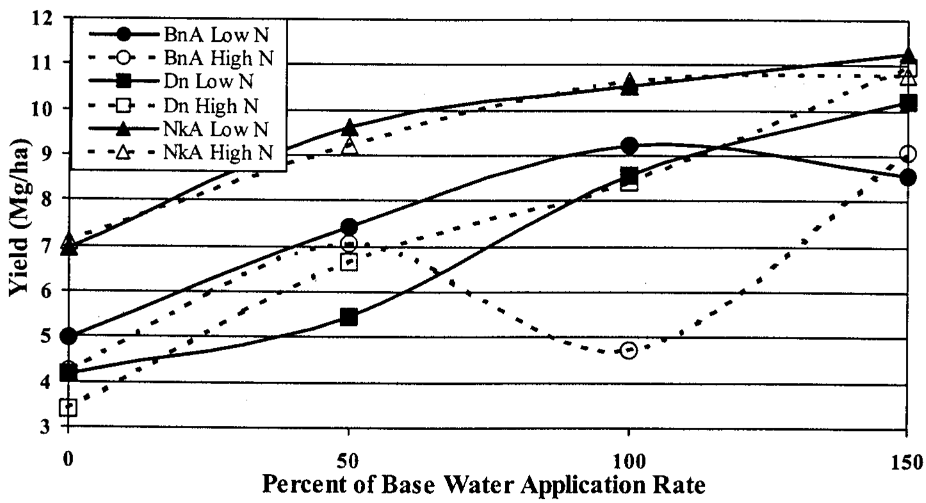

Figure 2. Corn Yield Response to Variable Water and N-fertilizer Rates for Three Soils (Bonneau, BnA; Dunbar, Dn; Norfolk, NkA) in Florence, SC.

Soil Water Content - Measured soil water contents for a non-irrigated, high nitrogen treatment (5), a 150% water, high nitrogen treatment (8), and a 100% water, low nitrogen treatment (3) are shown in Fig. 3. The measurements were taken on a Norfolk (NkA) on July 20, 1999. Soil water uniformity within control zones was fairly uniform (CV 16 – 56%). Positional accuracy of the irrigation applications was also reasonable as indicated by the change in soil water content at the treatment boundaries (especially noticeable between treatments 5 and 8).

Canopy Temperature - The means of two canopy temperature measurements for each treatment are also shown in Figure 3. As expected, canopy temperature generally followed an inverse pattern to the soil water content. Canopy temperature uniformity within treatment control zones appears acceptable (CV 0.8 – 3.4%), indicating that canopy temperature may possibly be used as an indicator for irrigation applications. Using devices like the IRTs with proper calibration and correction and an on-board PC with an appropriate algorithm, it may be possible to apply the required irrigation amounts at the proper time as the center pivot moves around the field.

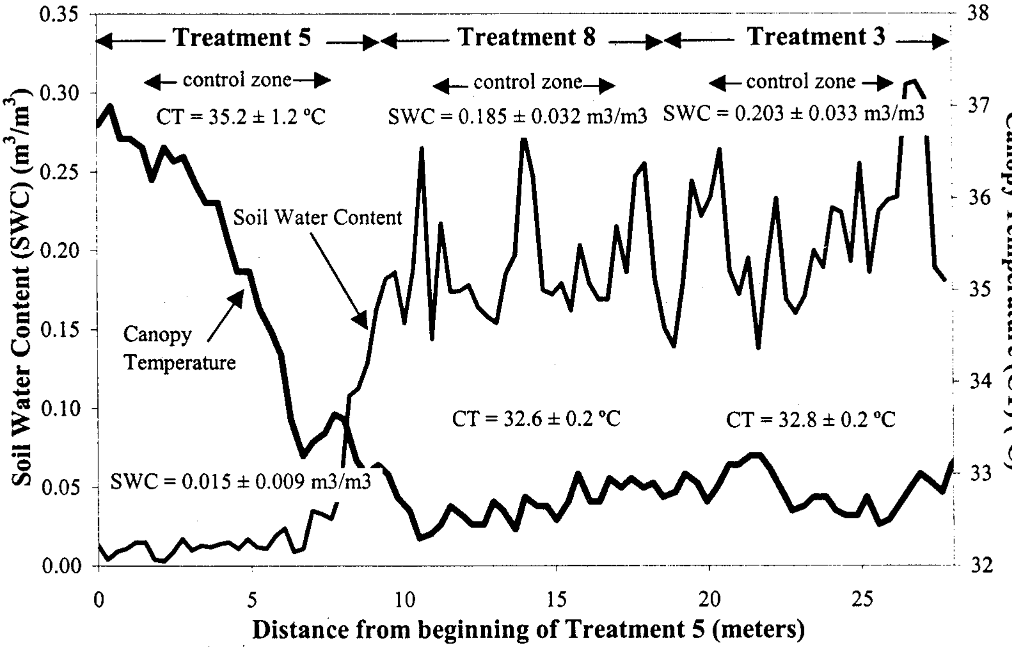

Figure 3. Surface Soil Water Contents and Canopy Temperatures for Three Contiguous Water-N-Fertilizer Rate Combinations Under a Center Pivot Irrigation System in Florence, SC, on July 20, 1999.

SUMMARY

A center pivot, modified to provide site-specific irrigation, was used to impose irrigation and N-fertilizer treatments on 12 soil mapping units and a corn crop during the 1999 crop season in Florence, SC. Irrigation rates had a significant effect on corn grain yield for the 0, 50, and 100% water treatments on the Dunbar (Dn) and Norfolk (NkA) soils. Irrigation application was reasonably uniform within control zones (CV 16 - 56%) as indicated by testing soil moisture levels across several contiguous treatments in a Norfolk (NkA) soil. An IRT system mounted on the center pivot showed that canopy temperatures were also reasonably uniform within control zones (CV 0.8 – 3.4%). This uniformity indicates that plant stress is similar throughout the control zones. Comparing IRT measurements and soil moisture measurements indicate that different irrigation levels cause varying levels of plant stress. With additional result, it may be possible in the future to provide site-specific irrigation based on IRT measurements. This would greatly improve the water use efficiency of irrigated crops.

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