CORN YIELD RESPONSE TO N FERTILIZER FOR A RANGE OF WATER REGIMES AND SOIL MAPPING

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ABSTRACT

Availability of affordable global positioning systems and yield monitors for many crops has stimulated interest in site-specific management of crop inputs such as irrigation and fertilizers. Farmers can now directly measure the effects of varying inputs on crop yield. Two commercial center pivot irrigation systems were modified (one in 1995, the second in 1998) to provide site-specific water and fertilizer applications to management zones as small as 100m^2. These modified systems were used in 1999 to determine the effects of a range of water and N-fertilizer rates on corn grain yield. One system was sited on a fairly uniform soil area while the other was located on a site with 12 soil map units. Corn grain yield increased with increased irrigation amount at both sites. Yield increased with N-fertilizer rate between the 50% and 75% rates, but not for higher rates at the uniform-soil site or for the two N-fertilizer rates at the variable-soil site. Yield responses to irrigation varied among the various soil map units, with some soils responding more to irrigation than others. Once crop yield effects of variable inputs, soils, and economic factors are known, site-specific water and N-fertilizer rate recommendations can be developed for individual management zones.

Keywords: Irrigation, Site-specific management, Center pivot, Coarse-textured soils, Rainfall, Spatial variability, Humid areas, Precision agriculture, Zea mays

INTRODUCTION

Affordable global positioning systems with improved spatial resolution and development of yield monitors have allowed yield mapping of many crops, which permit identification of meaningful yield patterns that may be related to various site conditions and management inputs. These advances have led to the development of variable-rate application technologies that permit site-specific management of nutrients and other agro-chemicals. More recently, there has been increased interest in the precision management of water and chemicals, either separately or together.

A major reason for this increased interest is the farmer can now directly measure the effects of variable water and chemical inputs.

Site-specific application of fertilizers over large areas using ground-driven equipment has been practiced for several years, but most irrigation is still being applied uniformly within a given system. Programmable management systems on some commercial traveling irrigation systems allow variable application depths by changing travel speed for the system (e. g. wedges in a center pivot). More precise, dynamic control of water and chemical applications require smaller management zones both in the direction of travel and along the system structure. Several techniques have been developed for site-specific applications of water and chemicals, ranging from switching several sprinklers (McCann and Stark, 1993) or multiple manifolds (Roth and Gardner, 1989; Lyle and Bordovsky, 1983; Camp, et al., 1998) to changing sprinkler orifice size (King and Kincaid, 1996; King et al., 1997) or time-based pulsing of sprinklers (Duke et al., 1992; Evans and Harting, 1999; Fraisse et al., 1992).

When commercial systems for dynamic control of water and chemical applications to management zones within a total system become available, crop production functions for a range of water and chemical inputs will be needed for all soils within the management area. Conventional statewide fertilizer recommendations for rainfed and irrigated production may be helpful but more specific crop responses to fertilizer and irrigation inputs for individual soils will be needed to optimize economic return and minimize environmental degradation. Furthermore, crop response to reduced water and fertilizer inputs will be needed for those instances when water supplies are inadequate, either on a continuing basis or during severe drought.

Little information has been published on corn response to irrigation and nitrogen rates for diverse soils, especially in the southeastern Coastal Plain. Gascho and Hook (1991) found greater corn grain yields on two sands in Georgia using fertigation and multiple N-fertilizer applications than when using conventional methods. Lamm et al. (1993) reported corn grain yields on a silt loam in northwest Kansas for nine resource-allocation schemes that included combinations of irrigation timing and amount, N-fertilizer rate, and seeding rate. While fully irrigated and fertilized corn produced the greatest net income, they found that management-induced variations in crop production had major impact on corn yield and profit. Others have investigated the impact of various irrigation and N-fertilizer inputs on corn grain yield and nitrate leaching in the north central U. S., but mostly on single soils (Ferguson et al., 1991; Oberle and Keeny, 1990; Sexton et al., 1996).

The objectives of this experiment were to determine corn grain yield response to a range of irrigation levels and N-fertilizer rates on two sites in the southeastern Coastal Plain; one with uniform soils and one with extremely variable soils.

MATERIALS AND METHODS

Irrigation System

Two three-span, commercial center pivot irrigation systems were purchased in

1993 (Valmont Industries, Valley, NE[1]). Each system was 137 m long and had an irrigated area of 5.8 ha. Both systems included computer management control systems that could be programmed and controlled either locally or from a remote base station. One system (CP1) was modified in 1995 to provide variable-rate water and nutrient applications. The second system (CP2) was modified in 1998 with a water and nutrient delivery system similar to that used for CP1. CP1 was sited on a fairly uniform soil area and CP2 was sited on a highly variable soil area that reflects conditions for a typical, highly-variable Coastal Plain field. Water for both systems was supplied from a lined reservoir via several pumps staged to automatically vary water flow and maintain constant pressure. Water level in the lined reservoir was maintained via a vertical-shaft turbine pump in a well adjacent to the reservoir.

Water Application

The variable-rate water application system on both systems consisted of 13 segments along the pivot length (truss), each 9.1 m long, ending on the outer tower. Each segment had three parallel manifolds with six industrial spray nozzles spaced 1.5 m apart and 3 m above the ground surface. Water was supplied to each set of manifolds from the center pivot pipe via 5-cm-diameter ports and distribution pipes and hoses. Each manifold had a pressure regulator, air entry port, and low pressure drain. Solenoid valves controlled flow to each manifold. The three manifolds and nozzles were sized to provide 1/7, 2/7, and 4/7 of a base application depth, which was 12.7 mm when the center pivot was operated at 50% speed. All combinations of the three manifolds provided 0, 1/7, 2/7, 3/7,...7/7 (or 100%) of the base application depth. Additional details regarding the water application system were reported by Omary et al. (1997). Irrigation application uniformity within both the 9-m by 9-m management zones and the central 6-m by 6-m control zones as well as positional accuracy of water applications using both spatially-measured soil water contents and crop canopy temperatures were reported by Camp et al. (1999).

Controls

The variable-rate water application system was controlled by a computer, which was mounted on a programmable logic controller (PLC) backplane (GE Fanuc model 90-30, Charlottesville, VA) and was connected via the system buss. The computer and PLC assembly were mounted on the mobile portion of the center pivot about 5 m from the center, from which they controlled all manifold solenoid valves. The computer received angular position data from and transmitted start/stop signals to the center pivot C:A:M:S® (Valmont Industries, Valley, NE) management system via an RS232 link. Using the angular position data, spatially-indexed data stored on the computer, and software developed by USDA-ARS in Florence, the PLC switched

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[1] Mention of trademark, proprietary product, or vendor 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.

the proper solenoids to obtain various combinations of manifolds/nozzles to provide the appropriate application depth for each management zone. The control software also included checks for out-of-range values and fail-safe operation. Additional details regarding the control system were reported by Camp et al. (1998).

Fertilizer Application

N fertilizer was applied by injecting urea ammonium nitrate (UAN) into the center pivot water line at rates that maintained a constant concentration in the water distribution system. Variable N amounts were applied to each management zone by varying the water depth applied. In order to maintain a constant concentration, UAN was injected at a rate proportional to the water flow rate. This was achieved with a variable-rate four-head injection pump (Ozawa R & D, Inc. model 40320, Ontario, OR). The on-board computer calculated the instantaneous injection rate based on the water flow rate and transmitted the appropriate control signal (0-5 VDC) to the injection pump control unit. A minimal water depth (4 - 19 mm) was used to apply the required N-fertilizer amounts, even in the non-irrigated treatments. In most cases, flexible hoses were fastened around the nozzles during fertilizer applications so that the solution was applied directly to the soil surface instead of the corn canopy.

Experimental Design

In 1999, experiments to determine the effect on corn grain yield of a range of irrigation and N-fertilizer amounts were conducted in Florence, SC, on both CP1 and CP2. The soils at the CP1 site were fairly uniform (Norfolk lfs (NkA) and a deeper Norfolk lfs(NoA)). Treatment variables included three irrigation regimes (0, 75%, and 150% of a base rate), four N-fertilizer regimes (50%, 75%, 100%, and 125% of a base rate), and three antecedent crop rotation treatments. The irrigation base rate was intended to provide adequate water for crop growth and development. The two N-fertilizer base rates were those recommended by the South Carolina Cooperative Extension Service for either rainfed or irrigated corn production (135 and 225 kg/ha, respectively). The rainfed base N-rate was used only for the non-irrigated water regime. The antecedent crop rotations (previous 4 years) were continuous corn, corn/soybean, and soybean/corn. Four replications of each treatment resulted in a total of 144 plots arranged in a randomized complete block design (Figure 1). Each plot was 9.1 m wide (12 rows) and 10 to 16 m long.

Soils at the CP2 site were more variable and included 12 soil map units. These soils are Bonneau lfs (BnA), Coxville l (Cx), Dunbar lfs (Dn), Dunbar lfs overwash (Do), Emporia fsl (ErA), Goldsboro lfs (GoA), a deep Noboco lfs (NbA), Noboco lfs (NcA), Noboco fsl (NfA), Norfolk lfs (NkA), a deep Norfolk lfs (NoA), and Norfolk fsl (NrA). Soil map units were determined by NRCS personnel from samples taken on a 15-m by 15-m grid, with additional sampling to identify soil boundaries. Additional information on the site description and cropping history were reported by Karlen et al. (1990) and Sadler et al. (1995).

At the CP2 site, irrigation treatments included 0, 50, 100, and 150% of a base irrigation rate. N-fertilizer rates were the recommended rainfed and irrigated rates (135 and 225 kg/ha). The number of treatment combinations and number of

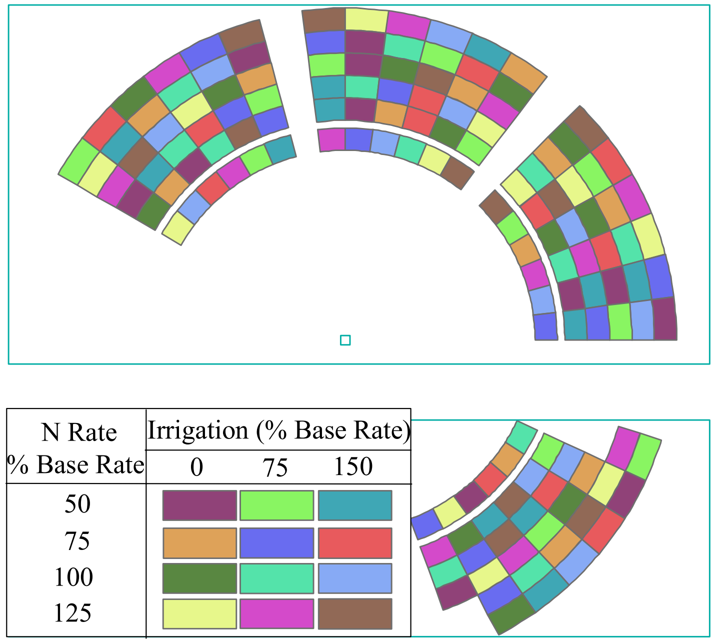

Figure 1. Schematic diagram of an experiment (CP1) on fairly uniform soils to determine corn yield response for various irrigation and N-fertilizer rates on a Coastal Plain soil in Florence, SC.

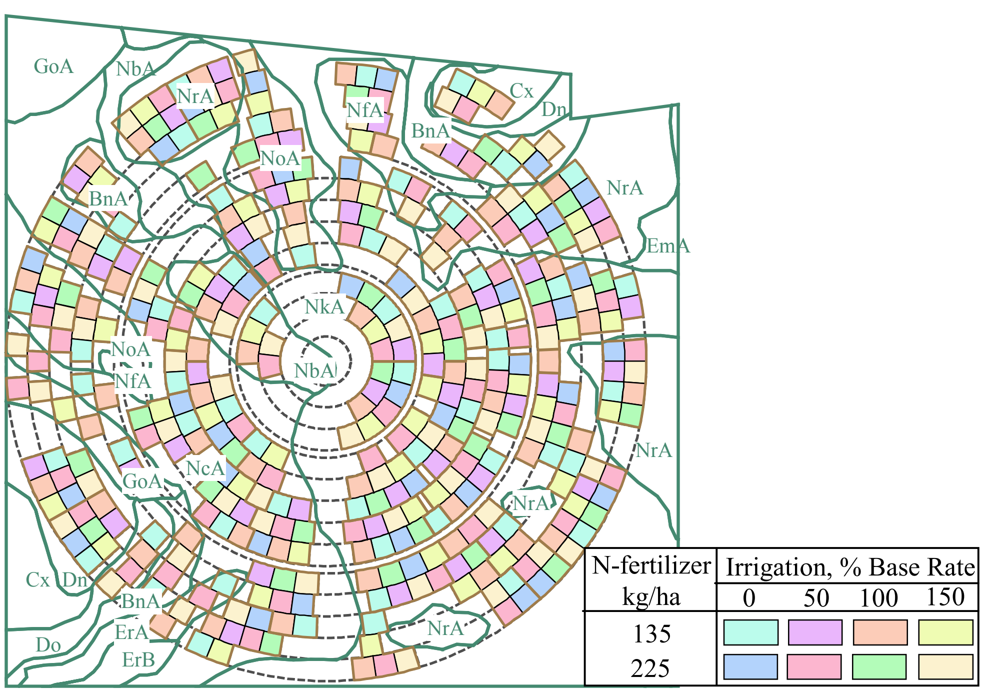

Figure 2. Schematic diagram of an experiment (CP2) on extremely variable soils to determine corn yield response for various irrigation and N-fertilizer rates on 12 Coastal Plain soil map units in Florence, SC.

replications within a soil map unit varied, depending upon the available land area within a specific soil map unit. This design provided a total of 396 plots as shown in Figure 2. Each plot was, at minimum, about 9 m by 9 m in size, but boundaries were determined in 1^{o} increments. Transition areas that included portions of two soil map units were not irrigated and received the lower N-fertilizer rate.

Management and Measurements

Conservation tillage culture was used on CP1 and conventional surface tillage (disking) culture was used on CP2, and both were subsoiled to a depth of 40 cm within the row at planting. Glyphosate (Roundup®) was applied broadcast to CP1 prior to planting to control weeds. Granular fertilizer (31 kg/ha N, 53 kg/ha P_2O_5, and 53 kg/ha K_2O) was applied broadcast to both sites prior to planting. Corn ('Pioneer 3163') was planted March 22-23, 1999, using a six-row planter at a seeding rate of 71,500 seeds/ha. Final plant population was about 64,000 plants/ha. Pre-plant, pre-emergence, and post-emergence herbicides and a banded insecticide were applied as recommended by South Carolina Cooperative Extension Service. Urea ammonium nitrate with sulphur (UAN 24S) was applied according to the treatment plan via the irrigation systems at both sites during the period May 28 - June 3, 1999. Physiological maturity (black layer observed) occurred in non-irrigated treatments on August 3 on CP2 and on August 10 on CP1 and in irrigated treatments on August 10 on CP2 and on August 17 on CP2. A 6.1-m length of the center two rows of each plot was harvested during the period August 31 - September 13 using a plot combine. Corn grain yields were determined by weighing the harvested grain and correcting the weight to 15.5% moisture content based on individual grain moisture samples. Yield data were statistically analyzed using analysis of variance and Waller - Duncan K-ratio T test (SAS, 1990).

Tensiometers were installed at the 30- and 60-cm depths at both the CP1 and CP2 sites to measure soil water potential (SWP). At the CP1 site, four sets of tensiometers were installed in the NkA and the NoA soils, two sets in each. At the CP2 site, four sets of tensiometers were installed, one set in each of the NoA, NkA, NcA, and Dn soils. Measurements were recorded at least three times each week. These data were used to determine irrigation initiation and to monitor soil water potential during the growing season. The irrigation base rate for both sites varied during the growing season (4-13 mm/application) depending upon crop growth stage and weather conditions. Irrigation was initiated in all irrigation treatments when SWP at the 30-cm depth in the 100% base rate treatment was $\leq$30kPa. Because there was no 100% base rate treatment on CP 1, that SWP was estimated by interpolating between the measured 75%- and 150%-rate SWP values (tensiometer) at the 30-cm depth. Standard meteorological variables were measured at an automated weather station adjacent to the experimental site.

RESULTS AND DISCUSSION

Soil Water Content

Daily rainfall, solar radiation, and maximum and minimum air temperatures

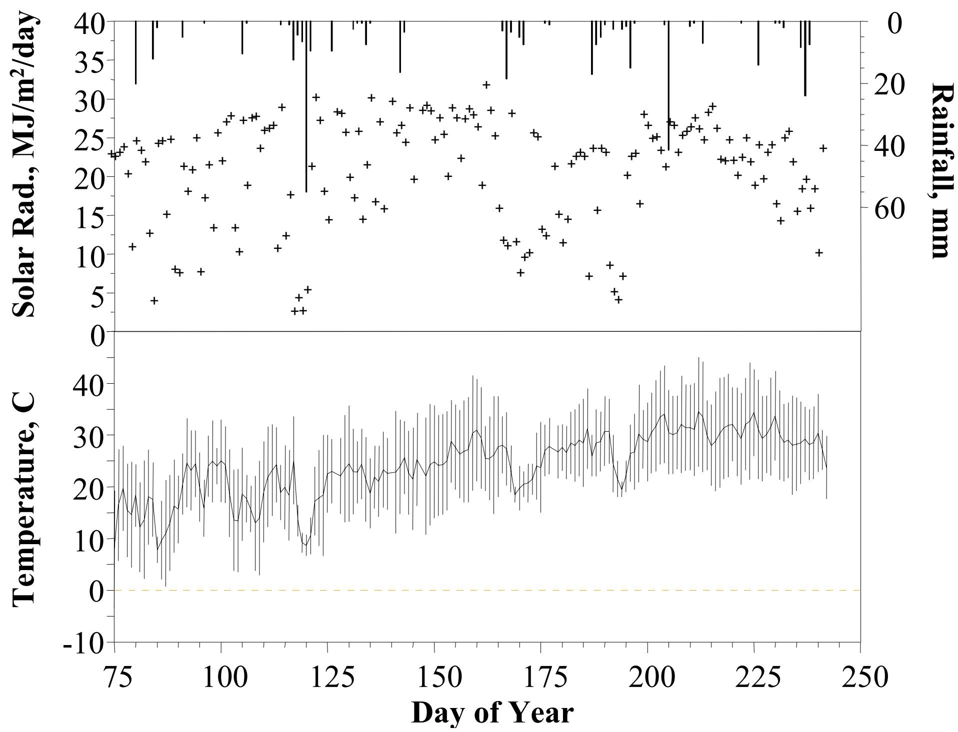

Figure 3. Seasonal weather conditions during 1999 in Florence, SC.

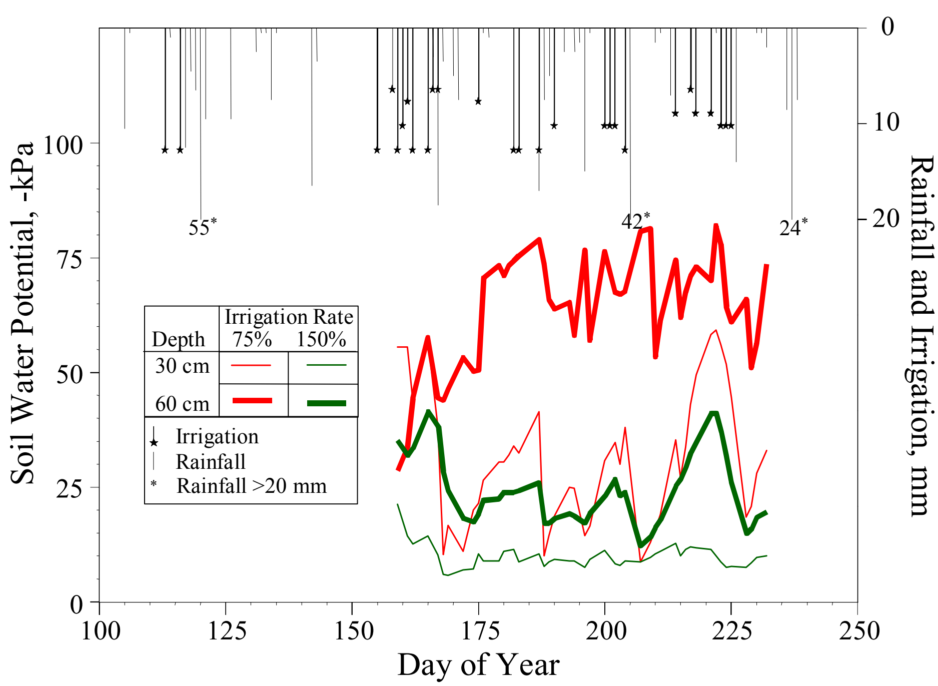

Figure 4. Daily rainfall, irrigation events, and soil water potential values at 30-cm and 60-cm depths for two irrigation rates during 1999 on an experimental site (CP1) with fairly uniform soils in Florence, SC.

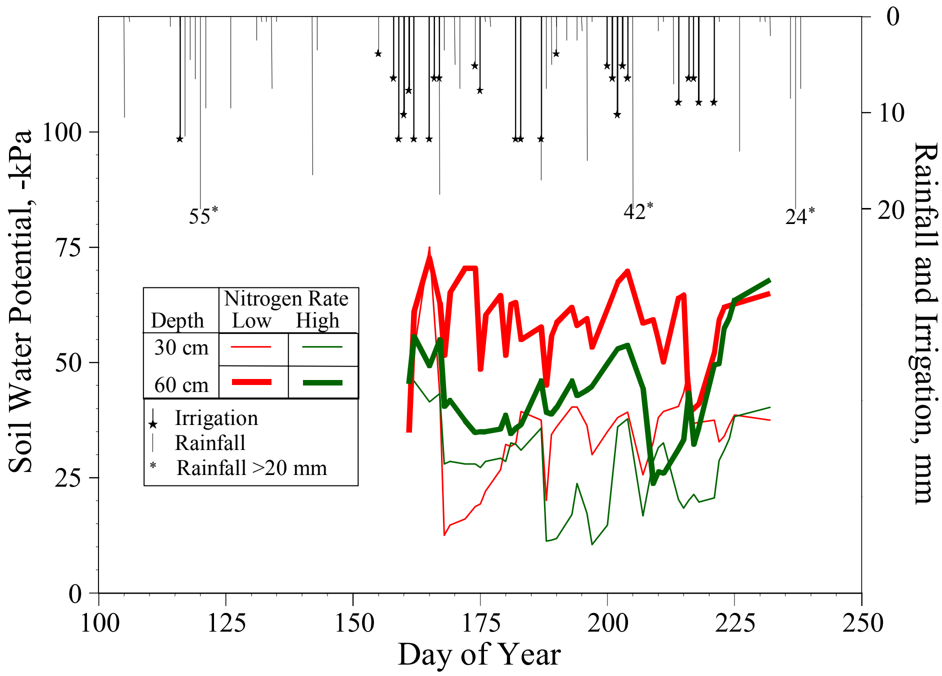

Figure 5. Daily rainfall, irrigation events, and soil water potential values at 30-cm and 60-cm depths for two irrigation rates during 1999 on an experimental site (CP2) with extremely variable soils in Florence, SC

for the 1999 growing season are shown in Figure 3. Seasonal rainfall, irrigation applications, and soil water potential (SWP) values for the 30-cm and 60-cm depths in the 75% and 150% irrigation rates, and 100% N-fertilizer rate on CP1 are shown in Figure 4. For the 150% rate, SWP values were wetter than -15 kPa at the 30-cm depth and wetter than -35 kPa at the 60-cm for most of the season. As expected, soil in the 75% rate was drier but SWP values for the 30-cm depth remained greater than -50 kPa most of the season. Soil at the 60-cm depth was much drier than at the 30-cm depth, with SWP values of about -75 kPa much of the season. The drier soil in the 75% irrigation rate indicates inadequate irrigation amounts and depletion of stored water in the soil profile at the 60-cm depth.

Season rainfall, irrigation applications, and SWP values for the 30-cm and 60-cm depths in the 135 kg/ha and 225 kg/ha N fertilizer rates, both at 100% irrigation rate, on CP2 are shown in Figure 5. SWP values at the 30-cm depth are similar for both N-fertilizer rates and were wetter than -40 kPa most of the season. At the 60-cm depth, SWP values indicated drier soils, with the higher N fertilizer rate being slightly wetter (>-50 kPa) than the low N rate (>-70 kPa). Again, depletion of water stored in the deeper soil depths indicates a slight water deficit. Because tensiometers were installed in several different soil map units in CP2, some of the SWP differences may have resulted from soil water characteristic differences among soil map units.

Daily irrigation events are shown in Figures 4 and 5, and seasonal total irrigation amounts and total water available (including rainfall) for all treatments in

Table 1. Seasonal rainfall and irrigation amounts for CP1 and CP2 during 1999 in Florence, SC.

Irrigation - % Base Rate	Irrigation depth*		Rainfall	Total water	
	CP1	CP2		CP1	CP2
	---------------------------mm ------------------------				
0	0	0	286	286	286
50	---	109	286	---	395
75	214	---	286	500	---
100	---	218	286	---	504
150	429	328	286	715	614

* Additional 4-19 mm irrigation applied to all treatments with N fertilizer

both CP1 and CP2 are reported in Table 1. Irrigation amounts ranged from 109 mm for the 50% irrigation rate in CP1 to 429 mm for the 150% irrigation rate in CP1. Based on the irrigation amounts required for the 150% rate (only rate common to both CP1 and CP2), CP1 required more irrigation than CP2. This was probably caused by differences in soils. However, SWP values for the 150% rate indicated that the soil in CP1 was slightly wetter than in CP2. With the 286 mm seasonal rainfall, the total amount of water available for crop growth ranged from 286 (rainfed, no irrigation) to 715 mm (150% rate in CP 1).

Yields

On CP1, where the soils were fairly uniform, mean corn grain yields increased with irrigation rate ($P \leq 0.05$), ranging from 6.4 Mg/ha (0 rate) to 10.0 Mg/ha (150% rate). There were also significant yield differences for antecedent crop rotation. Corn grain yield for continuous corn (8.0 Mg/ha) was lower than for the corn-soybean rotations (8.6-9.1 Mg/ha). Yields for the 75, 100, and 125% N-fertilizer rates were similar (8.6, 8.8, and 9.1 Mg/ha, receptively), and were significantly greater than the yield for the 50%-base rate (7.9 Mg/ha). Corn grain yield in relation to N-fertilizer rate for the three irrigation regimes is shown in Figure 6.

In CP 2, corn grain yield increased with irrigation ($P \leq 0.05$) for all irrigation rates, with mean grain yields of 6.5, 8.9, 10.1, and 10.7 Mg/ha for 0, 50, 100, and 150% base rate, respectively. When soils were analyzed separately, there was no difference in yield between the 100% and 150% irrigation rates on some soils, but differences among other rates remained. There were also other differences among the 10 soil map units. Yields were significantly greater for the NbA soil than for all other soils except NkA and NoA. The BnA and Dn soils had the lowest grain yields (7.2-7.3 Mg/ha) followed by the NfA, Cx, and GoA soils (8.3, 8.4, and 8.5 Mg/ha,

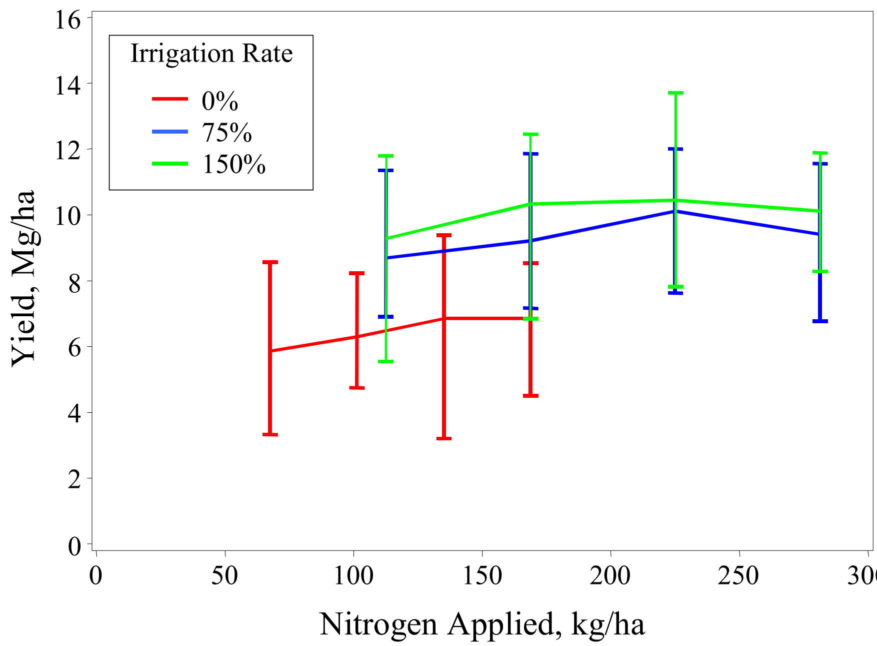

Figure 6. Corn grain yield for three irrigation regimes and four N-fertilizer rates during 1999 on an experimental site (CP1) with a fairly uniform soil in Florence, SC. Yield values are the means of three antecedent crop rotation treatments.

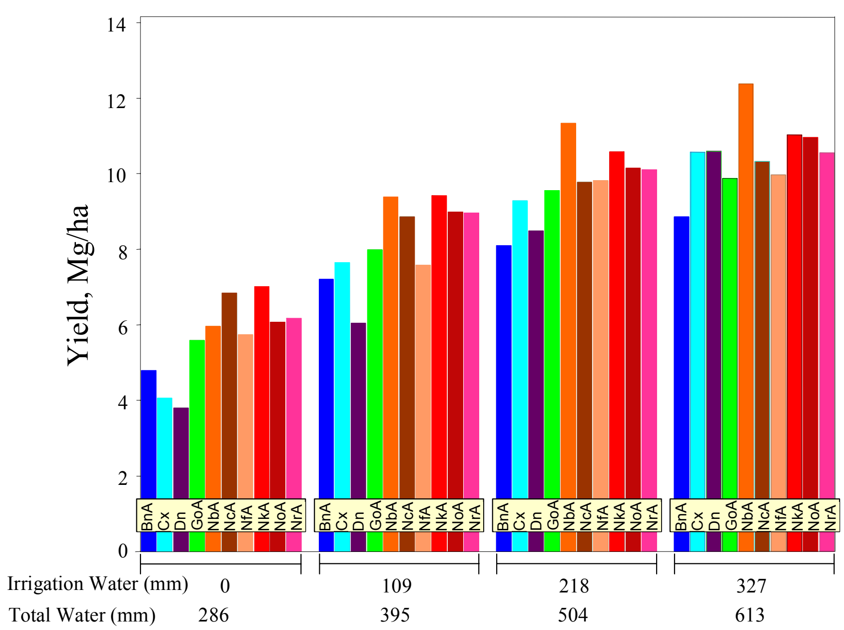

Figure 7. Corn grain yield for four irrigation regimes and ten soil map units (CP2) during 1999 in Florence, SC. Yield values are the means of two N-fertilizer rates.

respectively). There was no difference in corn grain yield for the N-fertilizer rates.

Corn grain yields in relation to irrigation rates for 10 soils (Do and ErA soils were not included because of insufficient observations) are shown in Figure 7.

SUMMARY

Center pivot irrigation systems modified to provide site-specific irrigation and chemical applications were used to apply a range of irrigation and N-fertilizer rates to corn on two sites in 1999. Three irrigation and four N-fertilizer rates were applied at the first site, where the soils were fairly uniform. At the second site, where the soils were extremely variable, four irrigation and two N-fertilizer rates were applied to corn on 12 soil map units. Corn grain yields increased with increased irrigation at both sites. Yields did not increase with N-fertilizer except between the 50% and 75% N-fertilizer rates at the more-uniform soil site. There were significant differences in yield response to irrigation among the various soil map units, with greater yield response on some soils than others. Determination of crop response to variable inputs and soils in combination with economic factors will allow development of site-specific irrigation and fertilizer recommendations for individual management zones.

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