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A SITE-SPECIFIC IRRIGATION SYSTEM FOR THE SOUTHEASTERN USA COASTAL PLAIN

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ABSTRACT

Yield maps from 1985 to present on a highly variable Coastal Plain field increasingly implicate soil water relations as the cause of spatial yield variation. Soils are sandy, often with dense horizons. Together, these factors limit water storage in the root zone, a conclusion reached through experience, observation, and process-level crop modeling. Management of water through irrigation in this region is complicated by the limited soil water storage and the significant chance of rain, which increases the risk of leaching if deficit irrigation is not practiced. However, spatially variable soils mean that even careful management of water, if done uniformly across the field, will still be improperly done on a significant portion of the area. It appears that the only method of addressing water stress on spatially variable fields while minimizing the potential of leaching under wetter areas is by site-specific water management. Therefore, in 1995, two site-specific center pivots were built by adding custom hardware to commercial center pivots. The first machine was used to control water and fertilizer application for a replicated experiment with 144 small plots (9 m radially x 7.5° [10-15 m]), which tested the hardware and software under controlled conditions. The second machine is undergoing modifications at the current time.

INTRODUCTION

The southeastern USA Coastal Plain is roughly the coastal one-third of Virginia to Georgia. It is comprised of nearly level, sandy surface soils and sandy clay subsoils (Pitts, 1974; USDA-SCS, 1986). The landscape contains numerous shallow (<3 m) depressions of varying size and unknown origin. Surface texture within the depressions is generally finer than that outside, where the soils are generally sandy loam or loamy sand, with extensive inclusions of sands. Many soils also have an eluviated E horizon of similar texture to the A, but with very little organic matter (<1%) and high bulk density (up to 1.8 g cm^{-3}). The sandy soils and root-restricting eluviated horizons combine to reduce available water holding capacity (commonly 20 to 40 mm) and thus make nonirrigated crop production a challenge in the area. To increase rooting depth, management practices commonly include subsoiling to a depth of about 0.4 m beneath the crop row to fracture the E horizon.

Coastal Plain climate is warm, humid, and cloudy. Average rainfall is >1000 mm/yr. Most summertime rain occurs during thunderstorms, causing June, July, and August to be the months with greatest rainfall, averaging from 100 to 150 mm/month. However, each month during the growing season has ranged from 20 to 250 mm during the past century. Such variability in rainfall, with the poor water relations described above, means that yield-reducing drought stress frequently occurs in an area that appears to have plentiful rain. Sheridan *et al.* (1979) reported a 50% probability of 22 day droughts during the growing season. Such drought dramatically reduces crop growth and yield.

Spatial patterns in crop growth, particularly during dry years, suggest water management may be critical for managing soil variability in the Coastal Plain (Karlen *et al.* 1990; Sadler *et al.*, 1995a; 1995b). Persistence of relative yield patterns for drought and non-drought years supports this assumption. Difficulties in scheduling irrigation for a center pivot on variable soils had illustrated the problems encountered when attempting to manage soil water under these circumstances (Camp *et al.*, 1988).

In 1991, a team designed a computer-controlled, variable-rate center pivot (see Camp and Sadler, 1994). Two commercial machines were acquired (description below), and modifications were made to achieve this objective. The first machine, used since 1995, was demonstrated under the controlled conditions of a replicated experiment on a reasonably uniform field. The second machine, which will be modified based on experiences with the first, will be the culmination of the project - variable-rate management of water, fertility, and pesticides on a highly variable Coastal Plain soil.

Literature and communication with independent researchers working toward similar goals contributed to the design of the machine. Lyle, W.L. (personal communication, 1992) described a multiple-orifice emitter design that could be individually switched to provide a series of stepwise incremental flow rates. This was part of the Low-Energy Precision Application (LEPA) system. Duke *et al.* (1992) and Fraisse *et al* (1992) switched sprinklers on and off for varying proportions of a base time period, usually 1 min. This design can provide a continuous range of application rates using a single nozzle, where other systems require additional nozzles, manifolds, and switches to achieve additional increments of rate. However, the on/off sprinkler action may be in or out of phase with the start-stop motion of the irrigation tower, impressing additional variability in application depth. This disadvantage is minimized when the wetted radius is larger, the alignment of the irrigation machine is controlled very closely, and the base time period of the sprinkler is small relative to the duration of tower stoppage. Stark *et al.* (1993) used a similar concept with a patented (McCann and Stark, 1993) control system for a variable-rate linear-move system, in which individual conventional sprinklers were controlled by computer. Three sprinkler sizes (¼, ¼ and ½ of full flow) provided ¼, ½, ¾, and full irrigation. This system was installed on a field-scale center pivot, and uniformity of application was reported. Further developments on a linear move system were reported by King *et al.* (1995).

The objective of this presentation is to describe a variable-rate center pivot machine and to illustrate its capabilities to the European precision agriculture audience.

DESCRIPTION OF THE CENTER PIVOT

Commercial machine

The commercial system is described in Camp *et al.* (1996). It will be summarized here. Two small, 3-tower, 137 m commercial center pivots were purchased in 1993 (Valmont

Irrigation, Inc., Valley, NE[1]). In anticipation of increased load, truss design was heavier than normal; otherwise, the unit was conventional. A set of overhead sprinklers and a set of LEPA quad sprinkler heads on drop tubes were installed on both machines, to provide immediate ability to irrigate, albeit uniformly.

Modifications

PLC control system. All electrical output devices (solenoids, pumps, controllers, etc.) were controlled using a programmable logic controller (PLC: GE-Fanuc model 90-30, Charlottesville, VA) mounted on the mobile unit, about 5 m from the pivot point. Expansion units (3/pivot) with analog and digital cards were installed along the truss and connected by cable to the PLC. The PLC had an on-board 80386 PC with software written in Visual Basic (Microsoft Corp., Redmond, WA) to convert a map of control values to on-off settings in the directly-addressable solenoid control registers of the PLC. In order to determine location from the C:A:M:S® (Valmont Irrigation, Inc.) controller, the communication link required between the mobile PC and the stationary C:A:M:S was made with short-range radio-frequency modems (900 MHz, broad-band modems; Comrad Corp., Indianapolis, IN). The on-board PC repeatedly interrogated the C:A:M:S unit to determine the angle of the pivot and other parameters to provide assurance the system was functioning properly, and also exerted some control over the C:A:M:S unit, setting speed and shutting down in emergencies. The position in polar coordinates was found using the angle and the segment position on the truss. (The angle reported was found to be systematically in error, so a correction was determined with surveying techniques and built into the software.) When the location had been determined, the program checked whether a plot boundary had been crossed. If not, the interrogation cycle repeated. When a boundary was crossed, the expected application map was checked, the appropriate table lookup was performed, and the solenoid registers set accordingly.

Water delivery system. The design and modification of the manifolds and sprinklers for the first commercial pivot were done in cooperation with The University of Georgia Coastal Plain Experiment Station, Tifton, GA (Omary *et al.* 1996). The truss was segmented into 13 sections 9.1 m (30 ft) long (see Figure 1). Each section had three parallel, 9.1 m manifolds, each with six industrial spray nozzles at 1.5 m spacing. Water was supplied to each set of three manifolds directly from the boom via 5 cm (2 in) ports, drop pipes, a distribution manifold, and hoses. Each individual manifold had a solenoid valve, pressure regulator, low-pressure drain, and air entry port. The three manifolds and their nozzles were sized to provide 1x, 2x, and 4x a base depth at the position of the section, which depended on distance from the center to account for the greater area subtended per unit angle traveled. Octal combinations of the three manifolds provided 0x, 1x, 2x,...7x the base depth. The 7x depth was designed to be 12.5 mm (0.5 in) at 50% duty cycle on the outer tower. The small size of the unit, 120 m, meant that at 100% duty cycle, a full circle could be irrigated in less than 4 hr, and at a 17% setting, in less than 24 hr.

Distribution uniformity of the water application depth was examined for the worst-case

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[1] Mention of tradenames is for information purposes only. No endorsement implied by USDA-ARS or any cooperator of preference over other equipment that may be suitable for the application.

scenario, in which one element (9.1 m square) was irrigated at a nominal depth of 12.5 mm and was surrounded by elements without irrigation. Distribution was measured using 50 cups spaced 0.3 m apart along a line in the radial direction. In the tangential direction, the 50 cups were staggered so that one line of 25 was beneath a nozzle, and the other line of 25 was between nozzles. Each test was repeated three times. As can be seen in Figure 2, spray carryover and drift caused an area about 3 m on either side of the nominal control zone to be irrigated at depths other than the target. This was expected from indivdual nozzle characteristics. Baffles are being considered to limit the carryover in the radial direction, but it appears that a buffer zone will be needed between elements in the tangential direction. All buffer areas are avoided for plot yield measurements.

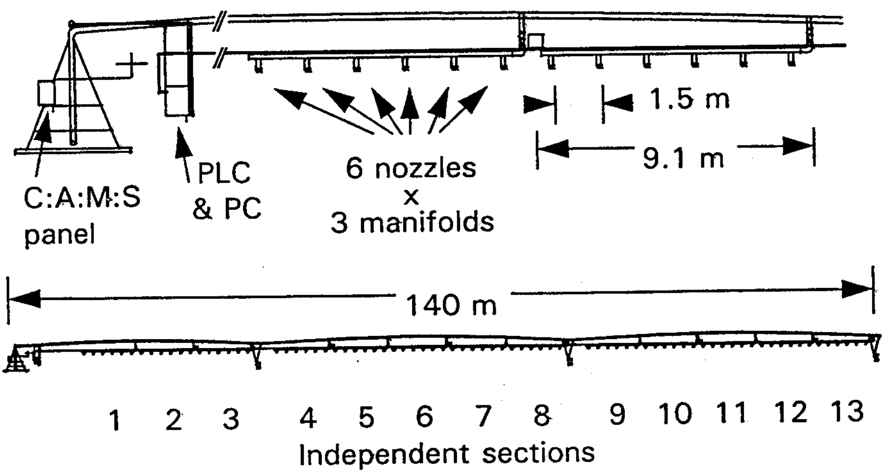

FIGURE 1. Side view of site-specific center pivot and closeup of tripod and example section.

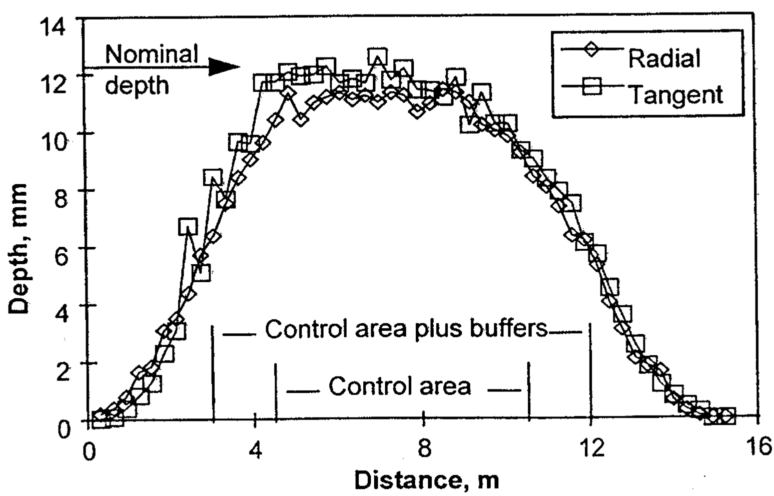

FIGURE 2. Radial and tangential distribution of application depth for a single element surrounded by unirrigated elements. Each point is the mean of three measurements.

Nutrient injection system. Injection of nutrients (Urea-ammonium nitrate, UAN) was accomplished using a 4-head, 24 V DC variable-rate pump (Ozawa Precision Metering Pump, model 40320), check valve, and nurse tank connected to the stationary vertical riser. Since the flow rate of water could vary depending on the spatial application schedule, the amount of fertilizer injected into the water supply pipe was varied proportionately in order to hold the concentration constant. This was done by the PC on board the PLC, which calculated the aggregate flow rate, the required injection rate, and the 0-5 V DC voltage required, and then reported that to the operator. Spatially-variable application of nutrients was done using a minimal, spatially-variable irrigation, but with uniform concentration.

Pesticide application system. A proprietary, ultra-low-volume (130 liter/hectare) pesticide application system was installed on the first pivot in summer 1996. The 13-segment organization and control system were used, although the pesticide system (pump, sprinklers, and nurse tank) was completely separate and used the pivot solely as a ground transport.

Canopy temperature system. The center pivots were rigged with aluminum booms and masts to hold small infrared thermometers for each of the 13 sections. The booms extended about 3 m in front of the leading edge of the manifold, and the masts were designed to adjust 1.5 m above or below the boom, which was at 3 m height. Pivot #1 had one IRT installed per section, with the footprint nominally centered within the 9.1 m section. Pivot #2 had two IRTs per section, with the footprints about 3 m inside the ends of the 9.1 m sections. The IRTs were Exergen Irt/c .3X with 3:1 field of view (~17°) and type K thermocouple leads. The IRTs were read using analog cards on the PLC, and the data were stored on the on-board PC. Figure 3 shows dry, bare soil surface temperature under pivot #2. The cooling trend as the pivot rotated clockwise from straight up (0 degrees) is evident, as are the grassed access roads at 0 and 175 degrees. Circular patterns are attributed to sensor differences from nominal calibrations.

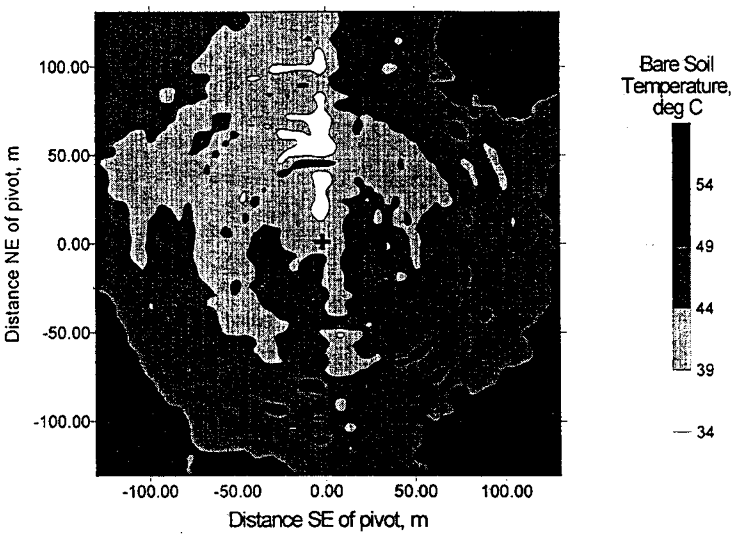

FIGURE 3. Map of dry, bare soil surface temperature, taken from 12:00 to 15:35 local standard time.

Use in replicated plot experiment. The pivot described above was sited on a relatively uniform soil area (USDA-SCS, 1986), chosen specifically for proving the technology under controlled conditions. The primary experimental objectives were to test rotation and irrigation effects on a corn-soybean rotation vs continuous corn under conservation tillage. A secondary objective was to test subsoiling against not doing so, in the possible trade-off of irrigation to manage water rather than subsoiling to increase the rooting depth.

Experimental design. There were 144 treatment plots in total: 4 replications x 3 rotations (corn-corn, corn-soybean, soybean-corn) x 2 tillage (subsoiled, non-subsoiled) x 3 water managements (rainfed, tensiometer, crop stress) x 2 nitrogen (single sidedress, incremental applications). In 1995, both the tensiometer and crop stress treatments were operated based on tensiometers. The individual plots were laid out in a regular 7.5° by 9.1 m (30 ft) pattern, which made the minimum plot length 10 m in section 7 and 15 m in section 13. As seen in Figure 4, the four replicates were sited in the outer annuli, which had the most uniform soil areas. The outer rings were used so that planting and other operations could be done without sharp turns. All operations were done on the circle rather than with straight rows to simplify operations in this experiment.

Fertilization during this experiment was achieved by injecting urea-ammonium-nitrate (UAN 24S) into the system. To prevent spray drift, 38-mm layflat hose was placed around the 2x nozzles and extended to the ground. The 2x nozzles provided 3.6 mm of irrigation at 50% duty cycle and 1.8 mm at 100%.

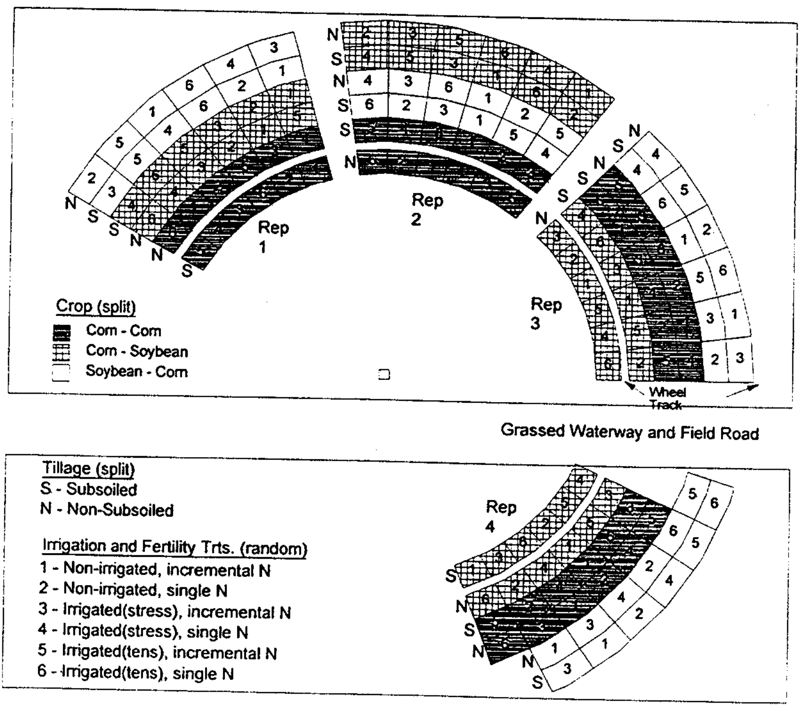

FIGURE 4. Plot plan for replicated field experiment used to test site-specific center pivot under controlled conditions. (After Sadler *et al.*, 1996).

Conclusions

Since this description is of the design and testing of an apparatus,.conclusions must be limited to the performance thereof. The site-specific center pivot evolved from the basic commercial machine in March 1995 to a functioning, proven technology by August. Control software was primitive and fragile initially, but similarly evolved through modification and experience such that operation was possible via the remote C:A:M:S unit by the end of the summer. The second year's experiences were acceptable. Prior measurements of system uniformity had demonstrated acceptable distribution within control elements as well as expected border effects between elements with contrasting application depths (Omary *et al.*, 1996). Further tests confirmed this as fact. No evidence was seen that uniformity or border width had changed. Surface redistribution had been a concern during design, because of the small wetted radius of the sprinkler, but even the collection into layflat hose for fertilization did not cause excessive local ponding and runoff. Preliminary tests with infrared thermometers to map spatial variation suggest that methods must be developed to account for temporal skew, unit-specific calibration, and solar irradiance.

Plans are to complete outfitting the second pivot with variable rate irrigation, fertilization, and low-volume pesticide variable-rate application equipment based on experiences gained with the first pivot. The software will be modified to accommodate irregular soil unit boundaries, using map units as the primary control factor initially, but general enough to handle any spatial control factor.

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