MODIFIED CENTER PIVOT SYSTEM FOR PRECISION MANAGEMENT OF WATER AND NUTRIENTS

C. R. Camp, E. J. Sadler, D. E. Evans, L. J. Usrey, M. Omary

ABSTRACT. *Spatial yields since 1985 in a corn-wheat-soybean rotation at Florence, S.C., show little correlation of yield data with expected yields for soil map units. Research suggests that spatial yield variability for the southeastern Coastal Plain may be caused primarily by water relations. This causes difficulties in scheduling irrigation for conventional center pivot irrigation systems, which are not capable of applying variable depths of water to small areas of variation within the total system. Thus, the objectives of this work were to design and construct a site-specific center pivot irrigation system that could independently apply variable rates of water and chemicals to 100-m² areas within the irrigation system. A commercial center pivot system was modified by adding three 9.1-m manifolds in each of 13 segments along the truss. Nozzles were spaced 1.5 m apart along each manifold, and both manifolds and nozzles were sized to provide 1x, 2x, and 4x nominal application rate at a given tower speed. All combinations of the three manifolds provided up to 7x nominal depth, which was 12.7 mm, in 1.8-mm increments when the outer tower traveled at 50% of full speed. A programmable, computer-controlled management system was installed near the pivot on the moving portion of the center pivot system. This controller obtained the position from the center pivot controller via a radio frequency modem and switched on the appropriate valves to obtain the application rate for a specific area. During 1995 and 1996, the system applied water and N fertilizer in a fixed-boundary field experiment. Measurements and observations of water and N application uniformities were acceptable; however, more extensive evaluation will be required before definitive conclusions can be reached regarding N application. Surface temperatures measured with an integral infrared thermometer system produced encouraging results that may be useful in management of water and nutrients. Using experience gained with this system, a second commercial center pivot system is being modified for site-specific water, nutrient, and pesticide management on a field with soil variation (irregular boundaries) typical of the Coastal Plain.*

Keywords. *Site-specific management, Soil variability Nitrogen fertilizer, Application uniformity.*

The coarse-textured soils of the southeastern Coastal Plain often exhibit greater variability within comparable field sizes than do soils of other regions. The region is comprised of nearly level, sandy surface soils with a sandy clay subsoil (Pitts, 1974; USDA-SCS, 1986). The landscape includes numerous shallow depressions of variable size. Within the depressions, surface texture is generally finer than that outside, where the soils are sandy loam or loamy sand with extensive inclusions of sands. Many of the soils have compacted layers, which restrict root growth to very shallow depths (0.30-0.45 m). The low water-holding capacity and root-restricting layers that limit soil volume available for water removal by plants combine to reduce plant-available water storage. Rooting depth is often increased by the current management practice of subsoiling to a depth of about 0.4 m (directly under each row) annually. All of these factors, in various combinations, are responsible for the soil spatial variability in the region.

The climate is humid, subtropical, and has a mean frost-free growing season of about 250 days. Average annual rainfall in Florence, South Carolina, is 1100 mm/yr and normally exceeds evapotranspiration, but rainfall is often poorly distributed during the year and growing season. Most growing-season rainfall results from afternoon convective thunderstorms, which cause both significant runoff and high spatial variability in rainfall. Mean monthly rainfall during the growing season is about 125 mm/mon, but can vary from lows of about 20 mm to highs of about 250 mm. This high rainfall variability, in combination with the effect of many soil variables on water and nutrient availability, creates a complex management scenario, which is generally ignored in current cropping management systems. Consequently, yield-reducing stress occurs frequently in a region that appears to have sufficient rainfall. Sheridan et al. (1979) reported a 50% probability that 22 consecutive days with 6 mm or less rainfall would occur during the growing season. Drought of this length reduces growth and yield of most crops on these soils.

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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., 1995a). Results from an ongoing study that investigated crop yield for 14 crops during an 11-year period in the southeastern Coastal Plain found no useful correlation between yield and several patterns of variation, including soil classification and fertility. Because of the combined effect of climate and soil variability and the uniform application rates of most center pivot irrigation systems, optimum management of irrigation and nutrients applied via an irrigation system is often not possible, even for relatively small systems (Camp et al., 1988).

Consequently, in 1991 a Florence ARS team developed specifications for a computer-controlled, variable-rate center pivot system (Camp and Sadler, 1994). Other research groups have worked independently toward similar goals. Lyle and Bordovsky (1981, 1983) used three individually controlled manifolds, each delivering discrete but different flow rates, in various combinations to achieve a series of discrete incremental application rates. This system was installed on a Low Energy Precision Application (LEPA) irrigation system to provide a range of application rates that were uniform for all segments along the truss. Roth and Gardner (1989) used three lines on a linear irrigation system to apply five different water depths to a series of plots, but the depth distribution among plots was fixed, and independent control of application depth either along the system length or travel direction was not possible. Duke et al. (1992) and Fraisse et al. (1992) modified a linear irrigation system to provide variable water and nutrient applications using pulsed sprinklers mounted on discrete manifolds (21 m in length) along the truss. The application rate was determined by the duty cycle of solenoid valves that supplied water to each manifold. The valves were pulsed by switching the solenoids on and off for varying portions of a base time period, usually 1 min. The advantage of the pulsed-manifold/sprinkler system is that only one sprinkler is needed, where other designs require multiple sprinklers, nozzles, and manifolds. The disadvantages of this system are the interactions among pulse rate, sprinkler diameter, and the start/stop movement of towers. Stark et al. (1993) patented a similar control system (McCann and Stark, 1993) to provide site-specific application of water and chemicals for both linear and center pivot irrigation systems. This system consisted of conventional sprinklers individually controlled by a microprocessor and used three sprinkler sizes (1/4, 1/4, and 1/2 of full flow) to provide 1/4, 1/2, 3/4, and full irrigation rates. The computer also controlled irrigation system travel speed and chemical injection pump flow rate, both based on a spatially referenced mapping system. King et al. (1995) reported further developments on a 100-m linear system and a seven-tower, 210-m center pivot system using two sprinklers delivering one-third and two-thirds of a target application depth.

The objectives of this article are to describe the variable-rate center pivot irrigation system developed at Florence, to report results of its use in a replicated experiment during 1995-1996, and to illustrate its capabilities for application in site-specific management of water and chemicals.

MATERIALS AND METHODS

DESIGN CONSIDERATIONS

The basic requirement of the irrigation system was to apply water and chemicals to discrete areas based on soil, crop, and weather data stored in a database or measured directly by sensors. Both maximum water application uniformity and minimum water or chemical effect on adjacent areas were desired. Sufficient water application depth was needed to replace crop evapotranspiration (ET) while the system moved at moderate operating speeds (about 50% of maximum speed). Seven discrete fractions of the design application rate were selected as a first approximation of true variable-rate irrigation. For design purposes, a control element area of 100 m^2 was selected, which relates to a length along the truss of about 9.1 m and an appropriate angular sector provided by a minimum travel distance of about 11 m. Spatial location of each element was to be determined by system operating parameters (angle of rotation, location along the truss). Target application rates were to be determined from digitized maps in computer files. Appropriate application depths were to be selected by algorithms based on one or a combination of several parameters, including soil and crop properties, historical yields, and real-time sensors (e.g., soil water, canopy temperature, etc.). The variable-rate application system would be achieved by modification of commercial center pivot irrigation systems that were equipped with computer-aided management systems.

Sprinkler application rates must increase linearly with distance from the center. This range of application rates must be incorporated into the design of any variable-rate water and chemical application system. The desired range of irrigation application depths per revolution was 0 to 12.5 mm at a moderate tower speed. In commercial center pivot systems, the range of tower speeds is obtained by changes in the duty cycle of the end tower drive motor (range of 0 to 100%). For this system, the speed selected was half of maximum speed (cycle timer = 50%). The cycle base period is selectable (e.g., 30 or 60 s), which, in connection with the cycle timer, determines the actual on/off times for the end tower. The step-wise movement of the truss has an undesirable effect on water and chemical application uniformity because the sprinkler moves at a constant velocity for part of the cycle but otherwise remains stationary. Generally, the larger the sprinkler wetted diameter, the better the application uniformity for the step-wise movement and tower misalignment of commercial center pivot systems. Unfortunately, both the relatively short manifold length (9.1 m) of this modified system and the requirement to confine water and/or chemicals to the intended application area require smaller sprinkler wetted diameters, which severely limit the potential selection of acceptable sprinklers, especially for locations nearer the outer end. The tower drive system was not modified at this time to provide continuous but variable-speed movement because of added system complexity and cost, although this could improve application uniformity.

Another concern was the magnitude of error in position determination when the angular position of the truss (measured at the pivot) and sprinkler location along the truss are used to determine locations within the system. Truss misalignment at each tower (unknown deviation from straight line) can contribute error to this position determination. For small systems such as the one used here, this error is smaller than it is for large systems with 10-12 towers, where a bow-shaped truss alignment would cause accumulated rather than offset errors. The truss alignment system was not modified, but it was adjusted to provide minimum misalignment error.

SYSTEM MODIFICATION

Two small, three-span, commercial center pivots were purchased in 1993 (Valmont Industries, Inc., Valley, Nebr.). With a total length of 137 m, each provided an irrigated area of 5.8 ha. The systems were standard commercial systems except for two specifications: oversized truss rods to increase the truss load capacity, and oversized ports in the system pipe to supply water to individual manifold segments. Both systems also included computer management control systems that could be programmed and controlled from a remote base station. To allow immediate irrigation capability, two sprinkler systems were provided with each system: overhead spray, and LEPA Quad-Spray heads on drop tubes. These sprinkler systems, not used for the variable rate application system, remain on the center pivot systems.

The variable-rate water application system was designed, constructed, and installed on Center Pivot 1 (CP1) in cooperation with Coastal Plain Experiment Station, University of Georgia, Tifton, Ga. The center pivot length was divided into 13 segments, each 9.1 m long, starting with the outer tower (see fig. 1). (A small section of the truss (10.7 m) near the pivot was not modified.) Each segment had three parallel, 9.1-m manifolds, each with six industrial spray nozzles spaced 1.5 m apart, and all were 3 m above the ground surface. Water was supplied to each set of three manifolds (one segment) from the system pipe via 5-cm-diameter ports, distribution manifolds, and drop hoses. Each manifold had a solenoid valve to control flow, a pressure regulator, a vacuum breaker, and a low pressure drain. The last two items facilitated rapid evacuation of the manifold, which caused application of this water at the zone boundary rather than dripping erratically inside adjacent zones. The three manifolds and their unique sets of nozzles were sized to provide 1x, 2x, and 4x of a base application depth at the location of that specific segment, which meant that actual flow rates of the nozzles increased with distance from the center to account for the increased area irrigated per unit angle traveled. All combinations of the three manifolds provided 0x, 1x, 2x, 3x, . . . 7x the base depth. The 7x depth was designed for 12.7 mm when the outer tower was operated at 50% duty cycle. Additional details regarding construction, evaluation, and operation of this variable-rate application system were reported by Omary et al. (1997). The small size of these center pivot systems, 137 m, allows the system to travel the full circle in about four hours at 100% duty cycle. When drift is excessive or of special concern, the application system can be converted to a LEPA-type bubbler by fastening flexible tubes around each nozzle, which delivers water near the ground surface, depending upon tubing length.

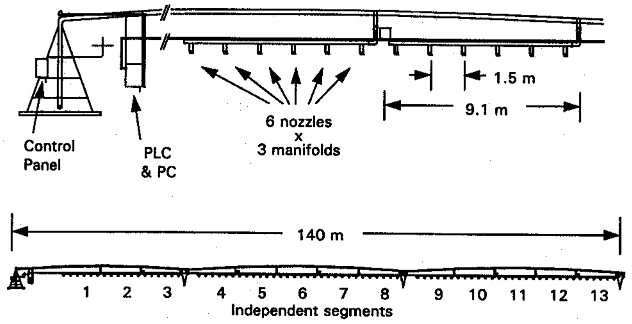

Figure 1–Schematic diagram of modified center pivot irrigation system showing side view and detail of communication hardware and two segments along the truss. The center pivot control panel was a standard, commercial unit while the PLC-PC control system was part of the modification.

CONTROL SYSTEM

The variable-rate application system was under the overall control of an 80386 PC (Horner Electric, Indianapolis, Ind.) with hard disk 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 about 5 m from the pivot, from which it controlled all manifold solenoids. Angular location of the truss was determined from the C:A:M:S™ (Valmont Industries, Inc., Valley, Nebr.) management system via a communication link between the mobile PC and the stationary management system. This was achieved with short-range, radio-frequency modems (900 MHZ, spread-spectrum modems; Comrad Corp., Indianapolis, Ind.). A schematic diagram of various communication links is shown in figure 2. Power for the computer and PLC system was provided by a 480-240 V transformer. Power for the solenoid control circuit was provided by 120-24 V transformers.

Software was written in Visual Basic for DOS (Microsoft Corp., Redmond, Wash.) to convert a set of control values to on-off settings in the directly addressable solenoid control registers of the PLC. The on-board PC repeatedly interrogated the stationary computer management system to determine the angular position of the first span and other parameters to provide assurance of proper operation. From the angular position and the fixed radius of each segment along the truss, the segment location, expressed in polar coordinates, was established for that time. The control program checked each segment

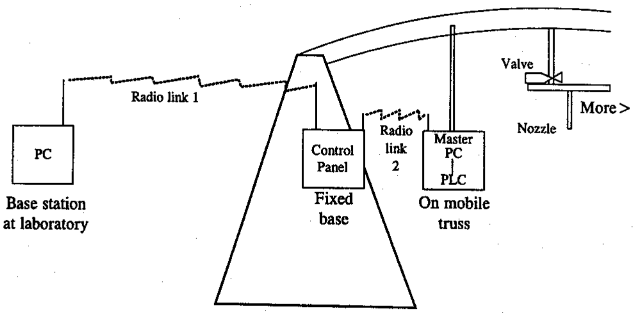

Figure 2–Schematic diagram of system communication links for a site-specific, variable-rate center pivot irrigation system. The center pivot control panel was a standard, commercial unit while the PLC-PC control system was part of the modification.

to see whether a zone boundary had been crossed. If not, the interrogation cycles continued until a zone boundary was crossed by one or more segments, and a change was needed. When a zone boundary was crossed, the appropriate table lookup was performed, and the solenoid registers were set accordingly. The software also determines the correct system speed from the table and sets the appropriate value in the stationary management system. The software also includes a routine, based on position measurements, to correct consistent errors in truss angular position reported by the stationary management system. If one of several system variables (pressure, flow rate, position, voltage, etc.) was reported as out of the specified range, the PLC controller closed all solenoid valves and stopped the center pivot drive system. The problem was recorded to a log file for user information. A diagram showing the control logic of the software is included in figure 3.

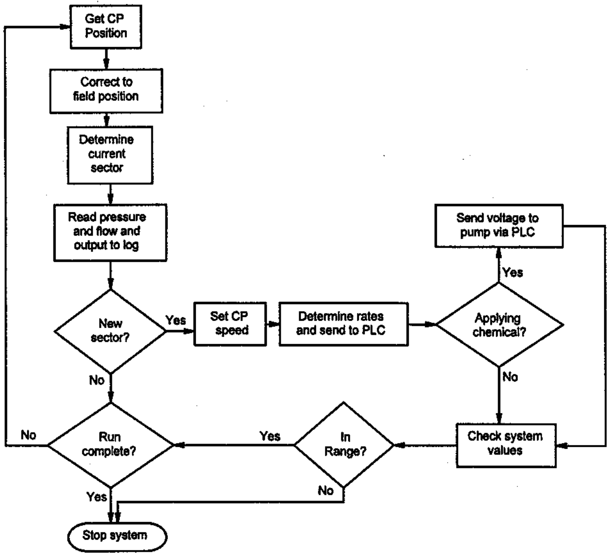

Figure 3–Diagram of control program logic for management of a variable-rate, site-specific irrigation system for application of water and nutrients.

NITROGEN APPLICATION

The nutrient injection system designed and installed on the modified center pivot system is based on the principle of maintaining a constant nutrient concentration in the water supply line. Consequently, variable nutrient application amounts can be applied to each segment by varying the water application depth. To achieve constant nutrient concentration in a system where the water flow rate varies frequently with the number of solenoids switched on at any time, the nutrient injection rate must also vary with water flow rate. 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 was located at the pivot center and injected the nitrogen fertilizer (N) solution (stored in an adjacent nutrient storage tank) into the pivot water supply pipe. Pump injection rate was varied by the number of heads used and the pump speed, which was controlled by adjusting the 0 to 5 VDC signal sent to the pump controller. To keep the nutrient application rate proportional to the water flow rate, the on-board PC calculated the water flow rate, calculated the required nutrient injection rate, computed the 0 to 5 DC voltage setting required to provide the required injection rate, and reported it to the operator. This nutrient injection system was used to apply all sidedress N [urea ammonium nitrate (UAN) 24S] for corn during the 1995 and 1996 growing seasons. The operation was monitored and controlled manually, which required the operator to manually input values to a CR7 data logger/controller (Campbell Scientific Inc., Logan, Utah). In the future, the 0 to 5 VDC value will be communicated directly to the pump controller using the PLC control system and on-board computer. The spatially variable nutrient applications in 1995 and 1996 were accomplished using a minimum-depth, spatially variable water application. Independent spatial application of water and nutrients using this multiple-manifold application system would require control of multiple injection points, at least one for each segment. Control of such a system would be complex, but not particularly difficult; however, the requirement for multiple pumps and distributed nutrient storage made this option too costly and generally not feasible at this time.

A preliminary evaluation of spatial uniformity of nitrate concentration in irrigation application was conducted during 1995. Samples were collected by placing a 500 mL container directly under randomly selected (both in space and time after pressurizing the manifold) nozzles with the center pivot irrigation system in normal operation, while applying UAN 24S to corn. The total discharge from each nozzle was collected for the time required to fill the container. Nitrate concentration of the collected solution was analyzed using a specific-ion electrode (Orion electrode model 93-07, Boston, Mass.). While the UAN solution included other forms of nitrogen, analysis for nitrate was used for comparing concentrations among spatially variable samples.

PUMPING PLANT

Because water application rates in this system can change frequently, the system flow rate varied almost continuously, which imposes unusual requirements on the pumping plant. This pumping plant was designed and constructed about two years before the center pivot irrigation systems were purchased, in anticipation of needs for variable application rates. It also supplies water to other irrigation systems at the location, ranging from drip to high-volume guns. A lined reservoir (about 7600 m^3 capacity), constructed to exclude runoff water, was filled by a float-controlled vertical-shaft turbine pump delivering 1500 L/min open discharge from a well 128 m deep. Water was pumped from the reservoir into the pressurized supply pipe via five pumps, the number in operation depending upon the water flow rate required. The system control pressure was 275 kPa and the pumping system flow rate varied from 0 to 3000 L/min. A PLC-based control system measured water pressure in the supply line and, based on a table of values, switched on the appropriate combination of pumps to maintain the desired pressure. For more precise control of flow rates, especially those between the discrete values provided by the various pump combinations, a pressure-relief valve discharged excess water (normally very small volume) into the reservoir when pressure exceeded the control value. Water was supplied at variable flow rates but at constant pressure via an underground pipe to all irrigation systems, including both center pivot systems.

OPERATION IN A REPLICATED FIELD EXPERIMENT

The modified center pivot system (CP1) was sited on a relatively uniform soil area. Because of the relatively good soil uniformity, a traditional field experiment with fixed plot boundaries was selected for fine-tuning the technology under more controlled conditions than the highly variable soil conditions where CP2 was sited. The objectives of the experiment were to test crop rotation, irrigation, and subsoiling effects on a corn-soybean rotation and on continuous corn, both with conservation tillage. Subsoiling and not subsoiling were tested to see whether managing water via irrigation would offset the need to increase rooting depth through subsoiling because both practices are energy intensive and add significant operating costs.

There were three rotations (corn-corn, corn-soybean, and soybean-corn), two tillage practices (subsoiled and not subsoiled), three water managements (rainfed, tensiometer-controlled and crop-stress-controlled irrigation), two nitrogen regimes (single sidedress and multiple sidedress), and four replications, which provided a total of 144 plots. 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. 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 15 m in segment 13. As shown in figure 4, the experimental plots were sited on the outer six of 13 segments of the center pivot system, on the most uniform soil areas. The outer segments were used so that planting and other field operations could be performed easily. Each of the four replicates were located in angular sectors of the circle (fig. 4).

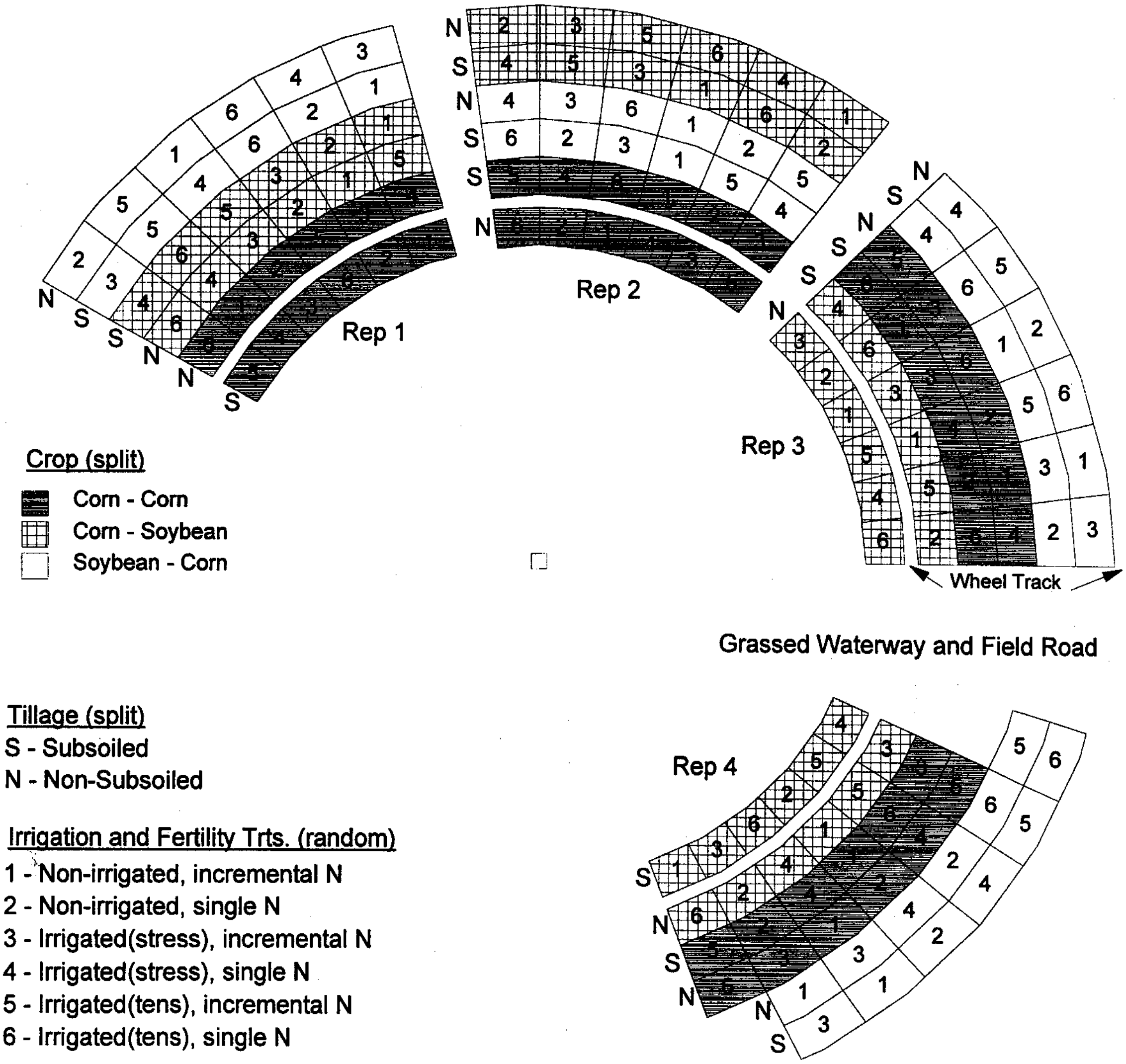

Figure 4–Diagram of field experiment where water and nitrogen fertilizer were applied via a site-specific center pivot irrigation system, showing segments 8-13 (after Sadler et al., 1996).

APPLICATION UNIFORMITY

Water distribution uniformity was measured for a single element (9.1 × 9.1 m) to determine a worst-case value when a target rate of 12.7 mm was applied and all adjacent elements had no irrigation. Water was collected in 50 cups spaced 0.30 m apart on the soil surface along a system radius. Water was also collected in 50 cups placed along the travel pathway (tangential to the circle), alternatively in either of two lines, one under a nozzle and one midway between nozzles, so that they were spaced 0.60 m apart within each line. Water mass in each cup was determined with a balance and the depth calculated from cup diameter. For the tangential test, the manifolds were switched on when the manifolds reached the cup at 3.0 m and switched off when it reached the cup at 12.1 m, providing an on-cycle travel distance of 9.1 m. Each test was repeated three times. Uniformity coefficient (UC), as defined by Christiansen (1942), was calculated for each test using the measured water depths for appropriate zones.

CANOPY TEMPERATURE MEASUREMENT

Aluminum masts and booms were installed on both center pivot systems to mount small infrared thermometers (IRT) for each of the 13 segments. The booms extended about 3 m in front of the manifolds, and the masts allowed adjustment of the IRTs 1.5 m above or below the boom, which was at the manifold height (3 m). On CP1, one IRT was installed for each segment, with the measurement footprint nominally centered within the 9.1-m segment (IRT axis about 45° relative both to the truss axis and downward from horizontal). Center Pivot 2 had two IRTs per segment, with measurement footprints about 3 m inside the ends of the 9.1-m segments. The IRTs were Exergen Irt/c .3X with 3:1 field of view (~17°) and type K thermocouple leads (Exergen Corp., Newton, Mass.). IRT values were measured using analog thermocouple cards on the PLC system and stored on the PLC PC. Individual temperature offsets for each IRT, obtained from a black-body standard (Everest Interscience, Tustin, Calif.), were used to correct IRT measurements.

RESULTS AND DISCUSSION

The system (CP1) was changed from a commercial center pivot irrigation system to a site-specific center pivot irrigation system by installation of the three-manifold, multiple-segment water application system, the PLC control system, and control software. The control software evolved during the 1995 growing season through experience and modification so that by the end of the season, the system operated unattended, except for monitoring via the remote C:A:M:S™ base station. Improvements in radio communication reliability between the moving and stationary components during the 1996 growing season made system operation even more reliable. Acceptable distribution uniformity within control elements and expected border effects between elements with different application depths had been measured previously (Omary et al., 1997). Observations during the 1995 and 1996 seasons presented no evidence that the border width was different from that measured previously. Water ponding and surface redistribution had been a concern during design, because of the relatively high instantaneous application rates caused by the small wetted diameter of the industrial spray nozzle. Even collection of nozzle discharge into a 37-mm-diameter flexible hose during nutrient application did not cause excessive local ponding and runoff.

Water distribution depths (mean of three tests) along a radius under a single segment operating alone are shown in figure 5. As expected from individual nozzle tests (Omary et al., 1997), the spray pattern and drift caused an area about 3 m on either side of the segment length (9.1 m) to be irrigated at depths less than the target depth of 12.7 mm. As can be seen in figure 5, water depths were more uniform within the control zone (center 6.1 m of segment) and much closer to the target depth. Uniformity coefficients for the control zone ranged from 89.0 to 90.8 for the three tests. Considerable variance among the three tests, caused primarily by wind velocity and direction

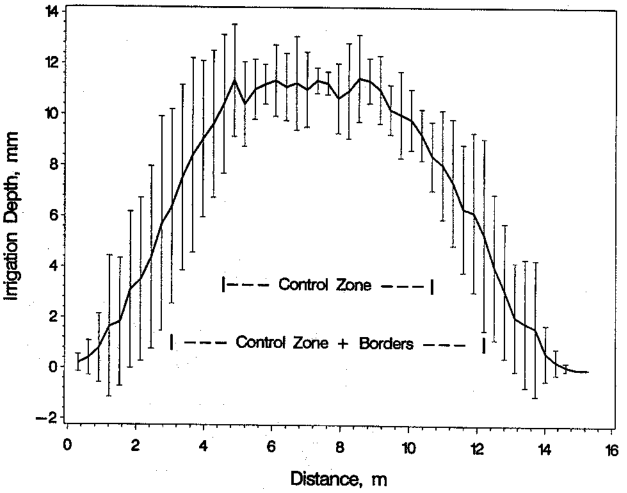

Figure 5–Water depth distribution along a system radius for segment 12 with three 9.1-m manifolds operating and cycle timer at 50% (0.7x, or 12.7-mm target rate). Each data point is mean of three measurements, with error bars indicating one standard deviation.

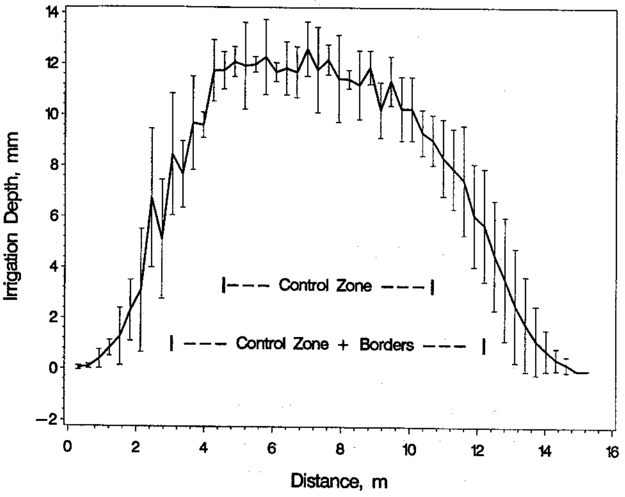

Figure 6–Water depth distribution along a system tangent (direction of travel) for segment 12 with three 9.1-m manifolds operating and cycle timer at 50% (0.7x or 12.7-mm target rate). Each data point is mean of three measurements, with error bars indicating one standard deviation.

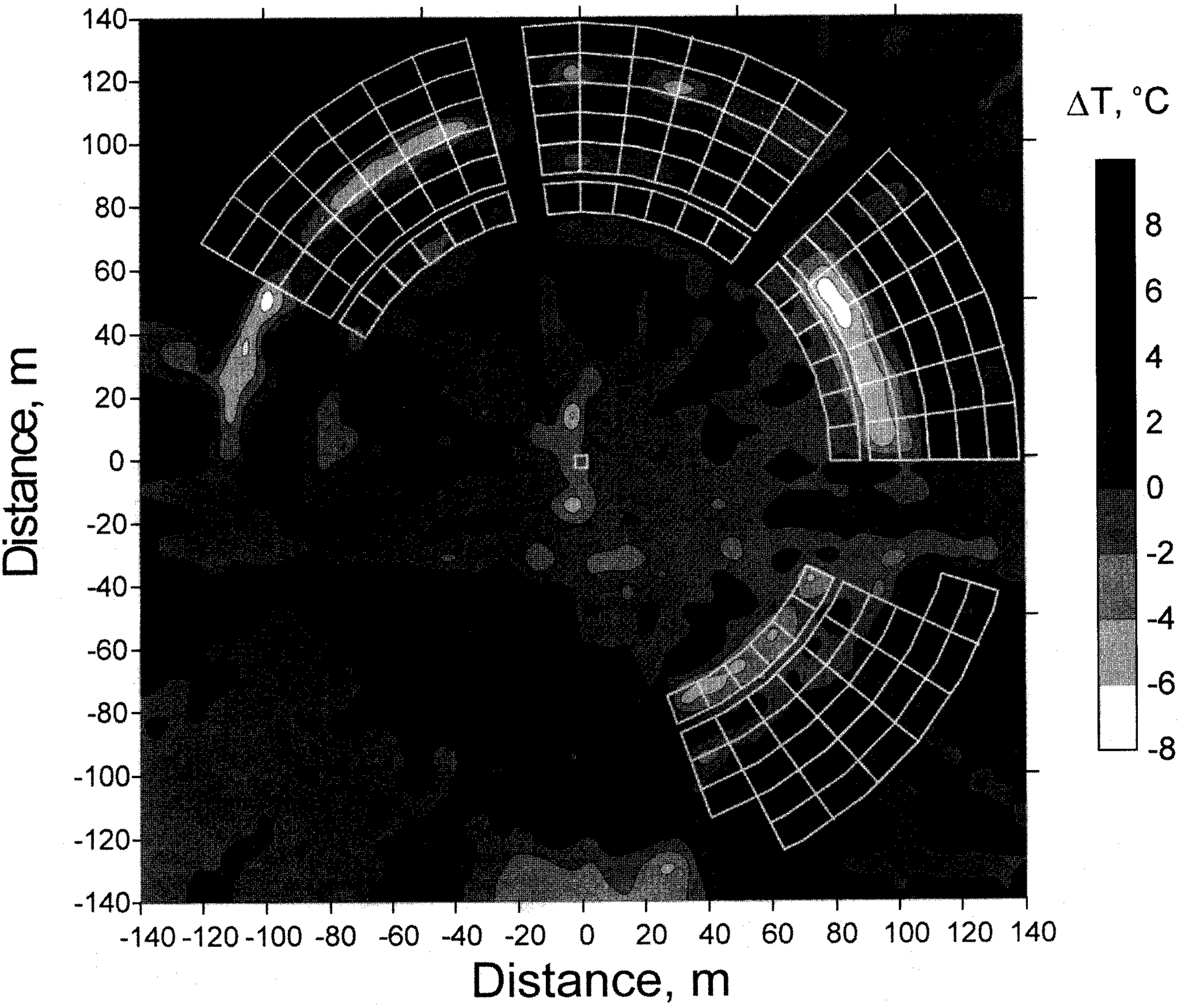

Figure 7–Map of difference between surface temperature and mean of 13 surface temperatures, all from infrared thermometers, for Center Pivot 1 taken from 11:45 to 15:09 local standard time. Replicated field experiment diagram is superimposed on the map. Surface cover is variously grass, residue, or corn (~20-cm height) growing in residue. Thermal map was produced by kriging about 525 observations (~0.7° increments) of 13 readings (9.1 m increments radially).

variations, is reflected by the standard deviation bars (fig. 5). To simulate the effect of having segments on either side irrigating at the same rate, appropriate measured water depths were added to those for this segment. The mean UC values for three tests were essentially equal (91.8-92.2) for zone widths of 6.1, 9.1, and 15.2 m, which correspond to the control zone, control zone plus borders, and full measurement area, respectively. This indicates good uniformity for the entire width when all segments are applying the same depth.

Water distribution depths (mean of three tests) along a line tangential to the circle (direction of travel) under a single segment operating alone are shown in figure 6. The variance was greater than that for the radial case, especially at one end of the zone, as indicated by the standard deviation bars. However, uniformity within the control zone (9.1 m) was similar to that for the radial case. Uniformity coefficient values for the control zone in the tangential case ranged from 89.3 to 92.0 for the three tests.

Sidedress nitrogen applications were made using the 2x manifold, which delivered 3.6 mm of water at 50% duty cycle and 1.8 mm at 100%. Nitrate concentration of the 10 samples collected in 1995 during each of two dates were 244 and 270 mg/L, respectively, with standard deviation values of 17.8 and 13.6 mg/L. These values indicate relatively uniform nitrate concentrations among the nozzles sampled, both in space and time after manifold pressurization. Further evaluation will be necessary before definitive conclusions can be reached regarding this nutrient application system.

A map of surface temperature measurements for a conservation tillage experiment under CP1 during spring 1997 is shown in figure 7. The thermal map was produced using the difference between measured and mean of all 13 IRT temperatures and by kriging about 525 observations (~ 0.7° increments) of 13 readings (9.1-m increments radially). Some circular cropping patterns are evident, but some of the circular patterns may be caused by sensor

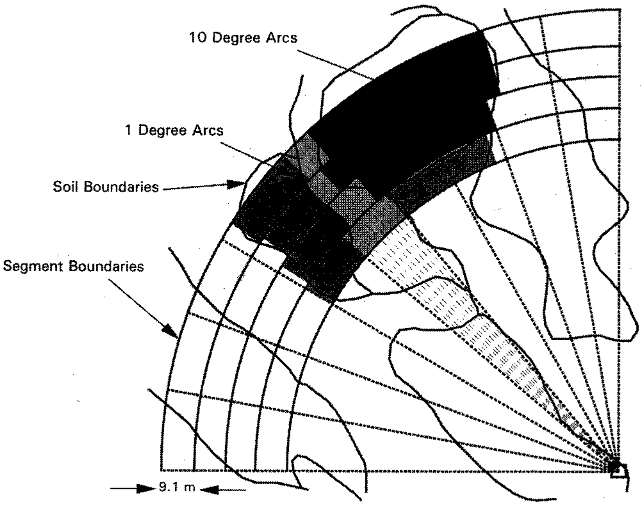

Figure 8–Schematic diagram illustrating possible implementation of control algorithms to approximate irregular soil mapping unit boundaries.

differences from normal calibration. Following refinement of the sensor system and improved data analysis techniques, the IRT system may be useful in determining crop stress and need for irrigation.

Center Pivot 2, sited on highly variable soils typical of many southeastern Coastal Plain fields, is being modified based on experiences gained with CP1 and on improved technology. A fully functional CP2 will represent full implementation of variable-rate management of water, nutrients, and pesticides for small areas of variation with irregular boundaries, which reflect the conditions found in a typical, highly variable Coastal Plain field.

The management software will also be modified to approximate irregular soil unit boundaries with a series of fixed-boundary areas of variable width (angular direction), and to optimize water and chemical applications for each segment in relation to the location of each soil unit (fig. 8). Sensors to provide real-time or near real-time feedback of crop conditions may be used to improve crop management and to detect dynamic crop variation during the season.

SUMMARY AND CONCLUSIONS

Modifications to a commercial center pivot irrigation system produced a system that provides site-specific, variable-rate application of water and nutrients. The system has 13 segments, each 9.1 m in length, along the truss, which allow variable application rates of water and nutrients to control areas of about 100-m^2 area, the exact size depending upon the segment position on the truss and its travel distance per unit angle of rotation. Seven discrete depths can be applied independently within each segment. A programmable, computer-controlled management system obtains positional and other information from the center pivot control system via a radio frequency modem and opens the appropriate valves to obtain application rates for specific areas. Water and nitrogen applications to a fixed-boundary field experiment were successfully accomplished during 1995 and 1996. Observations and measurement of water and N application uniformities indicate that system performance is acceptable. More extensive evaluation of the N application systems will be required before definitive conclusions can be reached with regard to system performance. The IRT system should provide useful information for crop stress and soil mapping, and feedback for near-real-time management of water and chemicals. A second commercial center pivot irrigation system is being modified for site-specific water, nutrient, and pesticide management on a site with variation (irregular boundaries) typical of Coastal Plain fields.

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