GEOSPATIAL MANAGEMENT OF WATER AND NUTRIENTS WITH A MODIFIED CENTER PIVOT IRRIGATION SYSTEM*

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ABSTRACT

Traditionally, site-specific farming suggests the management of fertilizers and pesticides for optimum crop yield on spatially-variable soils. However, in the southeastern Coastal Plain, research suggests that spatial yield variability may be caused primarily by water relations. Together, these requirements cause difficulties in managing water and chemical applications with conventional center pivot irrigation systems. Site-specific center pivot irrigation systems were developed to independently apply variable rates of water, nutrients, and pesticides to 100-m^2 areas within the system. Two commercial center pivot systems were modified by adding manifolds and nozzles in 13 segments along the truss to provide eight application depths within each segment at a given tower speed. Also, a programmable, computer-controlled management system was added to switch valves to obtain the appropriate application rate for each area and to collect and store required data. Primary control is based on stored GIS data but current conditions can be updated via dynamic measurements. Unique geospatial data are required to optimally manage water and chemical applications to these areas of variation. Response functions for water, nutrients, and pesticides must be developed before specific management strategies can be applied.

1.0 INTRODUCTION

The coarse-textured soils of the southeastern Coastal Plain are often quite variable with a nearly level, sandy surface and a sandy clay subsoil. The landscape includes numerous shallow depressions of variable size, where the soil profile has extensive inclusions of sands and the surface soil texture is generally finer than that outside the depressions. Many of the soils have compacted layers, which restrict root growth to very shallow depths (0.30-0.40 m) and limit soil volume available for water removal by plants. The low water-holding capacity and root-restricting layers combine to reduce plant-available water storage.

The climate is humid, subtropical, and has a mean frost-free growing season of about 250 days. Average annual rainfall in Florence, S.C., is 1100 mm and normally exceeds crop requirements, but rainfall is often poorly distributed during the year and growing season. Mean monthly rainfall during the growing season is about 125 mm, but can range from 20 mm to 250 mm. The combination of high rainfall variability and low water-holding capacity in soils creates a complex management scenario that can result in frequent yield-reducing crop stress in a region that appears to have sufficient rainfall.

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Based on observations of spatial patterns in crop growth, the major factor contributing to yield variability in the Coastal Plain appears to be plant-available soil water (Sadler et al., 1995a). Results from a study that investigated crop yield for 14 crops during an 11-year period found no useful correlation between yield and several patterns of variation, including soil classification and depth to the clay layer. 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). The objectives of this paper are to describe the variable-rate center pivot irrigation system developed at Florence and to illustrate its capabilities for application in site-specific management of water and chemicals.

2.0 SYSTEM DESCRIPTION

Two small, three-span, commercial center pivots were purchased in 1993 (Valmont Industries, Inc., Valley, Neb.**). Each was 137 m long and provided an irrigated area of 5.8 ha. The systems were standard commercial systems except for oversized truss rods to increase the truss load capacity and oversized ports in the system pipe to supply water to manifolds. Both systems also included the standard computer management control systems that could be programmed and controlled either locally or from a remote base station.

Initially, only one system (CP1) was modified for testing and further development. To fine tune the site-specific management technology, a traditional field experiment with fixed plot boundaries was implemented on CP1, which was sited on a relatively uniform soil area. The second system (CP2) was modified later with a water and nutrient application system similar to that for CP1; a similar pesticide application system is also planned for this system. CP2 was sited on a highly variable soil area that reflects the conditions found in a typical, highly-variable Coastal Plain field. When fully operational, CP2 will represent full implementation of variable-rate management of water, nutrients, and pesticides for small areas of variation with irregular boundaries.

The variable-rate water application system on Center Pivot 1 (CP1) was designed, constructed, and installed 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. Each segment had three parallel, 9.1-m manifolds, each with six industrial spray nozzles spaced 1.5 m apart and 3 m above the ground surface. For each segment, water was supplied to each set of three manifolds 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 three manifolds and nozzles were sized to provide 1/7, 2/7, and 4/7 of a base application depth. All combinations of the three manifolds provided 0, 1/7, 2/7, 3/7, ...7/7 (or 100%) of the base depth, which was 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

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by Omary et al. (1997). Measured water application uniformities for selected segments operating alone indicate acceptable system performance, especially for the control zone within each element (UC=89 to 95), which is the center 6 m of the 9.1-m width. [UC is uniformity coefficient described by Christiansen (1942).] When adjacent elements had different application depths, about 1.5 m at the edge of each element had reduced uniformity, as expected from the prototype evaluation (Omary et al., 1997). However, when adjacent elements had the same application depth, simulated UC values for the entire element were about 92.

The variable-rate application system was controlled by an 80386 PC (Horner Electric, Indianapolis, Ind.), 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 center, from which it controlled all manifold solenoid valves. Angular location of the truss was obtained from the C:A:M:S™ (Valmont Industries, Inc., Valley, Neb.) management system via short-range, radio-frequency modems (900 MHZ, spread-spectrum modems; Comrad Corp., Indianapolis, Ind.) between the mobile PC and the stationary management system. The PC controlled the PLC using custom software. Based on both stored and continuously-collected positional data, the PC signaled the PLC to switch on the appropriate solenoids to provide the desired application depth within each field element. The control software included checks for out-of-range values and fail-safe operation. Additional details regarding the control system and overall center pivot operation were reported by Camp et al. (1998).

The nutrient application system is based on the principle of maintaining a constant nutrient concentration in the water supply line and varying nutrient application amounts to each segment by varying the water application depth. This requires nutrient injection into the water supply in proportion to the flow rate, which was achieved with a variable-rate, four-head injection pump (Ozawa R & D, Inc. model 40320, Ontario, Oreg.) located at the pivot center. The on-board PC calculated the injection rate based on water flow rate and transmitted the appropriate control signal to the pump. A prototype, low-volume pesticide application system developed by Valmont Industries, Inc., was modified and installed on CP1. It provides a range of application rates for the same element size as for water and nutrients. This system operates independently of the water application system, using the center pivot only as a transport vehicle, but is operated by the same PC and PLC control system.

To aid in detecting and mapping soil and crop variation using thermal images, infrared thermometers (IRT) were installed on aluminum booms and masts that were attached to each center pivot system. The booms extended about 3 m in front of the water application system and the masts allowed adjustment of each IRT 1.5 m above or below the boom. One IRT was installed for each 9.1-m segment on CP1 and two IRTs were installed on each segment on the second system (CP2); see Camp et al. (1998) for additional details on CP1. A thermal scan of crop canopy and soil temperature, a few weeks after corn emergence but before soybean planting, in a fixed-boundary conservation tillage experiment on CP1 is shown in Figure 1.

3.0 USE IN EXPERIMENT WITH FIXED-BOUNDARY ELEMENTS

The field experiment consisted of 144 fixed-boundary plots (elements). Treatments in the field experiment 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 and multiple supplemental applications), and four replications. All rows were planted, and all subsequent operations were performed, in a circular pattern that coincided with the center pivot travel. Individual plots were established in a regular 7.5° by 9.1-m pattern, which made the minimum plot length 9.1 m in segment 8, and 15 m in segment 13 (outermost). A diagram of the experiment showing plot location superimposed on a thermal scan in 1997 is shown in Figure 1. All supplemental N fertilizer for corn during three growing seasons was applied via the system nutrient injection system using a minimum-depth water application.

In this experiment, all irrigation and nitrogen fertilizer were applied to specific elements (plots) according to the established experimental design, not according to spatial variation. Corn irrigation ranged from 0 to 221 mm in 1995, 0 to 178 mm in 1996, and 0 to 216 mm in 1997; applied in 18, 16, and 20 events, respectively. Soybean irrigation ranged from 0 to 178 mm in 1995, 0 to 114 mm in 1996, and 0 to 140 mm in 1997; applied in 13, 9, and 11 events, respectively. Supplemental nitrogen fertilizer applications ranged from 1 to 6, depending upon treatment. During the three-year period, the modified center pivot system successfully applied water and nitrogen fertilizer to elements (plots) with fixed, regular boundaries. The control system became more reliable and required less operator intervention during the period, a prerequisite for progressing to management of water and chemical applications on areas of variation with irregular boundaries or those requiring dynamic control.

4.0 MANAGEMENT OF IRREGULAR-BOUNDARY ELEMENTS

There are three requirements for site-specific management of crop production. The first is knowledge of the spatial variation that affects the crop. While some information may be available for rectilinear grid nodes, most information is available in map form (printed or electronic data file) with areas of similar value included within irregular boundaries. Examples include soil attributes such as classification, organic matter, fertility, water holding capacity, etc.; yield of preceding crop; crop variety or type; and type of tillage or other cultural practice. A second requirement is a response function for each type of variation, which provides an indication of crop response to changes in a source of variation; for example, the quantitative changes in crop yield with incremental increases in fertilizer or irrigation for specific soil, location, and weather conditions. The third requirement is a management strategy or objective. Management strategies may be based upon a variety of factors, including optimum use of a limited resource (water, land, etc.), environmental effects, maximum yield, cash flow, and statutory limitations. After these three requirements have been satisfied, decisions can be made within the context of existing economic conditions, including input costs and expected crop market prices.

Efforts to manage similar (near homogeneous) areas will most often result in polygon-shaped elements of similar management or treatment, the size depending upon the method of applying the treatment, e.g., width of the fertilizer applicator or harvester, wetted diameter and number of irrigation sprinklers under common control, or size of tillage equipment. In most cases, the treated element or combination of elements will not exactly coincide with the existing areas of similarity. Consequently, management schemes must be developed to optimize treatment of these areas of similarity within the overall context of profitability and environmental effects. Generally, the smaller the control polygon the better the fit with curved, irregular boundaries, but practical and economic considerations limit the minimum polygon size.

For center pivot irrigation systems, the polygon size is determined by the linear distance along the truss and the circular arc. In our modified center pivot systems, the segment length along the truss is 9.1 m and the minimum practical angular resolution is 1°; however, because of sprinkler wetted diameter and uniformity requirements, the minimum element size in the travel direction is about 9 m. Figure 2 illustrates how multiple polygons (1° by 9.1 m) of the same treatment (fertilizer rate, irrigation depth, etc.) can be used to approximate areas with irregular boundaries (soil mapping units in this illustration). The annotated codes in each area identify the soil classification; see Sadler et al. (1995b) or Karlen et al. (1990) for additional information. The criterion for determining treatment selection (grouping polygons) was a simple majority of the polygon (1° by 9.1 m) area within a given soil type. In some cases, isolated single 1° polygons, which are too small for practical independent treatment, must be aggregated to form minimum control elements (9.1 m by 9.1 m). Once the polygon grouping has been determined, a control program running on the computer can repeatedly manage applications using stored data and user-supplied information.

Multiple treatment types (e.g., fertilizer, water, pesticide) can be managed using one set of spatial variation data (e.g., soil type), or each treatment type can be managed with a unique set of variation data. In the latter case, multiple layers of information similar to that included in Figure 2 would be stored in data files. For example, one layer might relate to fertilizer, another layer could relate to irrigation, and still another could relate to pesticides. In some cases, operations would be accomplished sequentially, while in other cases they might be combined into a single operation (e.g., water and fertilizer applications). While the latter case could be more complex, it could be accomplished by combining two layers.

A major management decision is selecting the source of spatial variation to be used for managing various crop inputs. In many cases this decision is heavily influenced by the availability of reliable data with known relationships to crop yield. If these data are not readily available, obtaining them can be very expensive and time consuming. Yield maps are becoming more readily available with the increasing use of yield monitors for some crops and of software to convert these data into maps of yield variation for each field or management unit. Consequently, in some cases it may be more practical or convenient to use a map of normalized yield (previous year or mean of several seasons) for managing some crop inputs, e.g., fertilizer.

5.0 SUMMARY AND CONCLUSIONS

Modifications to two commercial center pivot irrigation systems provide site-specific, variable-rate applications of water, nutrients and pesticides. The systems have 13 segments, each 9.1 m in length, along the truss, which allow variable application rates of water, nutrients, and pesticides to control areas of about 100 m^2. Seven different irrigation depths can be applied independently within each segment. Based on stored and measured data, a programmable, computer-controlled management system opens the appropriate valves to obtain the desired application rates for specific areas. Water and nitrogen applications to a fixed-boundary field experiment were successfully accomplished during 1995-97 with one system. The second system will provide site-specific water, nutrient, and pesticide management on a site with variation (irregular boundaries) typical of Coastal Plain fields. Response functions must be developed for each controllable input in order to optimize management of spatial variability.

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6.0 REFERENCES

C.R. Camp, G.D. Christenbury, and C.W. Doty, "Florence, S.C." In *Scheduling Irrigation for Corn in the Southeast*, eds. C.R. Camp and R.B. Campbell, ARS-65, Washington, D.C., USDA-ARS, Chap. 5, pp. 61-78, 1988.

C.R. Camp and E.J. Sadler, "Center Pivot Irrigation System for Site-specific Water and Nutrient Management," *ASAE Paper No. 94-1586*, St. Joseph, Michigan, ASAE, 1994.

C.R. Camp, E.J. Sadler, D.E. Evans, L.J. Usrey, and M. Omary, "Modified Center Pivot System for Precision Management of Water and Nutrients," *Applied Engineering in Agriculture* Vol. 14, No. 1, pp. 23-31, 1998.

J.E. Christiansen, "Hydraulics of Sprinkling Systems for Irrigation," *Transactions of the American Society of Civil Engineers*, Vol. 107, pp. 221-239, 1942.

D.L. Karlen, E.J. Sadler, and W.J. Busscher, "Crop Yield Variation Associated with Coastal Plain Soil Map Units," *Soil Science Society of America Journal*, Vol. 54, pp. 859-865, 1990.

M. Omary, C.R. Camp, and E.J. Sadler, "Center Pivot Irrigation System Modification to Provide Variable Water Application Depth," *Applied Engineering in Agriculture*, Vol. 13, No.2, pp. 235-239, 1997.

E.J. Sadler, P.J. Bauer, and W.J. Busscher, "Spatial Corn Yield During Drought in the SE Coastal Plain," In *Site-specific Management for Agricultural Systems*, eds. P.C. Robert, R.H. Rust, and W.E. Larson, Minneapolis, Minnesota, 27-30 March 1994, Madison, Wisconsin, American Society of Agronomy, pp. 365-382, 1995a.

E.J. Sadler, W.J. Busscher, and D.L. Karlen, "Site-specific Yield Histories on a SE Coastal Plain Field," In *Site-specific Management for Agricultural Systems*, eds. P.C. Robert, R.H. Rust, and W.E. Larson, Minneapolis, Minnesota, 27-30 March 1994, Madison, Wisconsin, American Society of Agronomy, pp. 153-166, 1995b.

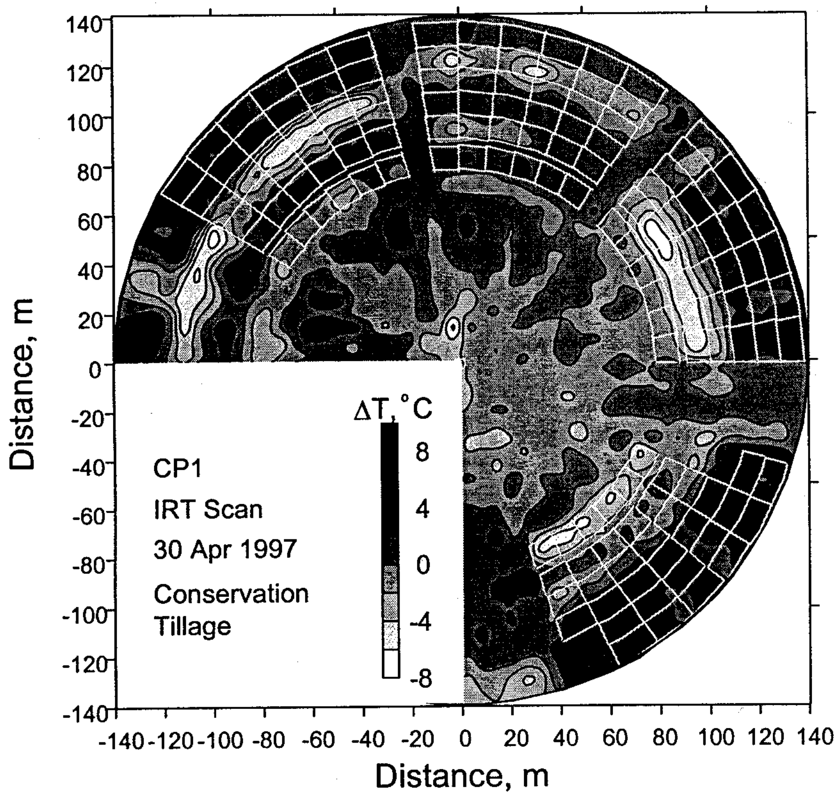

Figure 1. Thermal Image and Plot Diagram for Field Experiment on CP1.

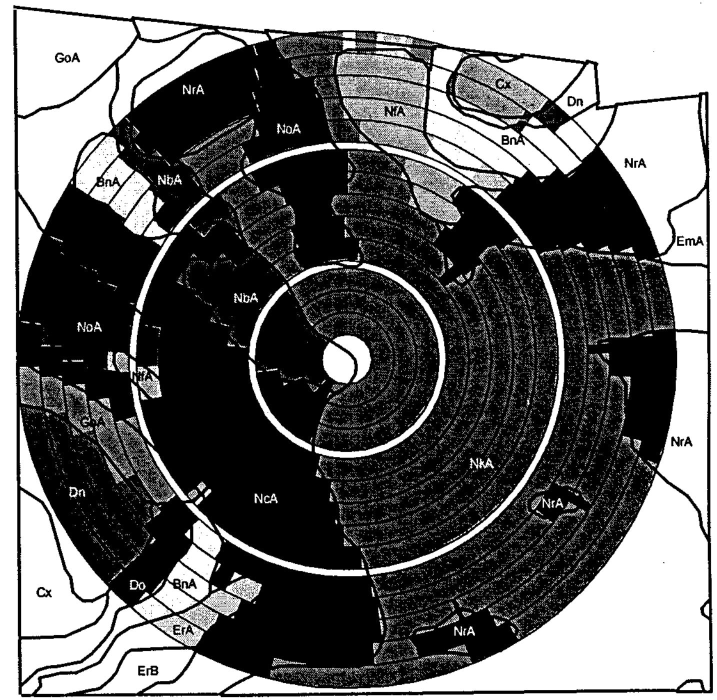

Figure 2. Polygon Approximation of Irregular Boundaries for CP2.