Site-specific crop management with a center pivot

C. R. Camp and E. J. Sadler

Interpretive summary

Site-specific application of irrigation water and fertilizer should offer opportunities to conserve water, to reduce plant stress, and to reduce loss of fertilizer or pesticides. Two center pivot irrigation systems were mod)fied to permit a range of water and chemical application rates to areas about the size of a 2-car garage. One of eight water application depths is selected by a computer with specialized software and a database of cultural information. These site-specific irrigation machines can be used for research to determine the agronomic and management information needed for commercial application of this technology.

Key words: center pivot, computer-controlled management, fertilizer, irrigation, nutrients, pesticide, precision agriculture, site-specific management, variable rate application.

ABSTRACT: Traditionally, site-specific farming suggests the management of fertilizers and pesticides but research in the southeastern Coastal Plain suggests that spatial yield variability may be caused primarily by water relations. Site-specific management of water and chemical applications is difficult with conventional center pivot irrigation systems. Site-specific irrigation systems were developed to independently apply variable rates of water, nutrients, and pesticides to 100-m^2 areas. Two commercial center pivot systems were modified by adding manifolds and nozzles along the truss to provide eight application depths within each of 13 10-m segments. A programmable, computer-controlled management system uses stored GIS data to provide the appropriate application rate for each area but can also be updated via real-time soil and crop measurements.

During the past few years, precision agriculture, or site-specific management of crop production systems, has become very popular. The primary reason for this increased interest is the availability of technology at affordable cost to accurately determine location while applying fertilizer at variable rates or measuring crop yields. In many cases, analyses of soils and yield maps have shown that water is the major variable affecting crop yield (for example, see Sadler et al., 1995a). Also, measurements and computer models have shown that crops in the southeastern Coastal Plain are particularly sensitive to differences in available water during the season. However, once a site, soil, and tillage system have been selected, little can be done to provide additional water for the crop after drought has begun unless irrigation is available

Even when available, current commercial irrigation systems offer little capability for variable-rate application within the system. Usually, water and chemicals are applied uniformly to entire fields under irrigation systems. Such uniform applications are usually based on average or most-limited conditions for the crop. Consequently, in fields with variable soils, some places will get applications that are less than or greater than optimal, resulting in lost yield or wasted resources. Wasted resources cause excess cost and increased possibility of environmental damage by runoff or leaching of chemicals through the soil profile.

Site-specific management of crop production inputs has three basic requirements. The first is a basic knowledge of the spatial variation that affects crop yield. Examples include soil properties, cultural practices, crop variety, and yield of preceding crop. The second requirement is knowledge of the manner in which each source of variation responds to variable inputs. An example could be the change in crop yield with incremental changes in fertilizer or irrigation for a specific location and weather conditions. The third requirement is a management objective or strategy, which could include maximizing profit, optimizing use of a limited resource, minimizing environmental effects, or complying with statutory restrictions. Once these three requirements are satisfied, operational decisions regarding crop production inputs can be made for those requirements within existing economic conditions.

Managing water, nutrients, and pesticides using conventional center pivot or linear move irrigation systems is hampered by spatial variation. For instance, when irrigating according to soil water content, where in the field should it be measured? In almost every field, some areas need water earlier than average; others need it later. How far conditions deviate from optimum depends upon the soil variation in the field. That variation differs among various regions of the country, ranging from fairly uniform to quite variable. Variability is severe in the Coastal Plain region of the southeastern US, where fields are small and have irregular boundaries. Also, most soils are sandy, have low fertility, and store little water. The site-specific application of irrigation water, nutrients, and pesticides should offer opportunities to conserve water, to optimize nutrient utilization, to reduce the chance of either drought or flooding stress, and to reduce potential leaching of fertilizers or pesticides into the groundwater.

In moving irrigation systems, the rate of travel can be adjusted, often under

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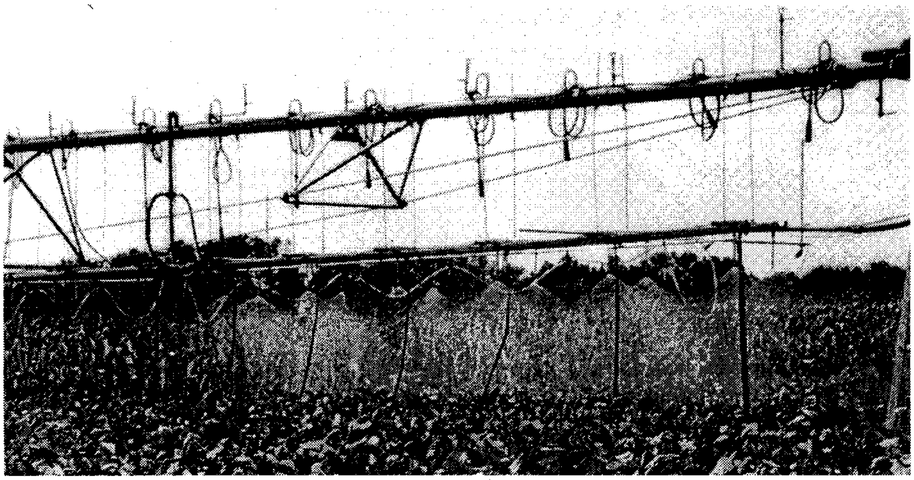

Figure 1. View from the side, showing discrete control of irrigation on soybean plots during 1998. Plot sizes here are 9.1 m (30 ft.) by 7.5 degrees. Dark vertical lines are tubes attached to one set of nozzles to deliver water to near soil surface and prevent drift in high wind conditions.

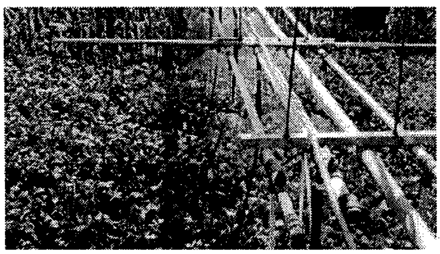

Figure 2. View of the site-specific center pivot from above, showing a portion of one 9.1-m (30-ft.) segment with three manifolds (fourth pipe is a conduit for power and control cables). Long, horizontal tubes attached perpendicular to manifolds support infrared thermometers (IRT).

computer control, to provide a different application rate for control areas that are typically pie-shaped for center pivot systems and rectangular-shaped for linear systems. Unfortunately, most areas requiring similar treatment in the field do not have the same size and shape as the irrigation system control areas. Consequently, new or modified irrigation systems are needed to apply water, nutrients, and pesticides to areas of similar variation within the field or irrigation system.

In 1993, we started to develop an irrigation system that could better manage water, nutrients, and pesticides on Coastal Plain soils. The general concept was to manage water and chemical applications to small areas within the total irrigation system area based on stored data, real-time plant and soil measurements, or a combination of the two. Two commercial center pivot irrigation systems with computer-aided management were purchased. They were modified, in cooperation with University of Georgia at Tifton, to allow site-specific application of water and nutrients to areas approximately 9.1 m by 9.1 m (30 ft. by 30 ft). Initial modifications of Pivot 1, which included both hardware and software, were installed early in 1995.

The water application system includes additional sets of manifolds, valves, and sprinklers attached to the truss (see figure 1). Each set is 9.1 m (30 ft.) long and includes three manifolds (see figure 2). Each manifold has nozzles sized to provide a different flow rate, and the three in a set apply 1/7, 2/7, and 4/7 of a set rate at each travel speed (see Camp et al. 1994, 1998; Omary et al. 1997 for additional detail). By operating one or more manifolds, seven application rates are possible for any given tower speed (see figure 3). For example, if the 1/7 and 4/7 manifolds are switched on, the application depth is 5/7 of the maximum or 9.1 mm (0.36 in.) when the pivot is moving at half speed or 4.5 mm (0.18 in.) when moving at full speed. The system provides application depths up to 12.7 mm (0.5 inch) in 1.8-mm (0.07-inch) increments when the pivot is moving at half speed.

The basis for the nitrogen application system is to vary nitrogen application by varying the water application rate, while maintaining a constant nitrogen concentration in the water. Constant nitrogen concentration is maintained by injecting the nitrogen fertilizer solution into the water supply at the stationary base of the center pivot at a rate that varies with system water flow rate. The variable nutrient injection rate is provided by a variable-speed, four head pump, for which the motor speed is controlled by a variable DC voltage. An on-board computer calculates the water flow rate and adjusts the motor speed to deliver the appropriate nutrient volume to achieve constant concentration (see Camp et al. 1998 for additional detail).

The control system consists of a computer that uses a stored database and specialized software written in the Visual Basic computer language to control all water and nutrient applications. This computer obtains positional information from and transmits system control signals to the commercial irrigation system computer-aided management system (C:A:M:S ™) by radio communication. During 1995-1998, the control system was tested and improved while it was used to make fixed, pre-selected water and nitrogen applications to an experiment consisting of 144 small, fixed-boundary plots (see figure 4). The control system was and continues to be developed under a Cooperative Research and Development Agreement with Valmont Industries, Valley, Nebraska.

Other additions were also made to the system during this period. In 1996, infrared thermometers (IRT) were added to each segment of both pivots to allow crop and soil mapping, and feedback control of irrigation based on canopy temperature (see figure 5) (Sadler et al. 1997). In 1997, a separate, proprietary low-volume pesticide delivery system was added to Pivot 1 and was later modified to allow pesticide applications in the same 9.1-m (30-ft) segments as water and fertilizer. Pesticides are supplied to this separate system via a separate pump and tank on a trailer pulled by tower 1. Thus, for pesticides, the center pivot functions solely as a transport machine. Experience gained from the use of Pivot 1 to manage water and nutrients for the experiment with 144 fixed-boundary plots was used to improve both hardware and control software for Pivot 2. Modification of Pivot 2 for water

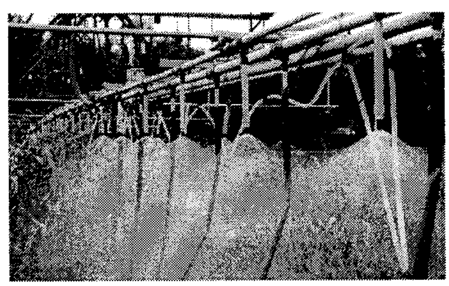

Figure 3. One segment of water delivery system with two manifolds in operation and flexible tubes attached to nozzles on the third manifold (not in operation). Note horizontal tubes for support of IRT (not installed).

Figure 4. View of soybean and corn in conservation tillage experiment that included 144 fixed-boundary plots. Note that all rows were circular in direction, conforming to the center pivot travel pattern.

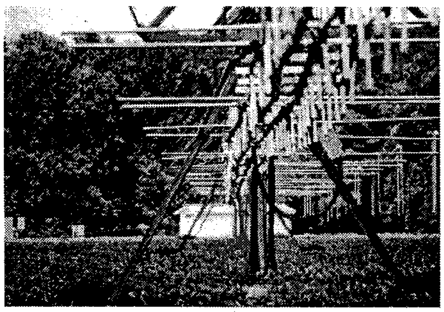

Figure 5. View of center pivot in direction of water delivery manifolds. IRTs are mounted on top of the vertical masts at right end of horizontal tubes, which support the entire assembly.

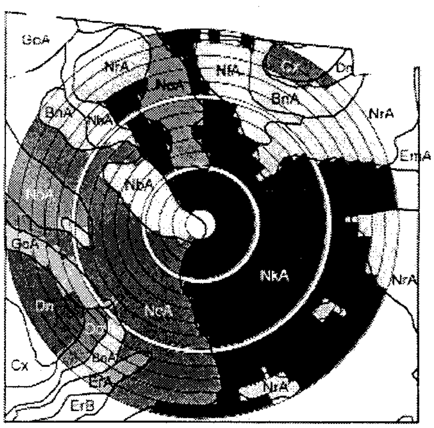

Figure 6. Combinations of polygon-shaped control elements to approximate areas of similar variance (same color) that will receive the same treatment. Soil mapping units are used in this diagram to illustrate areas of similar variation.
Note that some isolated, single polygon-shaped elements still must be combined with adjacent areas. (For definitions of soil mapping unit codes see Karlen et al.

and nutrient applications was completed in 1998.

While the soils at Pivot 1 site are fairly uniform, especially for the southeastern Coastal Plain, the soils at the Pivot 2 site are extremely variable, which is more representative of the region. Because the boundaries of areas that require similar treatment are irregular in shape, a combination of polygon-shaped control elements on the center pivot must be selected to approximate the area of similar treatment (see figure 6). However, the fit is not perfect. In our system, the control elements are fixed at 9.1 m (30 ft.) in one direction (along the system truss) and vary in 1° increments in the direction of travel (see Camp and Sadler, 1998 for more detail). Because of nozzle wetting patterns, the minimum practical element size is 9.1 m by 9.1 m (30 ft. by 30 ft.). Using spatially-indexed soil and crop data stored in the system computer, control software selects multiple polygon-shaped elements on the center pivot to approximate these areas with irregular-shaped boundaries.

We expect to continue refinements to the test system and to add to Pivot 2 a variable-rate pesticide system similar to the one on Pivot 1. Full implementation of Pivot 2 will be the culmination of the project — site-specific irrigation, fertilization, and pest control on highly-variable soils with irregular boundaries. We also plan to continue exploration of potential uses of infrared thermometry for management of water, fertilizer, and pesticides applications, and for mapping soil and crop variation within the system. Based on these experiences, site-specific management of water, fertilizer, and pesticides using a center pivot irrigation system is possible; however, control element or area sizes may be different. The control element size will vary with application and location, depending primarily upon the type and magnitude of spatial variation and the economic and environmental benefits of variable-rate applications. If segment length for this research-scale center pivot (30 ft.) is scaled up to a span length for large, commercial systems, the number of control segments would be about the same and this control system could be applied directly to the commercial systems.

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