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MONITORING IRRIGATION WATER APPLICATION WITH COMPUTERIZED CONTROLLERS

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INTRODUCTION

In the Central Plains area of Colorado, Kansas and Nebraska, approximately 10.6 million acres of cropland are irrigated by center pivot irrigation systems (USDA-NASS 2007 Census of Agriculture). Existing systems span the generations of center pivot technology evolution from water to electric and hydraulically driven machines. Standard sprinkler system designs seek to apply water as uniformly as possible. Due to their operating flexibility, center pivots are operating on varying topography, and often have a range in soil textures present under a single machine. Field anomalies such as perched water tables, surface drains, and rock outcroppings challenge managers of standard machines with the need to deliver different depths of water to specific areas of the field. Each of these factors provides some justification for using a monitor and control system to manage water applications based upon a predetermined management scheme.

On a more basic front, farming operations often include an average of 3 center pivot systems with some operations including 15 or more. Without a controller, the producer must physically be on site to determine the status of the center pivot. With new technology, producers can obtain knowledge of whether the system is operating on a real-time basis by communicating with the machine to determine operating status. The purpose of this article is to present some of the research that has been conducted to evaluate system controllers for use in monitoring and controlling center pivots and discuss how these systems could be used in a site-specific irrigation system.

CONTROLLERS

Center pivot manufacturers have developed proprietary means of monitoring and controlling center pivots using a variety of technologies. Computerized control panels provide center pivot operators with the potential to monitor and control center pivots using telephones, radio telemetry, internet connections and satellite communication. In addition, there are a few private venture monitor and/or controllers that are available under the trade names: FarmScan, AgSense, and PivoTrac. Table 1 provides a summary of the current monitor and control capability of programmable panels marketed by the four major center pivot manufacturers.

The first requirement of a controller is to know the system position. If a producer queries the control panel during the course of an irrigation event, knowledge of where the system is lets the producer determine if problems have occurred and also how soon the system will reach stop-in-slot (SIS) positions. Standard machines utilize a resolver located at the pivot point to report the position of the first tower. In nearly all cases, the main component of new controllers is a Wide Area Augmentation System (WAAS) enabled GPS unit that is mounted near the last tower of the center pivot. The WAAS is a publicly available GPS system that provides a differentially corrected signal to increase the accuracy of the unit at a relatively low cost. With the WAAS system, the position of the last tower is provided with ± 11foot accuracy. However, due to the pivot speed of travel and stop-start motion of the machine, ± 3 foot accuracy is possible.

Part two includes monitoring the center pivot control circuitry. This is accomplished directly at the main pivot panel. The main panel houses control circuitry for the end gun, system speed of travel and direction, and on/off controls. Since most of this circuitry terminates at the end tower, some after-market center pivot monitors and controllers are mounted near the last tower control box.

At the pivot point additional components can be monitored and/or controlled such as auxiliary chemical injection pumps, system operating pressure and flow rate. Likewise, weather sensors can be monitored to provide wind speed and direction, temperature and rainfall information if desired. Options also exist to continuously monitor soil water sensors in the field. Recent field research is aimed at developing decision support tools for using center pivot mounted infrared thermometer (IRT) or spectral sensors to help manage irrigation water, fertilizer, and pesticide applications.

Part three of the system includes a communication link between the controller and the end user whether that be cell phone, land line phone, radio or internet connection. Cell phone links are accomplished using an on-board modem. This arrangement requires cell phone service from the pivot location and from the user location. Despite the addition of many cell towers, there are still a few locations in the Central Plains where communications are not possible.

Some systems transmit GPS coordinates and system monitor information via radio to a satellite which is transmitted back to a ground-based facility where it is distributed via the internet and made accessible by phone using IVR solutions developed specifically for center pivot controls.

Table 1. Monitor, control, communication, and data reporting capability of center pivot control panels.

	Reinke	T-L	Valmont	Zimmatic
Monitors				
Position in field and travel direction	Y	Y	Y	Y
Speed of travel	Y	Y	Y	Y
Wet or dry operation	Y	Y	Y	Y
Pipeline pressure	Y	Y	Y	Y
Pump status	Y	Y	Y	Y
Auxiliary components[β]	Y (7)	Y (2)	Y (6)	Y (3)
Stop-in-slot and auto restart	Y	Y	Y	Y
Wind speed	Y	N	Y	Y
Controls				
Start and Stop	Y	Y	Y	Y
Speed of travel	Y	Y	Y	Y
Auto restart and auto reverse	Y	Y	Y	Y
End gun	Y	Y	Y	Y
High and Low pressure shutdown	Y	Y	Y	Y
High and Low voltage shutdown[£]	N/Y	N/Y	Y/Y	N/Y
System stall shutdown	Y	Y	Y	Y
Auxiliary components[β]	Y(7)	Y(2)	Y(6)	Y(3)
System guidance[§]	Y	Y	Y	Y
Maximum control points per circle[¶]	3600	360	180	180
Sprinkler application zones[£]	2	3	30	NL
Remote Communications				
Cell phone	Y	Y	Y	Y
Radio	Y	Y	Y	Y
Computer	Y	Y	Y	Y
Subscription required	Y	Y	Y	Y
Data Collection and Reports				
Soil water content	Y	Y	Y	N
Precipitation per season	Y	Y	Y	Y
Application date and depth	Y	Y	Y	Y
Irrigation events per season	Y	Y	Y	N
Chemical application rate	N	N	N	Y
Chemical application per season	N	N	Y	Y
System position by date	Y	Y	Y	Y

[£] *N/Y indicates no automatic shutdown for high voltage is provided but the panel does provide automatic shutdown for low voltage.*
[β] *Y(7) indicates that up to 7 auxiliary components (injection pumps, end guns, etc.) can be controlled by the panel.*
[§] *System guidance provided by above ground cable, below ground cable, furrow or GPS.*
[¶] *Number of positions in a revolution where set points may be changed.*
[£] Number of banks of sprinklers that can be controlled along the pivot pipeline.

Line-of-sight radio telemetry is another means of transmitting information from the field to the office or phone. However, since the radios are line-of-sight buildings, trees, and hills impede communications over long distances. Most radio communication links employ radios operating in the 900 MHz range to communicate over distance less than 15 miles. For longer distances, a bridge or repeater is positioned on a tower or other structure to communicate over longer distances.

Recent developments in the center pivot industry have resulted in contractual arrangements with developers of after-market control and monitor systems. These additions to the existing onboard control capabilities of center pivot panels make site-specific irrigation a reality for irrigation zones of 1000 ft^2 or larger. The main considerations remaining include the development of decision support systems that maximize the value of the applied water or chemical based on field-based information, the cost recovery potential of the cropping system, and the verification of water savings and/or improved productivity when there are a large number of management zones within the field area.

SITE SPECIFIC IRRIGATION

Precision agriculture technologies are based upon the premise that crop growth and/or yield is not uniform across a field. It further assumes that the field average yield would increase if inputs of water and/or nutrients could be differentially applied to small field areas based upon a predefined management scheme. Site-specific water application technologies make it possible to vary both water and chemicals to meet the specific needs of a crop in each unique zone within a field. The hypothesis is that the total water and nutrients applied could potentially be reduced on a per field basis and/or crop yield or quality will be greater. One project comparing site-specific irrigation to conventional uniform irrigation was conducted in Idaho on potatoes (King, et al., 2006). They found that while statistical differences in yield were not recorded, a trend toward greater yield using site-specific irrigation was noted. The mean yield increase would allow the equipment costs to be recovered in a 2-3 year time frame.

With a uniform application, the questions are '*when'* to irrigate and '*how much'* to apply. The implementation of site-specific irrigation adds a third question of '*where'* to the irrigation scheduling decision. Answering the question about where requires that specific management zones be identified in some fashion. Early efforts to develop methods for identifying where zones should be located and why included using soil survey maps, field topography, landscape position, and bulk soil electrical conductivity (Jaynes et al.,1995; Jones, et al., 1989; Sudduth et al.,1997). Missouri research concluded that the number of zones necessary in each field is dependent of the availability of water and the type of crop planted in the field (Fraisse, et al., 2001).

Over the last two decades research has been conducted by public and private groups seeking to development methodology and decision support tools necessary for application of water and plant nutrients based upon the physical limitations of a tract of land. In essence this work has added center pivot irrigation systems to the list of variable rate applicators. As the technology has evolved so has the list of terminology used to help lay claim to unique ways that standard center pivot controls are replaced and/or enhanced to allow variation in the center pivot's application depth and/or water application rate. Definitions for some of the terminology are included at the end of this paper.

Initial steps to define decision making tools used for site-specific irrigation began in the early 1980's. Sadler, et al (2005) stated one of the issues with site-specific irrigation is that *"most of these technologies have been developed without considering the knowledge levels, skills and abilities of farmers and service providers to effectively and economically manage these tools. In addition, the equipment is often expensive and the economic returns from adopting these technologies have not been easy to consistently demonstrate. Nevertheless, the economics are improving and there is little doubt that at least some of the emerging precision agriculture technologies will be part of future crop production systems in American agriculture"*. Technologies such as Low Energy Precision Application (LEPA) were developed based on the early efforts to define optimum flow rates for sprinkler heads operating within inches of the soil surface (Lyle and Bordovsky, 1981). A series of control manifolds were used to deliver different flow rates. Later work by Roth and Gardner (1989) sought to use the irrigation system to apply different amounts of nitrogen fertilizer with irrigation water.

Fully site-specific irrigation research was initiated in earnest in the early 1990's at four USDA-ARS research lab locations across the US. Reports of this work were published beginning in 1992 based upon work conducted the USDA-ARS researchers located in Fort Collins, CO (Fraisse, et al., 1992), Moscow, ID (McCann and Stark, 1993), Florence, SC (Camp and Sadler, 1994), and Pullman, WA (Evans et al., 1996). These efforts have helped to shape the technologies used to control moving sprinkler systems and individual sprinklers.

The major addition needed to convert center pivot irrigation systems to allow site-specific water application is a means of controlling water flow to individual sprinklers. Individual sprinkler flow control can be accomplished by using a series of on-off cycles or as it has become known as 'pulsing' the sprinkler (Karmeli and Peri, 1974). Changing the sprinkler on time is effective at reducing both the application depth and the water application rate. This is accomplished using either direct-acting or pilot-operated solenoid valves. Direct acting valves have a linkage between the plunger and the valve disc while the pilot-operated solenoid uses irrigation pipeline pressure to activate the valve.

A second method for controlling irrigation water application was developed by King and Kincaid (2004) at Kimberly, ID. The variable flow sprinkler uses a mechanically-activated needle to alter the nozzle outlet area which can adjust the sprinkler flow rate over the range of 35 to 100% of its rated flow rate based upon operating pressure. The needle can be controlled using electrical and hydraulic actuators. The main issue is that the wetted pattern and water droplet size distribution of the sprinkler changes with flow rate which creates potential water application uniformity issues due to a change in sprinkler pattern overlap.

A third method of controlling irrigation water application is to include multiple manifolds with different sized sprinkler nozzles. In this case, activation of more than one sprinkler manifold can serve to increase the water application rate and depth above that for a single sprinkler package. Control of each manifold is accomplished using solenoid valves similar to those described for the pulsing sprinkler option above.

These new systems have been installed in various locations across the country, but few site-specific systems have been installed in the northern High Plains area. As with any new technology, there are positives and negatives associated with each of these three methods of controlling sprinkler flow rates. Certainly long term maintenance could be an issue. Water flow rates to 13 water application zones were monitored on a center pivot with results indicating most were within 10% of the target flow rate (Stone, et al., 2006). Application uniformity of sprinkler pulsing type site-specific systems has been addressed by Dukes, et al., (2006) who found coefficient of uniformities in excess of 90% regardless of the system travel speed and cycling rate. An additional concern is verification of results which can be difficult since it requires that comparable areas of the field where site-specific irrigation and uniform irrigation methods have been employed over a series of years.

SYSTEM REQUIREMENTS

Selecting the method of sprinkler control may be the easiest decision to make since the main factor of concern is: Will it pay to install the controls? However, once the decision is made to use a variable rate sprinkler application system and the management zones have been defined, design of the remaining portions of the irrigation system becomes interdependent.

How will the pumping plant respond to changes is system flow rate requirements? And how much additional pressure can the distribution system safely take before a pipeline breaks? As sprinklers turn on and off, the flow rate required by the system varies. The response of a standard pumping plant is that the pump output will follow the pump curve to the right or left depending on whether more or fewer sprinklers are operating. More significant is that sprinklers near the end gun have flow rates that are significantly greater than sprinklers near the pivot point. Consequently, turning off sprinklers on the third span of the system will have much less effect than turning off the sixth span. The correct design response is to install a pumping plant with variable revolutions per minute (RPM) so that as more sprinklers are added, the pumping RPM is increased and visa versa. In this way the pumping plant can supply water at the design pressure regardless whether 50 or 150 sprinklers are in operation.

The difficulty arises when the motor used to supply power to the pump is the same one used to supply power to the center pivot. Changes is pump RPM require changes in engine RPM. Engines operating at too high of an RPM will provide too much power to the center pivot while engines with too low of an RPM will not deliver enough power to the pivot. So a separate energy supply may be required for the center pivot should the system be converted to site-specific irrigation applications. New installations would be best served by installing a variable frequency drive electric motor with a pressure sensor to control the motor RPM.

How do I adjust the chemical injection system to apply different chemical amounts (fertilizer or pesticides)? Application of variable chemical rates can be achieved by simply maintaining a design injection rate and let the difference in water application depth control the chemical application rate. However, we have a problem if our management decisions require high application of a plant nutrient to an area that is to receive little or no water? A second factor is that the time of travel for chemicals to be transported from the pivot point to a position on the pivot lateral varies with the velocity of water in the pipeline. As the number of sprinklers in operation changes so does the water flow velocity. Thus, chemical could enter the system with a velocity of 6 feet per second when all sprinklers are on and 3 feet per second when a large number of sprinklers are turned off. This factor will determine when a change in injection rate will reach different positions along the pivot pipeline.

How accurately can I determine system position if application rate changes are desired? Center pivot position on most systems (without special equipment) is determined by the resolver that is located at the pivot point. Alignment systems typically have an accuracy of $\pm 1.5^{o}$ of where the first tower is located. Thus, at a distance of 1320 feet from the pivot point, the position of the last sprinkler could be off by 34 feet or more. Research conducted by Peters and Evett (2005) found that resolver determined position errors could be up to 5 degrees or over 100 feet on a 1320 foot long center pivot. Installation of a WAAS enabled digital GPS system is needed to ensure water and chemical are applied accurately. The net effect of the WAAS system is that management zone size can be reduced without increasing the potential for a misapplication.

From an engineering perspective these are not trivial questions particularly if changes in water, nutrient and energy use efficiency are to be accomplished simultaneously. In the end, it is the accuracy of the data used to make decisions that is critical. And so another question must be answered: *Will the increase in water application to **Management Zone 25** increase yields enough to pay for the application?*

Information Requirements

To make full use of site specific irrigation techniques, site-specific field information is needed for variables that will be used in making irrigation management decisions. Field soil texture and fertility will be needed to help isolate field areas where plant available water is indeed the single most important factor. Yield maps could show areas with reduced yields that are due more to soil nutrient levels than plant available water or a combination of the two. The difficult factor is to have production functions that give accurate information about what will happen to yield if water or plant nutrients are altered. Acquiring this information may require a 3-5 years of in-field testing while harvesting with a yield monitor. Private companies are becoming more active in providing a service of collecting and summarizing the field data.

Field maps of each of these variables (field slope and soil texture, fertility level, grain or forage yield) represent information that make up levels in a Graphic Information System (GIS) analysis. It is important that these maps provide information with enough resolution to delineate the desired number of management zones. Limitations in the ability to collect point measurements due to cost or response time of sensors all impact the spatial resolution of the application map. For example, an 8-row combine operating at 6 mph and collecting yield estimates every 3-seconds provides a different spatial resolution than a center pivot with control of banks of 5 sprinkler heads. Consequently, variable rate irrigation controls will typically be at a lower resolution than any of the other crop production inputs. Ultimately, mathematical models will be needed to utilize the different sources of information to produce a water application map (Fraisse, et al., 2001; Fridgen, et al., 2004).

SUMMARY

Center pivot controllers and monitors are available to help producers manage water application on a whole or part of field basis. The combination of knowledge of current system status and location in the field help ascertain if the irrigation application is proceeding as planned. By recording other field based information water applications can be adjusted due to different crops, field topography, soils and productivity levels. Ultimately, the complete control of crop water inputs on an IMZ basis could save between 10-20% of the water applied per season. Lower installation costs and further development of decision support systems for use by producers are needed before site-specific technology will receive widespread use by row crop producers in the Central Plains area.

TERMINOLOGY

Listed below are general definitions for the acronyms that are used in the discussion of center pivot monitors and controls.

GIS Geographic Information Systems is a system that allows for sets of geo-referenced variables (layers) to be analyzed, managed, displayed, and used to develop site-specific maps for the application of water, pesticides, or plant nutrients.

GPS Global Position Systems is a satellite system means of determining field positions, speed of travel, and time with sufficient precision to allow site specific application of irrigation water, pesticides, or plant nutrients in response to productivity indices.

IMZ Individual Management Zone is an individual area of an irrigated field for which the technology exists to alter the application of water, pesticides, or plant nutrients in response to productivity indices.

IRT Infra-Red Thermometry is the use of an infrared thermometer to record plant leaf temperature as an indicator of plant stress.

IVR Interactive Voice Response is technology that enables users to retrieve or deliver information on time critical events and activities from any telephone.

LEPA Low Energy Precision Application is a water, soil, and plant management system for uniformly applying small frequent irrigations near the soil surface to field areas planted in a circular fashion and accompanied by soil-tillage to increase soil surface water storage.

PA Precision Agriculture, or site-specific farming is the precise delivery of water, pesticides and plant nutrients based upon suspected deficiencies in or need for water, pesticides, or plant nutrients.

PLC Programmable Logic Controller is a digital computer used for automation of electromechanical processes and is designed for multiple inputs and outputs, and is not affected by temperature, electrical noise, or vibration.

VRI Variable Rate Irrigation is the delivery of irrigation water to match the needs of individual management zones within an irrigated field.

VRT Variable Rate Technology is the process of applying irrigation water, pesticides, or plant nutrients at rates which are based on defined crop production indices.

WAAS Wide Area Augmentation System is a navigation aid developed by the Federal Aviation Administration to augment the accuracy, integrity and availability of the GPS for use in aircraft flight monitoring and control.

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