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Integrated Controls, Distributed Sensors and Decision Support Systems for Wireless Site-specific Sprinkler Irrigation

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INTRODUCTION

Traditional uniform water applications by self-propelled center pivot and linear move sprinkler irrigation systems ignore within field variations that cause varying crop yield and quality across most fields. This variability may include topographic relief, changes in soil texture, tillage, fertility and pests as well as various irrigation system characteristics. These effects on management can be additive and interrelated. Excessive applications potentially lead to drainage, soil erosion and disease problems as well as excessive energy use, whereas under applications can reduce yields and/or quality with the severity level often depending on management. Typical management objectives would be to optimize yield and quality goals while maintaining environmental health (reduced water and agrichemical use) and reduce chemical leaching.

Microprocessor controlled center pivot and linear move irrigation systems are particularly amenable to site-specific management approaches because of their current level of automation and large area coverage with a single lateral pipe. These technologies provide a unique control and sensor platform for economical and effective ways to vary agrichemical and water applications to meet the specific needs of a crop in uniquely defined zones within a field.

Advances in communications and microprocessors have enabled the implementation of site-specific water applications by self-propelled center pivot and linear move sprinkler irrigation systems. Site-specific irrigation usually involves some type of variable rate application method in combination with geo-referenced maps or tables. These decision maps specify the amount of water applied to each pre-defined management area within a field and are generated using some type of rule base predefined by the producer or a consultant. Ideally, these management maps or tables are frequently updated based on real time, spatially distributed data on field conditions. Management areas may be different for irrigation than for chemigation applications, and each may have its own maps.

Recent innovations in low-voltage sensor and wireless radio frequency technologies combined with advances in Internet technologies offer tremendous opportunities for development and application of real-time management systems for agriculture. Integration of these technologies into the irrigation decision making process can determine when, where how much water to apply in real time; which enables implementation of advanced state-of-the-art water conservation measures for economically viable production with limited water supplies.

Researchers at the USDA-ARS research laboratory in Sidney, Montana have developed and tested an automated closed-loop irrigation system for automated variable-rate linear move sprinkler irrigation system. This research integrated in-field sensor stations distributed across the field, an irrigation control station on the linear move system, and a decision support system on a base computer station.

INTEGRATION OF SYSTEMS

Variable-Rate Irrigation System

A site-specific controller and hardware were developed with the capability to switch between either mid-elevation spray application (MESA) or low energy precision application (LEPA) methods as well as to simultaneously vary water application depths by plot as the machines traveled down the field. The machine was converted to make groups of individual sprinkler nozzles electronically controllable by attaching a programmable logic controller (PLC), solenoids, air valves, and a low cost WAAS enabled GPS system. The linear move irrigation system was modified so that every plot could be irrigated using either MESA or LEPA methods. The control system was used on fifty-six 15 m × 24.4 m (50 ft × 80 ft) plots as well as several other smaller research projects in which there were a mix of crops and a prescribed set of management experiments in a single field for a total area of about 12 ha (28 ac).

All plots were irrigated with an 244 m (800 ft), 5 span, Valley[1] self-propelled linear move sprinkler irrigation system (Valmont Industries, Inc., Valley, NE) including the cart, which was installed in the spring of 2003. A diesel engine powered an electrical generator set (480 v, 3 phase) on the cart that provided electricity for the tower motors, cart motors, pump, air compressor and control valves. A buried wire alignment system was used with antennas located in the middle of the machine. The linear move machine used a screened floating pump intake in a level ditch as its water supply. Nominal operating pressure was about 250 kPa

[1] Mention of a trademark, vendor or proprietary product does not constitute a guarantee or warranty of the product by the USDA and does not imply its approval to the exclusion of other products that may also be suitable. This type of information is solely provided to assist the reader in better understanding the scope of the research and its results.

(36 psi). Two double direction boom backs were installed at each of the towers (although not at the cart). Spans were 48.8 m (160 ft) in length except for the center span with the guidance system which was a 47.5 m (156 ft) span. The machine moved at about 2.1 m min^{-1} (7 ft min^{-1}) at the100% setting. Equivalent depths of water were applied for both irrigation methods for the same crop.

The PLC-based control system activated grouped networks of electric over air-activated control valves. Thirty 15-meter (50 ft) wide banks of sprinklers were controlled with this system (15 MESA banks, 15 LEPA banks.) Both the depth and method of irrigation were varied depending on the location of each plot in the field. When not being used, low-cost pneumatic cylinders lifted the LEPA heads above the MESA heads to avoid spray interference when the MESA is operating over a given plot width and length. Water application depths were varied by modulating pulses of water through the sprinkler nozzles on and off to achieve targeted, variable application amounts on each predefined area (or plot) as the machine moved down the field. The controller, communications and modifications to the water application methods utilized off-the-shelf components as much as possible

The amount of water applied was adjusted by pulsing nozzle heads on and off to achieve a targeted, variable depth based on a predefined digital map stored in the PLC (or in a base computer) of depths for each nozzle location as the machine moved down the field. As was the case with other site-specific controllers in the literature, machine speed was set by the Valley panel, which established the maximum application depth and the PCL controller managed the sprinkler heads. Treatments were a percentage of maximum by varying on times in a 60 second cycle time. However, our software allowed us to easily change the cycle time if we needed to make adjustments.

Distributed Sensor Systems and Control

A distributed wireless sensor network (WSN) was integrated into the existing site-specific linear move sprinkler irrigation system described above. Field conditions were monitored by six in-field sensor stations with Campbell CR200 dataloggers (Campbell Scientific, Inc, Logan, UT) distributed across the field based on a soil property map and monitored soil moisture, soil temperature, and air temperature. WaterMark soil water sensors (Irrometer Company, Inc., Riverside, CA) were used in the decision support process and were calibrated with a neutron probe and individually identified for their response ranges at each zone. All in-field sensory data were sampled on 1 second intervals. A nearby weather station monitors micrometeorological information on the field, i.e., air temperature, relative humidity, precipitation, wind speed, wind direction, and solar radiation. Communication signals from the sensor network, weather station and PLC irrigation controller to the base station were successfully interfaced using low-cost Bluetooth wireless radio communication.

Decision Support System

A Windows based decision making program was developed with a simple click-and-play menu using graphical user interface (GUI), and optimized to adapt changes of crop design, irrigation pattern, and field location. This system offered stable remote access to field conditions and real-time control and monitoring of both inputs (field data) and outputs (sprinkler controls). In-field micrometeorological information was displayed on a geo-referenced field map at the base station screen. The PLC on the machine provided the current geo-referenced location of the machine from an on-board differential GPS. The base computer recalculated the position of individual sprinkler heads, analyzed soil water status, calculated crop water needs, updated machine instructions and sent control commands to the irrigation controller to site-specifically operate each individual sprinkler group and apply a specified depth of water for every time step (1 sec) based on criteria in a predetermined management map. An algorithm for nozzle sequencing was developed as part of the decision support software to stagger nozzle-on operations so as evenly distribute irrigation system flow rates over the 60-sec cycle to avoid hydraulic surges. Sensor-based closed-loop irrigation was highly correlated to catch can water with r^2=0.98.

CONCLUSIONS

Automated site-specific sprinkler irrigation system can save water and maximize productivity, but implementing automated irrigation is challenging in system integration and decision making. Irrigation decisions can be implemented site-specifically based on feedback from soil water and environmental conditions from distributed in-field sensor stations using wireless radio communications. The performance of the system was evaluated with the measurement of water usage and soil water status throughout the growing season.

Integration of the decision making process with the controls is a viable option for determining when and where to irrigate, and how much water to apply. Distributed in-field sensors offer a major advantage in supporting site-specific irrigation management that allows producers to maximize water productivity while enhancing overall profitability.

There are many reasons why site-specific sprinkler irrigation has not generally been a commercial success to date. These include the fact that servicing hardware and software on advanced, integrated systems can be difficult. Much hardware troubleshooting could be done via the internet from a central location and defective parts, computer cards or chips changed by on-site technicians, but the support infrastructure is not developed. Another reason is the lack of decision support applications (software) that is needed to take full advantage of the capabilities of these systems. This is likely due to the potential liability inherent in any decision support system, which has delayed their implementation. Every decision support application would have to be tailored to fit each individual field and even simple mistakes can have costly consequences. Growers usually do not have the interest, knowledge or the time to fuss with software; thus, dealers or consultants would likely have to provide this service. Specialized, continual training on the hardware, software and advanced agronomic principles would also be needed for dealers, technicians and other personnel to service these systems.

Additional Information

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