Wireless Sensor System for Variable Rate Irrigation

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Abstract. *Variable rate irrigation (VRI) systems use intelligent electronic devices to control individual sprinklers or groups of sprinklers to deliver the desired amount irrigation water at each specific location within a field according to VRI prescriptions. Currently VRI systems, including software tools for generate prescription maps, are commercially available for VRI practices. However, algorithms and models are required to determine the desired amount of water that needs to be applied based on the temporal and spatial variability of soil and plant characteristics. While irrigation scheduling can be based on soil water balance calculations, direct monitor of plant growing status is another method that has potential application for irrigation scheduling. Plant canopy temperature is related with plant water stress. Plant height is useful as an indicator of plant health conditions and can be used to estimate yield potential. Therefore, measurements of plant canopy temperature and plant height coupled with spatial information in field can be used for determining VRI water depths. A wireless data acquisition (WDAQ) system was developed to collect plant canopy temperature and plant height data in the field. The system included two WDAQ units installed on a 4-span center pivot VRI system. One unit was mounted at the middle of the third span, and the other at the fourth span from the pivot. Each unit consisted of a GPS receiver, programmable data logger, infrared temperature sensor, ultrasonic distance sensor, solar power supply, and wireless data transmitter/receiver. Inferred temperature sensors were used to detect the canopy temperature while the ultrasonic distance sensor to measure plant height. The WDAQ system was capable of continuously and simultaneously making measurements of plant canopy temperature and plant height, and recording spatial coordinates at each measurement location as the center pivot moved around the field. Data collected were wirelessly transferred to a wireless receiver for data process. This WDAQ system has been tested in field. The results indicated the system had great potential to be used for automatic creation of VRI prescription maps and plant-based irrigation scheduling.*

Keywords. *Variable rate irrigation, sensors, canopy temperature, plant height*

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Instruction

VRI technologies allow the producers to site-specifically apply irrigation water at variable rates within the field to account for the temporal and spatial variability in soil and plant characteristics. Adoption of VRI has the potential to improve water use efficiency. Currently VRI systems, including software tools for generate prescription maps, are commercially available for VRI practices. However, lack of algorithms and models to determine the desired amount of water to be applied based on the temporal and spatial variability of soil and plant characteristics constrained the adaption of VRI.

Use of plant canopy temperature as an indicator of crop water stress is one of the plant-based methods for irrigation control. Thermal sensing technologies have been used as tools for water stress detection and irrigation scheduling (Jackson, 1986; Cohen et al., 2005; Evett et al., 1996; O'Shaughnessy and Evett, 2009). Plant height or plant growth rate could be used as an indicator of plant health status and yield potential (Sui and Thomasson, 2006; Yin et al., 2011; Yin et al., 2012; Sui, 2014). With an understanding of the relationship between plant height and production-related inputs, a plant height could be useful information for predicting water needed by the plant.

The objective of this research was to develop a center-pivot-mounted wireless data acquisition system. As the pivot moves around the field, the system will wirelessly and automatically measure plant height and plant canopy temperature along with spatial coordinates in real time in situ for variable rate irrigation.

Material and Method

A wireless data acquisition (WDAQ) system was built to perform real-time in-situ measurements of plant height and plant canopy temperature for VRI. The WDAQ system was installed on a center pivot irrigation system at the Research Farm of USDA-ARS Crop Production Systems Research Unit at Stoneville, MS (latitude: 33°26'30.86", longitude: -90°53'26.60"). The system was made of two separate units. Each unit consisted of an ultrasonic distance sensor, an infrared temperature sensor, a data logger, a global position system (GPS) receiver, a spread-spectrum radio, and a solar power supply (Fig. 1). The ultrasonic distance sensor (TSPC-30S1-232, Senix, Hinesburg, VT) was used to measure the plant height. The infrared temperature sensor (SI-111, Apogee Instruments, Logan, UT) was used to detect the plant canopy temperature. The GPS receiver was employed to determine the location where the plant height and canopy temperature were measured. The WDAQ system was able to take simultaneous measurements of the plant height, canopy temperature, and spatial coordinates of the measurement location as the center pivot moved around the field. Data of the plant height and canopy temperature collected at each measurement point were wirelessly transmitted through the spread-spectrum radios. The data could be downloaded to a computer from the radio device.

Lateral length of the center pivot irrigation system is 233 m. One unit (Track 1) was installed at the middle of the third span of the pivot system, which is 140 m from the pivot, and the other unit (Track 2) was at the middle of the fourth span, 199 m from the pivot. The distance between the sensor and the canopy could be adjusted by moving the bracket up and down along the steel square tubing. In field operation, the ultrasonic distance sensor was kept at least 0.2 m above the plant canopy while the infrared temperature sensor was about 0.3 m above the canopy.

A CR1000 data logger (Campbell Scientific, Logan, Utah) was selected to collect data from the ultrasonic distance sensor, infrared temperature sensor, and the GPS receiver. All data collected were recorded in the data logger and were transmitted to the RF401 spread-spectrum radio through a communication port of the data logger, and the RF401 radios transmitted the data wirelessly to a RF430 spread-spectrum radio. Then, the data were downloaded to a computer through the USB port in the RF430 radio.

WDAQ system was tested statically and dynamically. In the static tests, WDAQ system measured the heights of objects including paper boxes, soybean plants, and cotton plants as the pivot was at non-moving status. The measurement of the ultrasonic distance sensor was compared with the tape-measured distance to determine the system measurement accuracy. The dynamic tests were conducted in field with corn, soybean and cotton crops in 2015 and 2016 seasons.

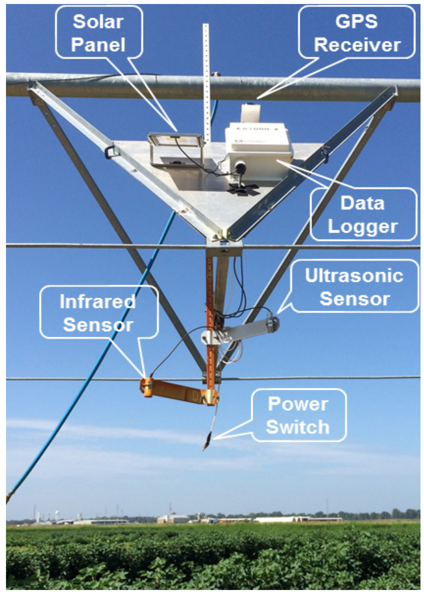

Fig. 1. One unit of the WDAQ system mounted on a center pivot irrigation system.

Results and Discussion

The sensor-measured height was compared with the manually tape-measured height. Static test results showed that WDAQ-measured height of paper boxes was very close to the manually tape-measured height. The measurement error varied from 0.2 cm to 3 cm in a measurement range from 14 cm to 209 cm. In the test with soybean plant, the average absolute measurement error was 5.8 cm within measurement range from 99.1 cm to 121.9 cm. It is notable that all of the soybean plant heights, except in one location, were underestimated by WDAQ system. In the test with cotton plants, the average absolute error of plant height measurement was 3.1 cm in a measurement range from 66.0 cm to 104.1 cm. The WDAQ measurements with soybean and cotton plants were strongly correlated with the tape-measurements (r^2=0.97).

The underestimate in soybean height by WDAQ system could be attributed to the misalignment between the ultrasonic sensor and the highest point of measured plant. Ultrasonic sensor measured the distance from the sensor detector to the closest plant leaf on the canopy. If the closest leaf under the sensor's field of view was not the highest point of the plant, the plant height would be underestimated by the WDAQ system. When the test was conducted, soybean plants was in the stage R5. The plant leaves started shedding and plant canopy was not closed well. This could cause the sensor-measured distance between the sensor and the canopy greater than the actual distance, and result in that the sensor-measured plant height was less than the tape-measured plant height. However, at that time cotton canopy was well closed. In comparison to the plant height measurement in soybean, cotton plant height measured by WDAQ system was closer to the tape-measured, and the measurement errors were distributed in a random pattern. Additionally, plant movement caused by wind could be another source of error with the WDAQ system measurements. Cotton plants were moved by wind less than the soybean plants.

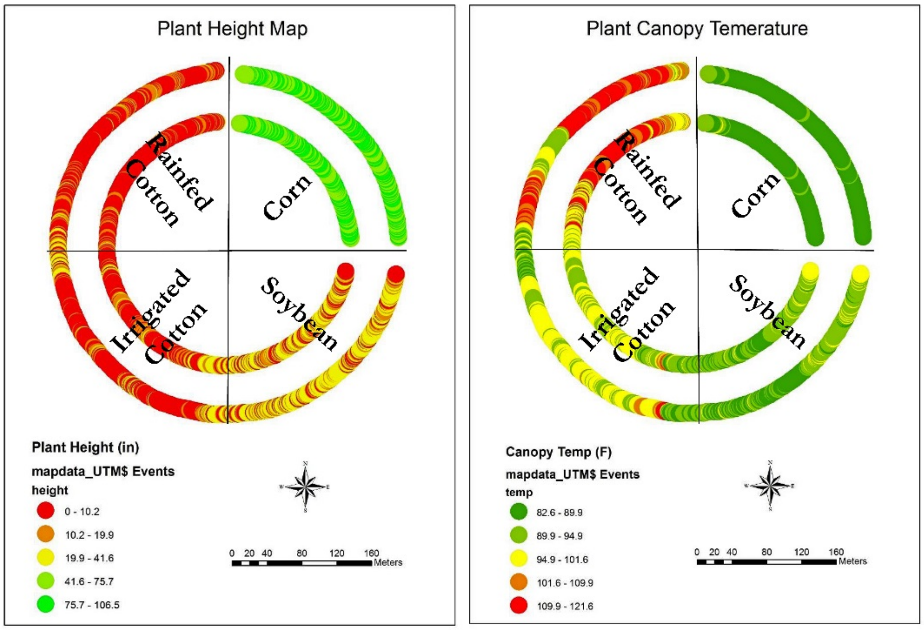

Fig. 2. Left: plant height map; Right: plant canopy temperature map. Using the WDAQ, corn field was scanned on June 11, 2015, and soybean and cotton fields on June 26, 2015.

The WDAQ system recorded about 3,200 measurement points from each sensor in one pivot circle (360 degree). Fig. 2 was the plant height and canopy temperature maps which were generated using the data collected by the WDAQ system in 2015. From the plant height maps it was obvious the system was able to determine the variation of plant height among crops and within a crop. In the time when the crops were scanned, corn plant was the tallest, cotton was the shortest, and the soybeans were in-between. Difference in canopy temperature was clear indicated in the canopy temperature maps. For example, canopy temperature of irrigated cotton plants was lower than that of the non-irrigated. Variability of canopy temperature within the rainfed cotton, irrigated cotton, and soybean fields was clearly shown up in the map as well. Variability in plant height and canopy temperature with each crop was caused by multiple parameters such as irrigation rate, fertilization rate, soil properties, etc. Analyses and use of the plant height and canopy temperature for variable rate irrigation and precision crop management would be reported in separate articles.

Previous studies showed the crop canopy temperature could be used to indicate plant water stress status. And the plant height was correlated with crop yield potential. Therefore, the canopy temperature and plant height data collected using the WDAQ system cpold be used as inputs to develop VRI algorithms or directly used as input parameters in an algorithm to general VRI prescription maps. The data loggers used in the system have more inputs available. By adding other types of sensors to the inputs, this WDAQ system could be easily expanded to measure more parameters in field.

Smmary

A WDAQ system was developed to measure the plant height and crop canopy temperature. The system was mounted on a center pivot irrigation device. The system was captable of scanning plant canopy to take simultaneous measurements of the plant height, canopy temperature, and spatial coordinates of the measurement locations as the center pivot moved around the field. The data collected using this system could be used to investigate plant responses to water stress and develop algorithms for variable rate irrigation and irrigation automation. More field tests will be conducted to systematically evaluate the performance of this WDAQ system. This system could be upgraded through adding more sensors to measure more plant characteristics.

Disclaimer

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