A Decision Support Tool for Managing Precision Irrigation with Center Pivots

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Abstract

A soil moisture sensor-based variable rate irrigation (VRI) decision support system was developed and tested to quantify the potential of integrated variable rate irrigation (VRI) with advanced irrigation scheduling driven by soil moisture sensor data. The decision support system consists of a wireless soil moisture sensing array, a web-based user interface and a VRI-enabled center pivot irrigation system. The soil moisture sensing array was installed to monitor soil moisture within delineated irrigation management zones. At the interface, the soil moisture data were used by an irrigation scheduling tool running in the background to develop irrigation scheduling recommendations by zone. The recommendations were then downloaded to the VRI controller on the center pivot as a precision irrigation prescription.

Introduction

Irrigation is becoming an essential component of farming in many areas of the world. This results in growing competition for available fresh water supplies between agriculture, industry and residential uses. An indicator of this competition is that during the last few decades, ground water is depleting at an alarming rate in many agricultural areas. In addition, agriculture will need to produce more food to address the needs of a growing population. If irrigated agriculture is to expand in order to meet growing demands for food, then new irrigation practices and tools must be developed for more efficient water use. Precision irrigation is one possible approach (Vellidis et al., 2013).
Irrigation decision support tools have been developed and applied in the most intensively farmed areas in the world since the early 1990's. Smith (1992) described the CropWat model which estimates crop water demand under different irrigation strategies. It utilizes the Penman-Monteith equation to calculate the crop evapotranspiration and a crop growth model to estimate growth and yield in conjunction with the evapotranspiration. Steduto et al. (2009) developed the AquaCrop model, which calculates the yield productivity in relation to the amount of water used. However, the model is complicated and uses several variables such as air temperature, reference evapotranspiration, soil evaporation, stomatal conductance and water productivity coefficient. Thysen and Detlefsen (2006) developed the PlantInfo Irrigation manager. This manager uses a crop and water model and requires downloadable weather data. The downloading of weather data and remote-sensing images were essential for IrriSatSMS (Car et al, 2012) as well. The IrriSatSMS manipulated weather data, crop coefficient (Kc) measurements and data from satellite images on a server in order to calculate the daily water balance. A website was also a part of the system with the server visualizing

Liakos, V., G. Vellidis, M. Tucker, C. Lowrance, X. Liang. 2015. A decision support tool for managing precision irrigation with center pivots. In: J.V. Stafford (Ed.), Precision Agriculture '15 - Papers Presented the 10th European Conference on Precision Agriculture (10ECPA), Tel Aviv, Israel, p677-683, doi:10.3920/978-90-8686-814-8.

the results. WaterSense (Inman-Bamber et al, 2007) is another decision support tool which was developed to optimize yield with a given soil type, precipitation and irrigation events. For better yield optimization, it uses crop models and algorithms to identify optimal irrigation strategies. Finally, IrrigatorPro is a well-known public-domain model used in the USA for optimizing irrigation in crops like cotton, peanuts and corn. Newer versions of the model use soil water tension (potential) and estimates of the phenological stage of the planted crop to deliver yes/no irrigation decisions. IrrigatorPro is one of a very few models that rely on measured soil moisture to make irrigation decisions. However, even IrrigatorPro does not recommend irrigation amounts. A smart irrigation decision support system should store sensor data and recommend the optimum allocation of irrigation water. The decision support system should also be capable of accepting data from various sensor types and formats.
Farmers require reliable recommendations in order for them to optimally use irrigation water. To meet these requirements, this paper describes a decision support system for precision irrigation and evaluates the results. The potential benefits of the decision support system are many because it can manipulate many data sets at the same time and represents the soil moisture data with user-friendly graphics. Moreover the web-based interface makes recommendations based on delineated irrigation management zones. Downloadable prescription irrigation maps can be used to initiate center pivot-based VRI.

Material and methods

The decision support system consists of a wireless soil moisture sensing array with a high density of sensor nodes, a web-based user interface, and supporting software.

Soil moisture sensing array

The University of Georgia Smart Sensor Array (UGA SSA) consists of smart sensor nodes (Figure 1) and a base station. The term sensor node refers to the combination of electronics and sensors installed within a field including a circuit board, a radio frequency (RF) transmitter, soil moisture sensors and temperature sensors. Each sensor node includes up to three Watermark® (Irrometer, Riverside, California, USA) soil moisture sensors and up to two thermocouples for measuring soil and/or canopy temperature. The three Watermark® sensors are integrated into a probe as shown in Figure 1. Soil moisture is measured in terms of soil water tension (potential) and reported in units of kPa. The radio frequency transmitter (Synapse, Huntsville, Alabama, USA) is responsible for transmitting sensor data. The transmitter is an intelligent, cheap, and low-power 2.4 GHz radio module. At the center of each field, a base station receives the data from all nodes at hourly intervals. The base station stores the data on a solar-powered netbook computer and transmits the data via cellular modem to a File Transfer Protocol (FTP) server hourly.
A wireless mesh network is used for communication between the nodes. Data are passed from one node to the other through the RF transmitter which also plays the role of a repeater. If any of the nodes stop transmitting or receiving, or if signal pathways become blocked, the operating software reconfigures signal routes in order to maintain data acquisition from the network. The published range of the RF transmitter is 500 m although its effective range has been observed to exceed 750 m.

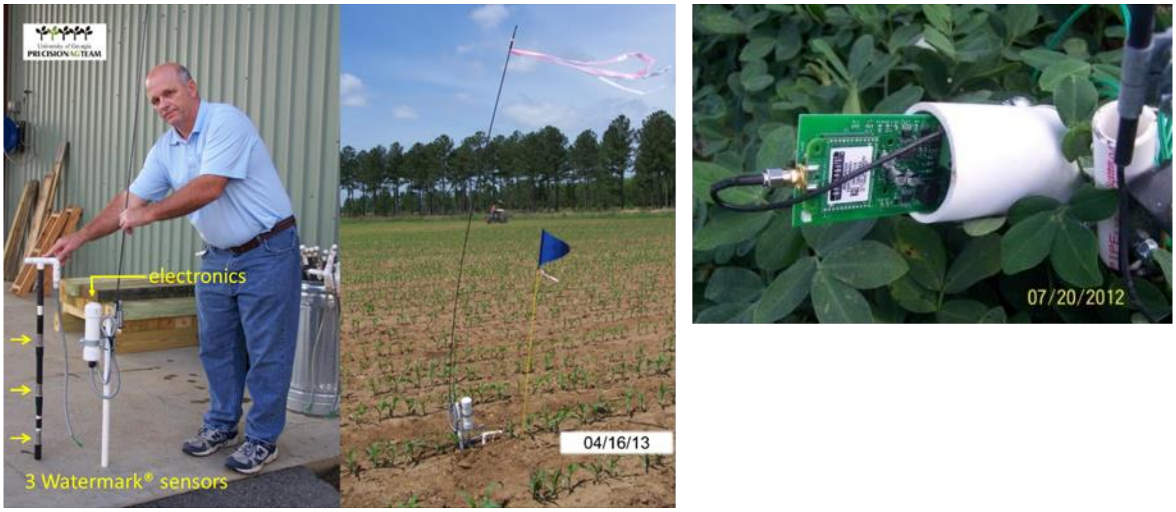

Figure 1. A UGA SSA probe with the three Watermarks® soil moisture sensors (left) and installed (center). The probe can be easily installed after planting and extracted prior to harvest. The electronic components of the UGA SSA node (right) include the main circuit board and the radio board. The black wire connects the radio board to the antenna.

To overcome the attenuating effect of the plant canopy, the RF transmitter antenna is mounted on spring-loaded, hollow flexible fiberglass rod (6 mm diameter). Variable antenna heights are used to ensure that the antenna is always above the crop canopy. The variable lengths are achieved by varying the length of the fiberglass rods. Rods which are 2.5 m long are used for low-growing crops like cotton, soybeans, and peanuts (Figure 1) and rods which are 4.5 m long are used for tall crops like corn. This design allows field equipment such as sprayers and tractors to pass directly over the sensors without damaging them. This is a feature that is typically not found on commercially available wireless soil moisture sensors as most of those require a solar panel to power the sensor and telemetry. The sensor boards used in the UGA SSA are powered by two 1.5 V alkaline batteries which in our system have a life of more than 150 days which spans an entire growing season. To optimize battery life, the nodes are programmed to be in a low-current sleep mode when not transmitting.

<u>Web-based users interface</u>

To date our system has been used primarily in fields located in southern Georgia, USA, which are irrigated by center pivot irrigation systems. The base is usually located at the pivot point for easy access. The base station sends the node data to an FTP server hourly using a cellular modem. The data are also stored on commercial server space which can manage geographic data with different formats including the GeoJSON (Geographic JavaScript Object Notation) format. GeoJSON is used for visual representation of the data. The FTP server stores the raw soil moisture data while the commercial server manipulates and processes the raw data, stores them after applying a classification process, and serves as the interface with users through a dedicated website. This classification process is very important for quick data manipulation and the functionality of the website.

The purpose of the web-based interface is to allow users to visualize their soil moisture data and to make irrigation recommendations. The PHP (Personal Home Page) and Javascript programming languages were utilized to create different visualizations of the soil moisture data. The different visualizations provide users and especially farmers with the opportunity to better understand the soil condition and irrigation management zone delineation within their fields. Thus, .php files were created to retrieve specific data from the server while .html files were generated for the data visualization. Moreover, PHP and Javascript programming languages use JSON (JavaScript Object Notation) format for better data organization and quick response to programming commands.

Irrigation recommendations

In addition to soil moisture data visualization, the web-based user interface offers irrigation recommendations. Aerial images as well as soil data from the United States Department of Agriculture Natural Resources Conservation (NRCS) web soil survey and ground measurements such as apparent soil electrical conductivity were utilized to delineate irrigation management zones for each field. The soil type within each irrigation management zone is considered the same. A modified Van Genuchten model is applied to convert the soil water tension data to volumetric water content. The Van Genuchten model is defined by Equation 1.

$$\theta(\psi) = \theta_r + [(\theta_s - \theta_r)/[1+(\alpha|\psi|^n)]^{1-1/n} \quad (1)$$

where, $\theta(\psi)$ is the water retention curve ($l^3 l^{-3}$)
$|\psi|$ is suction pressure ([l] or cm of water
θs is the saturated water content ($l^3 l^{-3}$)
θ_r is the residual water content ($l^3 l^{-3}$)
α is related to the inverse of the air entry suction, a>0 ([l^{-1}] or cm^{-1}
n is a measure of the pore size distribution, n>1

The Van Genuchten model uses the average of the hourly soil water tension data measured between 07:00 and 09:00 by all nodes within an irrigation management zone to calculate the volume of irrigation water needed to bring the soil profile back to field capacity. Each node's soil water tension value is a weighted average of the soil water tension values of the three Watermark sensors of the node (Figure 1). For most field crops, the sensors on the probe are arranged so that when installed they are at 20, 40, and 60 cm below the soil surface. The soil water tension values are weighted as shown in Equation 2.

$$(0.5)(\text{kPa at 20 cm})+ (0.3)(\text{kPa at 40 cm})+(0.2)(\text{kPa at 60 cm}) \quad (2)$$

Results and discussion

Soil moisture data visualization

Our precision irrigation decision support system was demonstrated and evaluated on 10 farmer fields and four university research farms during 2014. This resulted in many users of the data and to protect privacy, each user had a unique user ID and password which allowed

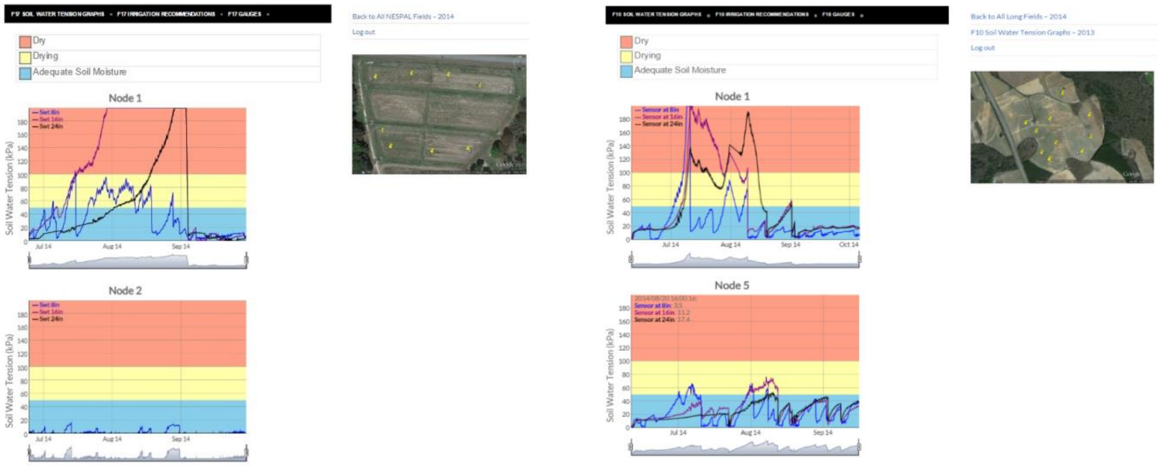

Figure 2. Soil moisture data visualization with graphs.

them access to their data only through our dedicated website (www.flintirrigation.com). The website is viewable from any internet-capable device including tablets and smartphones. The data are visualized in two different ways.

In the first visualization option, soil moisture data are displayed in the form of time-series graphs as shown in Figure 2. In this view, users can monitor the hourly soil moisture variability of the three different depths in real time from the installation date onwards. Moreover there is a bar under each graph which enables the users to zoom the graph for more detailed observation of soil moisture changes. To help farmers interpret the data, a color-coded background of blue, yellow, and red is used. The soil water tension range for the blue area is 0 kPa to 50 kPa indicating adequate soil moisture for most crops, for the yellow area 50 kPa to 100 kPa indicating drying soils, and for the red area 100 kPa to 200 kPa indicating dry soils. The soil water tension range of each color was selected based on the authors' experience and will likely be different for places with different climate and soil types. Field pictures are also placed next to the graphs showing the location of each node, contributing to better understanding by the user of the spatial variability of soil moisture within a field.

In Figure 2, the field on the left was cultivated with cotton while the field on the right was split between cotton (west side) and peanuts (east side). The soil moisture response at node 1 is much different than at node 2 (left field). This means that the soil profile at the location where node 1 was located is completely different than that at node 2 even though both nodes are close to each other. This also means that these two locations require different irrigation treatments. Spatial variability was also evident in the field to the right. One explanation for the variability in this field may be that node 1 was in the cotton crop while Node 5 was in the peanut crop.

The second visualization option uses analogue gauges showing the weighted average of soil moisture at the three measured depths in real time (Figure 3). The use of field pictures as a background is essential, as the location of each gauge in the picture corresponds to the real location of each node. The background colors of the gauges are the same as described above for the graphs. Furthermore, the size of the gauges can be enlarged by placing the cursor on the gauges. In Figure 3, the enlarged gauge shows a soil water tension value of 2.9 kPa which indicates nearly saturated soils. This view also presents the delineated irrigation management zones. This also helps the user to evaluate the irrigation management zones by comparing the values of the nodes within a zone.

Figure 3. Soil moisture data representation with analogue gauges.

Irrigation recommendations

The irrigation recommendations are presented in a window which displays an aerial image of the field (Figure 4). The aerial image is overlaid by the layer including the delineated irrigation management zones. At the bottom left corner of the window, a legend presents the irrigation recommendations for each zone. Irrigation recommendations are provided for shallow rooted (up to 0.38m) and deeper rooted (up to 0.76m) crops or for immature and mature crops. This is necessary because different volumes of irrigation water are required to replenish a shallow versus a deep soil profile.

For easy visualization, if an irrigation management zone is clicked then all the area polygons which belong at the same zone are highlighted. Additionally, the corresponding irrigation recommendation at the legend is also highlighted. Alternatively, by clicking on an irrigation recommendation at the legend, the corresponding zones are highlighted on the map.

Automating the decision support tool

During the 2014 growing season, farmers were able to review irrigation recommendations for their fields daily. Although the participating farmers did not always irrigate the amount recommended by our system, they did rely on the website for information which they used to decide on irrigation.

The next step in the development of our system is to automatically download the individual irrigation management zone recommendations to the variable rate control on VRI-enabled irrigation systems. This step is currently in development – the technical questions have been resolved but the solution has not yet been applied to an irrigation system. With this important modification, once the farmer reviews and approves the irrigation recommendations for each field, the VRI map will be automatically downloaded via cellular modem to the VRI controller. To irrigate using the recommendations, the famer would then just turn on the pivot. Moreover many pivots are enabled for remote start so the entire process could be done from a smartphone or from a desktop at the farm office.

Future work

One important factor for irrigation decision is the weather conditions. The current configuration of the web-based tool does not support weather predictions. However, farmers can visit other websites to find information about the weather forecast for an area. Considering that the weather forecast is very important, there are several research teams who are developing high resultion, high accuracy models for precipitaton forecasts. When these forecasts become reliable and available, they will be incorporated into our system to provide farmers with additional data with which to make an informed decision.

Figure 3. Website window with the irrigation recommendations for a field with two irrigation management zones.

Conclusions

The integration of a soil moisture sensor array with a web-based decision support tool showed promise as an alternative to existing decision support tools. The real time soil moisture data which are recorded by the sensor array and their direct transmision to a server enables farmers to supervise the soil moisture condition of their fields in real time. Moreover, the smart programming of the web–based decision support tool enables the whole system to make fast irrigation recommendation calculations. This tool can be very helpful for the farmers because it helps them to make decisions about variably applying irrigation water to address the spatial variability of soil moisture conditions. This ability is a key enabling technology for optimizing irrigation water use in the face of increasing demand and competition for available resources.

Acknowledgements

This work was funded by a grant from the United States Department of Agriculture Natural Resources Conservation Service Conservation Innovation Grants (CIG) Program titled "*Irrigation Automation to Improve the Efficiency of Water Resource Management in Row Crop Production in the Lower Flint River Basin of Georgia*."

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