# THE UNIVERSITY OF GEORGIA SMART SENSOR ARRAY FOR SCHEDULING IRRIGATION: NEW DEVELOPMENTS

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## Abstract

Irrigation has become essential to crop production in many agricultural areas of the United States. As a result, the competition for available fresh water supplies is increasing and in some regions, producers face diminishing water supplies. If irrigated agriculture is to survive in this competitive environment, we must use irrigation water efficiently and more cost-effectively. A soil moisture sensor-based variable rate irrigation (VRI) control 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 control 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 is installed to monitor soil moisture within delineated management zones. At the interface, the soil moisture data are presented with graphs and gauges and are used by an irrigation decision support tool running in the background to develop irrigation scheduling recommendations by zone. The recommendations are then downloaded to the VRI controller on the center pivot as a precision irrigation prescription.

## Introduction

Precision Agriculture (PA) is the result of the integration of technology in farming. The use of PA technologies in farm activities enables growers to cope with in-field variability and to handle and manage efficiently a vast amount of information (Fountas et al, 2006).

The aim of PA is the development of tools which can be used to assist growers and consultants to compile the appropriate information from a combination of raw data, documents and knowledge, to identify and solve problems, and to make an optimized decision (Rinaldi et al, 2005). Nowadays many growers use computers to monitor their crops or equipment (e.g. tractors, center pivots), to analyze field data and to track their transactions. This big change is mainly the result of access to the internet which plays the role of a data intensive library for agriculture. Furthermore, the internet enables growers to collect and evaluate large amounts of data from several devices located at different areas.

### Precision irrigation and irrigation decision support tools

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 agriculture 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 offers this promise (Vellidis et al., 2013).

Irrigation decision support tools have been developed and applied in the most intensive agriculture areas in the world actively since the early 1990's. Smith, (1992) described the CropWat model which estimates the crop water demands 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, water productivity coefficient, and many other indices. 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 was manipulating weather data, crop coefficient (Kc) measurements and data from satellite images on a server in order to calculate the daily water balance. Additionally, a website was also a part of the system where the server was visualizing 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 in USA for optimizing irrigation in crops like cotton, peanuts and corn. It measures the soil water potential and estimates 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 be able to store the sensor data and recommend the optimum allocation of water use by using models. The same system should integrate the available data and the irrigation models with the most efficient way and to accept various data formats.

Growers' demand for reliable recommendations and optimum water use is great. To deal with this issue, this paper describes a control system for precision irrigation and evaluates the results. The potentials of the control system are many because it can manipulate many data 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 while prescription irrigation maps can be downloaded to a center pivot to apply VRI based on the irrigation recommendations.

## Material and methods

The control system consists of a wireless soil moisture sensing array with a high density of sensor nodes and a web-based user interface.

### 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 transmitter, soil moisture sensors and temperature sensors. Each node allows the connection of up to three Watermark soil moisture sensors (Figure 1) and up to two thermocouples for measuring soil and/or canopy temperature. Soil moisture is measured in terms of soil water tension (potential) and reported in units of kPa. Responsible for the acquisition, analysis and transmission of the sensor data is the radio frequency transmitter (Synapse, Huntsville, Alabama, USA). This transmitter is an intelligent, cheap, and low-power 2.4 GHz radio module. At the center of each field, a base station is located which receives the data from all the nodes at 5 minute intervals. The base station stores the data on a solar-powered netbook computer and transmits the data via cellular modem to an FTP server hourly.

Wireless technology is used, for the communication between the nodes. Specifically, it utilizes a particular type of wireless network, which is called mesh. The node data passes from one node to the other through the RF transmitter, which plays the role of a repeater. If any of the nodes stops transmitting or receiving or even if signal pathways become blocked, the operating software re-configures signal routes in order to maintain data acquisition from the network. To overcome the attenuating effect of the plant canopy on the RF transmissions, the RF transmitter antenna is mounted on spring-loaded, hollow, 6 mm in diameter flexible fiberglass rods. This design allows field


Figure 1. The electronic components of the UGA SSA node are presented in the photo to the left. They include the main board which is connected with the three Watermarks® sensors and the radio board. The black wire connects the radio board with the antenna. The photo at the right shows a UGA SSA probe with the three Watermarks® soil moisture sensors. The probe can be easily installed after planting and extracted prior to harvest.

equipment such as sprayers and tractors to pass over the sensors without damaging them throughout the growing season – something which no other wireless system offers. The height of the antennas which are used in corn fields is approximately 4.5 m above the ground level, while in cotton and peanut fields it is 2.5 m. The variable antenna heights are used to ensure that the antenna is always above the crop canopy. The published range of the RF transmitter is 500 m although its effective range has been observed to exceed the 750 m.

The smart sensor boards used in the project were powered with 2 x 1.5 V alkaline batteries, which last for a growing season (>150 days). Lithium batteries are not a good solution for this system because several field experiments exposed their vulnerability to low voltage, especially at levels below 2 V. Furthermore, to optimize the battery life, the boards were programmed to set themselves in a low-current sleep mode when not transmitting data.

**Web-based users interface**

Currently the base station consists of a netbook computer, deep-cycle marine battery, and a solar panel to charge the battery. It is usually located at the pivot point of the center pivot irrigation system 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 GeoJSON (Geographic JavaScript Object Notation) format which are used for visual representation of the data. The responsibility of the FTP server is to store the raw soil moisture data while the commercial server manipulates and processes the raw data and stores them after applying a specific classification. This classification process is very important for the functionality of the website and the quick data manipulation.

The purpose of developing the web-based interface is to visualize the soil moisture data and to make irrigation recommendations. PHP (Personal Home Page) and Javascript programming languages were utilized to create different representations of the soil moisture data. The different representations provide growers with the opportunity to better understand the soil condition and the 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 representation. 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 representations, 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 website 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 and obtained from the NRCS web soil survey. A modified Van Genuchten model is applied to convert the soil water tension data to volumetric water content. In our application, the model uses the average of the hourly water tension data measured between 07:00 and 09:00 by all nodes within an irrigation management zone. The Van Genuchten model is defined by the function:

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

where:

$\theta(\psi)$ is the water retention curve ($L^3L^{-3}$)
$|\psi|$ is suction pressure ([L] or cm of water
$\theta s$ is the saturated water content ($L^3L^{-3}$)
$\theta_r$ is the residual water content ($L^3L^{-3}$)
$\alpha$ 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

## Results and discussion

**Soil moisture data visualization**

Our precision irrigation control system was demonstrated and evaluated on 10 grower 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 userid and password which allowed 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

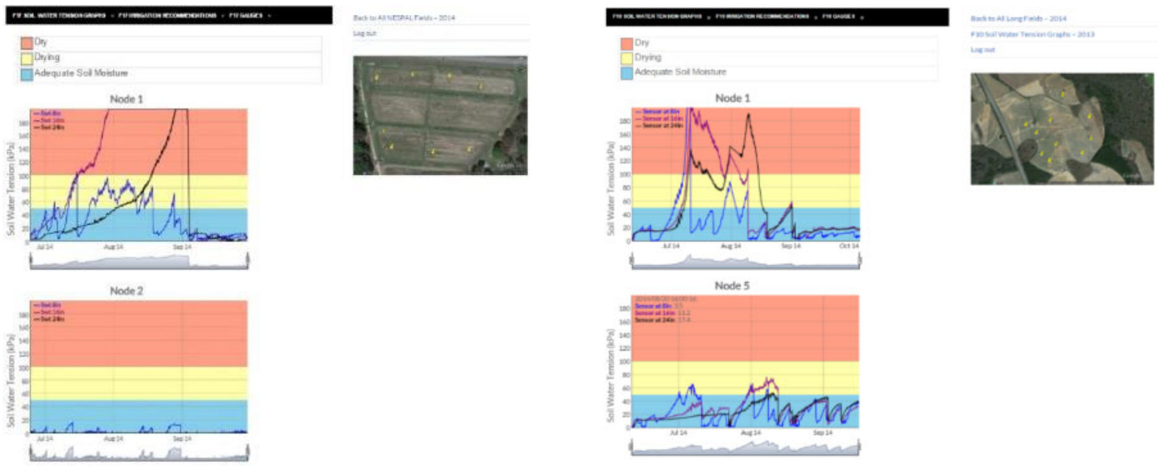


Figure 2. Soil moisture data representation with graphs. The left field was cultivated with cotton while the right half field with cotton and the other half with peanuts. The soil moisture response at node 1 is much different than at node 2 (left field). This means that the soil profile at the location where node 1 was placed is completely different than that at node 2 even if both nodes are close to each other. This means that these two locations require different irrigation treatments. The spatial variability was also present in field to the right. One explanation for the variability in this field may be that node 1 was placed in the cotton crop while Node 5 was in the peanut crop.

smartphones. The data are available in two different representations. In the first option, soil moisture data are displayed in the forms of time-series graphs (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 in or zoom out graph for more detailed observation of the soil moisture changes. To help growers 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 may 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 the user's better understanding of the spatial variability of soil moisture within a field.

The second view option uses analogue gauges showing a 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

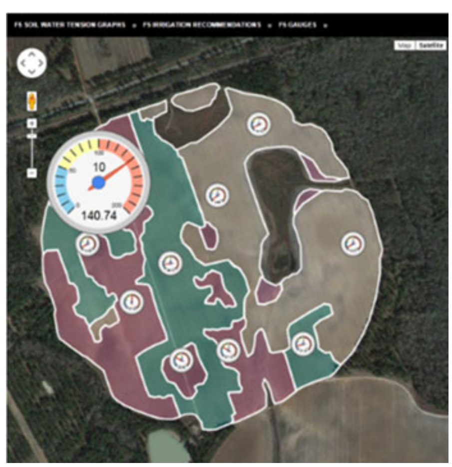


Figure 3. Soil moisture data representation with analogue gauges. Gauges are enlarged by placing the cursor over their image. The information depicted from the enlarged gauge is that the soil water tension at node number ten is 140 kPa. According to this gauge, the soil in this location is dry and the grower should irrigate.

gauges. This view also presents the delineated irrigation management zones. This also helps the users to evaluate the irrigation management zones by comparing the values of the nodes within a zone.

**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 irrigation zone individually. 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, growers were able to review irrigation recommendations for their fields daily. Although the participating growers did not always irrigate the amount recommended by our system, they did rely on the webiste 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 grower 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 a grower's house.

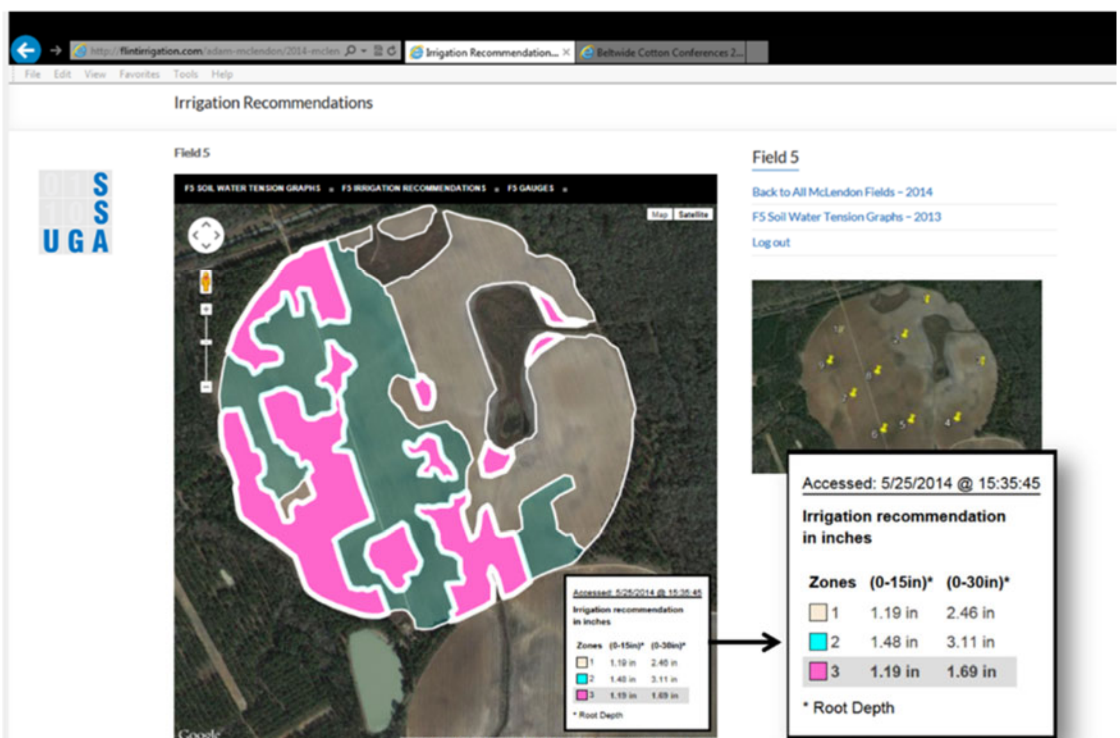


Figure 4. Window with the irrigation recommendations. The aerial image of the field is overlaid by the irrigation management zone layer. The legend at the bottom left shows the irrigation recommendations for shallow rooted (up to 15in) and deeper rooted (up to 30in) crops or for immature and mature crops. In the figure, the irrigation recommendations for zone 1 were selected and the area polygons which belong to the zone 1 were highlighted.

**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, growers can visit other websites to find information about the weather forecast for an area. Considering the weather forecast is very important there are several research teams which 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 growers with additional data with which to make an informed decisions.

## 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 growers 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 growers 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.

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