DYNAMIC VARIABLE RATE IRRIGATION SCHEDULING WITH UNIVERSITY OF GEORGIA SMART SENSOR ARRAY (UGA SSA)

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Abstract

Population and economic growth as well change social values about the importance of water quality and the environment. Moreover, American water right claims will continue the growing U.S. demand for water resources. Furthermore, projected climate change – through warming temperature and shifting precipitation patterns – is expected to reduce water supplies and increase water demand. If irrigated agriculture is to survive in this demanding environment, we must use irrigation water efficiently and cost-effectively. The University of Georgia Smart Sensor Array (UGA SSA) is a wireless soil moisture sensing system able to monitor a high number of sensor nodes. At the web interface, the soil moisture data are used by an irrigation decision support tool running in the background to develop irrigation scheduling recommendations. In 2015 an experiment was conducted to evaluate the performance of a linked dynamic Variable Rate Irrigation (VRI) system driven by real-time soil moisture data from the UGA SSA. The study was conducted in a 225ac field in southwestern Georgia. Initially, the study field was divided into irrigation management zones (IMZs). Three years of soil moisture data collected by the UGA SSA in this field were used for the delineation of the irrigation management zones. The field was divided into alternating conventional irrigation and dynamic VRI strips with each strip 120 rows wide. In three of the six strips, irrigation scheduling was based on Irrigator Pro recommendations and water applied uniformly. The other three strips were divided into IMZs which were irrigated individually based on UGA SSA recommendations. After planting, UGA SSA sensors were installed in each of the IMZs. Soil moisture sensor data were used to dynamically develop irrigation scheduling recommendations for each IMZ in the strips where UGA SSA recommendations applied. Soil moisture data from each IMZ were automatically converted into irrigation recommendations and then into a prescription map which was downloaded remotely to the pivot VRI controller. The results showed that the conventional (Irrigator Pro) strips received much more irrigation water than the strips scheduled with the UGA SSA.

Introduction

Demands on agricultural water supplies are likely to increase over time as alternative nonfarm uses of water continue to grow. Energy-sector growth is expected to significantly increase water demands for an expanding biofuels sector, utility-scale development of solar power, innovation in thermoelectric generating capacity, and commercial oil-shale and deep shale natural gas development. Expansion in these competing water demands, especially with water supply/demand impacts expected with climate change, presents new challenges for agricultural water use and conservation. While substantial technological innovation has increased the efficiency of irrigated agriculture over the past several decades, significant potential exists for continued improvement. At least half of the irrigated cropland acreage across the United States is still irrigated with less efficient, traditional irrigation application systems. In addition, most irrigators do not make use of science-based irrigation scheduling tools or methods. Due to these problems Precision Agriculture (PA) has been developed the last 15 years. PA is the result of the integration of technology in farming. The use of PA technologies into farm activities enabled farmers 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 farmers, 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, 2014).

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).

Besides the agricultural development, there are still issues concerning the irrigation. Farmers are used to overusing the available fresh water and this supports the existence of a growing competition for available fresh water supplies. However, during the last decades ground water is depleting at an alarming rate in many agriculture areas. Thus, different decision support tools have been developed and applied in the most intensive agriculture areas in the world from the early 90's. Smith, (1992) described the CropWat 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 with the amount of water used. However, the model is complicated and uses several data such as air temperature, reference evapotranspiration, soil evaporation, stomatal conductance, water productivity coefficient, and many other indices. The great concern about the environmental consequences of farming activities led to the development of the Hydrologic (Richards et al, 2008) model. The aim of this model was the evaluation of the economic and environmental aspects of several irrigation methods, the increase of the water use efficiency in cotton as well as the optimization of cotton yield. For this reason, the model was based on the OZCOT model which simulates the water use and the crop growth (Hearn, 1994). Thysen and Detlefsen, (2006) developed the PlanteInfo Irrigation manager. This manager was utilizing a crop and water model while it was able to download 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. Another decision support tool is the CropSyst model (Stockle et al, 2003), which recommends the optimum allocation of water use in pear orchards based on the plant water potential. The calculation of the plant water potential was estimated from the tree transpiration by using Ohm's law analogy. The WaterSense (Inman-Bamber et al, 2007) is another decision support tool which was developed to optimize the 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, Irrigator Pro is a very well-known model in USA which was developed by the USDA-ARS for optimizing irrigation in crops like cotton, peanuts and corn. The original versions of the model used easily measured parameters such as precipitation and soil and ambient temperature to make irrigation decisions. Newer versions of the model use soil water potential instead however most users still rely on the older versions of the model.

One efficient irrigation application system is the center pivot equipped with VRI system. Usually, a VRI system allows farmers to define custom irrigation zones and to load them into the VRI controller. After that the system irrigates the field in accordance with the imported zones. The different rates of irrigation are achieved due to sprinklers ability to turn on and off or pulse at the precise speed. This sprinkler ability is an advantage for the system because the sprinklers are used more efficiently and can be turned off over drains, tracks, crops and wet areas. Also the ability of the system to lower the application rates reduces runoff and leaching at the high risk areas. Finally, the fact that the VRI system can be programmed to irrigate a specific part of a field corresponds to the decrease of the power consumption.

This paper describes a study which was conducted to evaluate the performance of a linked dynamic VRI system driven by real-time soil moisture data from the UGA SSA. The study was conducted in a commercial peanut field. Two different irrigation strategies (UGA SSA and the original version of Irrigator Pro) were used to schedule irrigation.

a b c

Figure 1. a) The irrigation management zones as delineated by using soil moisture data of previous years. b) The six strips where two different treatments were applied. At the red strips the UGA SSA recommendations were applied while at the blue strips the Irrigator Pro recommendations. c) The final zones which were used for the evaluation of the dynamic irrigation scheduling system. Strips including many polygons were irrigated with VRI while strips without polygons within received irrigation in uniform pattern.

Material and methods

The experiment was carried out in a 225ac commercial field. The field is located in the area of Leary of Georgia and it was planted with peanuts. Initially the field was divided into IMZs. The IMZs were delineated according to soil moisture data which were recorded by the UGA SSA system the last three years. This enabled us to identify the wet and dry areas in the field. After IMZ delineation, the field was divided into alternating conventional irrigation and dynamic VRI strips with each strip 120 rows wide. In three of the six strips, irrigation scheduling was based on Irrigator Pro recommendations and water applied uniformly. The other three strips were divided into IMZs which were irrigated individually based on UGA SSA recommendations (Figure 1). After planting, UGA SSA sensors were installed in each of the IMZs. The UGA SSA control system which was installed in the field consists of a wireless soil moisture sensing array with a high density of sensor nodes and a web-based user interface.

UGA SSA soil moisture sensing array

The University of Georgia Smart Sensor Array (UGA SSA) consists of smart sensor nodes (Figure 2) 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 2) 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.

Figure 2. 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.

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 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). Furthermore, to optimize the battery life, the boards were programmed to set themselves in a low-current sleep mode when not transmitting data.

UGA SSA 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 farmers 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.

UGA SSA irrigation recommendations

In addition to soil moisture data representations, the web-based user interface offers irrigation recommendations. As it was mentioned at the Materials and Methods section, in the current work, soil moisture data from the last 3 growing seasons and six random strips were utilized to delineate irrigation management zones. A modified Van Genuchten model was being applied to convert the soil water tension data to volumetric water content. 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

θs is the saturated water content (L^3L^{-3})

θ_r is the residual water content (L^3L^{-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

Irrigator Pro

Irrigator Pro is a computerized expert system designed to manage peanut irrigation and pest management decisions. The version of Irrigator Pro used in this study uses precipitation and soil and ambient temperature to make irrigation decisions. It is widely used in the southeastern USA by consultants and some farmers to schedule irrigation. It is used regularly by the grower who cooperated with us in this study.

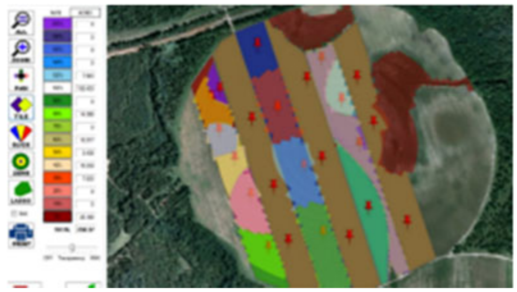

Figure 3. Irrigation Manager environment. Users can design several polygons within a field. After designing a polygon, they can select a specific color from the left list. Each color represent a specific irrigation rate. By coloring the polygons, it is clear that in every location is going to receive the desired water allocation.

Irrigation scheduling and VRI system

The pivot used at the experiment was an old but well maintained Valley pivot with FirstWater Ag VRI system (Atwood, Kansas) installed on it. The original Farmscan 7000 VRI controller was upgraded to allow for remote download of prescription maps. This required the installation and use of cellular modem.

During the growing season, at the beginning of each week, Irrigator Pro recommendations and UGA SSA recommendations were applied at the strips. The pivot required 3 days to make a complete circle due to the big size of the field. Because of this and the fact that some places within the field were drying very fast, the authors were changing the prescription maps up to three times per week. At the end of each week the results were evaluated.

The prescription maps were developed with the FirstWater Ag Irrigation Manager software version 2.1.0.11. This software allows the users to assign irrigation application rates to the predetermined IMZs and remotely upload the prescription maps to the VRI controller (Figure 3). Prescribed irrigation rates were compared to applied rates with tipping bucket rain gauges installed in the field. Specifically, at the begging of the experiment nine rain gauges were installed in nine randomly selected areas of the field. These areas were either in VRI strips or Uniform strips. The recorded rain gauge data also including precipitation data. To separate rain from precipitation, one rain gauge was installed outside of the field boundaries in order to record only precipitation.

Results and Discussion

UGA SSA soil moisture data vs Irrigator Pro soil moisture data

The UGA SSA website is accessible from any internet-capable device including tablets and 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 4 a, b). 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 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 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.

Figure 4a presents the soil moisture as recorded by the sensors at the strips where VRI strategy was applied. On the other hand, Figure 4b, presents the soil moisture readings at the strips where Irrigator Pro was applied uniformly. In most of the cases at Figure 4a the soil moisture tension ranges from 0 kPa to 100 kPa while in Figure 4b the soil moisture tension ranges from 0 kPa to 40 kPa. In some cases, in both Figures, the soil water tension exceeds the mentioned ranges due to the fact that the pivot required 3 days to irrigate the whole field.

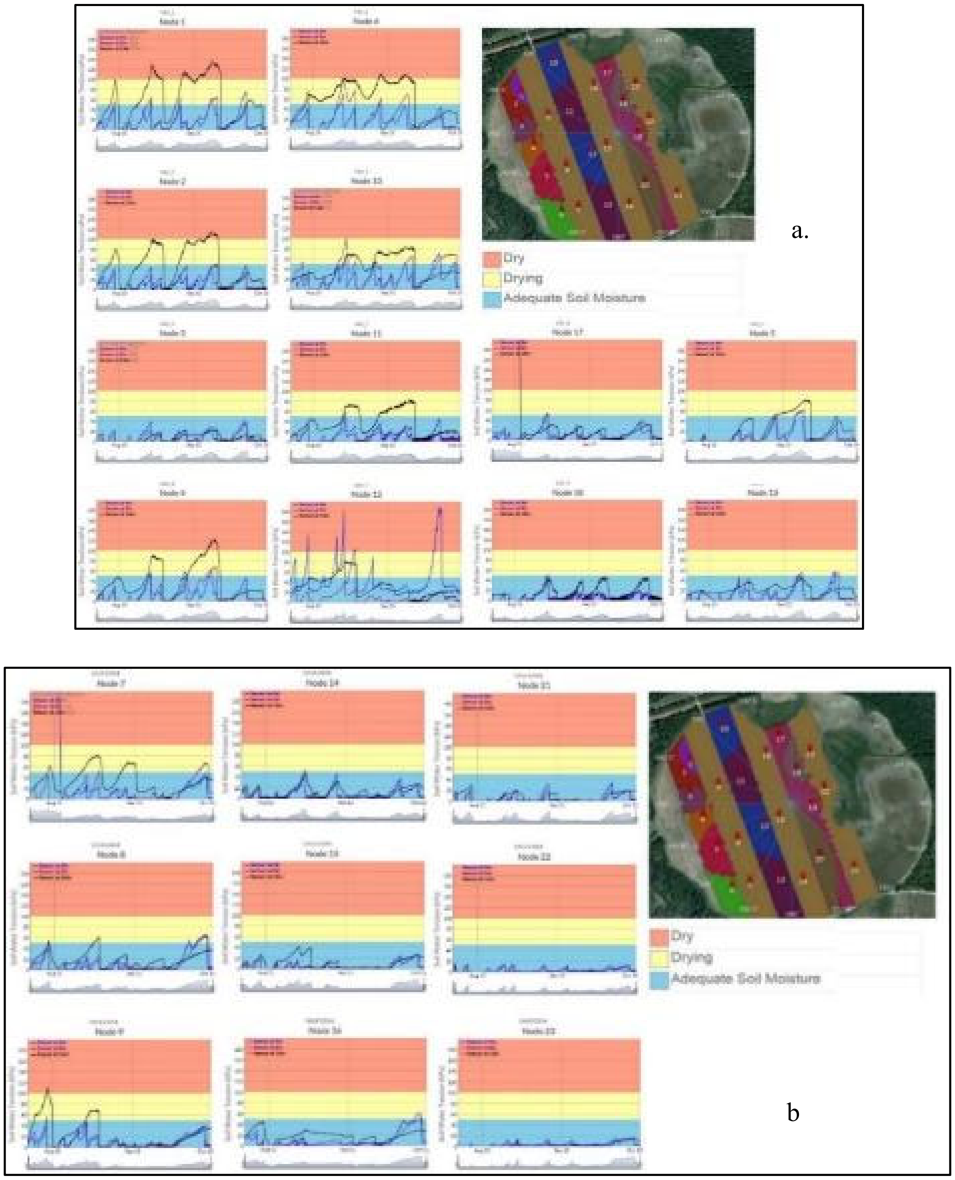

Figure 4. Soil moisture data representation with graphs. a) the zones where the nodes were installed were irrigated based on the UGA SSA recommendations with VRI technolgy, b) the zones where the nodes were installed were irrigated uniformly based on the Irrigator Pro. Irrigator Pro recommendations are more conservative than UGA SSA recommendations. This means that Irrigator Pro uses more water in order to keep the soil wet. On the other hand UGA SSA recommendations let the soil dry enough without causeing any damage on the plants. The picture next to graphs presents the pivot direction in degrees (0^o – 360^o) because the pivot was sending information about its current position in degrees every 5 minutes.

Figure 5. The picture of the field with the gauges. The size of the gauges can be enlarged by placing the cursor on the gauges.

The second view option uses analogue gauges showing a weighted average of the soil moisture at the three measured depths in real time (Figure 5). 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. This view also presents the delineated irrigation management zones.

Irrigation recommendations

The UGA SSA irrigation recommendations are presented in a window which displays an aerial image of the field (Figure 6). 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 immature (root length up to 15in) and mature (root length up to 0.76m) plants. 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.

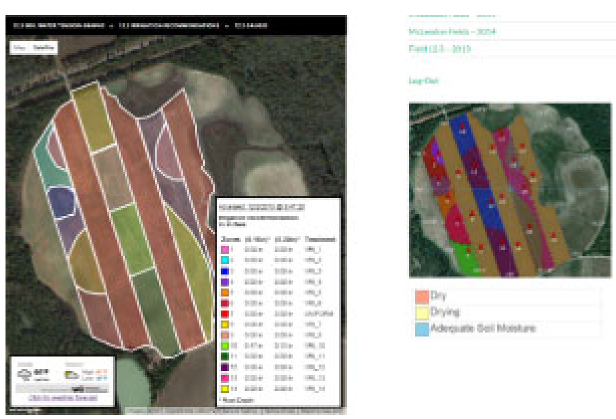

Figure 6. Window with the irrigation recommendations. The aerial image of the field is overlaid by the irrigation management zone layer and the strip layer. The legend at the bottom right shows the irrigation recommendations for immature (roots up to 15in) and mature (roots up to 30 in) plants respectively. The legend at the bottom left shows the weather forecast and the current weather conditions while there is an option for more detailed weather forecast including weather radar maps, too.

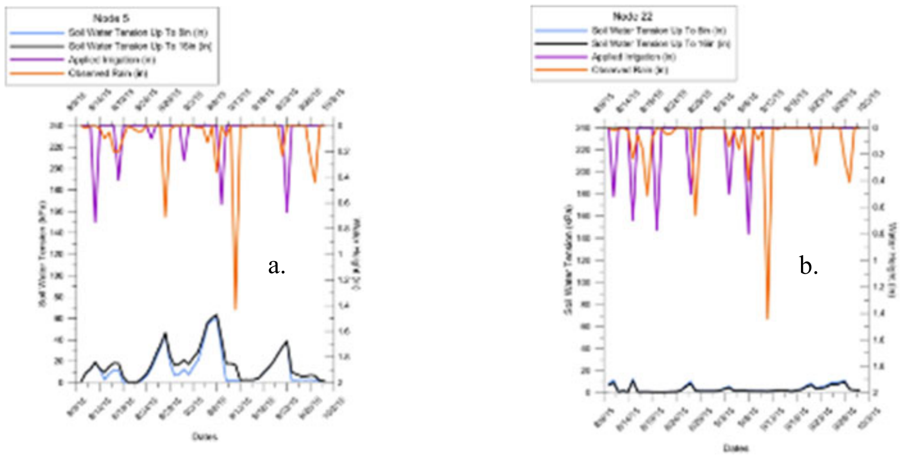

Figure 7. Example of the comparison between the two irrigation strategies. In both graphs the blue and black lines represent the weighted average of two swallow sensors and the three sensors respectively. The purple line presents the irrigation events and the orange line the precipitations. a) The area where Node 5 was installed received irrigation with VRI technology based on UGA SSA recommendations. b) The area where Node 22 was installed received irrigation uniformly according to Irrigator Pro recommendations.

UGA SSA vs Irrigator Pro

The evaluation of the two strategies is very important to understand how each irrigation method works. The installation of raingauges proved to be beneficial because it gave a clear view of the recommended irrigation events. Figure 7 shows two graphs and each graph represents a specific case. Node 5 was installed at an IMZ which received irrigation based on the UGA SSA recommendations. Node 22 was installed at a strip which was irrigated uniformly based on the Irrigator Pro recommendations. It is clear that at the UGA SSA case the range of the average soil water tension is from 0 kPa to 60 kPa. On the other hand, the average soil water tension of the Irrigator Pro case ranges between 0 kPa and 17 kPa. This means that the Irrigator Pro tends to keep the soil profile wet throughout the growing season. However, UGA SSA keeps the soil profile wet enough without stressing the plants and recommends irrigation only when plants need watering. A better look at the observed irrigation is making clear that both locations received six irrigation events. However the events took place in different periods. Node 22 received 4.1 in of irrigation water from the beginning of the growing season until the middle it while node 5 received 2.8 in throughout the growing season. This means the UGA SSA recommends less water than Irrigator Pro. Moreover UGA SSA distributes the water events in a better way throughout the growing season than Irrigator Pro.

The analysis of the irrigation data showed big differences at the recommended water allocations from the two irrigation strategies (Table 1). The average water allocations of UGA SSA recommendations is 2.93 in while the average water allocation of the Irrigator Pro is 4.03 in. This means that the Irrigator Pro suggested 1.1 in (average) more water allocations than UGA SSA. Considering that farmers pay 11$ for every inch of water per acre, If the farmer adopted the UGA SSA strategy thoughout the growing season then he would saved 247.5 in of water and $2722.5.

Future work - Automating the decision support tool

In the current work there was a try to irrigate the field according to the irrigation recommendations of both methods. However, sometimes it was difficult to irrigate the plants in the right time due to the big size of the field and the fact that some parts of the field were drying very fast and they required more water.

Having this in mind the next step in the development of the UGA SSA is to automatically download the irrigation management zone recommendations to the variable rate controller on VRI-enabled irrigation systems and to develop an algorithm by which the pivot will make the decision about its direction (clockwise or anticlockwise). This step is currently in development – the server has already been programmed to interpolate the hourly soil moisture data and to create high definition hourly irrigation prescription maps. By using this important modifications next year, once the

Table 1. UGA SSA and Irrigator Pro irrigation recommendations throughout the growing season.

UGA SSA		Irrigator Pro	
Node Number	Irrigation water (in)	Node Number	Irrigation water (in)
4	3.3	7	4.15
5	2.8	14	3.85
6	3.06	22	4.1
11	3.01		
13	2.8		
17	2.62		
Average	2.93	Average	4.03

farmer reviews and approves the irrigation recommendations for each field, the prescription 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 farmer's house.

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 were being recorded by the sensor array and their direct transmision to a server enabled the authors to supervise the soil moisture condition of the field in real time. Moreover, the smart programming of the web–based decision support tool enables the whole system to make fast irrigation recommendation calculations. The use of two different irrigation strategies gave the opportunity to evaluate the UGA SSA recommendations. The results showed that UGA SSA recomends less water allocations than the Irrigator Pro while the irrigation events distribution throughout the growing season is better in the UGA SSA case. Furthermore the results showed that the use of UGA SSA recommendations can help farmers to save water (247 in in average) and money ($2722 in average) thoughout the growing season. UGA SSA 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.

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