Management Zone Delineation for Irrigation Based on Sentinel-2 Satellite Images and Field Properties

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Abstract. *This paper presents a case study of the first application of the dynamic Variable Rate Irrigation (VRI) System developed by the University of Georgia to cotton. The system consists of the EZZone management zone software, the University of Georgia Smart Sensor Array (UGA SSA) and an irrigation scheduling decision support tool. An experiment was conducted in 2017 in a cotton field to evaluate the performance of the system in cotton. The field was divided into four parallel strips. All four strips were 240 m wide. Two strips received variable rates of irrigation based on the UGA SSA decision support tool (DST) while the other two received uniform irrigation based on the grower's practice. Sentinel-2 satellite images from the last two years were analyzed to find the NDVI (Normalized Difference Vegetation Index) and NDWI (Normalized Difference Water Index) variability of the field. Additionally soil electrical conductivity data, soil type data as well as elevation data were combined in the EZZone software to delineate irrigation management zones (IMZs). IMZs were delineated for the entire field but used only in the strips where irrigation was applied with variable rates. Eighteen UGA SSA sensor probes were installed in the 4 strips after planting to measure soil moisture. The UGA SSA system reported soil moisture data hourly and they were visualized on the UGA SSA web portal. The DST converted soil moisture data to actionable irrigation recommendations based on the latest soil moisture readings. This paper presents the results of the yield and irrigation water use efficiency (IWUE) comparison between the two irrigation treatments. The analysis of the data showed that the IWUE was considerably higher in the VRI strips than the strips irrigated uniformly.*

Keywords. *Decision Support Tool, Smart Irrigation, Internet of Things, Efficiency.*

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Introduction

Farming is the dominant water consumer because it uses the 70% of the available fresh water. But demands on agricultural water supplies are likely to increase over time as alternative nonfarm uses of water continue to grow.

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. Ground water is depleting at an alarming rate in many agriculture areas and surface water supplies are becoming less predictable. At the same time, competition from other users is increasing. If irrigated agriculture is to survive this competition, new irrigation practices and tools must be implemented so that we can dramatically increase irrigation water use efficiency.

Soil properties such as soil type, water holding capacity, and soil depth affect crop yield and hence irrigation methods should be adjusted according to these properties (Duncan, 2012). Soil variability exists in most agricultural fields but is especially common in the Southeast. Irrigating fields uniformly overlooks this variability and results in over-applying water in some areas while under-applying in other areas of the field. Variable Rate Irrigation (VRI) allows growers to change their irrigation application rates in response to perceived or measured variability. The use of VRI is expected to increase productivity, improve water use efficiency, increase growers' profit and decrease nutrient run off. Variable rate irrigation application rates are coded into a prescription map. The prescription map for each field is typically developed jointly by the grower and VRI dealer on desktop software (Figure 1) and then downloaded to the VRI controller on the pivot. The field is divided into irrigation management zones (IMZs) and application rates assigned to each of the IMZs using whatever information is available. At the moment, the prescription maps are static. In other words, they are typically developed once and used thereafter. Current prescription maps do not respond to environmental variables such as weather patterns and other factors which affect soil moisture condition and crop growth rates. So although VRI is a great leap forward in improving IWUE, the system could be greatly enhanced by having real-time information on crop water needs to drive irrigation application rates. One approach for creating dynamic prescription maps is to use soil moisture sensors to estimate the amount of irrigation water needed to return each IMZ to an ideal soil moisture condition. The individual IMZ application rates can be estimated with decision support tools (DST).

Decision support tools for irrigation

Several DSTs 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 well-known model in USA for optimizing irrigation in crops like cotton, peanuts and corn. It uses soil matric potential, soil temperature, as well as the specific growth stage of the planted crop to make Yes/No irrigation decisions. It does not recommend irrigation amounts. This paper describes the first application of dynamic VRI and an associated DST on cotton in Georgia. During the experiment two different irrigation strategies (dynamic VRI and grower's standard method) were used and evaluated throughout the growing season.

Material and methods

The experiment was conducted during the 2017 growing season in a 40 ha cotton field located in southwestern Georgia near the town of Colquitt. The field was divided into four parallel strips two of which are irrigated using dynamic VRI (20 ha total) and two are irrigated uniformly (20 ha total) using the grower's standard irrigation practice which was to apply 1.5 cm every Tuesday and Saturday (Figure 1a). The dynamic VRI strips were divided into several irrigation management zones (IMZs). The IMZs were delineated by combining data in the EZZONE software (https://ezzone.pythonanywhere.com). The combined data were soil electrical conductivity, RTK elevation and Normalized Difference Vegetation Index (NDVI) and Normalized Difference Water Index (NDWI) from previous growing seasons. The NDVI and NDWI values were extracted from Sentinel-2 satellite images with 10m and 20m spatial resolution respectively (Figure 2a; 2b). After the irrigation zone delineation four strips were designed. IMZs were delineated for the entire field but used only in the strips where irrigation was applied with variable rates. (Figure 1b; 1c).

Each IMZ was equipped with at least on University of Georgia Smart Sensor Array (UGA SSA) sensor node to provide information on soil moisture (Figure 1d). The UGA SSA (Vellidis et al. 2016; Liakos et al. 2017) consists of smart sensor nodes and a base station. The term sensor node refers to the combination of electronics and sensor probes installed within a field at a one location (Figure 3). The electronics include a circuit board for data acquisition and processing and a radio frequency (RF) transmitter. In the current design, the UGA SSA supports Watermark® soil moisture sensors. Each soil moisture probe integrates up to three Watermark® sensors as shown in Figure 3b.

Additionally, each node supports 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. For this study, each probe contained three Watermark which when installed were at 15 cm, 30 cm and 41 cm below the soil surface. This depth was selected based on the soil water extraction response we have seen in cotton during past studies.

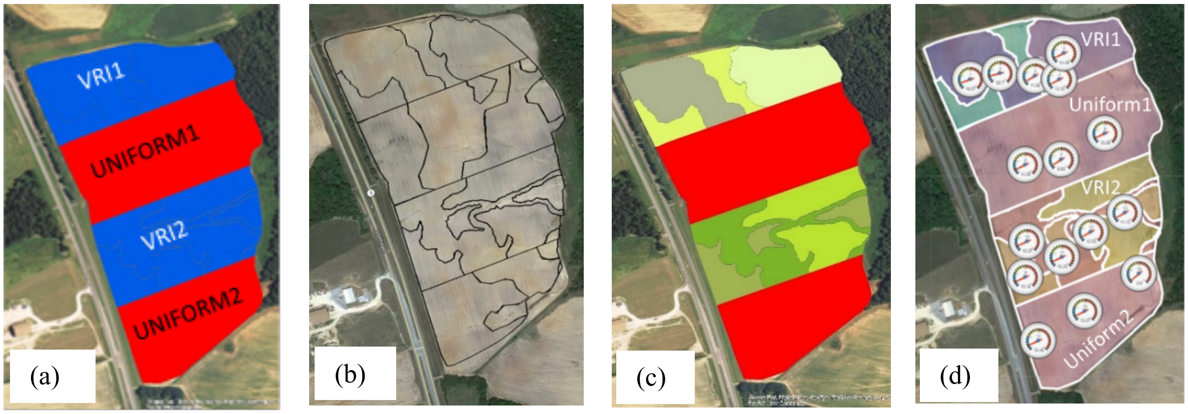
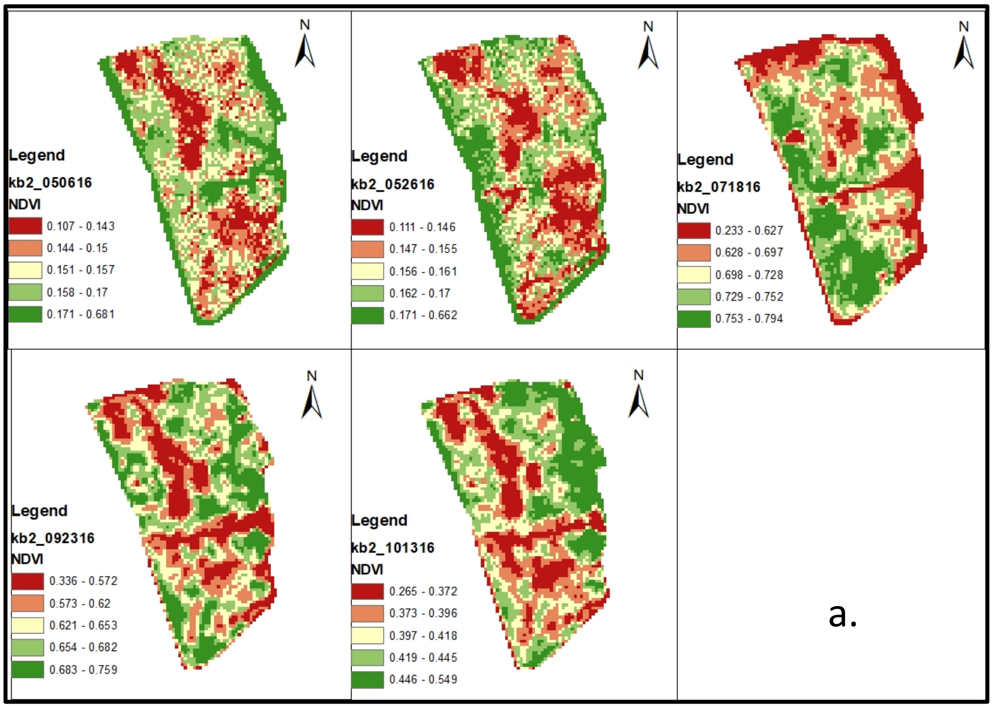


Fig 1 . (a) The four VRI and uniformly irrigated strips used in the study. The width of each strip was 240 m. (b) Delineated irrigation management zones (IMZs) based on the electric conductivity, elevation, NDVI and NDWI. (c) Individual areas in the field which received different application rates. Areas with the same color received the same rates. (d) Location of UGA SSA sensor nodes installed in the field. Gages show the weighted average soil water tension (SWT). Average SWT = (0.5 x SWT at 15 cm) + (0.3 x SWT at 30 cm) + (0.2 x SWT at 41 cm).



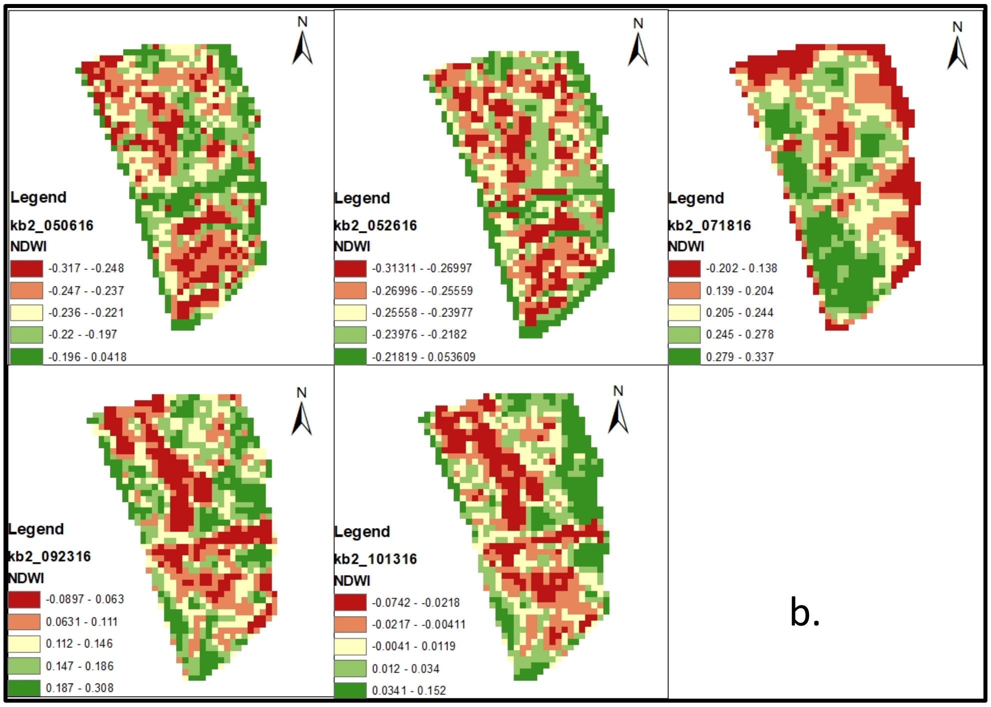


Fig 2. a) NDVI maps from 05/06/2016 to 10/13/2016, b) NDWI maps from 05/06/2016 to 10/13/2016.

Sensor nodes were also installed in the uniform strips to quantify the effect of the grower's irrigation strategy on soil moisture (Figure 1d). Prior to each scheduled irrigation event, we download a prescription map to the VRI controller based on soil moisture data from that morning. Each zone within the dynamic VRI strips was irrigated with the amount of water needed to bring the soil profile to within 75% of field capacity. If adequate moisture was available, the zone is not irrigated. The grower irrigated the field for the first time on 07 July. In this case the entire field was

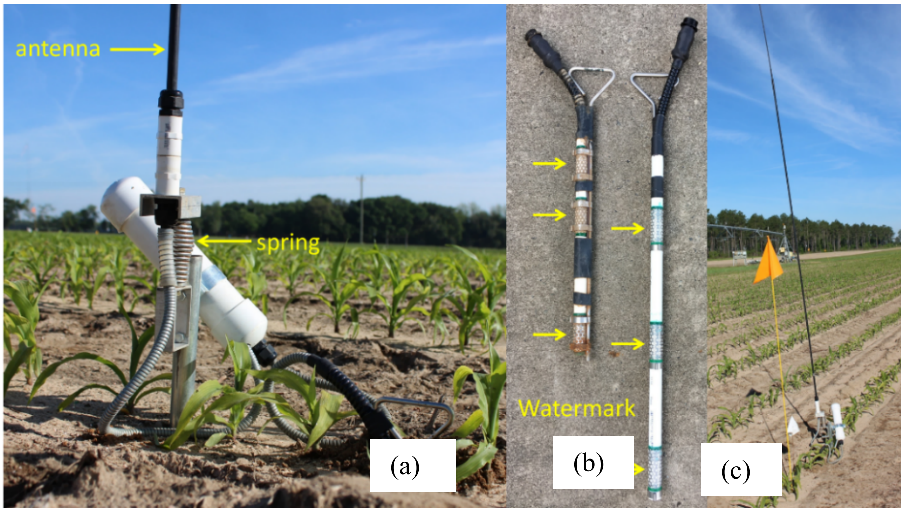


Fig 3. (a) A UGA SSA node installed in corn. The electronics are housed in the white PVC container. The spring allows the antenna to bend when farm vehicles pass overhead. (b) The UGA SSA sensor probe integrates three Watermark sensors and can be customized to any length. (c) Antennae can vary in length to accommodate the crop. For cotton, 2.7 m antennae are used while for corn 4.2 m antennae are used.

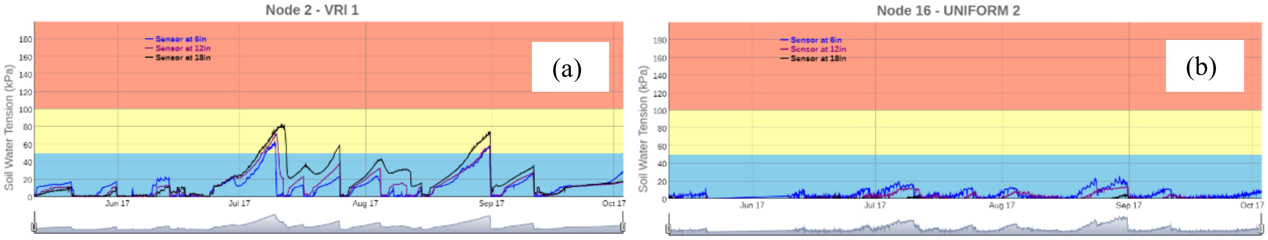


Fig 4. Soil water tension variability during the growing season. The blue line shows the soil water tension at 15 cm, the red at 30 cm and the black at 41 cm. (a) The location where node 2 was installed received irrigation with the VRI system based on the UGA SSA recommendations. (b) The location where node 16 installed was irrigated uniformly according to grower's recommendations.

irrigated uniformly to activate an herbicide. The 2017 growing season was rainy with 28 in of precipitation from May 1st to September 30th. There were 61 rainy days. Because of the frequent precipitation events, the field was irrigated using the experimental design only twice. The first irrigation event occurred on July 11th and the second on August 23rd. Both times the grower applied 15.24 mm while each of the dynamic VRI IMZs received amounts recommended by the UGA SSA Decision Support Tool (DST).

UGA SSA Web Portal and Decision Support Tool

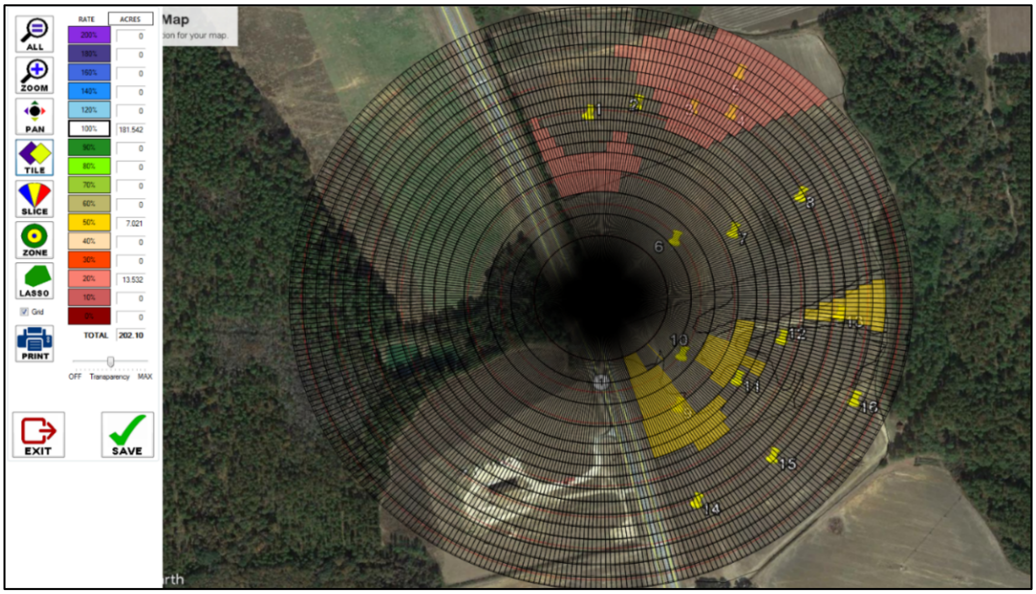
The UGA SSA web portal is accessible from any internet-capable device including tablets and smartphones and allows users to view their soil moisture data in using two visualization options. The first data visualization option uses analog gages showing a weighted average of the soil moisture at the three measured depths in real time (Figure 1d). The use of field images as a background is essential, as the location of each gage in the picture corresponds to the geographical location of each node. The background colors of the gauges are color-coded in blue, yellow, and red to help growers interpret the data. The soil water tension range for the blue area is 0 kPa to 50 kPa indicating adequate soil moisture for most cotton, for the yellow area 50 kPa to 100 kPa indicates 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. This view also presents the delineated irrigation management zones.

The second visualization option uses continuous SWT graphs (Figure 4) which allow users to understand their soil conditions by observing soil wetting and drying patterns. Each line on the graph represents the response of a Watermark sensor at a specific depth. This knowledge allows them to understand the effect of irrigation and precipitation events on soil moisture, to assess how quickly the soil profile is drying and to anticipate the next irrigation event. The graphs are color coded using the same colors and ranges as described for visualization option 2. Field images 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.

In addition to data visualization, the web portal incorporates a DST which offers irrigation recommendations. We use a modified Van Genuchten model to convert SWT data to irrigation recommendations (Liang et al., 2016). The strength of the method is that it uses soil parameters which are readily available from the USDA-NRCS Web Soil Survey to develop soil water retention curves specific to the soil in each IMZ. The soil water retention curves are then used to translate measured SWT into irrigation recommendations specific to that IMZ. Our DST calculates the amount of irrigation water needed to bring the soil profile in that IMZ back to the desired soil moisture condition. This could be field capacity or a percentage of field capacity. We prefer to return the profile to within 75% of field capacity which leaves "room" in the soil profile to absorb precipitation events. The DST is described by Liakos et al. (2015). At this point, irrigation recommendations use the same SWT threshold across all phenological stages. However, research by University of Georgia crop physiologist Dr. John Snider shows that a better strategy might be to change SWT thresholds to reflect the crop's phenological stages.

Irrigation scheduling and VRI system

The pivot used at the experiment was a well maintained pivot with a Farmscan 7000 VRI system. The VRI system varies water application rates along the length of the pivot by using electronic controls to cycle sprinklers and control pivot speed. The Farmscan controller used was an upgraded version of the 7000 series which allows remote upload of prescription maps via a cellular modem connection. Because of this feature, we were able to upload the prescription maps without physically visiting the field. The prescription maps were created by using the Irrigation Manager software version 2.1.0.11 (Control the Rain, Claremont, Australia). This software allows the user to digitally recreate the IMZs and assign application rates to each IMZ (Figure 5).



RATE	ACRES
200%	0
180%	0
160%	0
140%	0
120%	0
100%	181.542
90%	0
80%	0
70%	0
60%	0
50%	7.021
40%	0
30%	0
20%	13.532
10%	0
0%	0
TOTAL	202.10

OFF Transparency MAX

Fig 5. The Irrigator Manager software environment. After setting up the size of the pivot and pivot's VRI zones, growers can select the desired amount of irrigation water to be applied in every location of the field. The yellow pins show the location of the UGA SSA nodes.

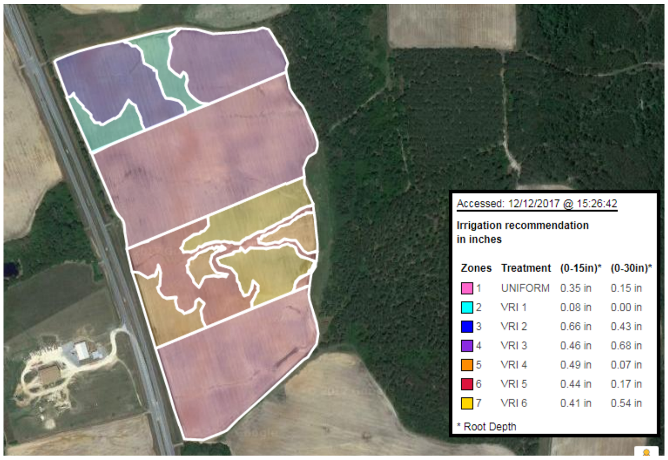
Results and discussion

UGA SSA soil moisture data vs Grower's irrigation method soil moisture data

Figure 4a presents the soil moisture as recorded by the sensors of node 2 which was located in the northernmost VRI strip (Figure 1a and 1d). Although on one occasion the SWT at all three sensor depths exceeded our desired limit of 50 kPa, in general this graph represents an ideal soil moisture condition for most of the growing season. Figure 3b, presents the soil moisture readings of node 16 which was located in the southernmost uniform strip which was irrigated using the grower's standard method. In Figure 4b the soil moisture tension ranges from 0 kPa to 20 kPa which indicates a wet soil profile which probably resulted in leaching of nutrients and may have generated runoff from irrigation.

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 IMZs. At the bottom right 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 38 cm) and mature (root length up to 76 cm) 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.



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Irrigation recommendation in inches

Zones	Treatment	(0-15in)*	(0-30in)*
■ 1	UNIFORM	0.35 in	0.15 in
■ 2	VRI 1	0.08 in	0.00 in
■ 3	VRI 2	0.66 in	0.43 in
■ 4	VRI 3	0.46 in	0.68 in
■ 5	VRI 4	0.49 in	0.07 in
■ 6	VRI 5	0.44 in	0.17 in
■ 7	VRI 6	0.41 in	0.54 in

* Root Depth

Fig 6. Window from the UGA SSA web portal showing 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 38 cm) and mature (roots up to 76 cm) plants respectively. The recommendations are for the amount of irrigation water needed to bring the soil profile to 75% of field capacity.

Dynamic VRI vs grower's irrigation method

Figure 7 shows the weighted average soil water tension of Watermarks at 15 cm and 30 cm (blue lines) and the weighted average SWT of Watermarks at 15 cm, 30 cm, and 41 cm (black lines) at node (left graph) and node 15 (right graph). The purple line presents the irrigation events and the orange line the precipitations. Node 2 was installed in a dynamic VRI IMZ. Node 15 was installed in a uniformly irrigated strip. It is clear that at the UGA SSA case the range of the average soil water tension is from 0 kPa to 65 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 grower's method tends to keep the soil profile wet throughout the growing season by overusing irrigation water. However, the dynamic VRI method kept the soil profile wet enough without stressing the plants and recommended irrigation only when plants need watering. A better look at the observed irrigation is making clear that both locations received two irrigation events. However these events took place in different periods. Node 2 received 1.8 cm of irrigation water from the beginning of the growing season until the middle of it while node 15 received 3 cm throughout the growing season. This means the the dynamic VRI method recommended less irrigation than the grower method.

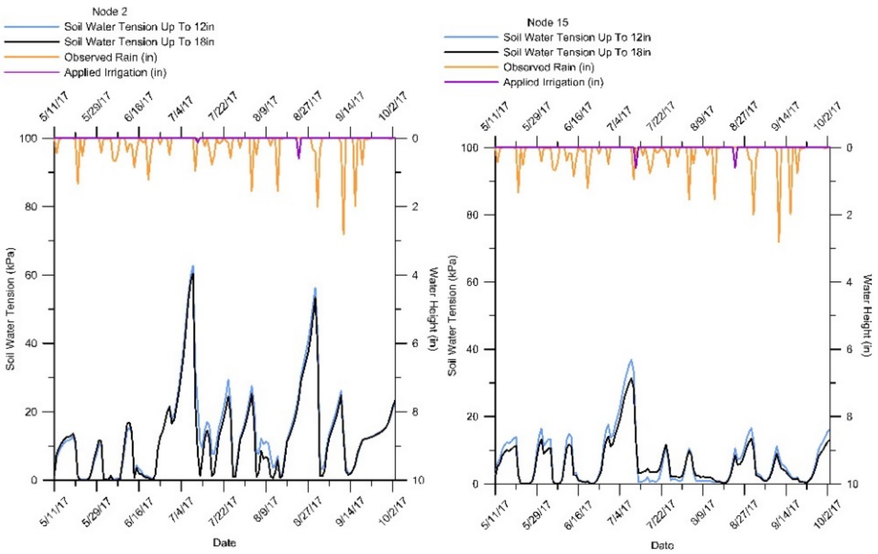

Fig 7. Example of the comparison between the two irrigation strategies. In both graphs the blue and black lines represent the weighted average of two swallow sensors and the three sensors respectively. The purple line presents the irrigation events and the orange line the precipitations. a) The zone where Node 2 installed received irrigation with VRI technology based on UGA SSA recommendations. b) The zone where Node 16 installed received irrigation uniformly according to Irrigator Pro recommendations.

The average water application resulting from the UGA SSA DST was 1.5 cm while the water application resulting from the grower's method was 3 cm (Table 1). Yield was measured with a John Deere cotton yield monitor so we were able to calculate the average yield of individual IMZs as well as of entire strips as shown in Table 1. The field's yields increase from south to north so the northernmost VRI strip (VR1) is not directly comparable to southernmost uniform strip (Unif2). Nevertheless, the yields of immediately adjacent strips can be compared. There is also high yield variability between delineated management zones within strips. This is the result of field features clearly visible from aerial images such as eroded areas and areas where eroded sand has accumulated in topographically lower areas.

There were clear yield benefits from using dynamic VRI with these specific IMZs. The yields of the VRI strips were either higher or the same as the yields of adjacent uniformly irrigated strips. IWUE of the dynamic VRI strips was much higher than that of the uniformly irrigated strips. In similar studies with peanut, we have found that dynamic VRI to increase IWUE by between 30 and 40% compared to grower methods. In this study, the estimated IWUE benefit from VRI was much higher. However, with only two irrigation events, it is difficult to make definitive statements about IWUE. This work must be repeated to assess the performance of the dynamic VRI system under a variety of precipitation years.

Table 1. Irrigation used, Yield and Irrigation Water Use Efficiency for every zone.

Treatment	Zone	7_11_2017 irrigation (mm)	8_23_2017 irrigation (mm)	Total Irrigation (mm)	Avg Irrigation (mm)	Yield (Kg/ha)	Avg yield (Kg/ha)	IWUE (Kg/ha-mm)	Avg IWUE (Kg/ha-mm)
VRI 1	1	3.0	3.0	6.1	9.9	3494	3161	573	380
VRI 1	2	3.0	15.2	18.3		3277		179	
VRI 1	3	3.0	3.0	6.1		2318		380	
VRI 1	4	6.1	3.0	9.1		3556		389	
Uniform 1	5	15.2	15.2	30.5	30.5	3300	2735	108	90
Uniform 1	6	15.2	15.2	30.5		3230		106	
Uniform 1	7	15.2	15.2	30.5		2958		97	
Uniform 1	8	15.2	15.2	30.5		1837		60	
Uniform 1	9	15.2	15.2	30.5		912		30	
Uniform 1	10	15.2	15.2	30.5		4171		137	

VRI 2	11	6.1	7.6	13.7	20.7	4054	2699	296	142
VRI 2	12	6.1	15.2	21.3		3394		159	
VRI 2	13	6.1	7.6	13.7		2538		185	
VRI 2	14	6.1	7.6	13.7		1060		77	
VRI 2	15	15.2	15.2	30.5		3146		103	
VRI 2	16	6.1	15.2	21.3		1447		68	
VRI 2	17	15.2	15.2	30.5		3250		107	
Uniform 2	18	15.2	15.2	30.5	30.5	4034	2143	132	70
Uniform 2	19	15.2	15.2	30.5		3258		107	
Uniform 2	20	15.2	15.2	30.5		501		16	
Uniform 2	21	15.2	15.2	30.5		778		26	

The irrigation treatments also affected soil temperature and consequently the temperature of the rootzone. The average soil temperature of the VRI zones was 25.97 °C while the temperature of the uniform zones was 21.09 °C. The soil temperature at the VRI zones was 4.9°C higher than that of the uniform zones. Considering that the optimum soil temperature for cotton root development ranges between 28 °C and 35 °C (Mauney and Stewart, 1986), it is clear that the average soil temperature in the VRI zones was closer to the optimum soil temperature than at the uniform zones and may have contributed to better yields.

Conclusion

Dynamic VRI based on a soil moisture sensor array with a web-based decision support tool showed promise as an alternative to existing decision support tools. The use of soil properties, terain data and vegetation indices proved to be very helpful to delinetate correct IMZs. The combination of IMZs with 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. The results showed that the integration of IMZs with the dynamic VRI method was very good because less irrigation water used than the grower’s standard method, had much higher IWUE, and resulted in equal or higher yields under the circumstances in which the study was conducted. However, the development of IMZs can be improved by using yield maps.

References

Car, N.J., Christen, E.W., Hornbuckle, J.W., Moore, G.A. (2012). Using a mobile phone short messaging service (SMS) for irrigation scheduling in Australia—farmers' participation and utility evaluation. *Computers. & Electronics in Agriculture*, 84, 132–143.

Duncan, H. A. (2012). Locating the Variability of Soil Water Holding Capacity and Understanding Its Effects on Deficit Irrigation and Cotton Lint Yield. Master's Thesis, University of Tennessee.

Hearn, A.B. (1994). OZCOT: a simulation model for cotton crop management, *Agriculture Systems,* 44, 257–259.

Inman-Bamber, N.G., Attard, S.J., Verrall, S.A., Webb, W.A. and Baillie, C. (2007). A web-based system for scheduling irrigation in sugarcane. In Proceedings of the International Society of Sugar Cane Technology, 26, CDROM.

Liakos, V., Porter, W., Liang, X., Tucker, M. A., McLendon, A., and Vellidis, G. (2017). Dynamic variable rate irrigation – A tool for greatly improving water use efficiency. *Advances in Animal Biosciences: Precision Agriculture (ECPA) 2017*, 8:2, pp 557–563 © The Animal Consortium 2017, doi: 10.1017/S2040470017000711.

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 2015, Proceedings of the 10th European Conference on Precision Agriculture (pp. 677-683). Tel Aviv, Israel, doi:10.3920/978-90-8686-814-8.

Liang, X., V. Liakos, O. Wendroth, and G. Vellidis. (2016). Using the van Genuchten model for irrigation scheduling. *Agricultural Water Management*, doi:10.1016/j.agwat.2016.05.030.

Mauney, J., Stewart, J. (1986). *Cotton Physiology.* Memphis, Tennessee: The Cotton Foundation.

Richards, Q.D., Bange, M.P., Johnston, S.B. (2008). HydroLOGIC: an irrigation management system for Australian cotton. Agricultural Systems, 98, 40–49.

Smith, M., 1992. CROPWAT, A computer program for irrigation planning and management, No. 46. FAO Irrigation and Drainage.

Thysen, I., Detlefsen N.K. (2006). Online decision support for irrigation for farmers. *Agriculture Water Management*, 86, 269–276.

Steduto, P., Hsiao, T.C., Raes, D., Fereres, E. (2009). AquaCrop—the FAO crop model to simulate yield response to water: I. Concepts and underlying principles, *Agronomy Journal*, 101, 426–437.

Stockle, C.O., Donatelli, M., Nelson R. (2003). CropSyst, a cropping systems simulation model. *European Journal of Agronomy,* 18**,** 289–307.

Vellidis, G., Liakos, V., Porter, W., Tucker, M., Liang, Xi. (2016). A dynamic variable rate irrigation system. In Proceedings of the 13th International Conference on Precision Agriculture. Monticello, IL: International Society of Precision Agriculture.