A soil moisture sensor-based variable rate irrigation scheduling system

G. Vellidis[1], M. Tucker[1], C. Perry[1], D. Reckford[2], C. Butts[3], H. Henry[1], V. Liakos[1], R.W. Hill[1], W. Edwards[3]
[1]*University of Georgia, USA*
[2]*Flint River Soil and Water Conservation District, USA*
[3]*United States Department of Agriculture – Agricultural Research Service, USA*
e-mail: yiorgos@uga.edu

Abstract

To assess the potential of precision irrigation, we began a research and demonstration project whose goal is to develop a soil moisture sensor-based variable rate irrigation (VRI) control system. The control system consists of a wireless soil moisture sensing array with a high density of sensor nodes, a VRI enabled center pivot irrigation system, and a web-based user interface with an integrated irrigation scheduling decision support system. This paper describes our system in detail providing some results from the components which have been completed and are operational and a detailed description of the components under development.

Keywords: decision support systems, Watermark, mesh networks

Introduction

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. If irrigated agriculture is to survive in this competitive environment, we must use irrigation water efficiently. A large number of techniques and tools have been developed to assist irrigation system users (irrigators) and especially producers to estimate when and how much water to apply to crops. Yet, despite the availability of these techniques and tools, the vast majority of irrigators still rely either on a fixed schedule or on visual cues of plant stress such as wilting. And typically, irrigators will apply a standard amount (for example 2.5 cm) at each irrigation event. As a result, both the timing and depths of irrigation may be inappropriate and may lead to yield, nutrient, and soil losses. Vories et al. (2006) found that improper timing of irrigation on cotton can result in yield losses of between USD 370/ha to USD 1850/ac.

Cheap, reliable, and wireless soil moisture sensing systems with a high density of sensor nodes are needed to account for soil variability and enable precision irrigation. To address this issue, we began a research and demonstration project whose goal is to develop a soil moisture sensor-based variable rate irrigation (VRI) control system. The control system consists of a wireless soil moisture sensing array with a high density of sensor nodes, a VRI-enabled center pivot irrigation system, and a web-based user interface with an integrated irrigation scheduling decision support system. This paper describes our system in detail.

Methods

The operational paradigm for our system is that the field is divided into irrigation

G. Vellidis, M. Tucker, C. Perry, D. Reckford, C. Butts, H. Henry, V. Liakos, R.W. Hill, W. Edwards. 2013. A soil moisture sensor-based variable rate irrigation scheduling system. In: J.V. Stafford (Ed.), Precision Agriculture 2013 – Proceedings of the 9th European Conference on Precision Agriculture (9ECPA), Lleida, Spain, p.713-720.

management zones (MZs), the soil moisture sensing array is installed to monitor soil condition within the zones and provides hourly soil moisture measurements to the web-based user interface. At the interface, the soil moisture data are used by an irrigation scheduling model running in the background to develop irrigation scheduling recommendations by MZ. The recommendations are then approved by the user (farmer) and downloaded to the VRI controller on the center pivot as a precision irrigation prescription. When the center pivot irrigation system is engaged by the farmer, the pivot applies the recommended rates.

The University of Georgia smart sensor array (UGA SSA)

The UGA SSA consists of smart sensor nodes and a Gateway. A “smart sensor node” is defined as the combination of electronics and sensors installed at each location in the field. A UGA SSA node consists of a circuit board, a radio frequency (RF) transmitter, soil moisture sensors and temperature sensors. Each sensor node accommodates up to 3 Watermark® soil moisture sensors and 2 thermocouples for measuring temperature (Figure 1a). The RF transmitter (RF200P81, Synapse, Huntsville, Alabama, USA) is a postage stamp-sized intelligent low-cost, low-power, 2.4 GHz radio module capable of acquiring, analyzing, and transmitting sensor data (Figure 1b). Data from all the nodes are routed to a centrally located node known as the Gateway at 5 minute intervals. At the Gateway, data are stored on a solar-powered net-book computer (Figure 1c) and

Figure 1. A UGA SSA sensor node consists of the sensors which are installed in the soil (a) and the electronic components (b). The three Watermark® sensors are integrated into a shaft (a) which can be easily installed after planting and extracted prior to harvest for agronomic crops. The photo at top right shows a sensor node's circuit boards pulled part-way out of its PVC enclosure. The node circuitry is powered by two alkaline AA batteries mounted to the back side of the sensor acquisition board. The photo at bottom right shows the Gateway for UGA-SSA system. The enclosure houses the net-book computer. The solar panel above recharges a 12VDC battery.

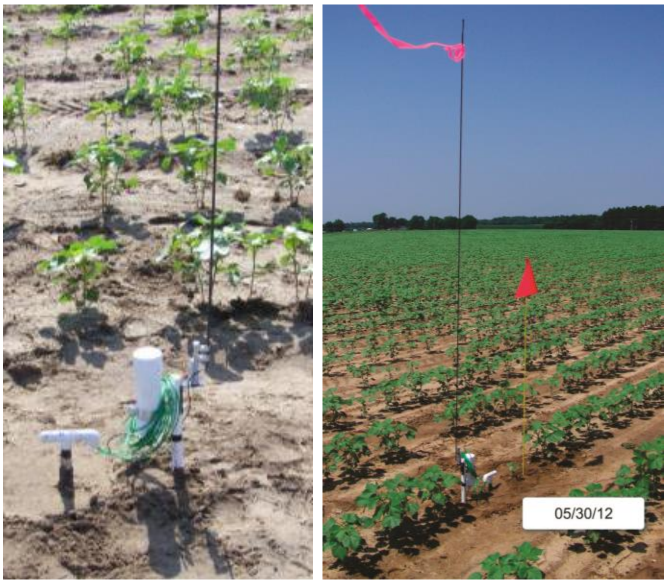

Figure 2. To increase transmittance range and to allow for farm vehicles to pass over the node, the electronics are kept at the soil surface and the antenna enclosed in a 2.5 m, 60 mm diameter hollow, flexible, spring-loaded fiberglass rod.

transmitted via cellular modem to an FTP server hourly.

One unique characteristic of the UGA SSA is that it uses wireless mesh networks to communicate between irrigation sensor nodes. As the name implies, mesh networks create a wireless network between the nodes. The RF transmitters act as a repeater to pass along data from other nodes to form a meshed network of nodes. If any of the nodes in the network stop transmitting or receiving or 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 radio transmissions, the RF transmitter antenna is mounted on spring-loaded, hollow, 6 mm diameter, flexible fiberglass rods approximately 2.5 m above ground level (Figure 2). This design allows field equipment such as tractors and sprayers to pass over the sensors – something which no other wireless system offers. The published range of the RF transmitter is 500 m although we have found its effective range to exceed 750 m.

An important characteristic of our system is its affordable cost – a 12-node system can be installed for a onetime cost of USD 5200. Installing irrigation sensors throughout an irrigated field is critical to understanding and managing the soil moisture variability which exists in all fields. Another important characteristic of the UGA SSA is that it reports soil moisture condition in terms of soil water potential (soil water tension) in units of kPa. This allows the system to be installed in any soil type without calibration. This is in contrast to capacitance-type soil moisture sensors which require calibration. Although Watermarks respond more slowly to soil moisture changes than capacitance sensors, their response time is adequate for scheduling irrigation in agronomic crops.

The UGA SSA has been tested in its current configuration under field conditions for two entire cropping seasons. During the 2012 cropping system, the UGA SSA was deployed in eight of ten demonstration fields with a maximum of ten sensor nodes per field. Field size averaged 80 ha. The fields were delineated into irrigation MZs based on soil survey maps, topography, aerial photographs, and visual inspection of the fields. At least one node was installed in each MZ. In subsequent years, the MZ boundaries will be refined by using apparent soil electrically conductivity maps, yield maps, and additional information as it becomes available. The number of sensor nodes will be adjusted accordingly with the goal of installing at least three nodes in each MZ.

The eight instrumented fields which were located in the Lower Flint River Basin (LFRB) of southwest Georgia, USA, were planted to cotton or peanuts. Soil moisture data were collected hourly for the entire growing season and streamed to an FTP server where they were stored. All ten of the fields were equipped with VRI center pivots.

<u>Variable rate irrigation (VRI) for center pivots</u>

Fields everywhere contain variability in soil type and texture, moisture holding capacity, and slope. In addition, many fields have irregular shapes and may contain non-farmed areas, waterways, small wetlands, and other features which should not be irrigated (Figure 3). Conventional center pivot irrigation systems apply the same rate of water along the entire length of the pivot and cannot account for these features.

VRI is a patented and commercialized technology developed by the University of Georgia (UGA) in partnership with FarmScan (Perth, Australia), an Australian electronics company (Perry et al., 2002; Perry and Pocknee, 2003). Advanced Ag Systems (Dothan, Alabama, USA – www.advancedagsystems.com), coordinates sales, installation and service of the FarmScan VRI system and has installed 47 systems in LFRB. Most of the large pivot suppliers began offering VRI systems of their own during 2012.

The UGA/FarmScan VRI allows center pivots to vary water application rates along the length of the pivot by using electronic controls to cycle sprinklers and control pivot speed. Sprinklers are grouped together in banks of 3 to 10 depending on the level of resolution desired by the farmer. Each group or bank of sprinklers represents a grid with a 2 to 10 degree arc in which the irrigation water application rate can be set as percentage of the normal application rate ranging from 0% to 200% (Figure 3). The number of degrees in the arc is determined by the level of resolution desired.

A 50% application rate is half the normal rate and is achieved by cycling the sprinklers on and off every 30 seconds. A 150% application rate is achieved by leaving the sprinklers on continuously while decreasing the travel speed of the pivot by 50%. If other grids along the length of the pivot require lower application rates, the VRI controller adjusts the sprinkler cycling pattern within those grids accordingly. An irrigation application map for each field is developed jointly by the farmer and VRI dealer on desktop software (Figure 3) and then downloaded to the VRI controller on the pivot. A detailed description of VRI is available at www.nespal.org/vri.html.

The UGA/FarmScan VRI system can be installed retroactively on most existing pivots. Installations costs range from about USD 5500 for a limited installation on a small pivot to USD 18,000 for full installation on a large pivot. Costs vary depending on the length of the pivot and the level of resolution desired by the farmer to address the variability of

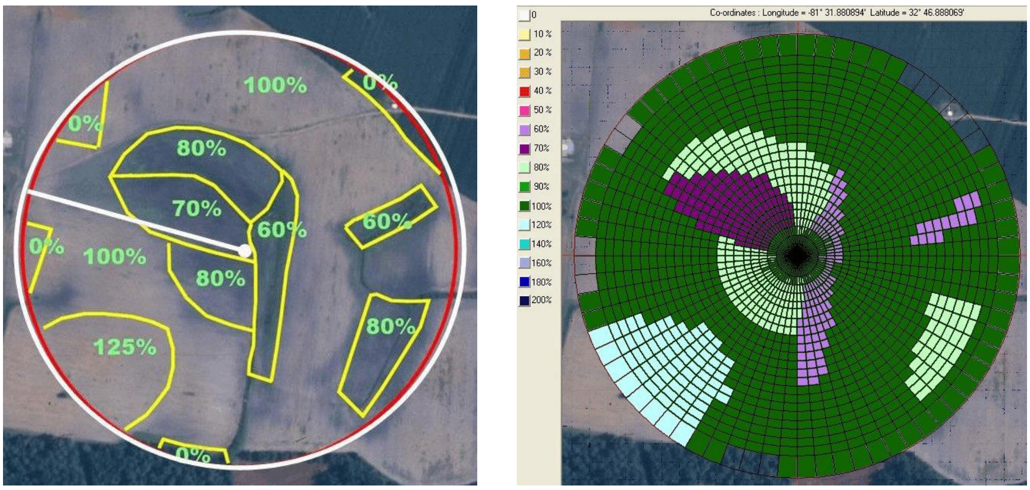

Figure 3. Irrigation application rates assigned to different areas under a 48 ha center pivot irrigation system (left) and VRI implementation of the application map (right).

the field. Water savings from VRI range from 7.5% to 19% of conventional application rates (Perry, unpublished data).

The Flint Irrigation Scheduling Tool (FIST)

We are developing a web-based irrigation scheduling tool called the Flint Irrigation Scheduling Tool (FIST) which will allow farmers to remotely check soil moisture of fields but will also provide irrigation scheduling recommendations. With FIST, farmers will be able to check soil moisture status from any device with access to the internet (mobile phone, iPod, office or home computer, internet café). If multiple fields are equipped with the UGA SSA, farmers will be able to check soil moisture status of all fields form one portal. FIST will provide irrigation scheduling recommendations for conventional irrigation systems as well as precision irrigation systems. For precision irrigation systems, FIST will provide MZ-based recommendations (Figure 4, top). Farmers could then make a fully-informed decision about initiating irrigation.

FIST collects data from the field by dialing up the cell modem of the UGA SSA gateway computers at hourly intervals, downloads the data stored by the gateways, and then incorporates the data into a database. The FIST website makes this information available to users through a dashboard-style display (Figure 4, bottom).

The Irrigator Pro suite of models will be used to develop irrigation scheduling recommendations. Irrigator Pro is a decision support system developed by the United States Department of Agriculture Agricultural Research Service National Peanut Research Lab for irrigation scheduling in peanuts, cotton, and corn. The models are public domain and available online (http://www.ars.usda.gov/Research/docs.htm?docid=16805) Irrigator Pro irrigation scheduling recommendations are made to maintain soil water in the optimum ranges. The algorithms used to make these recommendations are based on 25 years of irrigation research. The most recent release of Irrigator Pro uses daily soil water potential (soil water tension) data in units of kPa.data. Because the UGA SSA also measures soil water tension, it is ideally suited to provide data that drive Irrigator Pro.

As a deliverable for this project, we are integrating the Irrigator

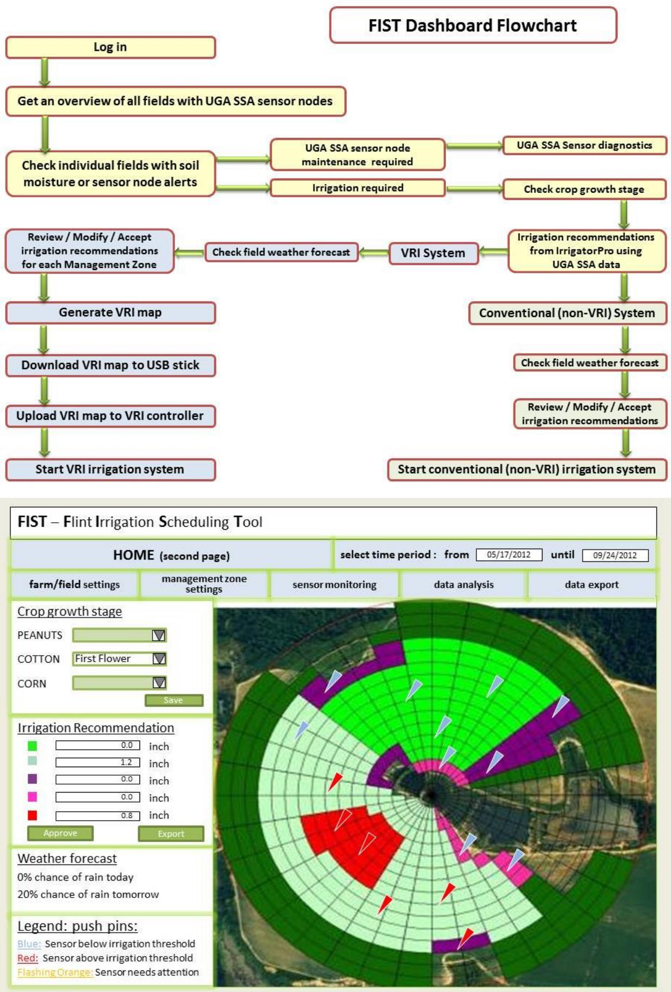

Figure 4. FIST flow diagram (top) and FIST dashboard (bottom).

Pro peanut, cotton, and corn models into FIST and will use Irrigator Pro to drive irrigation scheduling decisions. Data from the UGA SSA will stream hourly to the FIST database and will be drawn from there by Irrigator Pro and used to develop daily irrigation scheduling recommendations for the project's demonstration fields. High resolution precipitation forecasts will be incorporated into the irrigation scheduling recommendations providing farmers with additional irrigation management options.

Fields equipped with VRI-enabled pivots will be divided into a maximum of five irrigation MZs. Depending on size, each zone will be equipped with three or more UGA SSA sensor nodes. Multiple nodes within each zone will provide some redundancy in case of failures but will primarily be used to account for within-zone soil variability. The data from the nodes within each MZ will be used to provide summary statistics (max, min, average) of soil water tension to drive Irrigator Pro.

Irrigator Pro will use the UGA SSA data from each MZ to develop irrigation scheduling recommendations specific to each zone. FIST will in turn create irrigation prescription maps for the VRI controllers. Participating farmers will then be able to download these maps to their pivots and irrigate using the Irrigator Pro-generated irrigation recommendations. Fields equipped with conventional irrigation systems will be considered to have one irrigation management zone. For these fields, Irrigator Pro will develop one daily irrigation scheduling recommendation for the entire field.

The daily irrigation scheduling recommendations will be available to users through traditional internet access and smartphones. Coupling a state-of-the-art remote soil moisture sensing system with a highly sophisticated irrigation scheduling model and high resolution precipitation data and providing farmers with unparalleled access to irrigation scheduling information in real time is a unique contribution.

Automating the FIST – VRI link

During the 2013 growing season, FIST will provide MZ-based irrigation scheduling recommendations for each field as shown in Figure 4. The farmer will be able to review and approve these recommendations via the website or via a smartphone app, but will still need to physically download the new VRI map from FIST and physically upload it to the VRI controller at the pivot point. Clearly this is a cumbersome arrangement which requires several steps and may inhibit the farmer from fully utilizing the unique capabilities of FIST coupled with VRI.

As another project deliverable, we will automate the link between FIST and the VRI controller. With this important modification, once the farmer reviews and approves the irrigation scheduling recommendations for each field, the VRI map will be automatically downloaded via a wireless connection to the VRI controller. To irrigate using the recommendations, the farmer would then just turn on the pivot. Many pivots are enabled for remote start so the entire process could be done from a smartphone without the farmer physically visiting the field. We will demonstrate this link on a minimum of three pivots during the life of the project.

Results

The UGA SSA performed well during the 2012 growing season. A total of 75 sensor nodes were installed. Each node contained 3 Watermark soil moisture sensors and two thermocouples for a total of 375 individual sensors. Of these, only one individual soil moisture sensor did not perform properly. This particular sensor never responded to soil water moisture changes showing dry conditions continuously.

The soil water tension graphs created from the UGA SSA data collected during the 2012 growing season show very different soil water moisture conditions within fields again confirming that there is tremendous in-field variability. During 2012, the demonstration fields were irrigated using conventional practices and the data clearly show that VRI can improve irrigation efficiency. Figure 5 shows aerial images of two adjacent demonstration fields, the location of the UGA SSA sensor nodes in those fields, and representative soil water tension graphs from three nodes in each field. Both fields were planted to cotton. The graphs show dramatically different soil moisture conditions between these adjacent fields throughout the growing season indicating that one farmer may have been over-irrigating while the other may have been under-irrigating.

FIST is under development and will be operational for the 2013 growing season. The Irrigator Pro suite of models was originally designed for direct user input. The peanut, cotton, and maize models were modified to accommodate automatic transfer of UGA SSA data from the FIST database to the models and likewise automatic transfer and display of the results to the FIST website.

Conclusions

Field studies in many parts of the world have shown that water is often the limiting factor in crop production. Increasing competition for water resources will likely result in less water available for agricultural production. Precision irrigation promises to optimize the use of this precious resource. The project described here is the first attempt to implement precision irrigation in large-scale agronomic crop production. The study will provide valuable information for future implementation efforts.

Acknowledgements

The authors wish to acknowledge the Flint River Soil and Water Conservation District for promoting state-of-the-art conservation practices in the LFRB and for its farmer members who provided their time, fields, and knowledge to make this project a success. 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*."

References

Perry, C., Pocknee, S., Hansen, O., Kvien, C., Vellidis, G. and Hart, E. 2002. Development and Testing of a Variable Rate Irrigation Control System. ASAE Paper No. 02-2290. St. Joseph, MI: ASAE.

Perry, C. and Podcknee, S. 2003. Development of a Variable-Rate Pivot Irrigation Control System. Proceedings of the 2003 Georgia Water Resources Conference at the University of Georgia, April 23 - 24.

Vories, E.D., Teague, T., Greene, J., Stewart, J., Clawson, E., Pringle, L., Phipps, B. 2006. Determining the optimum timing for the final irrigation on mid-south cotton. In. Proceedings National Cotton Council Beltwide Cotton Conference, January 3-6, 2006, San Antonio, Texas. 516-521, 2006 CDROM.

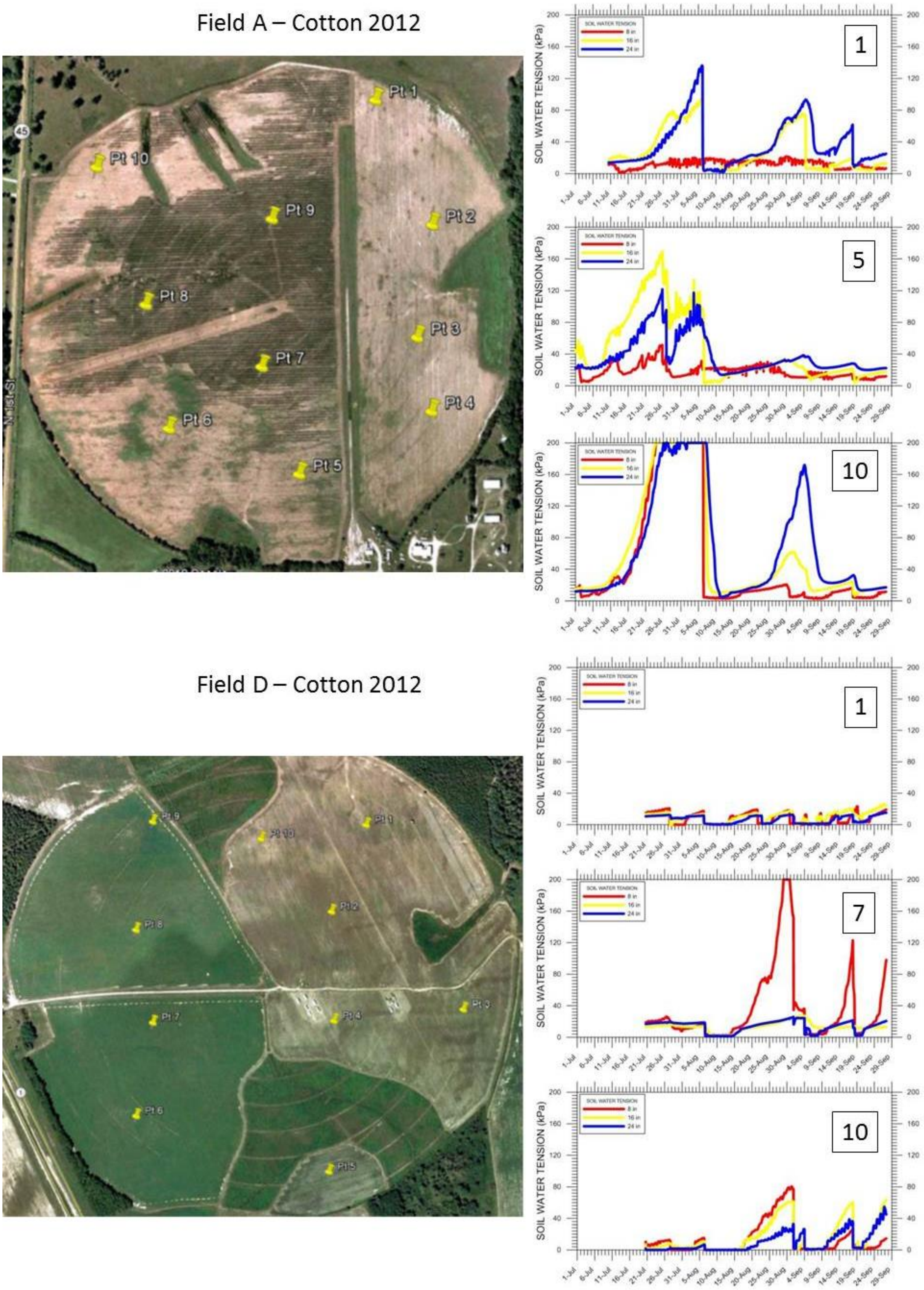

Figure 5. Map of demonstration Field A (top) and Field D (bottom) showing location of the UGA SSA sensor nodes used during the 2012 growing season and representative soil water tension graphs from three nodes. The soil water tension curves in each graph represent the 3 depths (0.2, 0.4, and 0.6 m) monitored by each sensor node. High soil water tension indicates dry soils. Note the lower soil water tension values in in Field D indicating significantly wetter soils than in Field A