CONSERVATION TILLAGE AND CONVENTIONAL TILLAGE: IMPACTS ON WATER RESOURCES AND SOIL QUALITY IN GEORGIA

by

RACHEL WHILDEN COLLIER

(Under the Direction of ERNEST B. TOLLNER & GARY L. HAWKINS)

ABSTRACT

This thesis investigates the rate of soil moisture retention, soil quality, and field specific water balance under conservation tillage (ST) versus conventional tillage (CT) systems in cotton production in Georgia. Experiments were conducted at three locations in the counties of Oconee, Bulloch and Pulaski with two fields per county, one each of conservation tillage and one of conventional tillage. Soil moisture data were analyzed to determine the rate of soil moisture loss during drying periods between rainfall events. Field-specific water balance calculations were conducted based on the rainfall, drainage, crop evapotranspiration, and runoff. The water loss rates vary by location, with combined averages of CT losing water 16% faster than ST. Overall, ST sites retained 21.5% more soil moisture and had less runoff than CT sites. Soil organic matter was 96% greater in ST than CT for Bulloch County and not statically different in the other two counties. Results from the water balance calculations were not statistically different between tillage type.

INDEX WORDS: agriculture, conservation tillage, soil moisture, soil quality, water balance

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CHAPTER 1

INTRODUCTION

1.1 Background

Water is a valuable resource in agricultural production. Too much water leads to over saturation of crops, excessive runoff leading to soil erosion, and inability to harvest or plant crops due to the threat of farming equipment getting stuck in fields. Too little water results in crops wilting and the soil displaced due to wind erosion. The increased variations in climate result in more frequent droughts and larger, more intense storm events meaning that the periods of too little and too much water are increasing (Dourte and Fraisse, 2014). Management of water resources begins at the field level, with the cultivation practices used by the farmers.

Cultivation practices are defined in this study by the selected tillage methods employed by farmers. Conventional Tillage (CT) and Conservation Tillage (ST) are two of the primary tillage practices employed by farmers in the Southeast Region of the United States. Primary conventional tillage is deep, frequent turning of the soil to create a fine seedbed for cultivation. Conservation tillage is the reduction of tillage and the use of cover crops and crop residue to maintain a cover on the soil surface year-round.

Many researchers have studied the environmental and economic impacts of each tillage system, but the water retention times in the soil profile is an area which needs further research. There are many claims to the benefits of reduced tillage systems (ST), and this practice has long been advocated for by the USDA NRCS; however, the adoption rate in many regions is still low

(Claassen et al., 2018). Understanding how the tillage systems retain water under wet and dry conditions will aid in the wise management of water resources for all producers in this region. This research seeks to assess the state of long-term tillage practices managed by real farmers on soil quality and water resources in the state of Georgia.

1.2 Expected Outcomes

The outcomes of the study are to provide the agriculture industry with knowledge to improve management of natural resources while aiding crop production. The work presented here should be replicable for future studies to conduct a performance analysis on agricultural production systems. This research seeks to provide possible solutions for analyzing rural field-level water usage by the use of soil moisture sensors to determine the water loss rates within the soil profile remotely.

1.3 Research Objectives

This research was divided into two primary components. The focus of the thesis is on the evaluation of the performance of two crop production systems on soil quality and water resources and the development of a methodology to perform replicable hydrologic assessments on crop production land. The methodology involved using soil moisture sensors and edge-of-field water monitoring technology to identify soil water retention rates and overall water use. Evaluations will provide comparisons between selected tillage types. Results of the evaluations will be disseminated to agricultural producers to aid in the selection of management practices.

The specific objectives of this research are the following:

(1) Assess differences in bulk density and soil organic matter for soil quality assessment on fields managed under long-term conservation tillage and conventional tillage,

(2) Develop a methodology to determine soil moisture loss rates to conduct water budget analyses for future research, and

(3) Analyze field-level hydrologic conditions for both types of management systems.

1.4 Organization of Thesis

This thesis is divided into four chapters that organize, illustrate, and describe the steps taken to meet the defined research objectives throughout this project. Following this chapter, *Chapter Two: Literature Review*, examines current agriculture production systems, soil physical properties, and research relevant in this field. *Chapter Three: Means and Methods*, outlines the design, site descriptions, methods of data collection, and the calculations conducted for this research. *Chapter Four: Results and Discussion*, details the findings of the performed experiments. This chapter includes data, observations, and analyses conducted for all experiments performed as part of this effort. *Chapter Five: Conclusions*, provides insight on the water use of agricultural production systems and performance of long-term production systems. Additionally, this chapter identifies further research that can be conducted to advance this research effort.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This literature review explores two commonly used agricultural tillage systems' impact on soil quality and water resources. These production systems have been extensively studied globally on their effectiveness at meeting producer and environmental quality requirements (USDA, 2015). Many factors impact how a production system performs including, but not limited to, soil type, climate, water availability, access to farm machinery and technology, and landscape conditions. Because of the high likelihood of regional differences, most of the research presented in this review was conducted in the Southeastern U.S. region, unless otherwise stated. The research objectives of this thesis are to assess the current state of soil quality, conduct a water budget analysis, and identify how quickly water dissipates through the soil profile under two types of long-term management systems.

2.2 Background

Agricultural systems require a balance of water and soil for favorable growing conditions. The majority of U.S. cotton is produced without irrigation and is more reliant upon weather conditions (NAAS, 2004). The current trend in climate is more frequent droughts and larger, more intense storm events resulting in increased periods of too little and too much water (Dourte and Fraisse, 2014). The use and stewardship of water begins at the field level by farmers who use established cultivation practices. Cultivation practices can hinder or aid in the water retention within the soil profile and have a large role in soil quality.

2.3 Production Systems

Tillage to one extent or another is integral to any production system to prepare the land for planting, growing, and harvesting crops. Tillage is used for a variety of reasons such as preparing the soil for planting, weed control, soil aeration, leveling the planting surface, incorporating fertilizer and amendments into the soil, and integrating crop residue into the soil. This section explores the common types of production systems and further examines research on production systems in the Southeast U.S. The two primary production systems are conventional tillage and conservation tillage.

2.3.1 Conventional Systems

Conventional tillage (CT), a historic farming method, is where all crop residues are turned into the soil before to planting using techniques such as inversion plowing and/or disking. Conventional tillage involves a combination of moldboard, chisel and disc-tillage systems. These methods are widely used in the literature to describe conventional tillage systems which often involve harrowing or plowing multiple times before planting with essentially no crop residue remaining at the surface (Bosch et al., 2005; Nouri et al., 2019; Potter et al., 2015; Price et al., 2018; Raczkowski et al., 2009; Weyers et al., 2017).

In the early 1900s, settlers used intense tillage excessively in the semi-arid Great Plains U.S. region, destroying native grassland and exposing the bare soil. When drought struck in 1931, most of the soil was no longer being held in place by native vegetation and was subject to intense wind erosion. This event, infamously termed the Dust Bowl, brought attention to the harmful impacts of frequent tillage. Additionally, conservationists such as Hugh Hammond Bennett began to point out the degrading soil quality across the United States (Helms, 2010). Management practices came under scrutiny for their effects on soil and stream health.

The historical effects of conventional tillage can also be seen in the Southeastern U.S. Trimble (1974) explores the history of man-induced erosion on the Southern Piedmont and estimates that an average of seven inches of topsoil was removed from the 1700s to 1970s. The soil parent material of highly weathered saprolite, rainfall events, changes in land use from natural forest to row crop agriculture, and conventional tillage practices led to the loss of some 6 cubic miles of soil material from the region (Trimble, 1974). For example, in the Coastal Plain region just south of the Southern Piedmont, Providence Canyon, is the result of erosion due to poor farming practices in the 19th and 20th centuries. The cleared land allowed rainfall to accumulate unchecked through the sandy soils of the region, quickly forming massive gullies, some of which are 150 feet deep (Joyce, 1985). This location, often called Georgia's "Little Grand Canyon" by visitors, further demonstrates the need for wise land use and management strategies to prevent further soil loss.

2.3.2 Conservation Production Systems

Conservation production systems were developed in response to the detrimental effects of conventional farming on soil erosion and soil loss (Langdale, 1994). Conservation production practices involve reduced tillage, maintaining a permanent surface residue, and increasing biodiversity by incorporating crop rotations. The three types of tillage under conservation production are no-till, mulch-till, and strip-till (ERS, 2000). In some regions, no-tillage systems are used successfully for farming practices (Claassen et al., 2018; Li et al., 2018; Tan et al., 2002; USDA, 2015). No-tillage is the practice of refraining from using any method to disturb the sub-surface soil from harvest of the previous crop to harvest of the current crop. Mulch tillage is a type of tillage where the soil is tilled, but soil disturbance is low and residue cover remains high. Strip tillage is a system used to minimize soil disturbance in row crops by tilling only in narrow strips where seeds are planted, and fertilizer may be incorporated into this strip during planting.

The predominant soils in the Atlantic Coastal Plain are Ultisols, which contain high amounts of clay with subsurface horizons that restrict internal drainage and promote lateral subsurface flow (Potter et al., 2015; Radcliffe et al., 1988). These soils are prone to compaction and thus require some form of tillage to break up the developed subsurface hardpan and reduce compaction (Raper et al., 1994). The most common conservation practice in the Southeast United States region is strip tillage, particularly in Georgia Coastal Plain soils (Balkcom et al., 2018). Strip tillage disrupts only a small amount of soil while maintaining residue cover on the soil surface.

2.4 Effects of Tillage Type on Soil and Water

There have been other studies comparing conventional tillage systems to conservation tillage systems, especially in the Southeastern USA. The amount of organic matter in a soil is an indicator of soil health and is linked closely with soil carbon; ample literature is available on the importance of carbon sequestration in soils for improving crop productivity and reducing global greenhouse gas emissions (Causarano et al., 2006). This thesis focused on soil organic matter, bulk density and additional soil report tests as indicators of soil quality.

Continuous cropping systems and frequent tillage deplete the soil quality, resulting in reduced yields because of reduced organic matter (Reicosky et al., 1995). Soil organic content and soil carbon are reduced with conventional farming practices (Franzluebbers et al., 1999). The tillage upturns soil and creates an environment which is not conducive for microorganism growth and organic matter. Deeper and more complete incorporation of residues with conventional tillage hastens the decomposition of crop residues and decreases the amount of carbon available for supporting fungal activity and binding surface soil aggregates (Karlen et al., 1994).

Tillage systems which incorporate a cover crop and allow a thick plant residue to remain on the soil surface typically increase soil organic matter because plant residues decompose slower at the soil surface than when incorporated into the soil (Causarano et al., 2006). Soil organic matter lowers bulk density and improves water-stable soil aggregation which increases pore volume (Eden et al., 2017; Kus et al., 2006). An increase in organic matter thus increases the soil's potential to retain water (Franzluebbers, 2002a; Obour, 2018; Rawls et al., 2003; Sullivan et al., 2007). Conservation tillage systems have proven to be more effective at increasing soil organic matter and producing these benefits compared to conventional tillage systems (Causarano et al., 2006; Chalise et al., 2018; Kay and VandenBygaart, 2002; Reicosky et al., 1995). Sandy soils are especially sensitive to changes in soil organic content, so agricultural land in this region could benefit from the accumulation of higher organic matter (Rawls et al., 2003).

It is well documented within the literature that cover crops and minimal tillage reduce soil erosion and runoff by providing a protective layer over the soil surface (Bosch et al., 2012; Langdale et al., 1992; Raczkowski et al., 2009; Truman et al., 2009). Soil quality concern was the main reason for the creation of conservation tillage methods. Long-term studies have demonstrated the ability of surface residue remaining on the soil surface to protect from the highly erosive and frequent storm events typical to the Southern U.S. (Endale et al., 2015; Langdale et al., 1979; Raczkowski et al., 2009; Truman et al., 2011). The accumulated benefits associated with conservation tillage develops over a period of three to five years and can be quickly lost under conventional tillage (Reicosky et al., 1995).

Infiltration is also increased with reduced tillage and cover crop residue due to the creation of water-stable soil aggregates and reduction of surface sealing (Bruce et al., 1992; de Almeida et al., 2018; Franzluebbers, 2002b). Conservation strip tillage systems enhance infiltration, and reduce runoff, sediment, and supplemental irrigation amounts compared to conventional tillage systems (Truman and Nuti, 2010). Bruce et al. (1992) also reported increased plant available water during the summer months for conservational tillage compared to conventional tillage. Many articles highlight the greater water retention and plant available water capabilities of conservation tillage, but do so with experiments conducted on soil cores treated in a laboratory (Kus et al., 2006; Nouri et al., 2019; Unger and Vigil, 1998).

There have been some studies in which water applications are reduced on cotton crops, but the final reported measurements were in terms of cotton lint yield (Durham, 2005; Zhao et al., 2008; Zurweller et al., 2019). Some of these studies favor conservation tillage methods in dry years but show no difference for wet years. Limited research is available on the water loss rates in cotton production soils.

Hawkins et al. (2016) conducted research to determine the rate of soil moisture loss for conventional and conservation tillage systems for peanut crops. The researchers used gravimetric soil moisture sensors and reported findings in terms of water tension lost per hour and found that only under dry conditions did the conventional tillage system lose water at a faster rate than did the conservation tillage system. Additional information concerning the water retention rates for conservation tillage compared to conventional tillage could lead to more farmers adopting conservation practices to reduce irrigation requirements, improve crop production during dry years, and improve soil quality.

2.5 Adoption Rates

The widely known environmental benefits of conservation tillage do not explain the low adoption rates in the Southeastern USA. The most recent reports of conservation tillage adoption rates vary from 21% to 36%, with the least common adoption rates identified under cotton crop production (CTIC, 2008; Sullivan et al., 2007; USDA-NASS, 2018; Wade et al., 2015). Bauman et al. (2005) in a research review of data from 1998 through 2002, found that even though there were not significant increases in cotton yield between tillage practices due to the large variances in the study sites, profit was always positive for no-till systems compared to other tillage systems. Similar studies found a lack of increased cotton yield between the two practices (Brown et al., 1985; Longest et al., 2018) while other studies found cotton yields increased with conservation tillage (Bouquet et al., 2004; Schomberg et al., 2003). These findings suggest that profit determines the persistence of growers in following conservation tillage practices.

2.6 Water Balance

Limited water supplies have historically driven studies of plant water uptake. The understanding of water movement becomes much more critical for agricultural production in drier regions than in humid regions where most agriculture can be irrigated without water supply shortages. Field-level water balance methods are generally the same, with few differences depending on the factor under study. Figure 2.1 is a general water balance showing the inputs and outputs of water typical to an agricultural system. Inputs into the system are rainfall and irrigation, while outputs from the system usually include surface runoff, evapotranspiration, change in soil water storage, and deep percolation or drainage (Liang et al., 2016; Mohammad et al., 2018; Moiwo and Tao, 2015). This simple water balance equation (Equation 2.1) can help determine water use and movement differences under different management systems. Not many studies utilize water balance methods to determine differences in water movement within cotton fields.

$$P + I - D - R - ET = \Delta S \tag{2.1}$$

Where:

ΔS = Storage (m^3)

P = Precipitation (m^3)

I = Irrigation (m^3)

D = Drainage (m^3)

R = Runoff (m^3)

ET = Evapotranspiration (m^3)

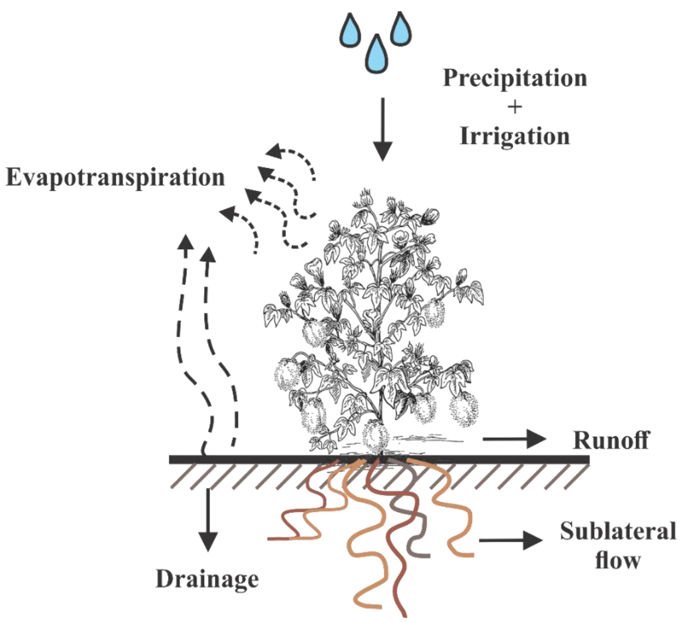


Figure 2.1 Water Balance Diagram of an Agricultural System with Inputs and Outputs

2.7 Summary

Conservation tillage has benefited the soil quality in the Southeastern U.S. region greatly since its conception and implementation (Langdale, 1994; Truman et al., 2009; USDA, 2015). A trend in the literature is that the crop water use and yield result in more benefits under conservation tillage during dry years than in wet years compared to conventional tillage. Adoption rates of conservation tillage are still relatively low. The trend in climate indicates more frequent droughts and intense storm events for this region. Identifying practices in which farmers can reduce irrigation requirements and produce a better crop during drought periods might help increase adoption.

Despite all the available research, we still do not fully understand water retention within the soil profile under conservation tillage or conventional tillage systems in sandy soils. This thesis aims to repeat similar aspects of the study conducted by Hawkins et al. (2016) with focus on water and soil in cotton production systems in the Southeastern U.S.

CHAPTER 3

METHODS AND MATERIALS

3.1 Introduction

Three counties throughout Georgia were selected for the study. Within each county, one conservation tillage (ST) field and one conventional tillage (CT) field were identified and chosen for the study. To our knowledge, the selected fields had been under the same type of production system for at least ten years, whether ST or CT. Farmers permitted us to install sensors in their fields and collect soil samples periodically. This section describes the locations and how the researchers investigated the water use and some aspects of soil quality for the two production systems.

3.2 Site Descriptions

The northern county, Oconee, is in the Southern Piedmont, while the two southern counties, Bulloch and Pulaski, are in the Southeastern Atlantic Coastal Plain (Figure 3.1). The soil types in the Piedmont are generally high in clay content with more rocky outcroppings, whereas the soil types in the Coastal Plain are composed of soft, sandy materials.

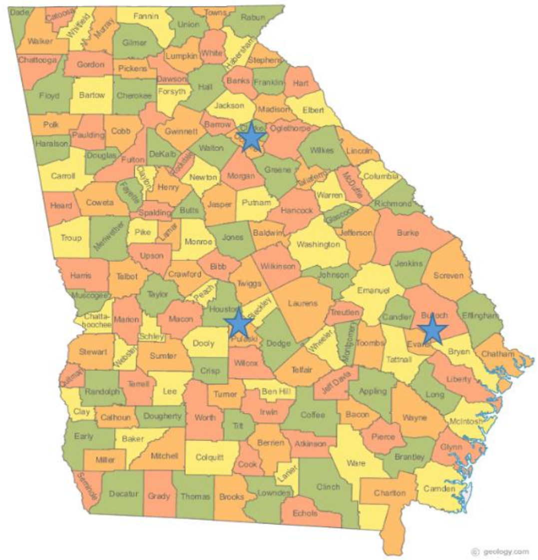


Figure 3.1 County Map of the State of Georgia with Blue Star Indicators of Experimental Site Locations

3.2.1 Oconee County Experimental Sites

In Oconee County, the two sites are located on the University of Georgia's J. Phil Campbell Sr. Research and Education Center near Watkinsville, Georgia. The conservation tillage (ST) field is at 33°53'N Lat., 83°25'W Long.; and 236 m (774 ft.) above sea level. The conventional tillage field (CT) is at 33°52'N Lat., 83°26'W Long.; and 238 m 780 (ft.) above sea level. Both of these fields have been used in previous research studies to collect surface water runoff in edge of field H-flumes as described by Langdale et al. (1979) and Endale et al. (2002a). The size of the fields was 28,328 m^2 (7 acres) for the ST site and 3,237 m^2 (0.8 acres) for the CT site (Soil Survey Staff, 2018). The predominant soil type for both fields is Cecil sandy loam (clayey, *kaolinitic thermic Typic Kanhapludult*). The conservation tillage method, no till, has been used on the ST site beginning in 1974, along with a fallow season cover crop. Endale et al. (2015) describe in detail the cropping rotation and management practices implemented at this conservation tillage location from 1974 to 2011. At the CT site, the soil was leveled and tilled using a moldboard plow at 18 inches several times before to planting, leaving no residue at the soil surface.

3.2.2 Bulloch County Experimental Sites

The sites in Bulloch County are located south of Register, Georgia. The ST site is at 32°16'N Lat., 81°51'W Long.; and 52 m (170 ft.) above sea level. The CT site is at 32°16'N Lat., 81°51'W Long.; and 48 m (157 ft.) above sea level. These two study sites are located approximately 0.609 km (2,000 ft.) apart. The size of the sites was 71,225 m^2 (17.6 acres) for the ST site and 53,014 m^2 (13.1 acres) for the CT site (Soil Survey Staff, 2018). The predominant soil type in these fields is Tifton loamy sand (fine-loamy, *kaolinitic, thermic, Plinthic Kandiudult*).

The ST site, seen in Figure 3.2 (a), has been managed under conservation strip tillage consistently for over 15 years. The farmer uses a no-till winter cover crop and utilizes strip tillage method to plant crops. Both fields in Bulloch County have alternating production schedules of cotton and peanuts and are non-irrigated. The CT site has historically been tilled with a disc plow each year multiple times, leaving no residue at the soil surface. The growing season of 2018 was the first season the CT site had been planted with a cover crop and managed with reduced tillage practices. As shown in Figure 3.2 (b), there is more residue remaining on the surface than what would be seen in a typical conventional tillage operation. Since the benefits from conservation production practices require a few years to manifest, this site was deemed suitable to use in this research as a CT field.

(a) ST site with a thick cover crop residue and EM50 data logger **(b) CT site with some cover crop and bare soil**

Figure 3.2 Bulloch County Field Photographs of ST and CT Ground Cover

3.2.3 Pulaski County Experimental Sites

The sites in Pulaski County are located south of Hawkinsville, Georgia. The ST site is at 32°13'N Lat., 83°23'W Long.; and 7 3m (240 ft.) above sea level. The CT site is at 32°09' N Lat., 83°34' W Long.; and 79 m (260 ft.) above sea level. These fields are separated by approximately 18.98 km (11.80 miles). The size of the sites was 59,894 m^2 (14.8 acres) for the ST site and 161,470 m^2 (39.9 acres) for the CT site (Soil Survey Staff, 2018). The predominant soil type is Dothan loamy sand for both sites (fine-loamy, *kaolinitic, thermic, Plinthic Kandiudult*).

Ideally, the distance between the selected fields would be small, however, locating a farmer who practiced true conservation tillage as defined in Chapter 2 resulted in a large distance from the conventional tillage site. The contrasting difference between the two tillage types in the amount of residue cover can be seen in Figure 3.3. Figure 3.3 (a) displays ST in Pulaski County, Georgia with a thick residue protecting the soil surface and minimal tillage. Figure 3.3 (b) shows CT in Pulaski County, Georgia with numerous tread marks from multiple tractor passes and a bare soil surface.

(a) ST site with a thick cover crop residue at the surface

(b) CT cite with no surface residue

Figure 3.3 Pulaski County Experimental Sites Photographs Showing Groundcover

3.3 Data Collection

3.3.1 Soil Moisture Content

Soil moisture sensors were installed at three depths throughout the soil profile at 10, 20, and 30 cm. Within each field, there were three repetitions. The locations of the soil moisture sensors were selected to represent the entire field (maps of each field with sensor locations shown in Appendix A). All sensors were installed in June 2018, approximately 25 days after planting. Some farmers had different planting dates. The planting dates for each field in this study were all within one week of each other, which is why one general planting date was used.

The sensors used to determine soil moisture content were the Em50 data logger, the ECH_2O 10HS soil moisture sensor, and the TEROS 12 soil moisture sensor[1]. The TEROS 12 sensors include electrical conductivity measurements, which was included in the initial design of the project to quantify nutrient movement along with volumetric water content data. Two TEROS 12 sensors per field were purchased for the study and were each installed at the 10 cm depth. The remaining sensors were 10HS soil moisture sensors. Volumetric water content (m^3 m^{-3}) data were recorded to the EM50 data logger every 10 minutes.

<u>3.3.2 Soil Sampling</u>

The first research objective, assessing soil health, was accomplished by the following tasks. Soil samples were collected with a 7.5 cm diameter hand auger at 10, 20, and 30 cm depths to evaluate the long-term impacts of tillage method on soil quality. Soil samples were collected once a month from June 2018 to December 2018. Three composite cores per field were collected and fractioned into three depth increments at 10, 20 and 30 cm. The sampling sites were randomly located within 5 meters of the three data loggers in each field. Soil samples were delivered to the UGA Agricultural and Environmental Services Laboratory (AESL) where they were air dried, crushed to pass through a 2-mm sieve, and analyzed for pH, Nitrate nitrogen (NO_3-N), organic matter (OM), and Mehlich 1 extraction of Ca, K, Mg, P, and Zn. The organic matter content is determined by Loss on Ignition (LOI) method and is expressed as percent by weight. The full tables of the soil reports are in Appendix B.

Soil bulk density and porosity measurements were taken to validate the volumetric water content readings and identify differences among tillage types. To ensure that the volumetric

[1] METER Group, Inc. 2365 NE Hopkins Ct, Pullman, WA 99163

water content readings were not wildly inaccurate, we made sure that the porosity was higher than or equal to the highest volumetric water content for each field. Samples were collected by hand at 10, 20, and 30 cm depths near the three data loggers in each field. These cores were weighed, oven dried, and weighed again to determine the bulk density (ASTM International, 2018). Soil porosity was calculated as the fraction of total volume not occupied by soil assuming a particle density of 2.65 Mg m^{-3} (equation 3.1) (Radcliffe, 2010):

$$Porosity\ (\%) = 1 - \frac{Bulk\ Density\ (g/cm^3)}{Particle\ Density\ (g/cm^3)} \tag{3.1}$$

3.3.3 Rainfall Data

Weather data was collected from the nearest UGA Weather Network station, instead of using in-field rain gauges which have data quality issues due to infrequent field visits (UGA Weather Network, 2018). This adds error in the water calculations, as there may have been differences in the rainfall amount in the area over the station versus the area over the field. The error associated with station distance from the field sites were deemed to be less than in-field gages that collect insects and other debris.

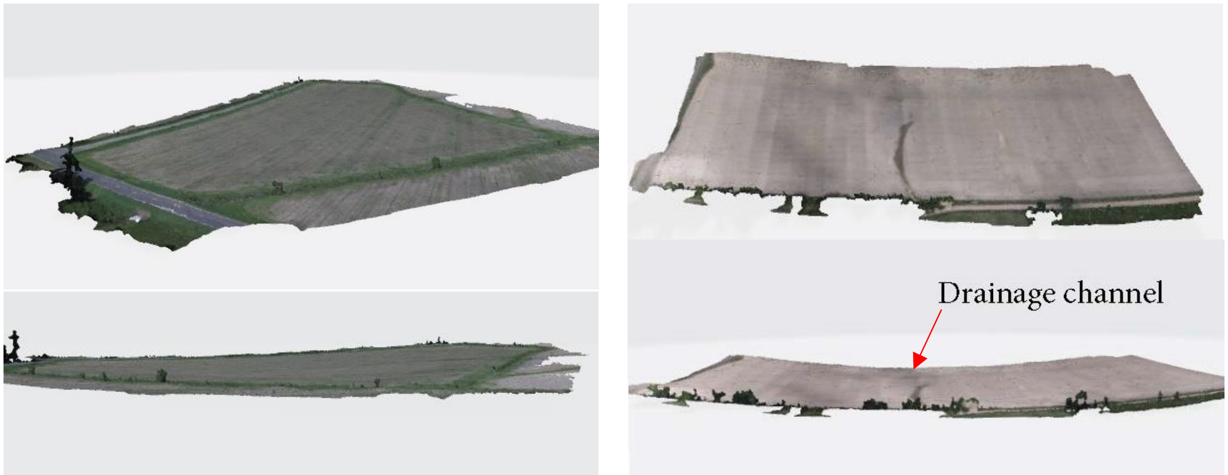
Weather stations from the Georgia Automated Environmental Monitoring Network were used to access daily precipitation data (UGA Weather Network, 2018). For the Oconee fields, the station was located within 3.30 km (2 miles) of both fields; for the Bulloch County fields, the weather station was located approximately 23.50 km (14.6 miles) away from the ST field and 24.30 km (15.1 miles) from the CT field; and for the Pulaski County fields, the weather station was located 26.23 km (16.3 miles) from the ST field and 13.19 km (8.20 miles) from the CT field. Increased distances of the weather stations from the experimental site locations leads to increased error in the actual rainfall amount on the study sites. The soil moisture sensor data at

10 cm plotted with rainfall data is in Appendix C to show the accuracy of rainfall data and soil moisture response.

3.3.4 Edge of Field Monitoring

Edge of field monitoring stations were installed in the Bulloch and Pulaski sites; Oconee County had existing edge of field monitoring stations. Drone-captured images were processed and used to create a digital elevation model of the sites to determine the lowest point at the edge of the field for the installation of the H-flume. The Pix4D[2] images created from the survey for Pulaski County are shown in Figure 3.4. The ST site was relatively flat, with no obvious water drainage location, whereas the CT site was bowl shaped with one highly eroded visible drainage channel. The fields in Bulloch County were also relatively flat with no obvious drainage channel. Once the most suitable location was determined, researchers installed H-flumes with wooden boards on each side to funnel the water through the flumes. The size of the H-flume was determined based on the drainage area contributing to the flume and the expected flows from a 25-year rainfall event.

[2] Pix4D Inc., Version 4.3.15, San Francisco, CA 94105.



(a) ST site with little slope and no obvious drainage channel

(b) The bowl-shaped CT site with a large, visible drainage channel

Figure 3.4 Pulaski County 3D Images of Sites Created with Drone-Captured Imagery

3.4 Water Loss Rates

The objective of this research was to determine the moisture loss rates and compare tillage type and depth. Soil moisture sensor data were graphed according to depth for each field. These graphs are displayed in Chapter 4 for the 10 cm depths and in Appendix D for the 20 and 30 cm depths. The spikes in soil moisture content were due to water passing through that sensor's measurement zone, which is a 5 cm radius around the sensor. When these spikes occur, they are followed by a period of decline in the volumetric water content as the soil profile drains water or plants use water in that measurement zone. To compare these moisture loss rates across two fields for each location, large-storm systems' wetting-drying events were selected for calculation and comparison. Table 3.1 lists the event dates that were selected for each county. The volumetric water content loss rate per day ($m^3\ m^{-3}\ d^{-1}$) was determined by calculating the slope from the wettest point to the driest point during each event for every soil moisture sensor.

Table 3.1 Selected Wetting-Drying Event Dates for Each Experimental Site Location in 2018

Oconee	Bulloch	Pulaski
June 22 - June 26	June 18 - June 24	June 28 - July 6
June 28 - July 13	June 25 - July 7	July 7 - July 14
July 21 - Aug. 1	July 7 - July 20	July 14 - July 18
Aug. 3 - Aug. 18	July 20 - July 29	July 23 - July 30
Aug. 19 - Aug. 28	July 29 - Aug. 2	Aug. 2 - Aug. 9
Aug. 29 - Sept. 12	Aug. 3 - Aug. 17	Aug. 10 - Aug. 17
Sept. 17 - Sept. 24	Aug. 17 - Aug. 20	Aug. 20 - Aug. 30
Sept. 27 - Oct. 10	Aug. 22 - Sept. 4	Aug. 31 - Sept. 28
		Sept. 29 - Oct. 9
		Oct. 11 - Oct. 16

After the loss rates were established, calculations were conducted to find out approximately how much water was lost at each site. The following equation (3.2) describes how water volume loss per day was calculated and used for the water balance equations.

$$VWC\ loss\ per\ day\ \left(\frac{m^3}{m^3 * d}\right) \times soil\ volume\ (m^3) = Water\ Loss\ (m^3/d) \tag{3.2}$$

For each field, the soil volume was calculated using the field area multiplied by the 10 cm soil depth measured by the soil moisture sensor. This water loss volume was calculated for each depth and study site.

3.5 Water Balance Calculation

Water entering an agricultural system comes in the form of rainfall and irrigation. Water is lost from the system via soil evaporation, transpiration from crops, runoff, drainage, and sublateral water movement. This simple soil water balance (Equation 2.1) was used to compare the change in water loss for each field. All calculations were conducted with daily total volume each data category ($m^3\ d^{-1}$): total rainfall per day, drainage per day, runoff per day, and evapotranspiration per day. Results were normalized for comparison by dividing by field area.

For this research, no irrigation was applied due to the ample rainfall which occurred during the growing season. Oconee County ST site and Bulloch Count sites were not irrigated. The two sites in Pulaski County and Oconee CT site had unused center pivot systems, as confirmed by the farmer. During the 2018 growing season, precipitation was well above average, meaning less required irrigation (US Climate Data, 2019). Therefore, input into the water balance system was the rainfall data collected from the nearest UGA Weather Station only.

Infiltration (or drainage) was determined by taking the calculated volume of water lost past the 0-15 cm depth and subtracting the volume of water lost past 25-35 cm depth. Because the water loss rates were calculated as an average loss rate for the duration of the event, the same volume of water was input for each day during the event time period. This provided an estimated amount of water moving past the 0-35 cm soil profile. Total runoff per day was collected from the edge of field monitoring stations.

Evapotranspiration was estimated using the cotton water use curve (Figure 3.5) developed by Bernardz et al. (2002). This curve was used to estimate the water loss due to evapotranspiration of a cotton crop. The planting date used for this calculation is May 22, 2018. The cotton water use per day was multiplied by the field area for an estimated volume of water usage during the growing season.

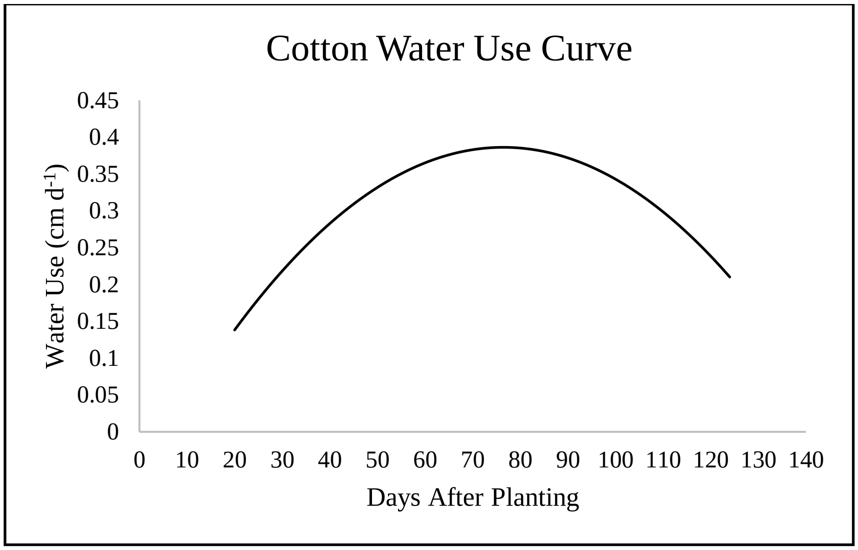


Figure 3.5 Cotton Water Use Curve

With all the required inputs, the daily data were input into an EXCEL sheet and totaled per event period. The result is defined as surplus water for this study. The surplus water was normalized by dividing by field area to get the final value in millimeters of water.

3.6 Statistical Analysis

Data were compared with JMP® statistical software[3]. For differences between tillage types, a paired t-test was applied. A one-way ANOVA tested the significance of the tillage type and depth. Data were checked for violation of ANOVA test assumptions. The Tukey-Kramer least squared difference method was performed on statistically significant ANOVA test results to summarize the effect of treatments on the response. All statistics were performed using a P-value of 0.05 to test for significance.

[3] JMP®, Version 14.1.0. SAS Institute Inc., Cary, NC, 1989-2019.

3.7 Limitations

There are many limitations to this type of study. For example, the initial project design included an economic analysis of the cotton crop, but a record-setting hurricane, Hurricane Matthew, devastated most cropland in South Georgia. The distance to each research field resulted in a few issues arising during the research timeframe. The data loggers were manually downloaded which lead to some data being lost as a result battery failure not realized until the next download time. In-field rain gauges originally installed were not used due to bird and insect debris resulting in poor quality data. Some sensors were lost due to wires being cut by farming equipment. Other issues were due to the sensors being lost due to rodents chewing through the sensor wires or being severed by farming equipment. Moisture entering the data logger box also caused damage to the equipment in some cases, and old sensors which had begun to malfunction (see Appendix D Soil Moisture Sensor Graphs). Even with all the limitations, this research is still very valuable to producers and researchers.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

Each project site location is presented and discussed in separate sections of this chapter. Within each section, the results of the soil sampling, soil moisture content, water loss rates, rainfall and recorded runoff, and water balance calculation will be shown and discussed. Conservation Tillage (ST) and Conventional Tillage (CT) will be analyzed and compared in each section.

4.2 Oconee County Experimental Sites

4.2.1 Soil Sampling

Percent organic matter was measured from June 2018 to December 2018. Over this period, CT sampling location had a significantly higher overall mean organic matter than ST averaging 2.1895 ± 0.6524% and 1.8648 ± 0.0617% respectively (paired t test, $P>0.05$). However, when a one-way ANOVA test was applied to the organic matter across tillage type and depth, Table 4.1 shows the average organic matter was not statistically significant for any depth or tillage type; means with the same letter are not significantly different from each other (Tukey–Kramer test, $P>0.05$). Figure 4.1 shows the percent organic matter per month at the three sampled depths. Each data value on the graph is the result of one sampling value, thus there are no error bars displayed in this figure. Large differences may be due to the collection of plant roots during sampling. Overall, the percent soil organic matter between tillage types by depth are not statistically significant.

Table 4.1 Oconee County Experimental Sites: Tillage and Depth Connecting Letters Report Arranged by Decreasing Mean Percent Organic Matter

Tillage & Depth (cm)		Mean OM%
CT 10	A	2.3742857
CT 30	A	2.3700000
ST 30	A	1.9928571
CT 20	A	1.9371429
ST 10	A	1.9314286
ST 20	A	1.6700000

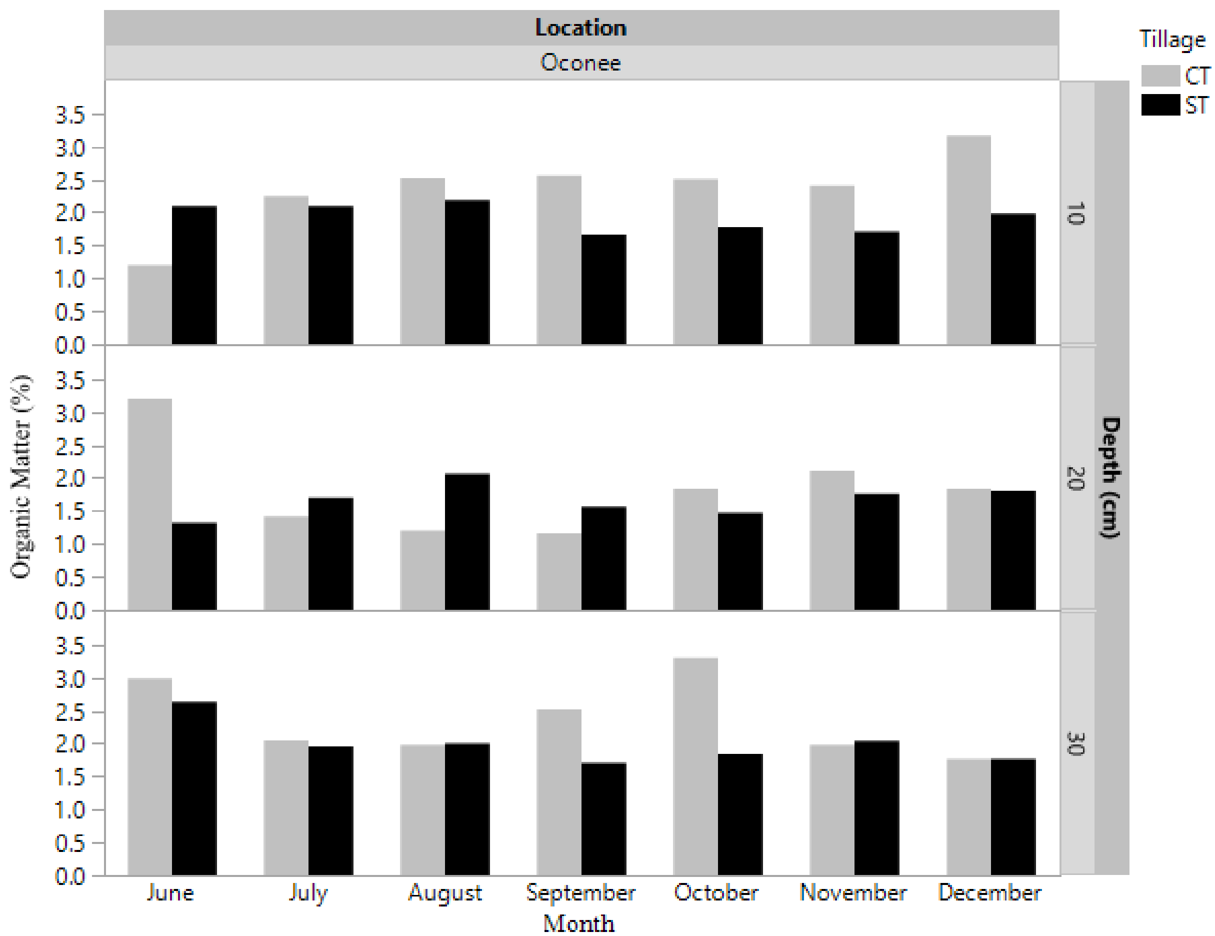


Figure 4.1 Oconee County Experimental Sites: Percent Organic Matter Graphed by Month and Depth

These were surprising results, as the ST site was managed under such practices since 1972. A larger difference in organic matter between the conservation tillage field and the conventionally tilled plots was expected than what was measured. A lack of difference in the organic matter is attributed to previous conservation tillage experiments on the same plot as this study was conducted (Endale et al., 2002b). It was known that previous research was conducted on these plots, however, the exact location of the conservation tillage plots in this study were unknown at the time of the design of the experiment. The plot which was selected to monitor was previously used as a no-tillage plot for several years. This indicates that a buildup of organic matter in this soil type remains even after deep tillage.

The bulk density results show no significant differences between tillage types or depth for the Oconee County study sites. The mean bulk density (g cm^{-3}) was 1.48 ± 0.07 and 1.45 ± 0.06 for CT and ST respectively. The conservation tillage field has not been tilled for several years, yet it had a lower bulk density than conventional tillage. Other studies have found also that conservation tillage reduces bulk density due to more stable soil aggregates (Chalise et al., 2018). Porosity was calculated by using the bulk density results and was found to be 45.27 ± 2.09% for ST and 44.22 ± 2.64% for CT. Franzluebbers (2002a) conducted soil analysis on this ST site and a nearby CT site. The author found similar soil bulk densities and porosity values as to those reported here. See Appendix E for graphical results of bulk density and porosity.

4.2.2 Soil moisture content

Volumetric water content (m^3 m^{-3}) data were collected in each field beginning on June 20, 2018 (approximately 29 days after planting) to October 18, 2018. The three locations of soil moisture sensor data were grouped and separated by depth for each field. The graphical data is displayed in Figure 4.2 for ST and Figure 4.3 for CT. Data skips as seen on Figure 4.2 with the solid black line, for example, are due to data logger failure resulting from a loose battery battery connection, farm equipment cutting through the cables, and other miscelaneous problems. Figures 4.2 and 4.3 are for the 10 cm depth of soil moisture only, and the data from 20 and 30 cm depths can be found in Appendix D.

Figures 4.2 and 4.3 represent the shallowest depth of the measured soil moisture. Thus, this data is most succeptible to show changes in response to rainfall events. As can be seen in Figures 4.2 and 4.3 for the September data, some rainfall events occurred on the ST site and not on the CT site, even though the distance between these fields is approximately 3.3 km. The frequent, spotty afternoon showers during late summer months make a comparison of field data difficult. Field capacity for this soil type is approximately 0.18 (cm^3 cm^{-3}) (Dayton, 1966). The horizontal red line in Figures 4.2 and 4.3 indicate that the soil was nearly at or above field capacity for the duration of the growing season.

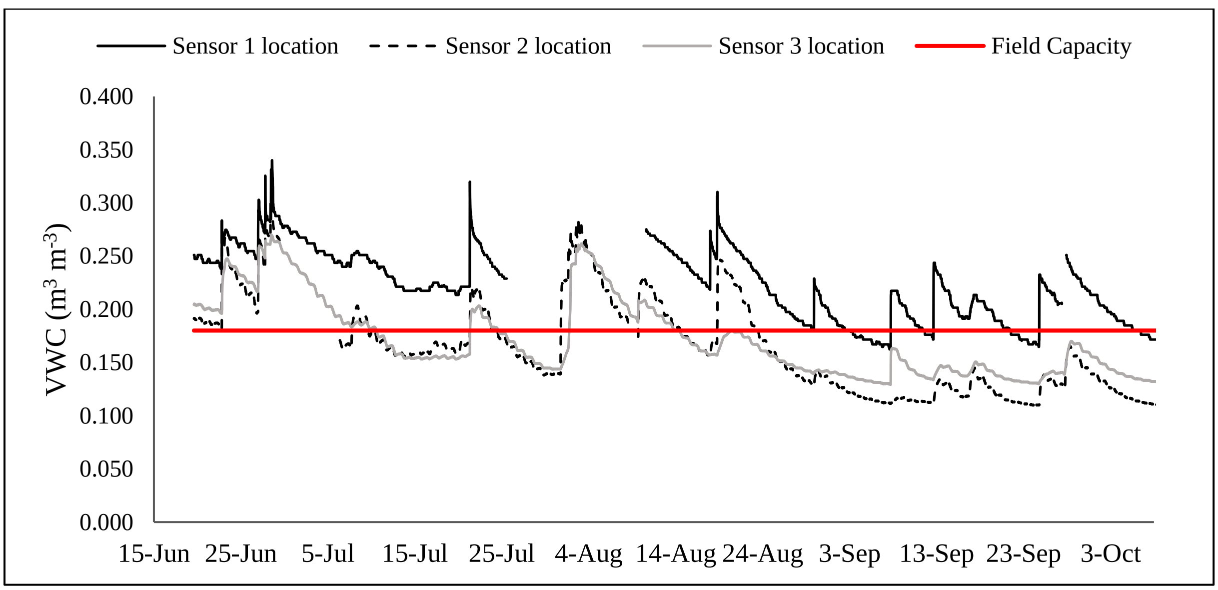


Figure 4.2 Oconee County ST Experimental Site Soil Moisture Graphs at 10 cm Depth

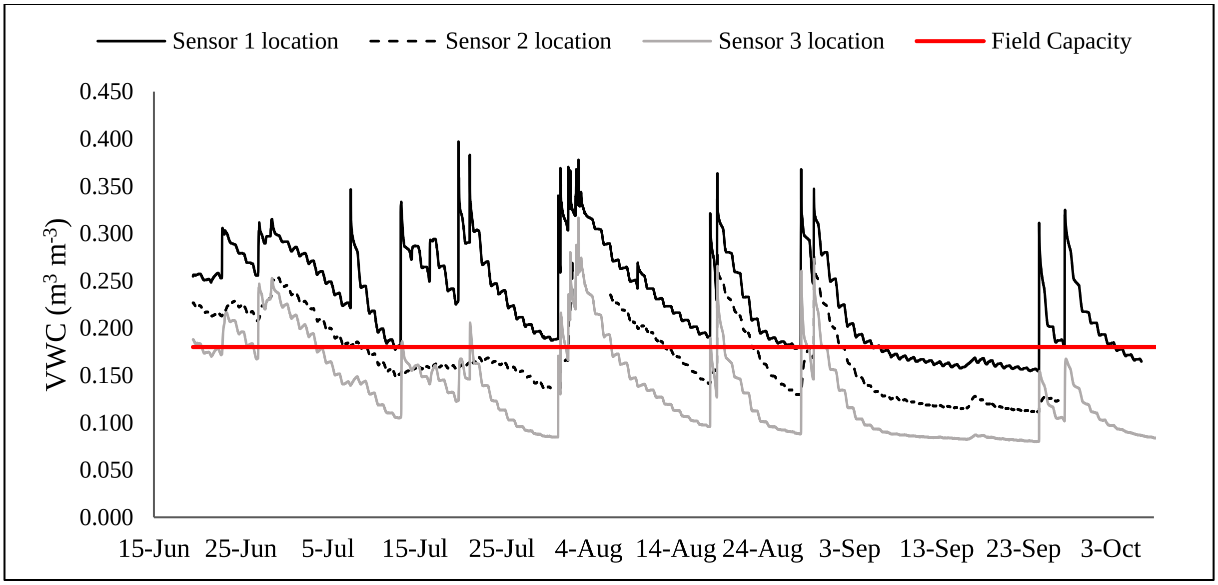


Figure 4.3 Oconee County CT Experimental Site Soil Moisture Graphs at 10 cm Depth

Figure 4.4 shows a plot of these average VWC per event for 10 and 30 cm depths. Additionally, for the sake of clarity, graphs are located in Appendix F that add the 20 cm depth result. Several similar wetting-drying time periods were isolated for both fields as indicated by the dates on the X-axis of Figure 4.4. These events were selected to reduce error due to differing rainfall. The overall volumetric water content averaged across all depths during each wetting-drying event was nearly identical between tillage types averaging 0.2471 ± 0.0812 (m^3 m^{-3}) and 0.2472 ± 0.0606 (m^3 m^{-3}) for CT and ST respectively. Volumetric water content compared by tillage at each depth was not statistically significant. However, ST had a higher VWC than CT at 10 cm and 20 cm depths. The average VWC per depth and tillage type is displayed in Table 4.2 with a connecting letters report where means with the same letter are not significantly different from each other (Tukey–Kramer test, P>0.05). Other studies support this trend of a higher volumetric water content under ST compared to CT (Braumhardt et al., 2017; Haruna et al., 2018; Liu et al., 2013).

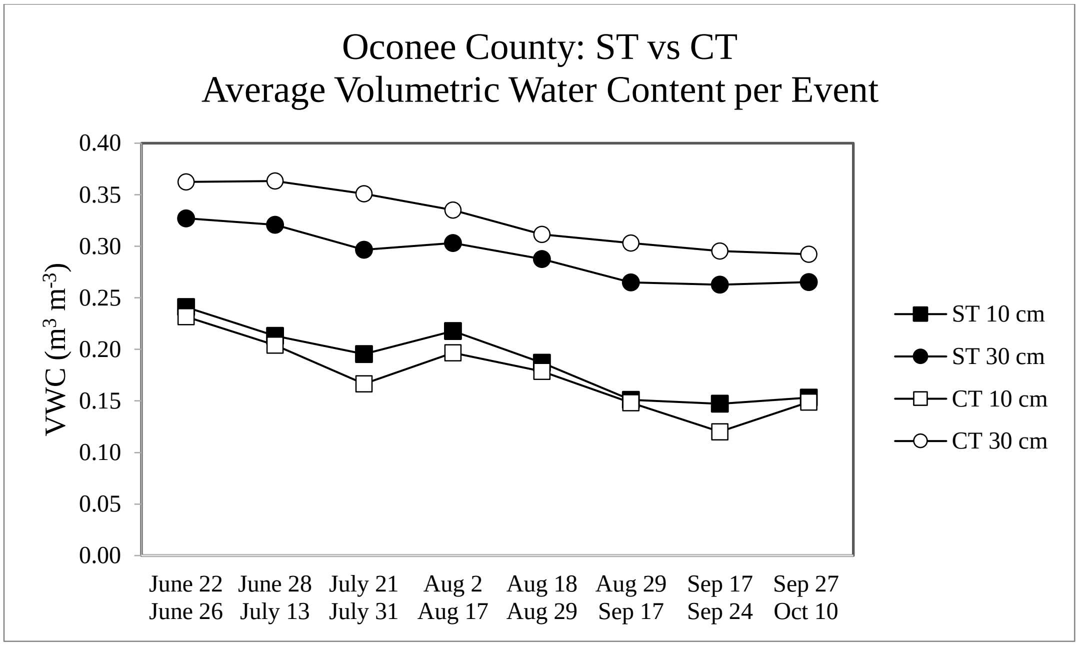


Figure 4.4 Oconee County Experimental Sites: Average Volumetric Water Content per Event at 10 and 30 cm Depth

Table 4.2 Oconee County Experimental Sites: Tillage and Depth Connecting Letters Report Arranged by Decreasing Mean Volumetric Water Content

Tillage & Depth					Mean VWC
CT 30 cm	A				0.32825565
ST 30 cm	A	B			0.29104542
ST 20 cm		B	C		0.26239333
CT 20 cm			C		0.23775130
ST 10 cm				D	0.18822083
CT 10 cm				D	0.17551043

4.2.3 Water loss rates

The research was designed to determine if there was a difference in the moisture loss rate between tillage types. From the previously mentioned wetting-drying events, the moisture loss rates were calculated as described in Chapter 3. The water loss rates per day (mm d^{-1}) are graphed in Figure 4.5 by event dates on the X-axis. Each error bar is constructed using one standard error from the mean. The water loss rates are much higher at shallower depths due to higher sand content, macropores, soil aggregates, higher evaporation, and higher infiltration rates. As can be seen in the graph, CT had a slightly higher loss rate at 10 and 20 cm depth than ST and no obvious differences at the 30 cm depth.

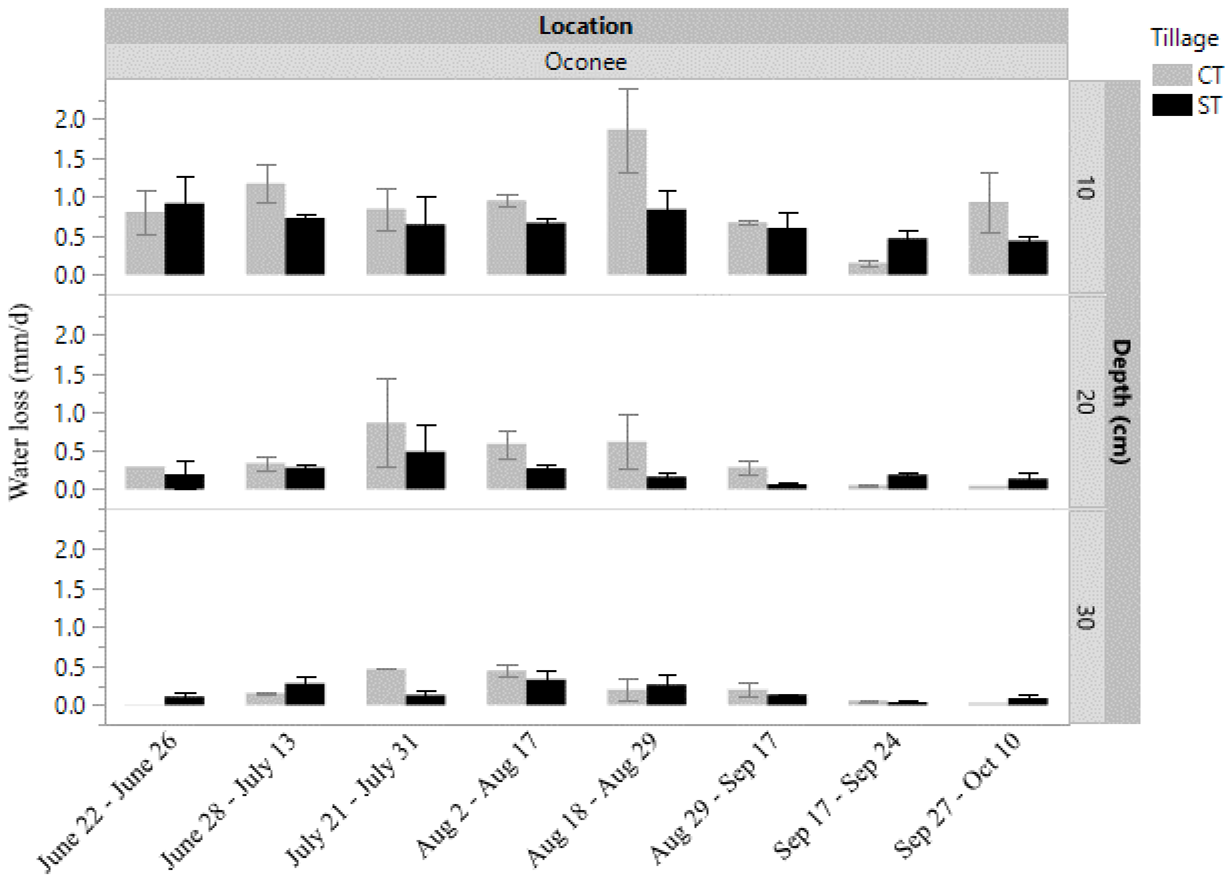


Figure 4.5 Oconee County Experimental Sites: Water Loss Rates Graphed by Wetting-Drying Events and Depth

Overall, there was a significant difference in water loss rate when compared by tillage type, with CT losing more water compared to ST at 0.5648 ± 0.5453 (mm d^{-1}) and 0.3595 ± 0.3414 (mm d^{-1}) respectively (t-test, P>0.05). The results of the one-way ANOVA test on water loss rates by tillage and depth are presented in Table 4.3 where means with the same letter are not significantly different from each other (Tukey–Kramer test, P>0.05). These results indicate that CT and ST at 10 cm depths differed significantly from the other depths in the amount of moisture lost per day, with CT losing water more quickly. One explanation for the greater water content loss in CT compared to ST at all depths could be an increased soil water evaporation caused by soil tillage (Schwartz et al., 2010). This result indicates that ST may be able to retain soil moisture for longer periods even under wet conditions.

Table 4.3 Oconee County Experimental Sites: Connecting Letters Report of Water Loss Rates by Tillage and Depth Ordered by Decreasing Mean Water Loss

Tillage & Depth				Mean Water Loss (mm d^{-1})
CT 10 cm	A			0.92554696
ST 10 cm	A	B		0.66408625
CT 20 cm		B	C	0.42410333
ST 20 cm			C	0.22566273
CT 30 cm			C	0.22556529
ST 30 cm			C	0.16978609

4.2.4 Rainfall and runoff

The runoff for both ST and CT sites along with rainfall are graphed in Figure 4.6. After large rainfall events, CT site had much more runoff per area than in the ST site. Runoff for the ST site was recorded, but when plotted with the same axis as CT, the runoff was not visible; Appendix G contains a graph of CT and ST runoff levels with different Y-axes. Visual inspection of the flumes and runoff channels (Figure 4.7) indicated that large volumes of soil were being washed from the CT site whereas little to no soil displacement could be seen in the ST site. This reduction in soil erosion and runoff is a widely supported phenomenon when using conservation tillage practices compared to conventional tillage (Jakab et al., 2017; Karlen et al., 1994; Langdale et al., 1979).

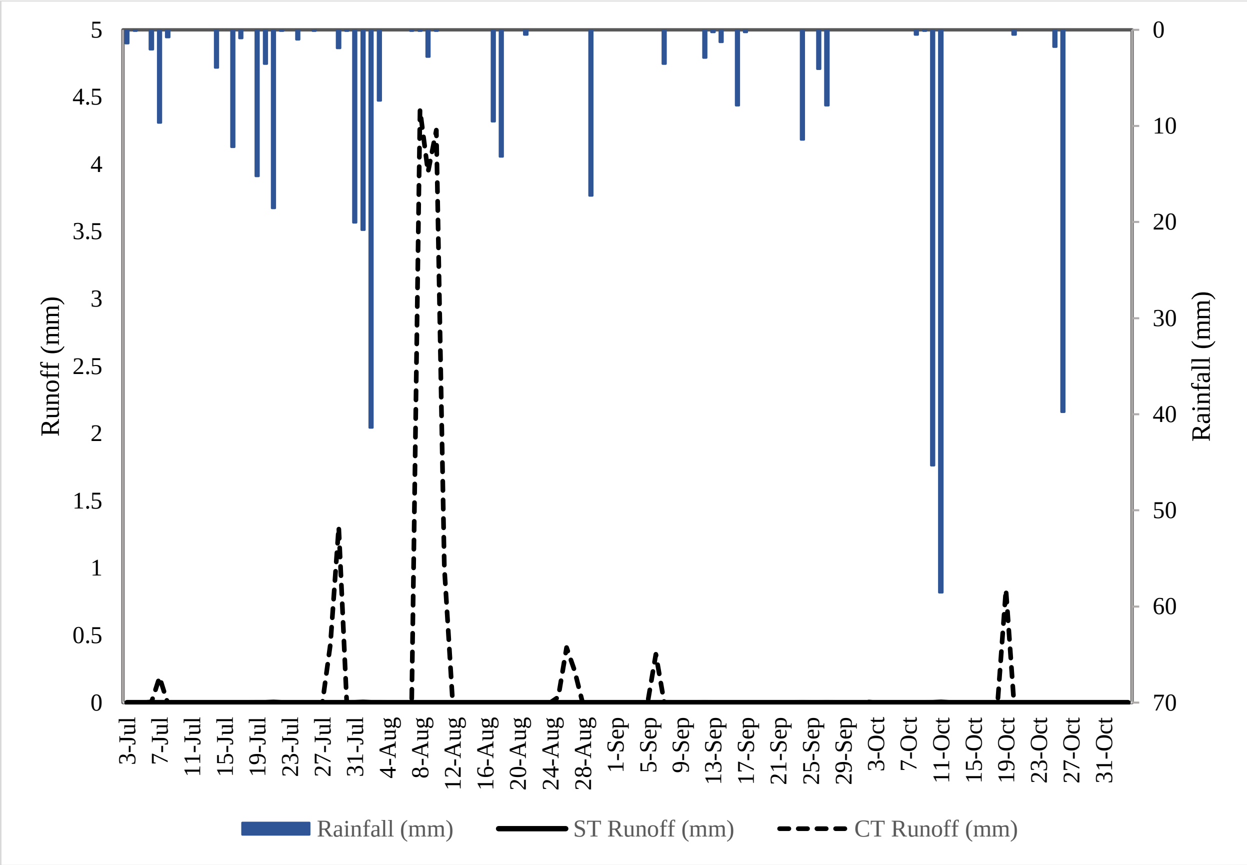


Figure 4.6 Oconee County Experimental Sites: Rainfall and Runoff

(a) ST edge-of-field H-flume

(b) CT edge-of-field drainage channel

Figure 4.7 Oconee County Experimental Sites: Edge of Field Monitoring Stations

4.2.5 Water balance

For this study, surplus water is defined as excess water lost to either runoff, unaccounted for evapotranspiration, or subsurface lateral flows. Because the runoff data is known for Oconee County, this water loss difference is attributed to subsurface lateral water movement and additional evapotranspiration unaccounted for with the simple calculation methods used in this research. Figure 4.8 is the graphical result of the water balance calculation along with the average volumetric water content during these drying periods. At high soil moisture contents, little differences can be seen in the surplus water or the drainage rates (Figure 4.8); however, when the soil moisture content is reduced, larger differences in the surplus water are apparent. The surplus water corresponds to a higher soil VWC; i.e., when the soil profile dries out, the surplus water amount decreases. This trend, seen especially during the prime growing months of July through September, is due to plant uptake and higher evapotranspiration losses due to higher temperatures. Again, it is important to note that for the majority of the study, the soil moisture content was at or above field capacity, meaning significant differences in water loss might be difficult to identify (Nouri et al., 2019).

The water balance calculation for the wetting-drying events produced an average surplus water of 3.633 ± 57.192 (mm) for the ST site and -68.583 ± 137.841 (mm) for the CT site. ST was able to retain more moisture throughout the drying time period compared to the CT site, though these values were not statistically significant (t test, $P>0.05$). Along with a higher average surplus water, ST had reduced variability compared to CT. This result indicates that crops could potentially have more reliable access to water during drying events under conservation tillage systems compared to conventional tillage systems.

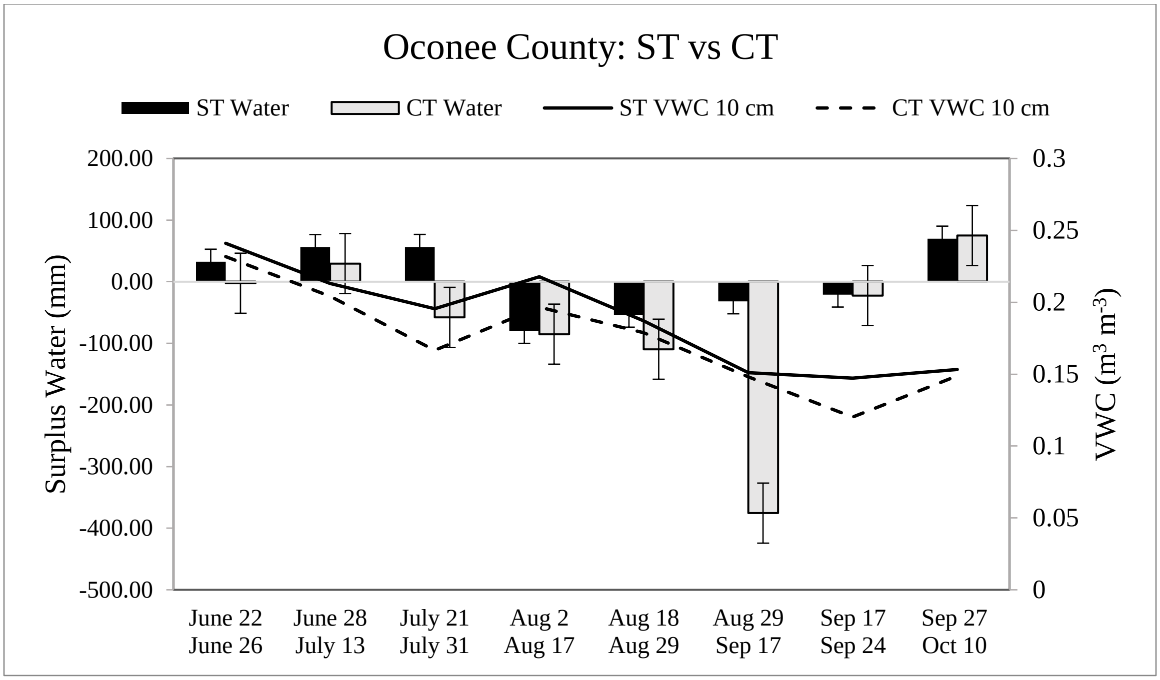


Figure 4.8 Oconee County Experimental Sites: Water Balance Results and Average Volumetric Water Content

4.3 Bulloch County Experimental Sites

4.3.1 Soil sampling

Organic matter was measured from June 2018 to December 2019. Results from the ANOVA test indicate that there is a statically significant difference in the overall organic matter between the ST and the CT sites, with an average soil organic matter content of 1.7205 ± 0.5609% and 0.6033 ± 0.1439% respectively. When broken down into separate depths and tillage type with the Tukey-Kramer HSD method, soil organic matter content at each depth of the ST site was statistically higher than the CT site as shown in the JMP output connecting letters report, Table 4.4 where means not connected with the same letter are statistically different (P>0.05). The highest SOM content was found at 30 cm below the soil surface with a trend of decreasing SOM content towards the surface. Figure 4.9 graph displays the ST percent organic matter content being consistently higher than in the CT site for each month and depth. Each data value on the graph is the result of one sampling value, thus there are no error bars displayed in this figure. These results are contrary to the results of other studies, which report a higher organic matter content near the soil surface (Franzluebbers, 2002b; Kay and VandenBygaart, 2002; Lipiec et al., 2006; Reicosky et al., 1995).

Table 4.4 Bulloch County Experimental Sites: Tillage and Depth Connecting Letters Report Arranged by Decreasing Mean Percent Organic Matter

Tillage & Depth (cm)					Mean OM%
ST 30	A				2.1571429
ST 20		B			1.7400000
ST 10			C		1.2642857
CT 30				D	0.6457143
CT 20				D	0.5828571
CT 10				D	0.5814286

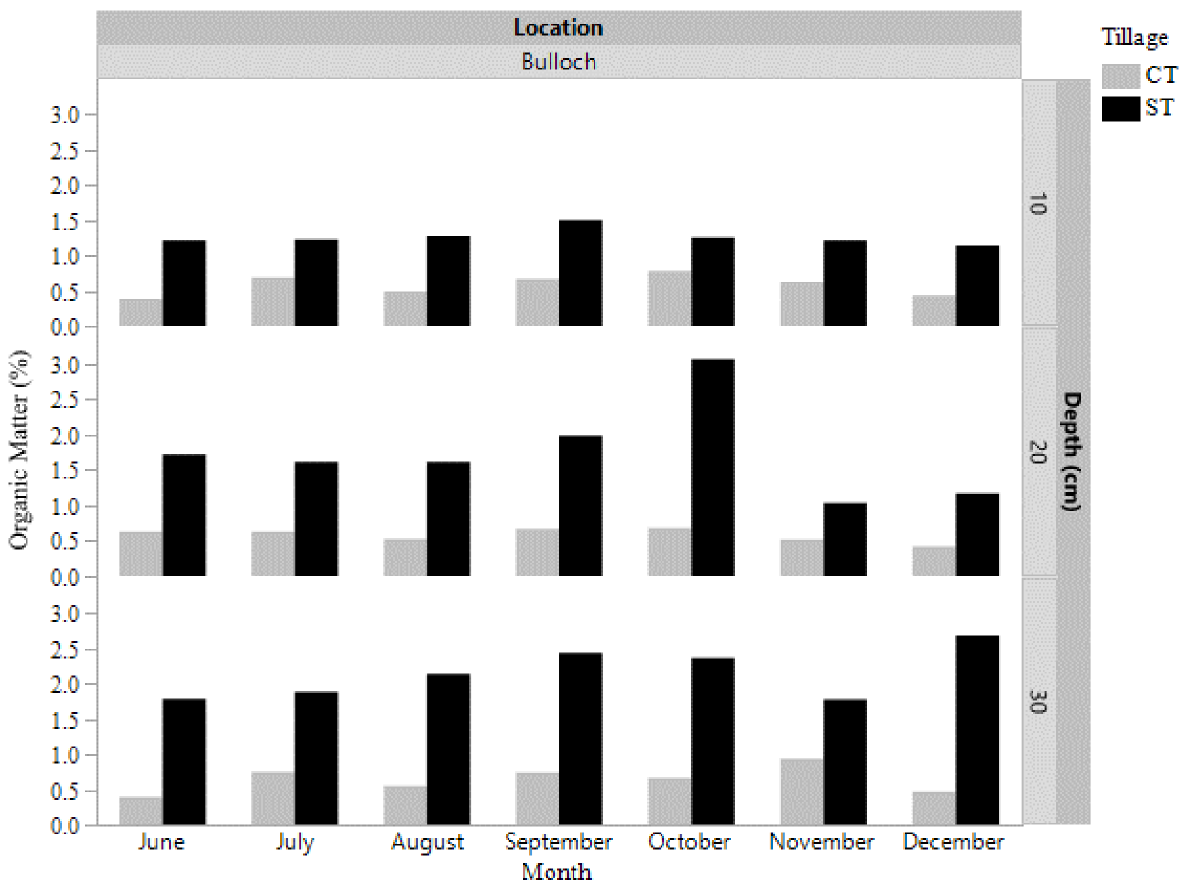


Figure 4.9 Bulloch County Experimental Sites: Percent Organic Matter Graphed by Month and Depth

The bulk density averaged 1.509 ± 0.089 (g cm^{-3}) for the ST site and 1.492 ± 0.085 (g cm^{-3}) for CT site with no statistical difference between the two (t-test, P>0.05). The porosity was 43.056 ± 3.372% and 43.678 ± 3.323% and for ST and CT sites, respectively. Graphical results of the bulk density and porosity separated by depth are provided in Appendix E.

<u>4.3.2 Soil moisture content</u>

Volumetric water content (m^3 m^{-3}) data were collected in each field beginning from June 16, 2018 (approximately 25 days after planting) to October 7, 2018. The soil moisture sensor data were downloaded and grouped by depth. The graphical data for the 10 cm soil moisture readings is displayed in Figure 4.10 for ST and Figure 4.11 for CT. Data skips as seen on Figure 4.11 with the solid black line, for example, are due to data logger failure resulting from a loose battery connection, improper sealing of the equipment which led to moisture imparing the datalogger, and other miscelaneous problems. Figures 4.10 and 4.11 are for the 10 cm depth of soil moisture only, and the data from 20 and 30 cm depths can be found in Appendix D.

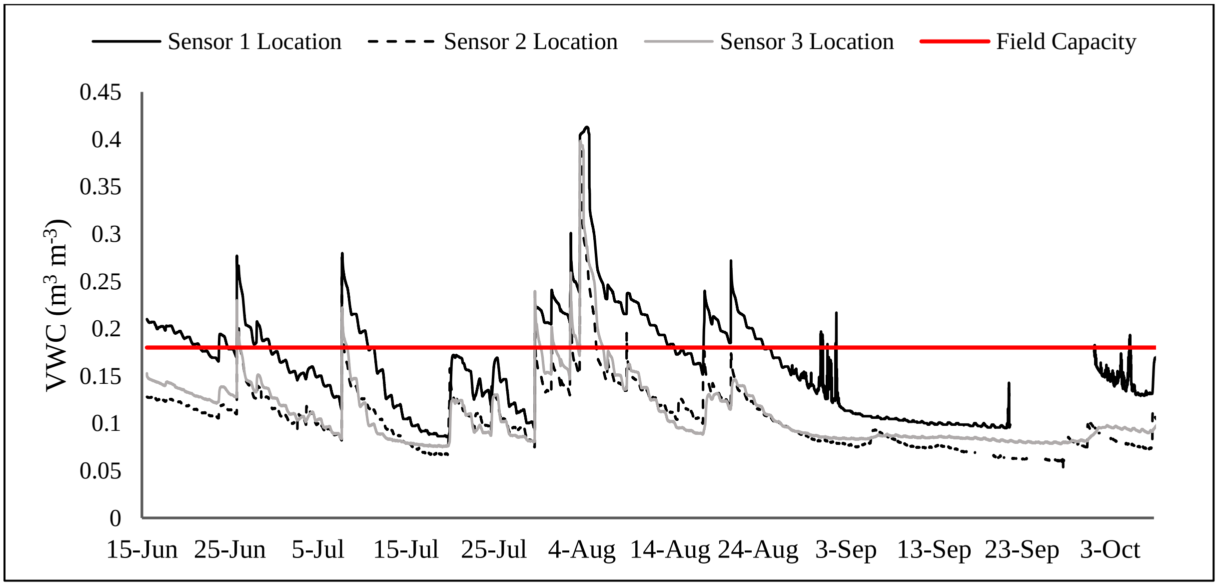


Figure 4.10 Bulloch County ST Experimental Site Soil Moisture Graphs at 10 cm Depth

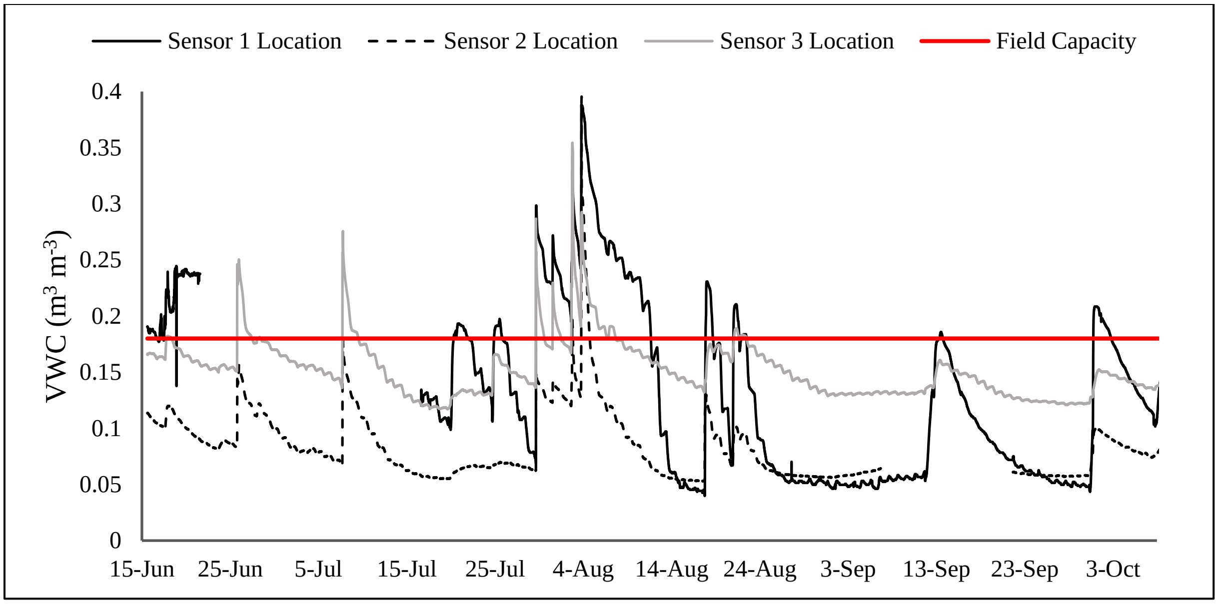


Figure 4.11 Bulloch County CT Experimental Site Soil Moisture Graphs at 10 cm Depth

Figures 4.10 and 4.11 represent the shallowest depth of measured soil moisture. Thus, this data is most succeptible to show changes in response to rainfall events. These fields are dryland agriculture, meaning the farmers rely on rainfall with no supplemental irrigation for their crop production. Liang et al. (2016) determined the field capacity for this soil type to be 0.18 (m^3 m^{-3}). These soils were generally not above field capacity, which aids in identifying differences between tillage types.

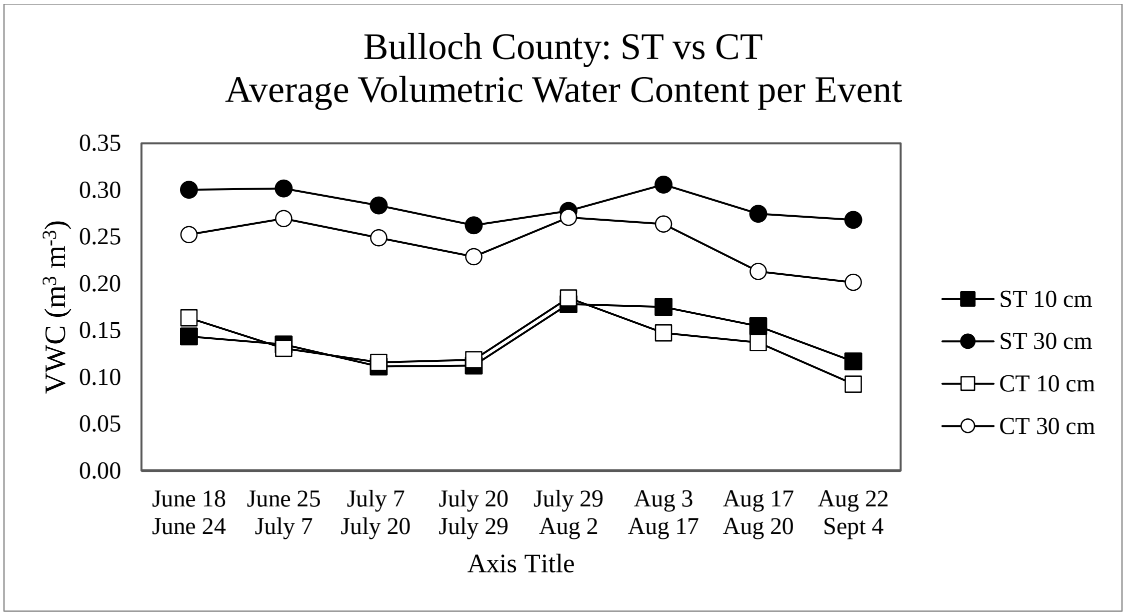


Figure 4.12 Bulloch County Experimental Sites: Average Volumetric Water Content Per Event at 10 and 30 cm Depth

Figure 4.12 shows the average VWC per event for 10 and 30 cm depths. Additionally, the average VWC per event graphs adding results at the 20 cm depth are provided Appendix F that add the 20 cm depth result. Several similar wetting-drying time periods were isolated for both fields as indicated by the dates on the X-axis of Figure 4.12 to conduct the volumetric water content comparisons and reduce some of the error due to differing rainfall. These events were selected to reduce error due to differing rainfall. The volumetric water content averaged across all depths during each wetting-drying event averaged 0.2040 ± 0.0694 (m^3 m^{-3}) for the ST site and 0.1831 ± 0.0771 (m^3 m^{-3}) for the CT site with no statistical difference (t test, P>0.05). The moisture content, when compared by tillage at each depth, indicated no differences between tillage type for each depth; however, ST consistently had a higher numerical volumetric water content compared to CT. The connecting letters report of mean VWC per depth is displayed in Table 4.5 where means with the same letter are not significantly different from each other (Tukey–Kramer test, P>0.05).

Table 4.5 Bulloch County Experimental Sites: Tillage and Depth Connecting Letters Report Arranged by Decreasing Mean Volumetric Water Content

Tillage & Depth				Mean VWC (m^3 m^{-3})
ST 30 cm	A			0.28431042
CT 30 cm	A			0.24240261
ST 20 cm		B		0.18436571
CT 20 cm		B	C	0.16972227
ST 10 cm		B	C	0.14082542
CT 10 cm			C	0.13653130

4.3.3 Water loss rates

The research was designed to determine if there was a difference in the moisture loss rate between tillage types. From the previously mentioned wetting-drying events, the moisture loss rates were calculated as described in chapter 3. Figure 4.13 shows the water loss rates per day (mm d^{-1}) graphed by event dates on the X-axis and separated by depth. Each error bar is constructed using one standard error from the mean.

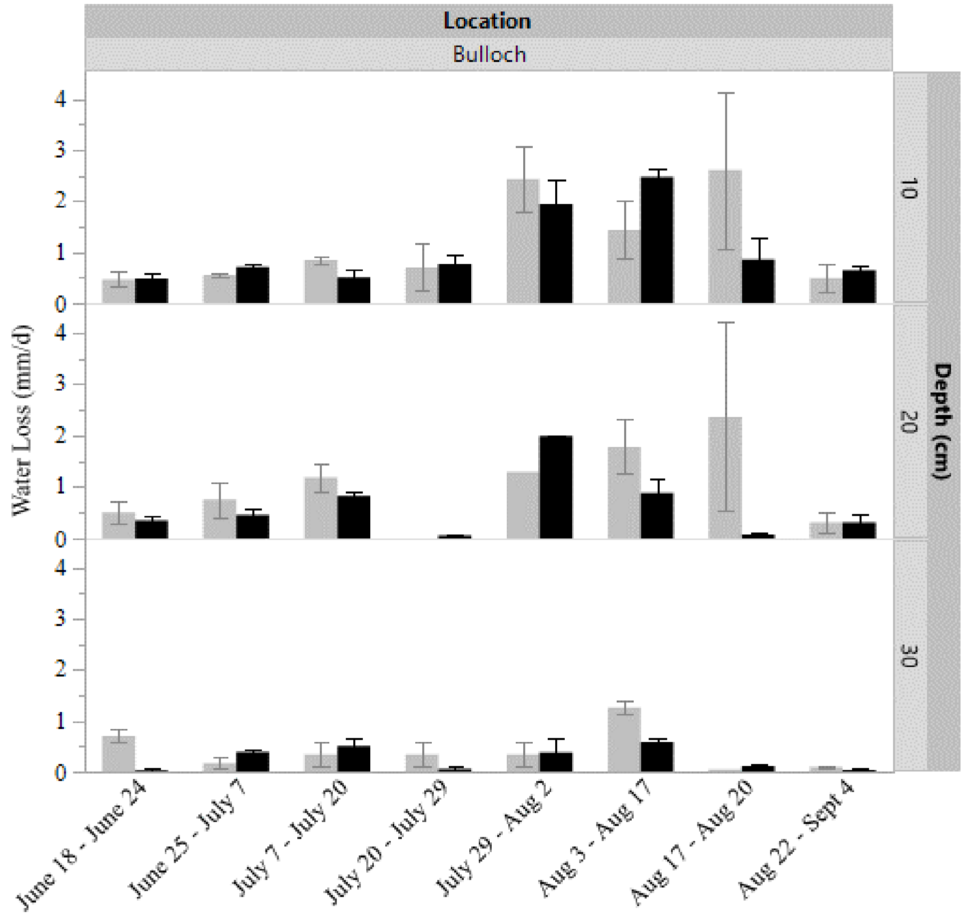


Figure 4.13 Bulloch County Experimental Sites: Water Loss Rates Graphed by Wetting-Drying Events and Depth

Overall, there was no significant difference in water loss rate compared by tillage type, with ST losing on average 0.6354 ± 0.6751 (mm d^{-1}) and CT losing on average 0.9161 ± 1.063 (mm d^{-1}). CT experimental site in Bulloch County had a greater water loss rate than ST. The results of the one-way ANOVA test on water loss rates by tillage and depth are presented in Table 4.6 where means with the same letter are not significantly different from each other (Tukey–Kramer test, $P>0.05$). When broken down by depth in Table 4.6, CT was consistently losing water faster than ST at each depth, but few statistically significant differences exist among tillage types for each depth. The frequent tillage in CT breaks apart soil structure, which leads to less water retention (Hawkins et al., 2016). This result indicates that conservation tillage methods in this region may be able to retain soil moisture for longer periods by improving soil structure.

Table 4.6 Bulloch County Experimental Sites: Connecting Letters Report of Water Loss Rates by Tillage and Depth Ordered by Decreasing Mean Water Loss

Tillage & Depth				Mean Water Loss (mm/d)
CT 10 cm	A			1.3040886
CT 20 cm	A	B		1.0522959
ST 10 cm	A	B		1.0483000
ST 20 cm		B	C	0.5729881
CT 30 cm		B	C	0.3928125
ST 30 cm			C	0.2446645

4.3.4 Rainfall and runoff

Continuous plowing and deep tillage of the CT site overtime created a berm around the entirety of the field. The H-flume and ISCO sampler were placed at what was measured to be the lowest point of the edge of field where water presumably flowed off into the woods. Figure 4.14 shows water flow lines in the soil where water flowed past the flume to the corner of the field. All traces of water flow lines in the soil dissipate in the corner of the field and it is presumed that the water ponds and infiltrates because it cannot escape the artificial berm placed around the field. The edge of field monitoring station for the ST site showed no indication of runoff in the soil due to heavy residue and grassy vegetation (Figure 4.15).

(a) CT Flume at installation

(b) CT Flume after a rainfall event, where there is evidence of runoff in the freshly deposited sand

Figure 4.14 Bulloch County CT Site: Edge of Field Monitoring Station

(a) ST H-flume after installation

(b) ST H-flume after a rainfall event, with no runoff indication

Figure 4.15 Bulloch County ST Site: Edge of Field Monitoring Station

The only time there was a runoff event in the ST site was for the August 2, 2018 rainfall storm where there was over 45 mm of rainfall in one day. This event occurred late in the evening which is why there are such high runoff reports from the CT site the next calendar day. Anecdotally, the ST farmer indicated that this was the only time he had seen runoff in his field all year. As Figure 4.16 shows, the reported runoff from these fields is much larger for CT than for ST.

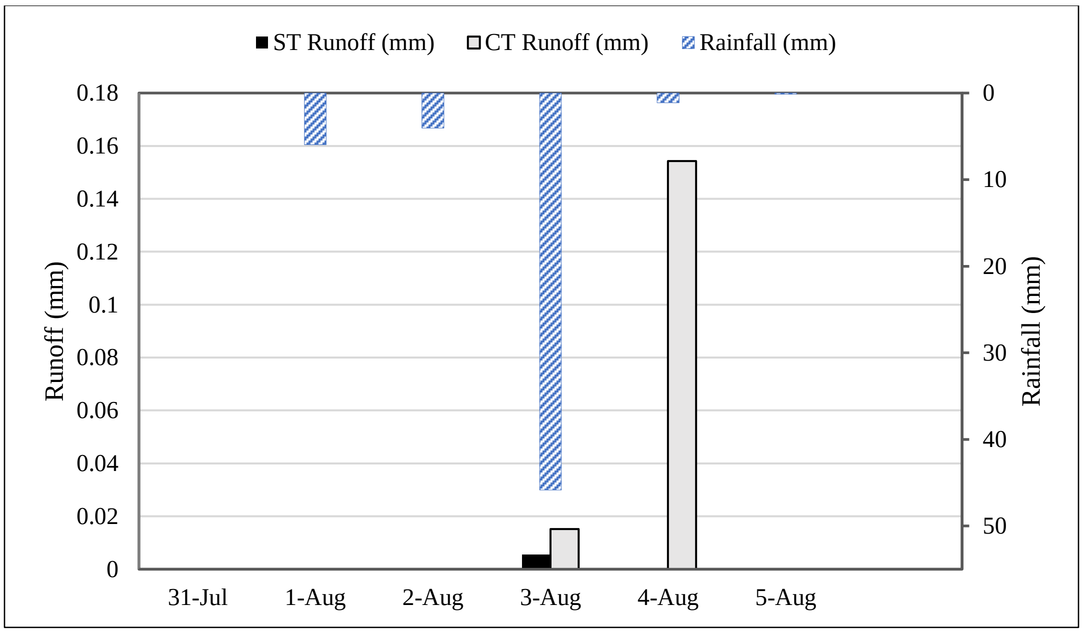


Figure 4.16 Bulloch County Experimental Sites: Rainfall and Runoff

4.3.5 Water balance

For this study, surplus water is defined as excess water lost to either runoff, unaccounted for evapotranspiration, or subsurface lateral flows. Figure 4.17 is the graphical result of the water balance calculation along with the average volumetric water content during these drying periods for Bulloch County Experiment site. The surplus water corresponds to a higher soil VWC; i.e. when the soil profile dries out, the surplus water amount decreases. This trend, seen especially during the prime growing months of July through September, is due to plant uptake and higher evapotranspiration losses due to higher temperatures.

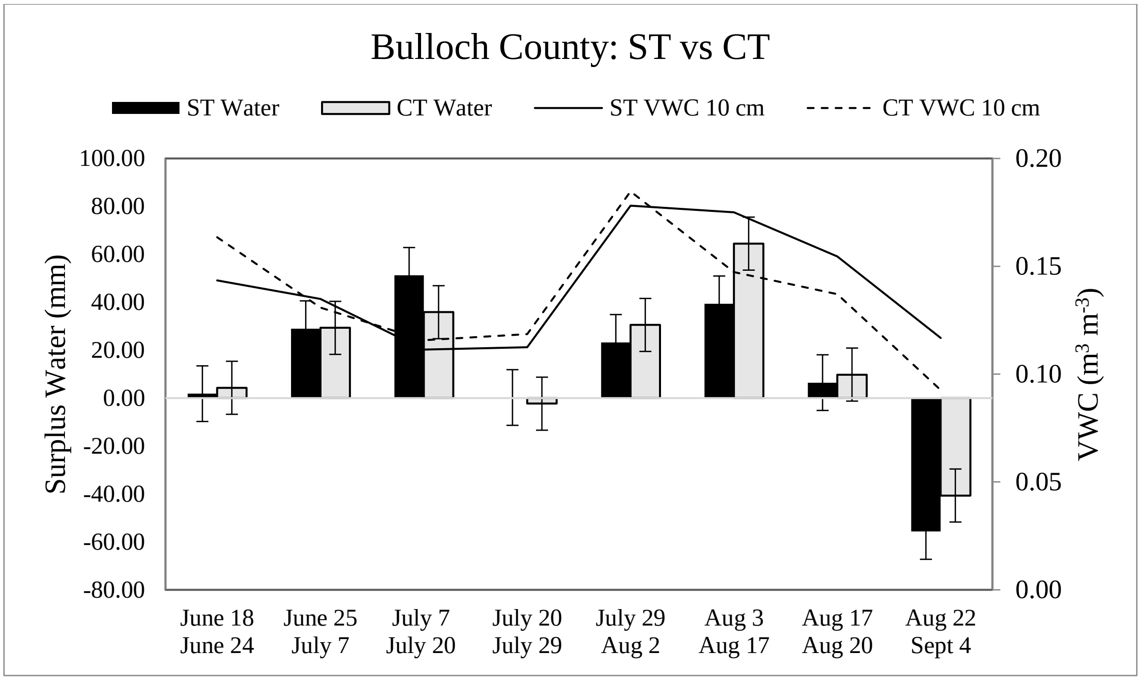


Figure 4.17 Bulloch County Experimental Sites: Water Balance Results and Average Volumetric Water Content

The simple water balance calculation for the wetting-drying events produced averages in surplus water of 11.965 ± 32.838 (mm) for the ST site and 16.419 ± 31.282 (mm) for the CT site. Little differences can be seen in surplus water whether the soil moisture content was high or low. Although runoff was not able to be captured accurately for the CT site due to placement of the flume and equipment malfunctions, visual inspections indicate that there was runoff in the CT site whereas no runoff indicators were visible in the ST site, except for the one recoded event described in the previous section.

4.4 Pulaski County Experimental Sites

4.4.1 Soil sampling

Anecdotally, the two selected fields in Pulaski County were originally owned by one farmer who claimed to use conservation practices as well as conventional practices. Upon inspection of his fields, it was discovered that the farmer did plant a cover crop; however, he used several passes of intensive tillage to incorporate the residue into the soil, leaving the surface bare. To amend this misunderstood idea of conservation tillage, another farmer was located in the same area who consistently practiced reduced tillage and maintained a permanent cover on the soil surface.

Percent soil organic matter was measured from June 2018 to December 2018. Over this period, the CT sampling location had a significantly higher overall mean organic matter than ST averaging 1.283 ± 0.250% and 1.056 ± 0.260% respectively. The results of the one-way ANOVA test on organic matter by tillage and depth are presented in Table 4.7 where means with the same letter are not significantly different from each other (Tukey–Kramer test, P>0.05). The only significant difference between tillage treatments at different depths was reported at 30 cm depth, where CT percent organic matter was significantly higher than ST.

Table 4.7 Pulaski County Experimental Sites: Tillage and Depth Connecting Letters Report Arranged by Decreasing Mean Percent Organic Matter

Tillage & Depth (cm)				Mean OM%
CT 30	A			1.4500000
CT 10	A	B		1.2514286
ST 10	A	B		1.2500000
CT 20	A	B	C	1.1457143
ST 30		B	C	1.0400000
ST 20			C	0.8771429

Figure 4.18 shows the graph of percent organic matter by month at each depth and tillage type. Each data value on the graph is the result of one sampling value, thus there are no error bars displayed in this figure. The differences in percent organic matter are statistically significant. Variations such as seen in October and November for CT 30 cm depth may be due to the collection of more plant roots in the soil sample.

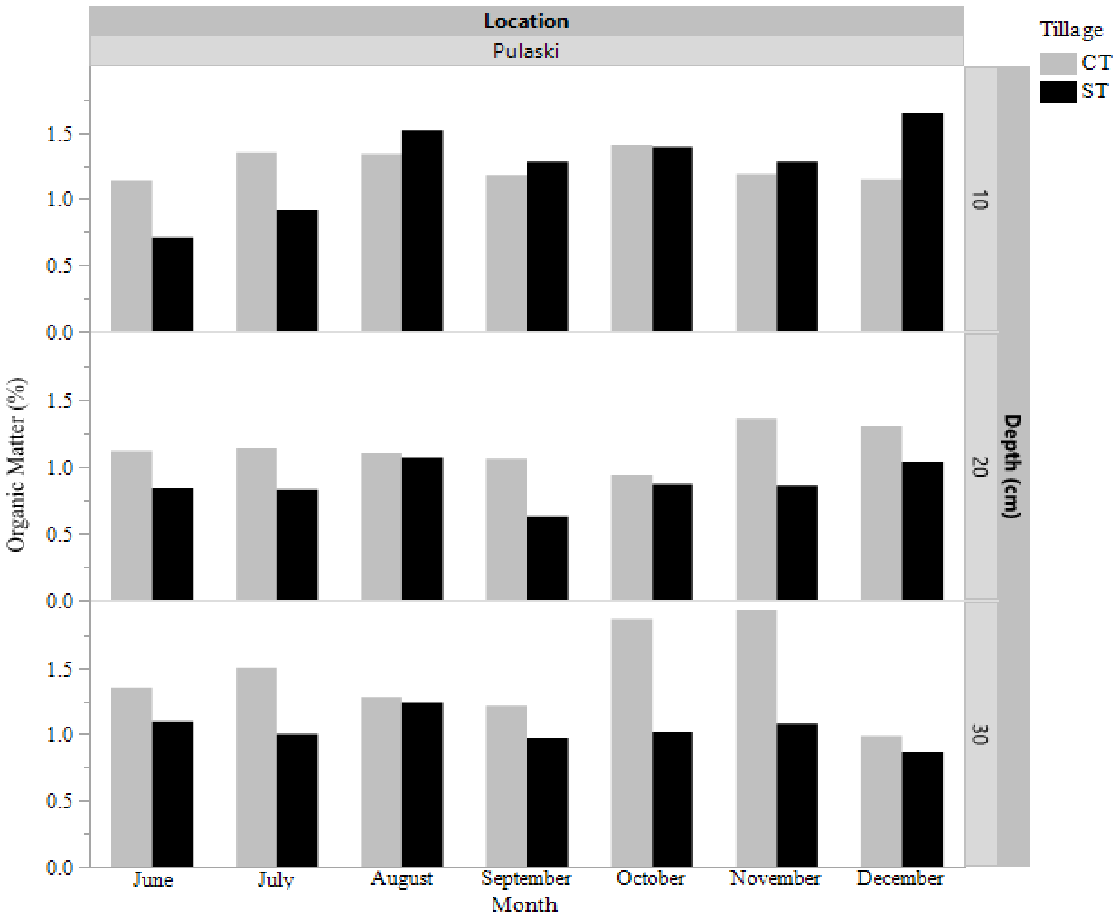


Figure 4.18 Pulaski County Experimental Sites: Percent Organic Matter Graphed by Month and Depth

The bulk density averaged 1.597 ± 0.113 (g cm^{-3}) for the ST site and 1.520 ± 0.135 (g cm^{-3}) for CT site with no statistical difference between the two (t-test, P>0.05). The porosity was 39.741 ± 4.267% and 42.629 ± 5.077% and for ST and CT sites respectively. Graphical results of the bulk density and porosity separated by depth can be found in Appendix E.

4.4.2 Soil moisture content

Volumetric water content (m^3 m^{-3}) data were collected in each field beginning from June 27, 2018 (approximately 36 days after planting) to October 7, 2108. The soil moisture sensor data were downloaded and grouped by depth. The graphical data for the 10 cm soil moisture readings are displayed in Figure 4.19 for ST and Figure 4.20 for CT. Data skips as seen on Figure 4.20 with the solid grey line, for example, are due to data logger failure resulting from a loose battery connection, improper sealing of the equipment which led to moisture imparing the datalogger, and other miscelaneous problems. Figures 4.19 and 4.29 are for the 10 cm depth of soil moisture only, and the data from 20 and 30 cm depths can be found in Appendix D.

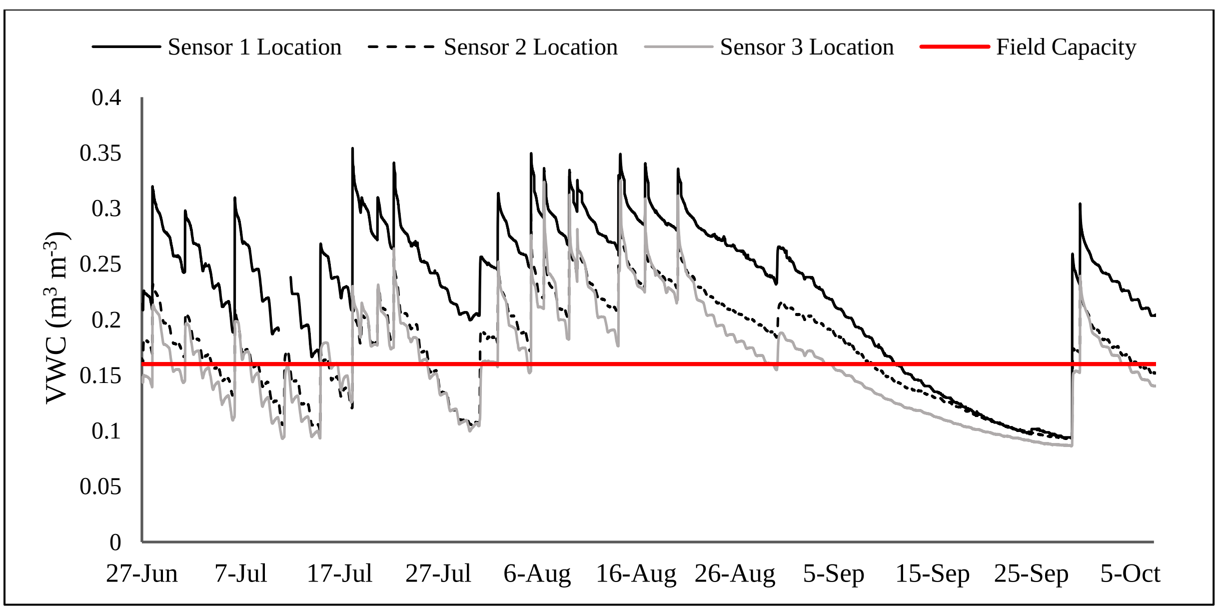


Figure 4.19 Pulaski County Conservation Tillage Experimental Site Soil Moisture Graphs at 10 cm Depth

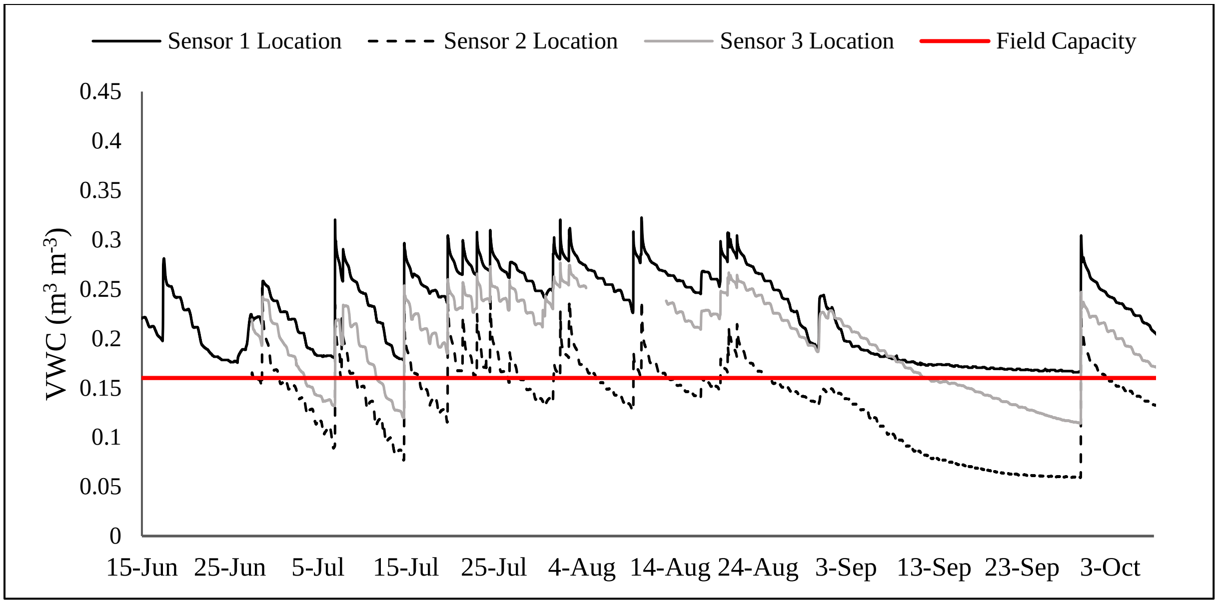


Figure 4.20 Pulaski County Conventional Tillage Experimental Site Soil Moisture Graphs at 10 cm Depth

Figures 4.19 and 4.20 represent the shallowest depth of measured soil moisture, which provide the most dramatic changes in response to rainfall or irrigation events. These two fields could be irrigated, but frequent rainfall events rendered irrigation unnecessary. Liang et al. (2016) determined the field capacity for this soil type to be 0.16 (m^3 m^{-3}). This frequent rainfall also caused the soil to be at or above field capacity for the duration of the growing season, as indicated by the horizontal red line in each of these graphs.

Figure 4.21 shows the average VWC per event for 10 and 30 cm depths, for the sake of clarity. Additionally, graphs are located in Appendix F that add the 20 cm depth result. Several similar wetting-drying time periods were isolated for both fields as indicated by the dates on the X-axis of Figure 4.4 to conduct the volumetric water content comparisons and reduce some of the error due to differing rainfall. These events were selected to reduce error due to differing rainfall. The volumetric water content averaged across all depths during each wetting-drying event was similar, averaging 0.2306 ± 0.04367 (m^3 m^{-3}) for the ST site and 0.2627 ± 0.0682 (m^3 m^{-3}) for the CT site with no statistical difference (t test, $P>0.05$). Here, the CT had a higher numerical VWC than in the ST site, and this is likely due to the less apparent sandy topsoil in CT compared to ST. The soil in the CT site appeared to transition to a deeper soil horizon at a shallower depth than was seen in the ST site at the same depth. The connecting letters report in Table 4.8 supports this observation, with CT 30 cm having a statistically higher VWC than all other layers and CT 20 cm and ST 30 cm having no statistical significance; means with the same letter are not statistically different from each other (Tukey-Kramer test, P>0.05).

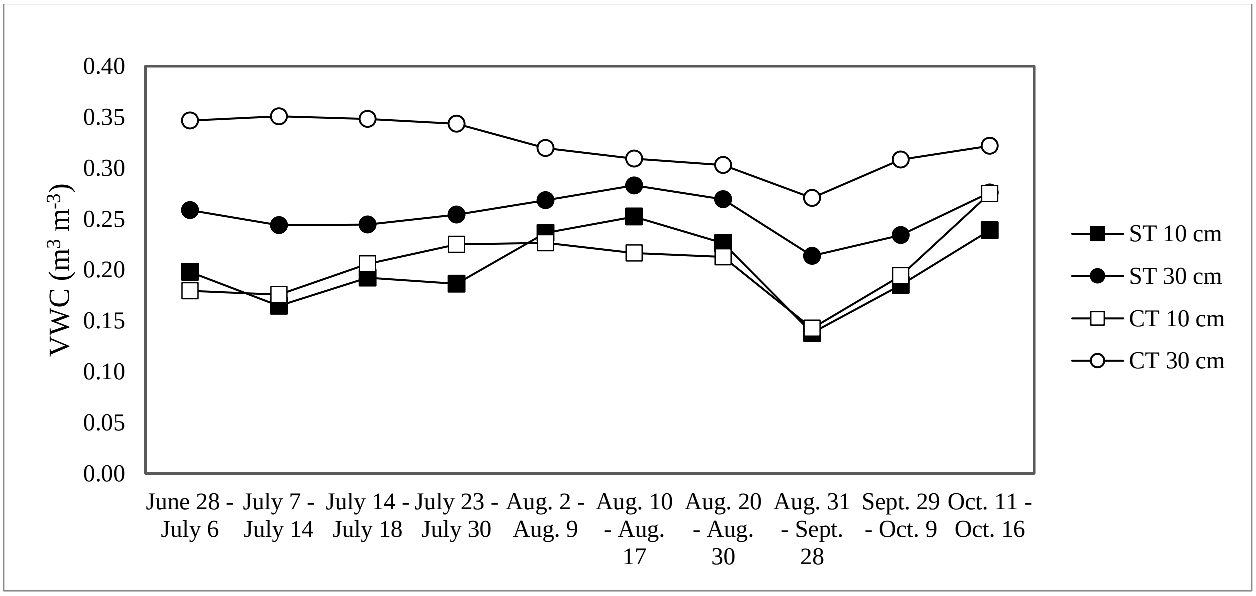


Figure 4.21 Pulaski County Experimental Sites: Average Volumetric Water Content Per Event at 10 and 30 cm Depth

Table 4.8 Pulaski County Experimental Sites: Tillage and Depth Connecting Letters Report Arranged by Decreasing Mean Volumetric Water Content

Tillage & Depth					**Mean VWC (m^3 m^{-3})**
CT 30 cm	A				0.32206733
CT 20 cm		B			0.25919133
ST 30 cm		B			0.25445467
ST 20 cm		B	C		0.23577310
CT 10 cm			C	D	0.20527800
ST 10 cm				D	0.20169733

4.4.3 Water loss rates

Moisture loss rates for each wetting-drying event were compared to identify differences in water loss rates between tillage types. Figure 4.22 shows the water loss rates per day (mm d^{-1}) graphed by event dates on the X-axis and separated by depth. Overall, there was no statistical significance in water loss rate compared by tillage type, with average losses of 0.8694 ± 0.5902 (mm d^{-1}) for the ST site and 0.7116 ± 0.7316 (mm d^{-1}) for the CT site. This water loss is either infiltrated to deeper layers, uptaken by plants, or loss via subsurface water lateral movement. The results of the one-way ANOVA test on water loss rates by tillage and depth are presented in Table 4.9 where means with the same letter are not significantly different from each other (Tukey–Kramer test, $P>0.05$). These results indicate that no significant differences exist among tillage types for each depth. ST did have a greater water loss rate for the 10 and 30 cm rates than in CT sites, suggesting higher infiltration and deep percolation under ST compared to CT (Bosch et al., 2005; Bosch et al., 2012; Endale et al., 2009; Franzluebbers, 2002b).

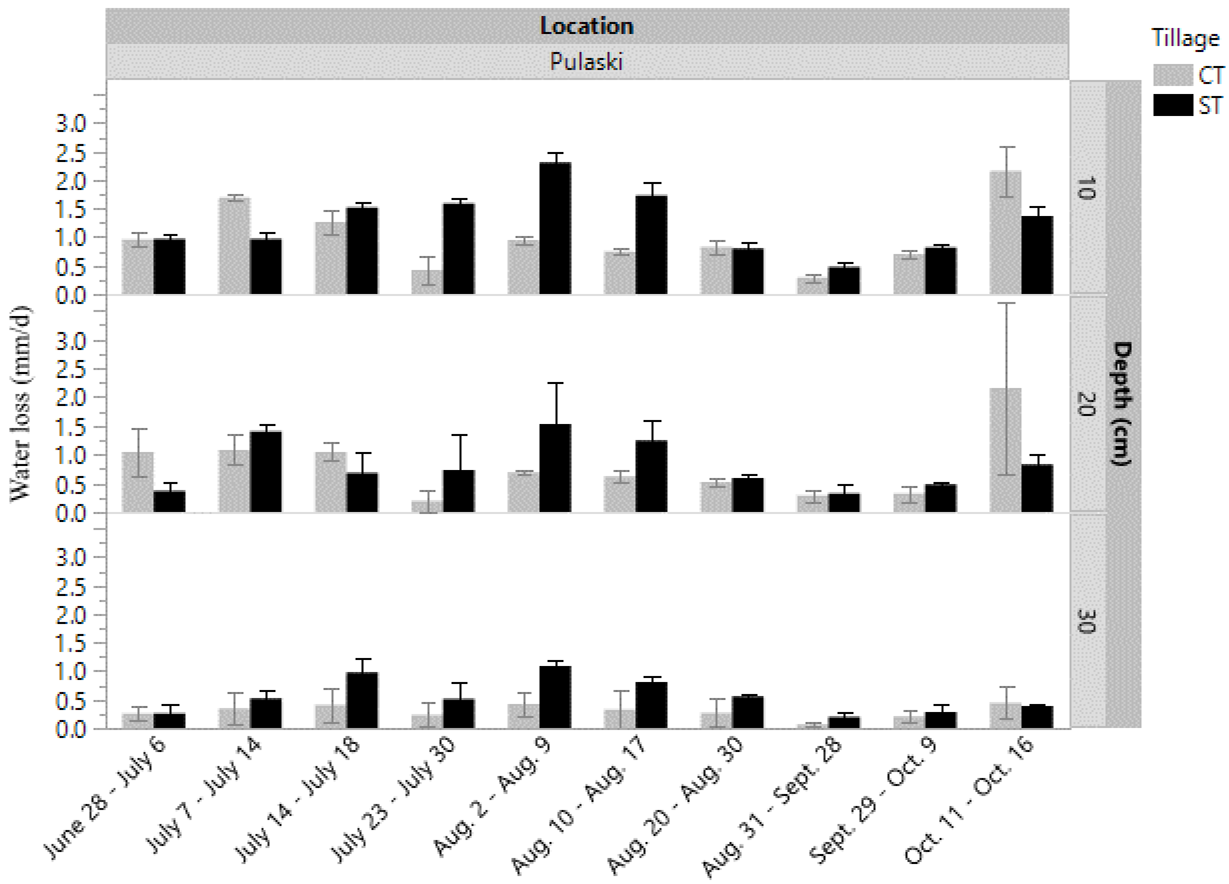


Figure 4.22 Pulaski County Experimental Sites: Water Loss Rates Graphed by Wetting-Drying Events and Depth

Table 4.9 Pulaski County Experimental Sites: Connecting Letters Report of Water Loss Rates by Tillage and Depth Ordered by Decreasing Mean Water Loss

Tillage & Depth				Mean Water Loss (mm d^{-1})
ST 10 cm	A			1.2556143
CT 10 cm	A	B		1.0024647
CT 20 cm	A	B		0.8215432
ST 20 cm		B		0.7853241
ST 30 cm		B	C	0.5587460
CT 30 cm			C	0.2921207

4.4.4 Rainfall and runoff

Runoff data were difficult to measure for the Pulaski County sites. For the ST site, there was no apparent drainage location. For the CT site, the entire field area drained to a single location. After H-flumes and ISCO stations were installed at each location, the flume on the Pulaski CT site had be redesigned quickly due to the large volume of runoff from the July 14, 2018 rainfall event. Figure 4.23 shows the flume before and after the first rainfall event and provides an idea of the vast amount of water which washed the flume out of its installed location and rendered the flume unusable. With such large volumes of water traveling to this point, the incapacitated flume was uninstalled and a pressure transducer at a known depth below the soil surface was installed instead, so that the water content in the channel could still be monitored. Water levels are provided in Figure 4.24 along with precipitation data for Pulaski County. This data is simply the daily total water level recorded in the drainage channel and is not the corrected runoff level by field area. It is important to note that the weather station and rainfall data were gathered about 13.2 km (8.2 miles) away from the field site, introducing the probability of some error.

(a) Flume at installation

(b) Flume after first rainfall event

Figure 4.23 Pulaski County CT Experiment Site: Edge-of-Field Monitoring Station Before and After a Rainfall Event

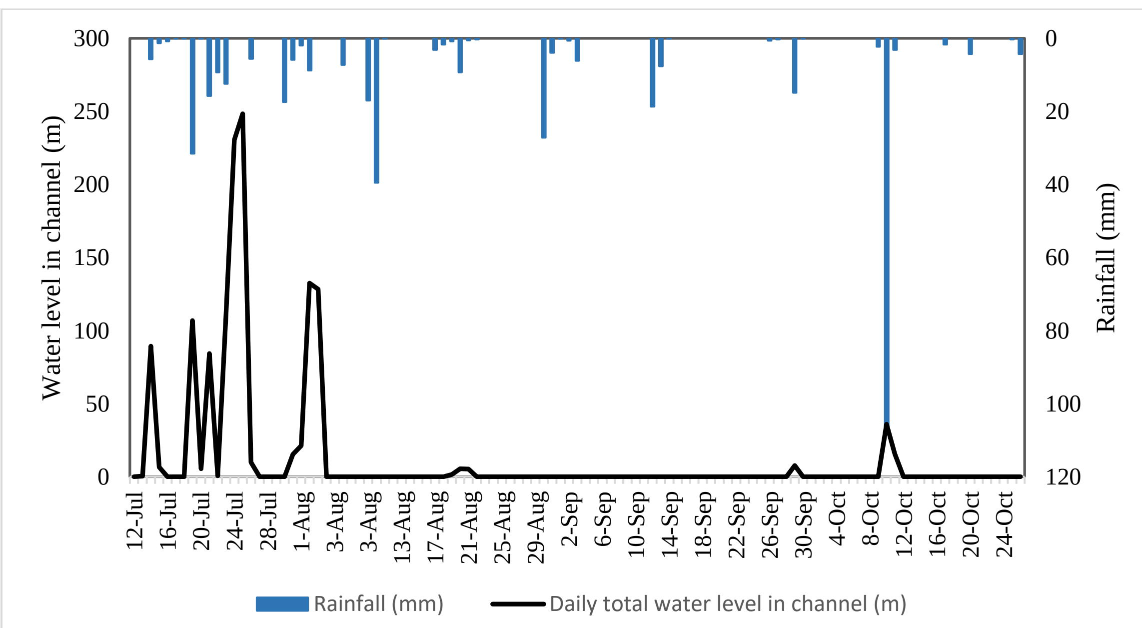


Figure 4.24 Pulaski County Experiment Site CT Water Level in Drainage Channel and Rainfall

This CT site experienced erosion and sediment loss due to runoff. Appendix H provides additional photos showing the progression of erosion and soil displacement. An extended version of Figure 4.24 is found in Appendix G, where visual inspections and the photographs confirm that the drainage channel turns into an intermittent stream in the later months of 2018.

In the Pulaski County ST experimental site, the H-flume in Figure 4.25 was placed too close to a multiple field-contributing grassed waterway to record any flow from the site. From preliminary digital elevation models, this location appeared to be the most probable drainage location. The site was inspected, as the study progressed, for signs of runoff but there were not any visible indications. The entire field was covered in a thick residue layer or vegetation as shown in Figure 4.26. This ST site did not have as much slope as the CT site or a single drainage location, which makes capturing runoff data difficult. Most studies which use edge of field monitoring stations have done so on designed research plots constructed for such purposes (Baker et al., 2018; Daniels et al., 2018; Potter et al., 2015; Tiessen et al., 2010).

(a) Flume at installation **(b) Flume after a large rainfall event**

Figure 4.25 Pulaski County ST Experimental Site: Edge-of-Field Monitoring Station

Figure 4.26 Pulaski County ST Experimental Site: Ground Cover[1]

1 - The left half of the picture shows the brown cover crop residue remaining on the cotton field, while the right (along the edge of the field) is covered by a thick layer of weeds and grasses.

4.4.5 Water balance

For this study, surplus water is defined as excess water lost to either runoff, unaccounted evapotranspiration, or subsurface lateral flows. Figure 4.27 is the graphical result of the water balance calculation along with the average volumetric water content during these drying periods for Pulaski County. As discussed in Bulloch County results section, the surplus water tends to be positive when the soil moisture content is higher, indicating more potential losses to runoff. When surplus water is negative, this indicates that the system is losing more water due to crop uptake or subsurface lateral movement. The surplus water corresponds to a higher soil VWC; i.e., when the soil profile dries out, the surplus water amount decreases. This trend, seen especially during the prime growing months of July 2018 through September 2018, is due to plant uptake and higher evapotranspiration losses due to higher temperatures.

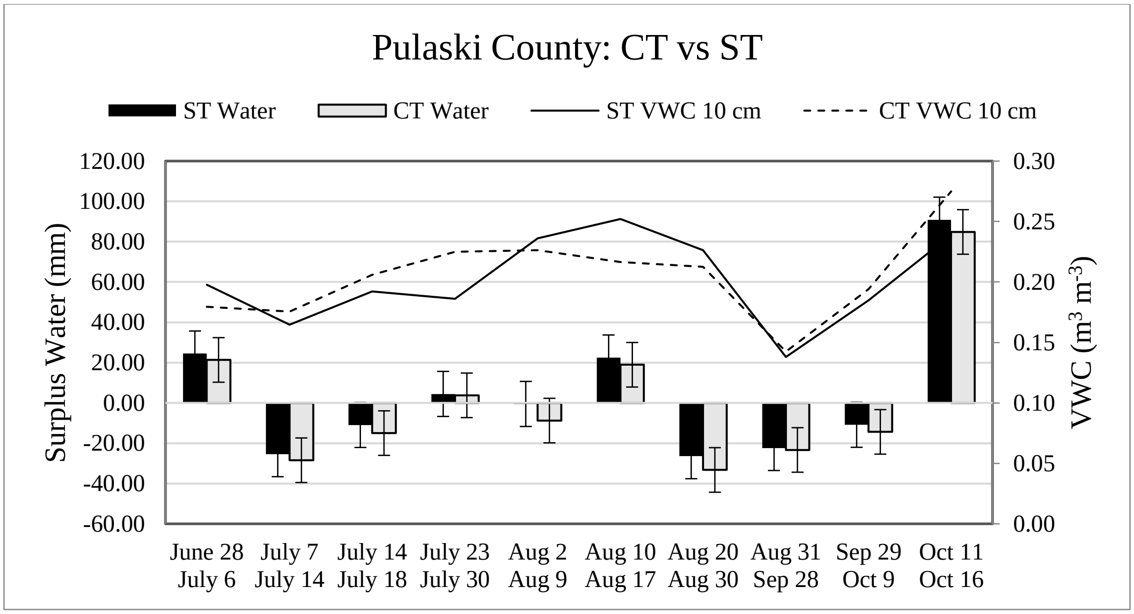


Figure 4.27 Pulaski County Experimental Sites: Water Balance Results and Average Volumetric Water Content

The water balance calculation for the wetting-drying events produced not significantly different averages in surplus water of 4.589 ± 35.377 (mm) for the ST site and 0.569 ± 34.943 (mm) for the CT site. Little differences can be seen in surplus water amounts whether the soil moisture content was high or low. Generally, ST always had a slightly higher amount of surplus water than CT, indicating the possibility of more plant available water. Although the volume of runoff was not able to be captured accurately for the fields in Pulaski County due to previously mentioned difficulties, visual inspections indicate that there was some amount of runoff in the CT site whereas no runoff indicators were visible in the ST site, suggesting that a large portion of the surplus water would be due to runoff in the CT site, that increased the surplus water deficit. The increased loss with conventional tillage points toward more available water to crops and less irrigation requirements for conservation tillage.

4.5 Summary

Soil Health

Sites where conservation tillage was utilized generally resulted in a higher percent organic matter in the soils. In Oconee County experimental sites, the results of the soil sampling on previous conservation tillage plots which were later conventionally tilled indicate that some portion of accumulated organic matter remains even after deep tillage. The Oconee County and Bulloch County experimental sites' results confirmed that large differences in soil organic matter result from management differences. Overall, little differences were seen in the bulk density and porosity for each tillage type, suggesting little differences in soil compaction.

Soil Moisture Content

Overall, the ST sites indicated a higher volumetric water content and reduced variability than CT sites. For Pulaski County experimental sites, the CT had a statistically higher VWC for each depth than ST due to the loss of topsoil due to erosion and shallower water restrictive clay layers. This data suggests that more plant available water to crops managed under conservation tillage practices, specifically strip tillage practices for sandy soil.

Water Loss Rates

Generally, CT had a greater water loss rate than ST. In the one location (Pulaski) where ST loss rates were greater than CT at 10 and 30 cm depths, the water loss is attributed to an increased infiltration and percolation ability of the ST soils. No runoff was indicated for this site and the moisture content was well above field capacity during these calculations. These results indicate that ST may be able to retain soil moisture for longer periods even under wet conditions while improving groundwater recharge and reducing runoff. It also supports the idea that ST sites are more drought tolerant than CT sites due to a higher water retention rate.

Rainfall and Runoff

Rainfall data was difficult to measure on sites far away from the researchers, where proper maintenance of measuring technology could not be carried out. Runoff data was difficult to capture on relatively flat fields and fields with large watershed areas. Conducting accurate runoff research which does not require interference with the farmer's operation proved to be challenging. However, evidence from visual inspection and the recorded runoff suggests that CT consistently resulted in more runoff than ST, whether no-tillage or strip tillage. The reduced runoff results in this research are seen in most conservation tillage verses conventional tillage research studies.

Water Balance

As seen from the data, surplus water tends to be positive when the soil moisture content is higher, indicating more potential losses to runoff. When surplus water is negative, this indicates that the system is losing more water due to crop uptake or subsurface lateral movement. Across the six experimental fields, the ST sites held more water and had less runoff than the CT sites, indicating that there will be more water available for plant uptake in ST systems. For the experimental site in the Piedmont region, our data suggest that crops could potentially have more reliable access to water during drying events under conservation tillage systems compared to conventional tillage systems. Less differences could be seen in the Coastal Plain region due to the high soil moisture content.

CHAPTER 5

CONCLUSIONS

5.1 Introduction

Agricultural systems require a large quantity of water for profitable crop production. The use and stewardship of this natural resource begins at the field level by farmers who use established cultivation practices. This thesis provided insight into the ways in which tillage practices affect hydrologic balances. Results illustrate the performance between two tillage practices and to suggest innovative analysis techniques for researchers, using farmer's fields. This work will ultimately lead to increased knowledge about the performance of tillage systems on water resources and soil health.

5.2 Soil Health - Objective One

Soil samples were taken periodically and compared between tillage type for each location. The percent organic matter was determined for each field in the study at three depths. Percent organic matter increased in the soil under conservation tillage for only one location (Bulloch) of the three locations tested ($P>0.05$). The remaining two locations indicated no difference between conventional tillage and conservation tillage, although conventional tillage systems had a slightly overall higher percent organic matter than conservation tillage. These results from the Oconee County location can be explained by previous long-term no-tillage research which, was conducted at the site of the conventional tillage plot used in this study. The lack of difference in soil organic matter for Pulaski County is surprising, considering the literature and research that indicates an increased organic matter content under conservation tillage. This result indicates that further inspection of the management and implementation of conservation tillage practices is required.

Future studies could answer the research question: why did one location in the Coastal Plain region show a 19% difference in organic matter favoring conventional tillage soils over conservation tillage soils and the other site had a 96% organic matter difference in favor of conservation tillage soils? Additionally, the bulk density and porosity were similar for both tillage types at all locations. Further soil analysis could be done than what was performed for this thesis.

5.3 Water Budget - Objective Two

The second objective was to develop a methodology to determine soil moisture loss rates and conduct water budget analysis for future research. The described methodology though less than ideal, provided estimations of change in the soil moisture profile. The results of the water budget analysis indicate that there were not statistical differences between ST and CT sites. Runoff data is critical to appropriately identify differences in water storage, especially between conservation and conventional tillage systems, where there are recorded notable differences in runoff volume. With the technique provided herein, researchers can estimate water movement when studying fields with less than ideal conditions for water monitoring. Using volumetric water content to determine the moisture loss rate allowed for the straightforward conversion to volume of water. A key part of the research aim was to develop a relatively simple, repeatable methodology. The calculations were all conducted in spreadsheet. One disadvantage of this calculation-heavy technique is that it cannot be used to provide instantaneous results to farmers; it is meant for use in an analysis of water usage on an agricultural field.

5.4 Hydrologic Conditions - Objective Three

The third research task was to analyze field-level hydrologic conditions for both types of management systems. This was accomplished through analyzing soil moisture data, collecting runoff and rainfall data, and estimating evapotranspiration. There were many limitations to the water analysis conducted at these sites and much error is present in the water balance results. However, with the available data, the most appropriate analysis was conducted and found to be useful because it provided a comparison of the moisture loss rates between production systems.

Overall, the conservation tillage sites had a statistically significant greater soil moisture content than the conventional tillage plots, even under wet soil conditions. Across all locations, conservation tillage soil moisture was 21.5% greater than conventional tillage soil moisture. In Pulaski County, where the moisture content was higher for conventional tillage than conservation, this was due to the loss of sandy topsoil and exposure of the soil moisture sensors to deeper layers sooner than would be seen in conservation tillage. This also implies that less water can be infiltrated, leading to more runoff. Visual inspections confirm this result. Conservation tillage sites had a more consistent water content in the soil and 16% lower water loss rates, suggesting these soils would be more drought tolerant than soils in conventional tillage sites. Water loss in this study is due to runoff, soil water evaporation, or plant uptake. Conservation tillage sites appeared to able to infiltrate water better at deeper depths than in conventional tillage sites based on the lower recorded runoff volumes and higher measured soil moisture content.

5.5 Limitations and Recommended Future Research

The results from this small study are not enough evidence to strongly support claims to the superior performance of one tillage system over the other. This research should be continued and replicated at numerous sites throughout the region in order to get an accurate outlook on the state of conservation tillage practices and the effects of different types of management systems on water resources. Additionally, each field site is unique. As seen in this study, capturing water from fields is difficult and often not often performed on locations which were not designed for this purpose. Ideally, fields would be selected on experiment station property that could be bermed in order to manage runoff. Future work can investigate the utilization of existing or new technologies to aid in the water monitoring of agricultural systems such as remote sensing technologies and soil moisture sensors.

5.6 Summary

In conclusion, this chapter provided the final remarks of the research conducted during 2018. This thesis investigated the rate of soil moisture retention, soil quality, and field specific water balance under conservation tillage (ST) versus conventional tillage (CT) systems in cotton production in Georgia. Experiments were conducted at three locations in the counties of Oconee, Bulloch and Pulaski with two fields per county, one each of conservation tillage and one of conventional tillage. Soil moisture data were analyzed to determine the rate of soil moisture loss during drying periods between rainfall events. Field-specific water balance calculations were conducted based on the rainfall, drainage, crop evapotranspiration, and runoff. The water loss rates vary by location, with combined averages of CT losing water 16% faster than ST. Overall, ST sites retained 21.5% more soil moisture and had less runoff than CT sites. Soil organic matter was 96% greater in ST than CT for Bulloch County and not statically different in the other two counties. Results from the water balance calculations were not statistically different between tillage type during the wet 2018 growing season. The water balance technique explained in this study will be used to more thoroughly assess the state of conservation production systems and conventional production systems in this region and provide evaluations in future research. Furthermore, this research identifies areas where the studies of such systems may be further improved.

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APPENDIX A – EXPERIMENTAL SITES: AERIAL PHOTO MAP WITH SOIL MOISTURE SENSOR LOCATIONS

Not to scale

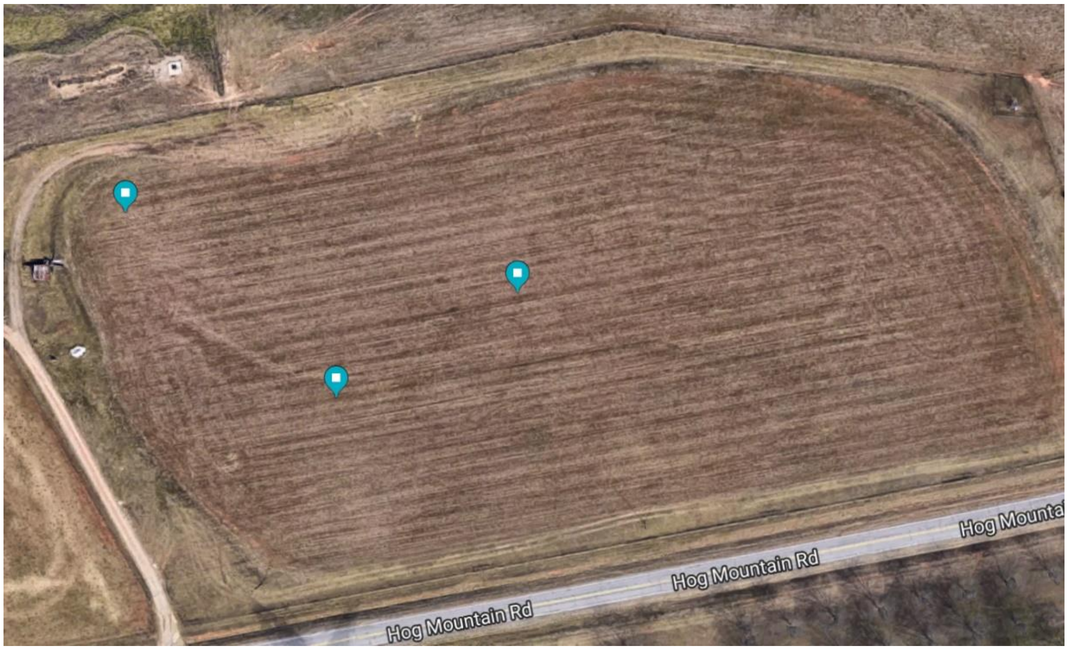

Figure A-1 Oconee County ST Experimental Site: Aerial Photo with Blue Dots Indicating Soil Sensor Locations

Figure A-2 Oconee County CT Experimental Site: Aerial Photo with Blue Dots Indicating Soil Sensor Locations

Figure A-3 Bulloch County ST Experimental Site: Aerial Photo with Blue Dots Indicating Soil Sensor Locations

Figure A-4 Bulloch County CT Experimental Site: Aerial Photo with Blue Dots Indicating Soil Sensor Locations

Figure A-5 Pulaski County CT Experimental Site: Aerial Photo with Blue Dots Indicating Soil Sensor Locations

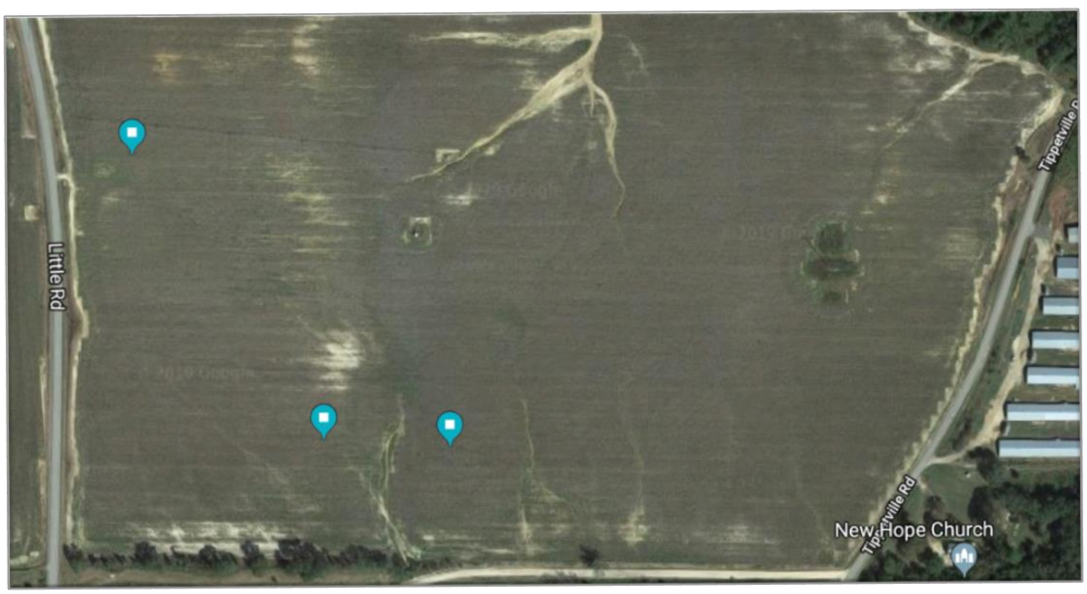

Figure A-6 Pulaski County CT Experimental Site: Aerial Photo with Blue Dots Indicating Soil Sensor Locations

APPENDIX B – SOIL SAMPLING REPORT TABLES

Table B-1 Soil Sample Report: June 2018

JUNE 2018				Mehlich 1 mg/kg (ppm)						mg/kg	%
Sample	LBC [1] (ppm $CaCO_3$/ pH)	pH CaCl2 [2]	Equiv. water pH	Ca	K	Mg	Mn	P	Zn	NO_3-N	OM [3]
B ST 10 cm	183	5.57	6.17	544.1	73.2	50.89	7.05	26.45	2.23	9.84	1.22
B ST 20 cm	199	5.30	5.90	370.7	85.4	54.14	4.63	4.02	0.82	20.19	1.72
B ST 30 cm	232	5.07	5.67	309.0	108.5	68.23	2.87	<0.97	0.42	3.61	1.79
B CT 10 cm	120	5.40	6.00	167.9	50.7	25.29	1.63	14.50	0.28	6.00	0.38
B CT 20 cm	136	5.07	5.67	125.7	52.0	23.99	1.80	10.55	0.29	13.12	0.63
B CT 30 cm	158	4.35	4.95	133.1	57.9	42.47	1.26	1.19	0.16	16.08	0.40
P ST 10 cm	139	5.34	5.94	246.0	83.1	26.74	6.41	14.25	1.40	11.60	0.71
P ST 20 cm	162	5.13	5.73	241.7	75.7	28.55	7.86	11.96	1.09	5.50	0.84
P ST 30 cm	171	5.31	5.91	346.8	97.7	45.36	3.96	4.79	0.47	3.80	1.10
P CT 10 cm	201	5.97	6.57	533.0	92.2	70.45	5.84	59.10	1.98	8.28	1.14
P CT 20 cm	205	5.93	6.53	406.9	114.1	69.90	3.60	18.06	0.87	5.65	1.12
P CT 30 cm	223	5.40	6.00	308.6	101.0	80.88	2.17	3.30	0.67	4.65	1.35
O ST 10 cm	250	5.56	6.16	745.8	136.1	59.71	29.12	62.74	3.78	6.80	2.10
O ST 20 cm	256	5.60	6.20	499.6	118.5	47.65	29.86	20.62	0.73	4.85	1.32
O ST 30 cm	257	5.69	6.29	384.0	101.5	59.60	17.77	<1.05	<0.13	7.76	2.63
O CT 10 cm	220	4.77	5.37	395.4	70.6	51.18	9.46	23.33	3.90	12.67	1.20
O CT 20 cm	185	4.70	5.30	226.3	59.2	32.01	10.29	33.25	5.34	11.37	3.99
O CT 30 cm	250	5.11	5.71	368.2	92.3	67.23	6.79	2.26	2.06	26.27	2.99

Table B-2 Soil Sample Report: July 2018

JULY 2018				Mehlich 1 mg/kg (ppm)						mg/kg	%
Sample	LBC [1] (ppm $CaCO_3$/ pH)	pH CaCl2 [2]	Equiv. water pH	Ca	K	Mg	Mn	P	Zn	NO_3-N	OM [3]
B ST 10 cm	171	5.17	5.77	358.5	61.22	31.72	4.61	12.65	1.22	5.53	1.23
B ST 20 cm	210	5.43	6.03	458.5	73.78	45.27	6.14	21.58	2.27	7.42	1.61
B ST 30 cm	211	5.41	6.01	517.4	83.11	52.53	6.72	23.01	3.06	8.79	1.89
B CT 10 cm	124	5.28	5.88	176.6	50.22	19.33	1.56	13.87	0.86	2.43	0.69
B CT 20 cm	123	5.16	5.76	143.9	59.31	16.49	1.47	14.87	0.34	2.17	0.63
B CT 30 cm	132	5.05	5.65	176.0	43.43	26.74	1.28	12.15	0.39	1.44	0.75
P ST 10 cm	156	5.43	6.03	318.7	53.89	32.74	6.69	15.35	1.33	7.35	0.92
P ST 20 cm	154	5.39	5.99	289.6	74.01	33.76	5.63	10.47	0.89	24.09	0.83
P ST 30 cm	172	5.48	6.08	326.8	81.60	44.10	5.06	7.84	0.67	21.46	1.00
P CT 10 cm	179	5.61	6.21	383.4	73.84	50.54	3.84	33.52	1.62	2.54	1.35
P CT 20 cm	186	5.33	5.93	350.8	60.14	43.74	3.66	26.40	1.96	8.41	1.14

Table B-2 (continued)

P CT 30 cm	201	5.15	5.75	364.4	73.49	61.47	3.64	25.01	1.32	8.53	1.50
O ST 10 cm	235	5.23	5.83	594.8	91.25	44.73	13.83	68.18	3.08	9.78	2.10
O ST 20 cm	202	4.99	5.59	314.4	73.29	33.16	13.31	41.23	1.21	17.14	1.70
O ST 30 cm	189	5.23	5.83	289.0	88.82	38.04	17.63	13.94	0.96	13.68	1.96
O CT 10 cm	276	4.31	4.91	253.1	42.22	31.27	10.02	16.64	3.47	28.72	2.25
O CT 20 cm	161	4.45	5.05	145.8	31.24	20.92	4.33	10.31	1.19	22.17	1.42
O CT 30 cm	197	4.48	5.08	182.6	50.13	36.30	4.72	3.46	0.55	35.02	2.05

Table B-3 Soil Sample Report: August 2018

AUGUST 2018				Mehlich 1 mg/kg (ppm)						mg/kg	%
Sample	LBC [1] (ppm $CaCO_3$/ pH)	pH $CaCl_2$ [2]	Equiv. water pH	Ca	K	Mg	Mn	P	Zn	NO_3-N	OM [3]
B ST 10 cm	192	5.24	5.84	392.5	45.5	28.70	3.34	14.40	1.81	1.03	1.28
B ST 20 cm	182	5.37	5.97	405.9	72.4	43.30	2.58	6.87	1.47	1.26	1.61
B ST 30 cm	227	5.62	6.22	394.6	87.6	63.64	3.08	7.27	1.16	2.51	2.14
B CT 10 cm	102	4.83	5.43	123.0	15.2	13.59	0.69	14.71	0.41	2.48	0.49
B CT 20 cm	120	4.88	5.48	142.5	24.2	16.61	0.79	14.42	0.30	6.93	0.53
B CT 30 cm	138	4.51	5.11	107.1	42.5	21.11	0.63	5.20	0.28	3.27	0.55
P ST 10 cm	189	5.46	6.06	579.0	54.7	75.52	4.67	17.54	2.94	5.99	1.52
P ST 20 cm	186	5.61	6.21	336.0	79.9	53.68	2.42	8.70	1.02	3.18	1.07
P ST 30 cm	205	5.18	5.78	318.7	74.6	46.88	2.30	3.80	0.63	1.01	1.24
P CT 10 cm	207	6.18	6.78	532.4	82.5	83.12	3.83	51.72	2.04	0.89	1.34
P CT 20 cm	206	5.86	6.46	382.7	76.8	61.54	1.72	30.49	1.33	0.76	1.10
P CT 30 cm	226	5.90	6.50	323.5	111.0	76.41	1.10	6.78	0.73	4.38	1.28
O ST 10 cm	301	5.49	6.09	639.4	84.73	47.68	19.77	52.99	3.43	2.27	2.19
O ST 20 cm	264	5.44	6.04	460.3	81.68	43.22	22.05	26.46	2.08	3.29	2.06
O ST 30 cm	249	5.48	6.08	322.5	73.35	44.16	17.83	5.03	0.71	1.84	2.00
O CT 10 cm	358	4.35	4.95	300.8	62.84	32.64	12.10	35.91	7.11	6.10	2.52
O CT 20 cm	172	4.55	5.15	151.1	40.09	20.86	6.90	17.56	1.61	2.25	1.20
O CT 30 cm	223	4.87	5.47	262.8	75.15	39.96	7.95	13.91	1.10	3.95	1.98

Table B-4 Soil Sample Report: September 2018

SEPTEMBER 2018				Mehlich 1 mg/kg (ppm)						mg/kg	%
Sample	LBC [1] (ppm $CaCO_3$/ pH)	pH $CaCl_2$ [2]	Equiv. water pH	Ca	K	Mg	Mn	P	Zn	NO_3-N	OM [3]
B ST 10 cm	215	5.30	5.90	496.8	77.2	42.21	6.31	22.85	3.30	3.91	1.50
B ST 20 cm	227	5.25	5.85	475.4	98.5	58.18	7.72	11.01	2.28	3.08	1.98
B ST 30 cm	252	5.33	5.93	494.2	105.4	76.61	5.86	12.37	2.57	3.57	2.44

Table B-4 (continued)

B CT 10 cm	131	4.97	5.57	185.3	24.2	17.58	2.10	16.24	0.94	1.99	0.67
B CT 20 cm	142	4.94	5.54	143.7	39.0	21.05	1.18	17.52	0.47	1.66	0.67
B CT 30 cm	162	4.52	5.12	129.7	39.0	30.87	0.68	11.61	0.46	1.77	0.74
P ST 10 cm	199	5.27	5.87	475.7	69.6	51.22	11.23	23.01	2.93	5.02	1.28
P ST 20 cm	145	5.60	6.20	264.2	53.8	31.88	4.99	12.65	0.92	1.09	0.63
P ST 30 cm	183	5.36	5.96	324.7	81.7	46.23	5.25	6.71	0.88	1.61	0.97
P CT 10 cm	202	6.27	6.87	582.9	72.2	87.73	5.23	48.19	2.35	1.63	1.18
P CT 20 cm	229	5.94	6.54	525.5	81.9	74.91	4.37	43.39	2.41	1.09	1.06
P CT 30 cm	210	5.85	6.45	455.7	91.6	85.97	4.16	21.94	1.77	0.96	1.22
O ST 10 cm	234	5.52	6.12	515.3	77.7	47.47	12.16	54.30	2.92	5.77	1.66
O ST 20 cm	248	5.53	6.13	357.2	95.4	38.71	14.87	19.43	0.70	2.14	1.57
O ST 30 cm	228	5.68	6.28	330.7	98.4	52.73	17.45	8.67	0.60	1.50	1.71
O CT 10 cm	320	4.44	5.04	345.1	66.0	36.75	10.22	31.00	7.36	17.43	2.56
O CT 20 cm	143	4.82	5.42	164.1	40.4	22.47	3.74	23.09	1.46	3.56	1.16
O CT 30 cm	244	5.12	5.72	327.1	63.9	64.10	4.97	7.57	0.77	9.39	2.52

Table B-5 Soil Sample Report: October 2018

OCTOBER 2018				Mehlich 1 mg/kg (ppm)						mg/kg	%
Sample	LBC [1] (ppm $CaCO_3$/ pH)	pH CaCl2 [2]	Equiv. water pH	Ca	K	Mg	Mn	P	Zn	NO_3-N	OM [3]
B ST 10 cm	191	513	6.20	501.7	78.1	40.09	6.16	15.34	2.19	2.46	1.26
B ST 20 cm	228	649	6.00	376.6	93.8	89.26	1.93	0.42	0.42	3.29	3.06
B ST 30 cm	225	638	6.02	387.8	106.0	55.36	4.70	1.15	0.70	2.07	2.37
B CT 10 cm	133	300	5.69	187.4	36.4	23.27	1.91	9.71	0.52	1.11	0.78
B CT 20 cm	144	340	5.44	123.2	47.4	19.77	1.51	8.42	0.38	0.56	0.68
B CT 30 cm	155	381	4.97	112.9	53.6	24.95	1.24	3.37	0.25	0.79	0.67
P ST 10 cm	194	524	6.16	475.1	85.5	48.37	11.71	13.93	2.30	4.07	1.39
P ST 20 cm	166	421	5.90	310.3	60.2	37.22	7.07	9.17	1.13	1.10	0.87
P ST 30 cm	185	491	6.08	348.8	82.5	44.19	5.14	2.25	0.42	1.50	1.02
P CT 10 cm	212	590	6.60	705.1	90.7	85.10	7.37	88.42	9.54	2.65	1.41
P CT 20 cm	194	524	5.89	293.9	56.8	43.40	3.73	43.04	1.56	0.94	0.94
P CT 30 cm	252	731	6.02	391.2	111.2	84.94	1.70	4.74	0.88	0.87	1.87
O ST 10 cm	266	771	5.73	451.1	93.8	36.96	27.37	44.86	2.45	2.39	1.78
O ST 20 cm	242	700	5.78	251.4	70.0	25.34	16.43	15.84	0.41	2.26	1.47
O ST 30 cm	204	561	6.10	298.2	86.8	40.11	25.52	2.40	0.39	2.77	1.84
O CT 10 cm	333	966	5.10	332.0	65.6	36.84	11.49	22.87	5.30	3.99	2.51
O CT 20 cm	189	506	5.45	211.2	48.6	29.14	7.48	4.70	0.60	3.01	1.84
O CT 30 cm	282	818	6.08	388.8	55.0	69.92	4.57	0.90	0.29	7.45	3.30

Table B-6 Soil Sample Report: November 2018

NOVEMBER 2018				Mehlich 1 mg/kg (ppm)						mg/kg	%
Sample	LBC [1] (ppm $CaCO_3$/ pH)	pH $_{CaCl2}$ [2]	Equiv. water pH	Ca	K	Mg	Mn	P	Zn	NO_3-N	OM [3]
B ST 10 cm	191	513	6.61	460.6	77.6	38.68	3.66	26.21	1.82	1.09	1.22
B ST 20 cm	165	417	6.61	359.9	64.1	32.21	1.93	8.02	0.83	0.51	1.03
B ST 30 cm	200	546	6.16	313.4	109.0	49.50	2.13	3.61	0.68	1.45	1.78
B CT 10 cm	127	278	6.09	178.8	49.8	19.45	1.04	10.56	0.55	0.45	0.63
B CT 20 cm	126	274	6.38	174.9	36.6	28.27	0.96	6.98	0.43	0.35	0.52
B CT 30 cm	158	392	5.51	177.0	40.8	59.85	0.40	1.62	0.23	0.81	0.94
P ST 10 cm	200	546	5.69	371.0	112.0	31.09	4.19	16.30	3.05	2.60	1.28
P ST 20 cm	180	473	6.11	320.3	62.0	40.00	2.90	8.59	1.08	1.84	0.86
P ST 30 cm	190	509	5.86	341.5	60.1	41.02	3.38	7.86	1.12	2.38	1.08
P CT 10 cm	207	572	6.85	538.2	85.6	67.44	3.62	61.81	3.33	1.13	1.19
P CT 20 cm	185	491	6.59	355.1	112.7	56.94	2.98	24.33	1.70	0.79	1.36
P CT 30 cm	239	689	6.35	417.2	144.9	85.72	1.47	8.99	1.27	1.45	1.94
O ST 10 cm	240	693	6.05	419.7	96.7	35.34	7.41	45.37	2.73	2.39	1.71
O ST 20 cm	236	678	5.94	291.3	84.6	32.54	8.16	23.02	0.56	1.53	1.76
O ST 30 cm	213	594	5.83	244.6	72.1	35.46	9.81	5.42	0.38	1.75	2.04
O CT 10 cm	272	789	5.54	403.8	115.0	42.72	4.95	22.29	5.23	4.10	2.41
O CT 20 cm	219	616	5.69	258.8	66.2	40.06	3.61	13.58	1.15	2.95	2.11
O CT 30 cm	206	568	5.99	273.7	46.8	43.52	2.45	5.84	0.52	3.03	1.98

Table B-7 Soil Sample Report: December 2018

DECEMBER 2018				Mehlich 1 mg/kg (ppm)						mg/kg	%
Sample	LBC [1] (ppm $CaCO_3$/ pH)	pH $_{CaCl2}$ [2]	Equiv. water pH	Ca	K	Mg	Mn	P	Zn	NO_3-N	OM [3]
B ST 10 cm	275	798	5.21	418.9	110.3	37.63	5.43	17.25	1.81	1.46	1.14
B ST 20 cm	240	693	5.37	301.7	98.4	26.15	4.04	9.38	0.86	0.79	1.17
B ST 30 cm	201	550	5.21	325.7	175.5	51.22	4.70	0.96	0.49	0.64	2.69
B CT 10 cm	250	725	6.11	143.8	22.5	18.44	1.33	16.04	0.46	0.87	0.43
B CT 20 cm	189	506	5.84	167.6	21.0	22.22	1.33	14.65	0.39	0.74	0.42
B CT 30 cm	227	645	5.84	150.5	26.8	18.29	1.29	16.44	0.26	0.27	0.47
P ST 10 cm	394	1143	6.65	506.8	86.2	38.10	10.27	24.05	3.24	3.62	1.65
P ST 20 cm	306	887	6.62	318.0	47.9	21.29	5.93	18.91	1.30	2.14	1.04
P ST 30 cm	267	774	6.69	272.0	36.2	20.37	5.52	13.09	0.87	0.77	0.87
P CT 10 cm	350	1015	6.66	509.2	78.0	65.62	5.41	53.41	2.08	1.79	1.15
P CT 20 cm	323	937	6.83	421.0	109.6	69.69	4.84	22.96	2.10	0.72	1.30
P CT 30 cm	333	966	5.74	343.0	96.3	78.88	2.58	2.14	0.96	0.65	0.99
O ST 10 cm	284	824	6.33	584.4	133.8	47.02	20.09	63.08	3.67	1.85	1.98

Table B-7 (continued)

O ST 20 cm	221	623	6.00	371.9	94.4	33.33	17.43	46.96	1.01	1.66	1.81
O ST 30 cm	261	757	5.58	328.9	81.9	30.59	18.35	26.73	2.35	1.01	1.77
O CT 10 cm	429	1244	6.29	356.2	115.8	41.73	10.77	31.29	7.98	3.85	3.17
O CT 20 cm	409	1186	6.17	236.7	57.3	29.55	7.40	28.71	2.68	1.33	1.84
O CT 30 cm	373	1082	6.42	177.7	51.3	25.03	7.10	28.76	1.43	0.62	1.77

APPENDIX C – SOIL MOISTURE SENSOR DATA AT 10 CM PLOTTED WITH RAINFALL

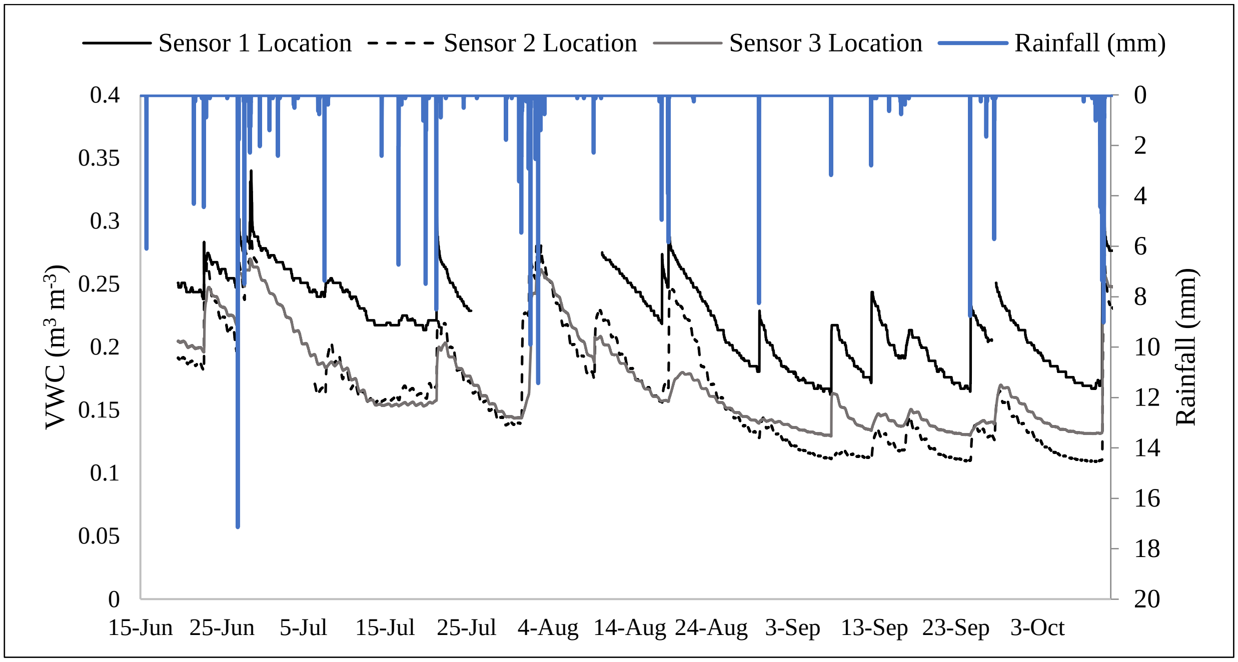

Figure C-1 Oconee County ST Experimental Site: 10 cm Soil Moisture Data Graphed with Rainfall (mm) Data

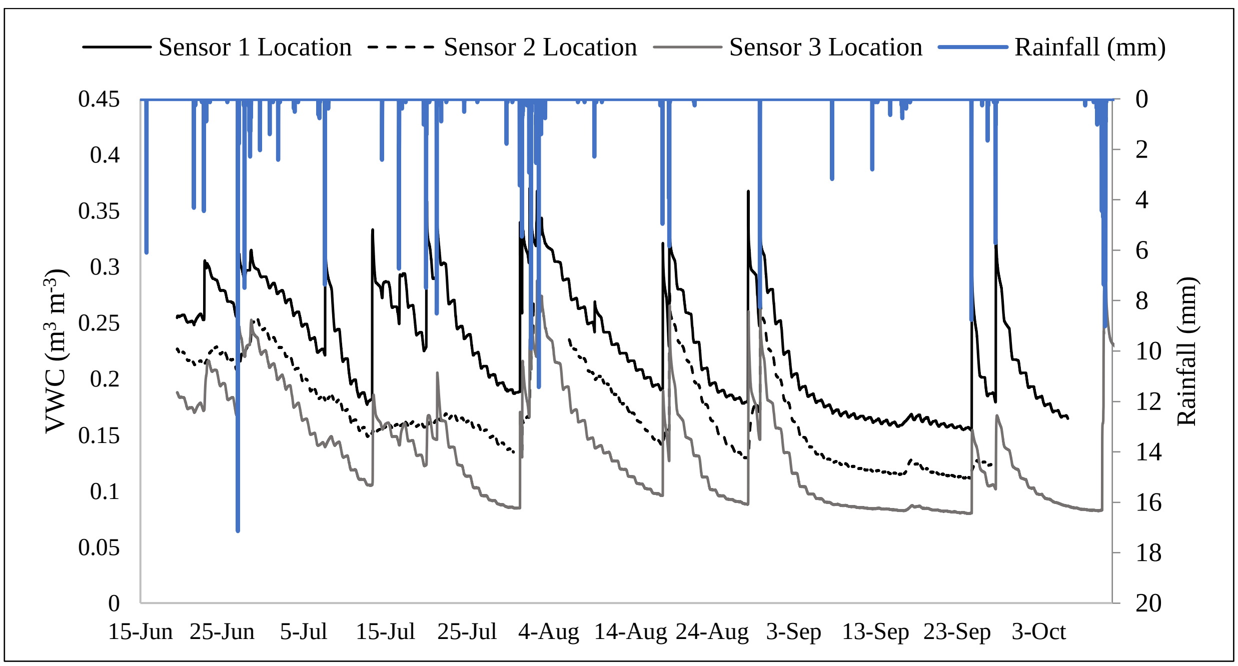

Figure C-2 Oconee County CT Experimental Site: 10 cm Soil Moisture Data Graphed with Rainfall (mm) Data

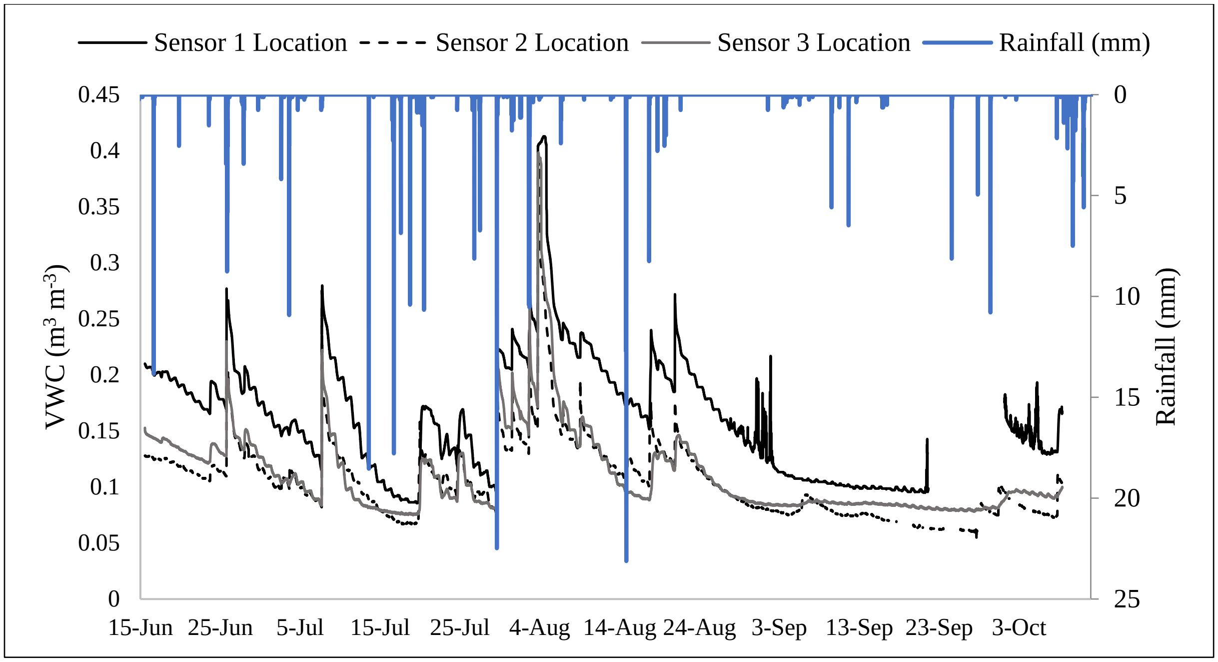

Figure C-3 Bulloch County ST Experimental Site: 10 cm Soil Moisture Data Graphed with Rainfall (mm) Data

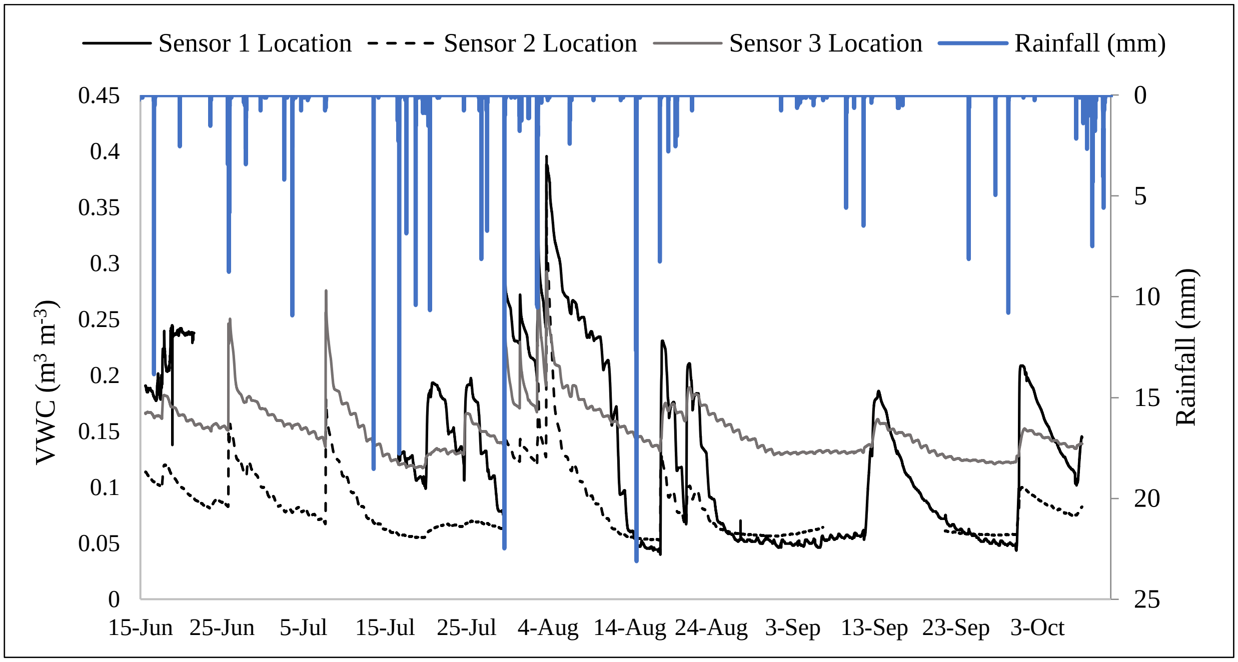

Figure C-4 Bulloch County CT Experimental Site: 10 cm Soil Moisture Data Graphed with Rainfall (mm) Data

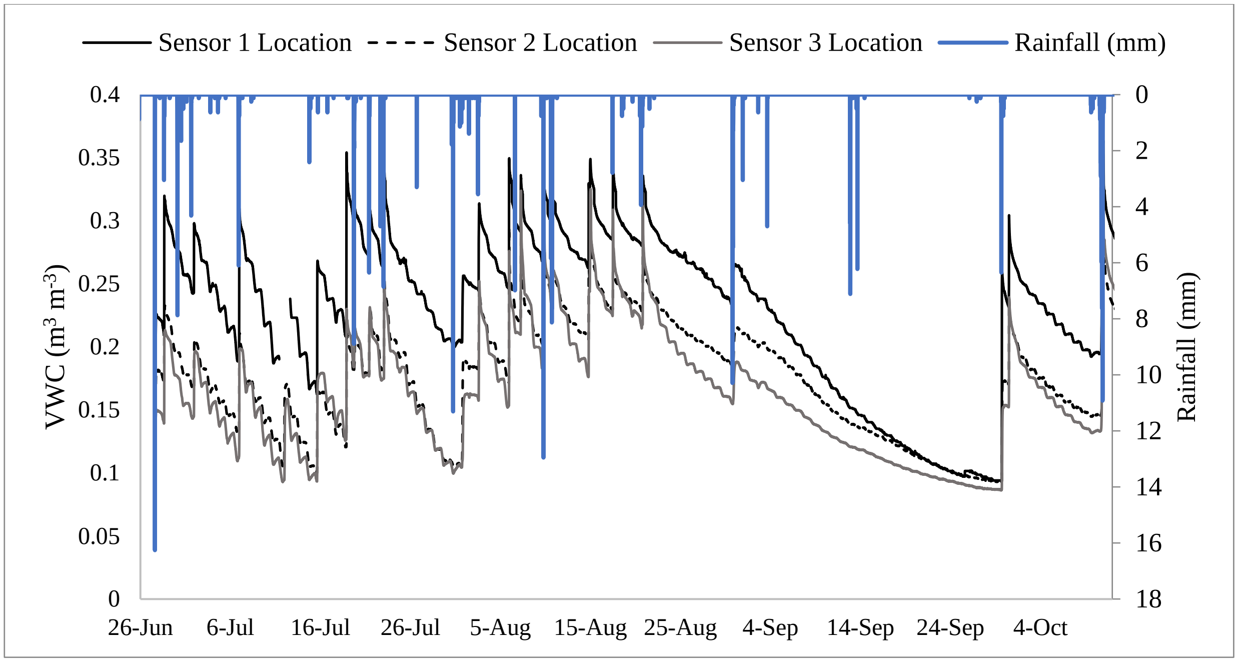

Figure C-5 Pulaski County ST Experimental Site: 10 cm Soil Moisture Data Graphed with Rainfall (mm) Data

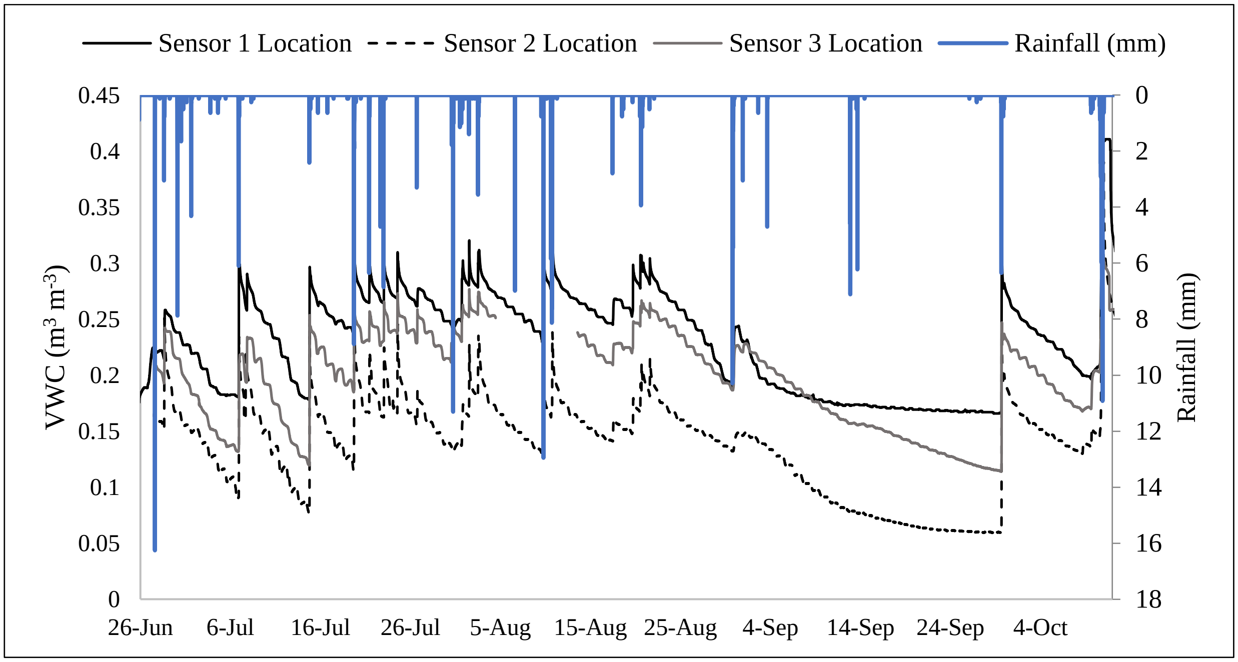

Figure C-6 Pulaski County CT Experimental Site: 10 cm Soil Moisture Data Graphed with Rainfall (mm) Data

APPENDIX D – SOIL MOISTURE SENSOR GRAPHS AT 20 AND 30 CM

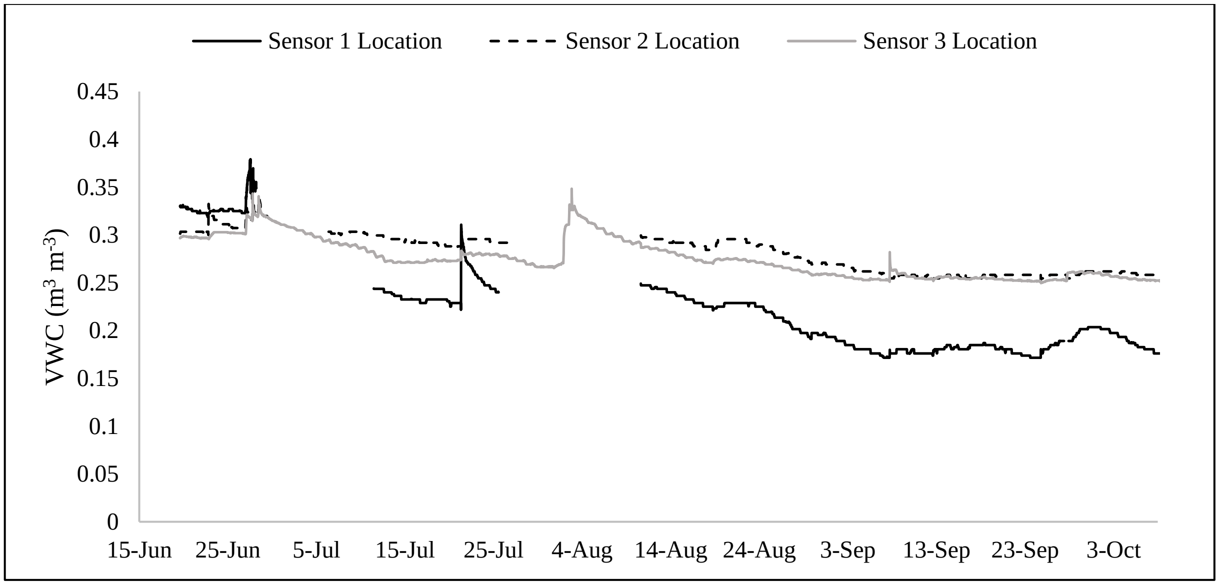

Figure D-1 Oconee County ST Experimental Site Soil Moisture Graphs at 20 cm Depth

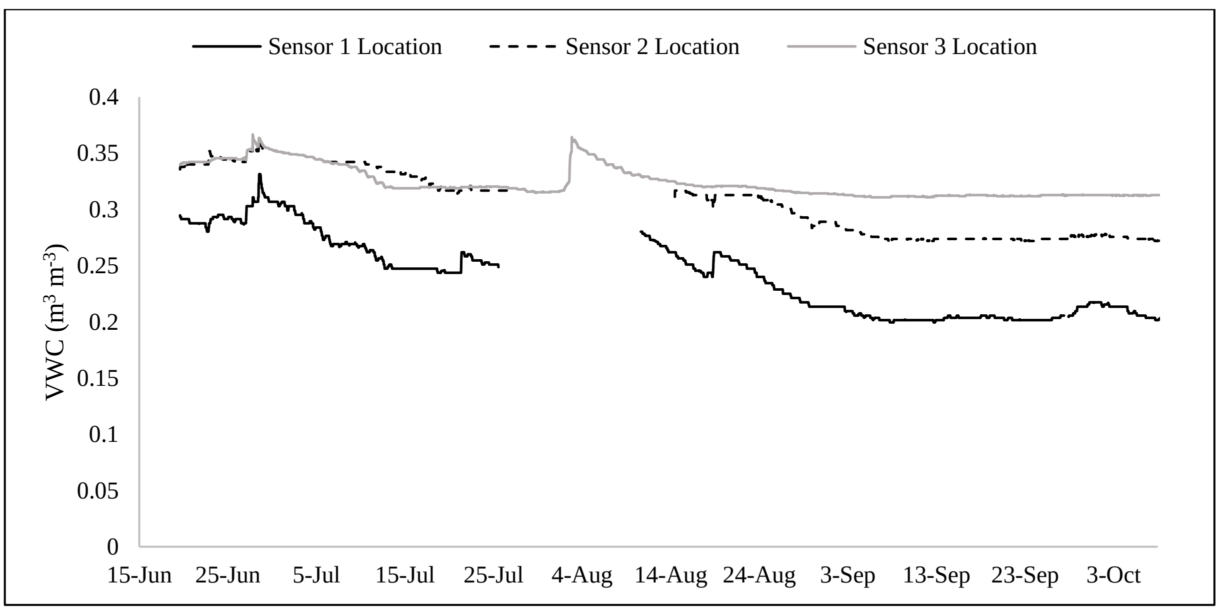

Figure D-2 Oconee County ST Experimental Site Soil Moisture Graphs at 30 cm Depth

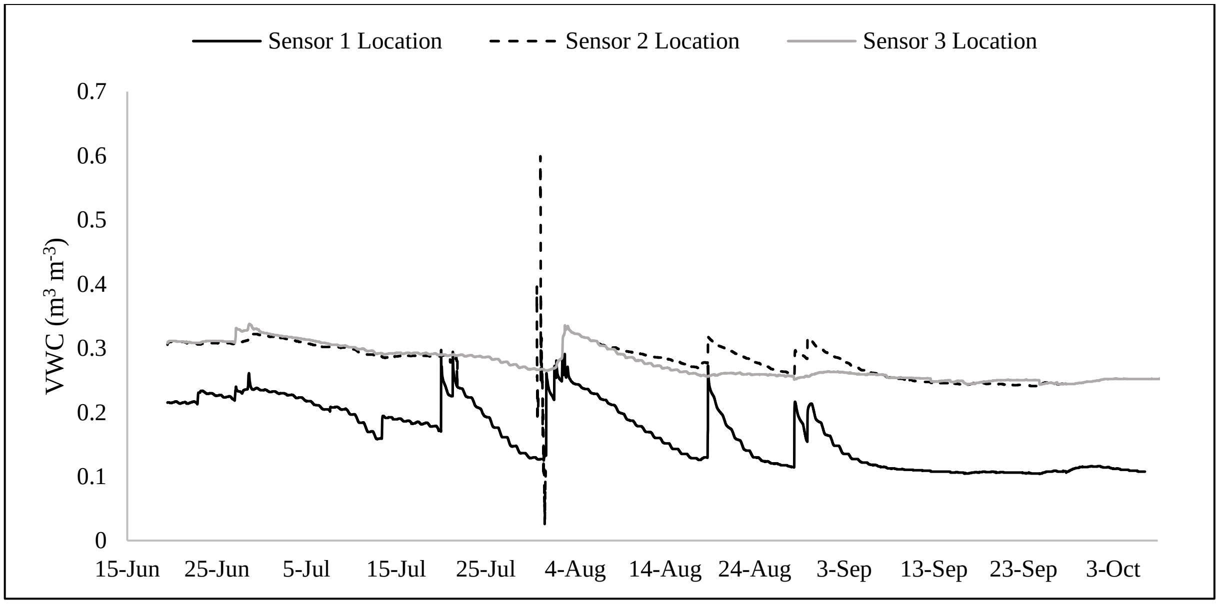

Figure D-3 Oconee County CT Experimental Site Soil Moisture Graphs at 20 cm Depth

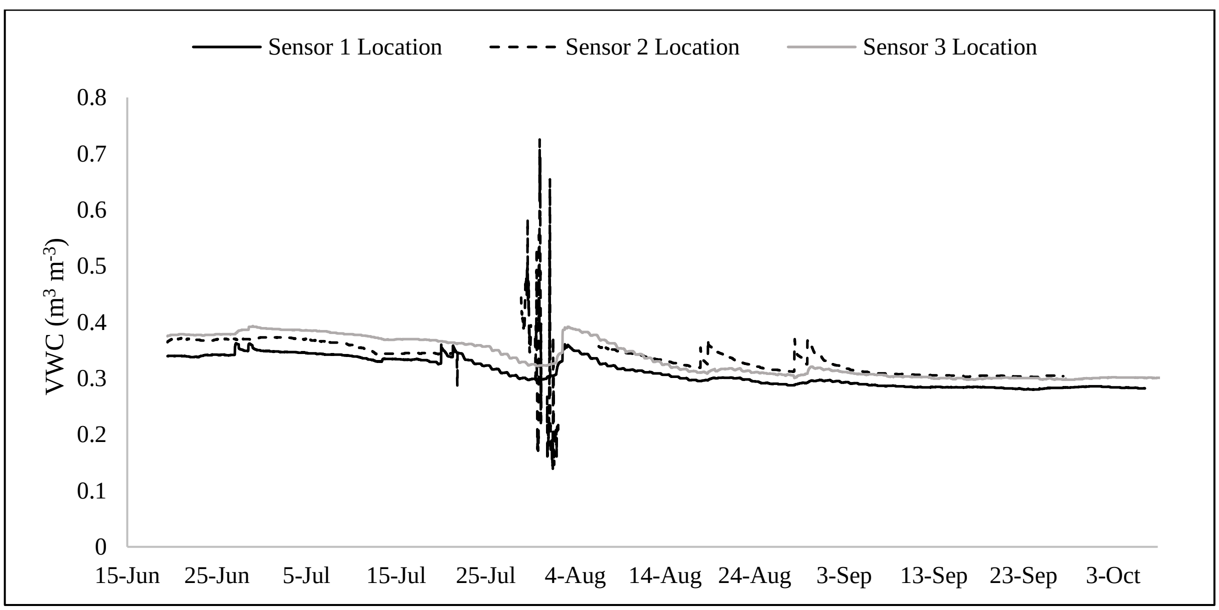

Figure D-4 Oconee County CT Experimental Site Soil Moisture Graphs at 30 cm Depth

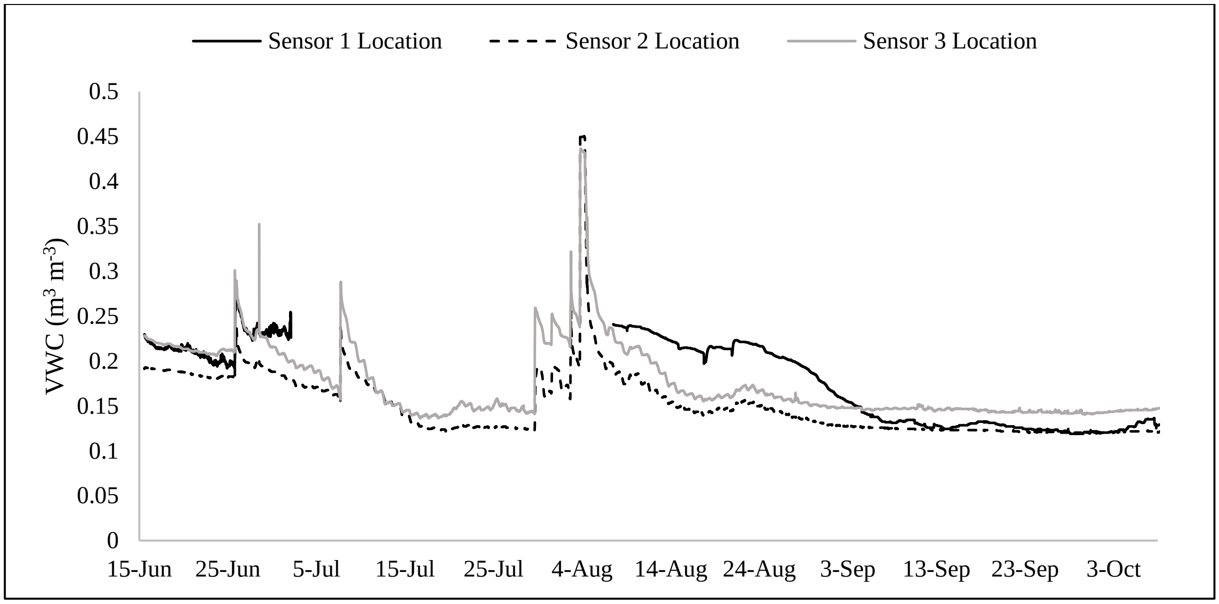

Figure D-5 Bulloch County ST Experimental Site Soil Moisture Graphs at 20 cm Depth

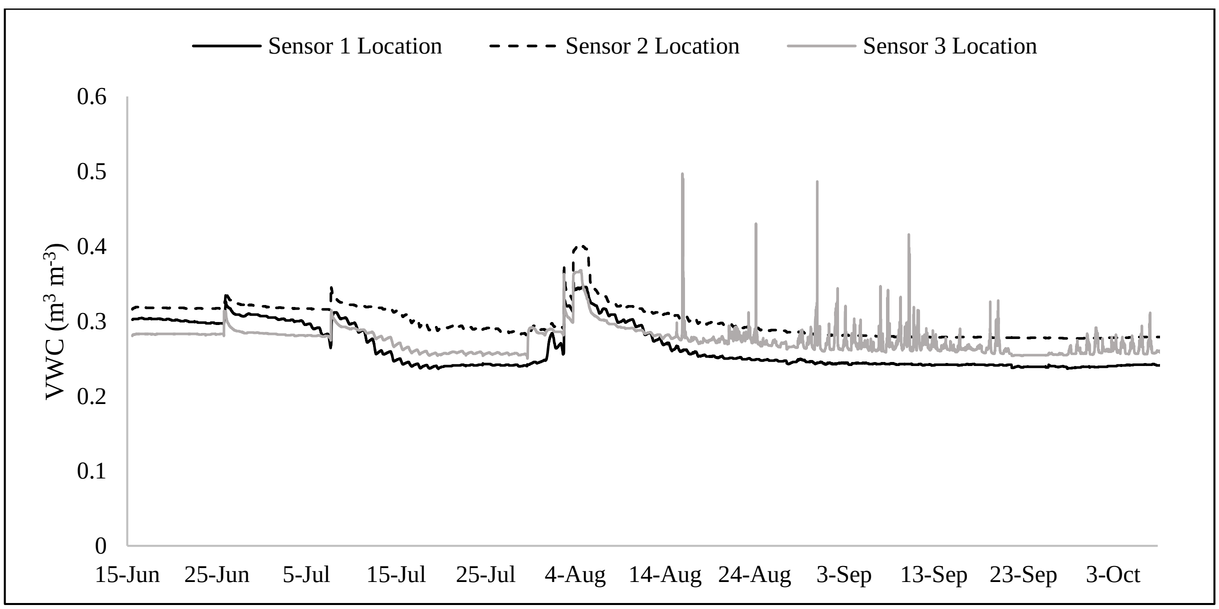

Figure D-6 Bulloch County ST Experimental Site Soil Moisture Graphs at 30 cm Depth

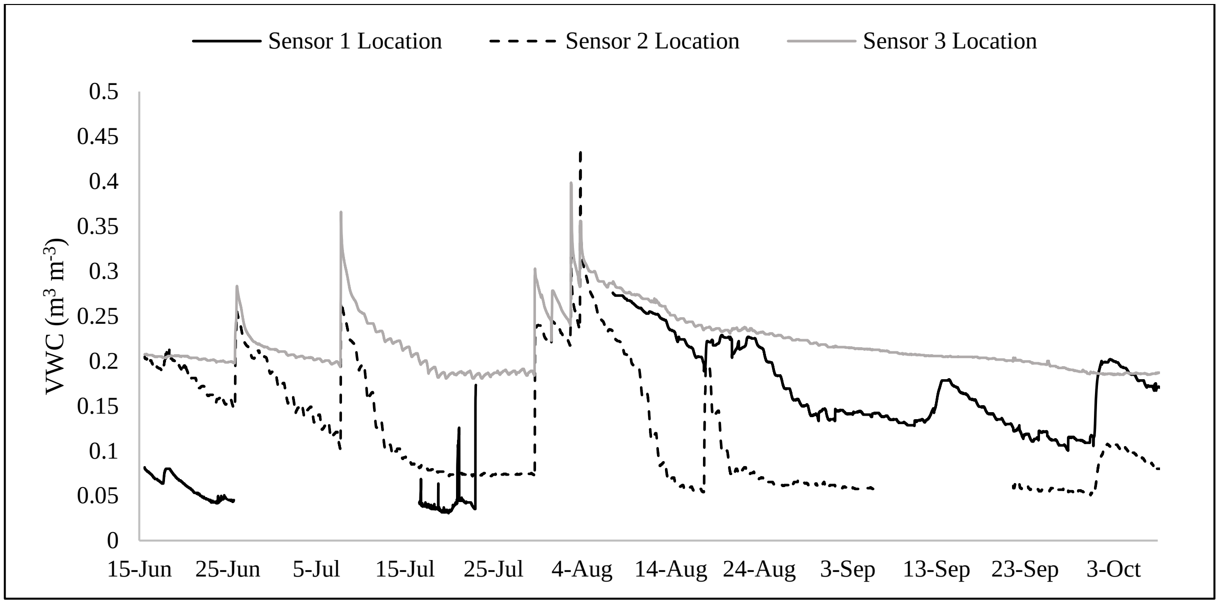

Figure D-7 Bulloch County CT Experimental Site Soil Moisture Graphs at 20 cm Depth

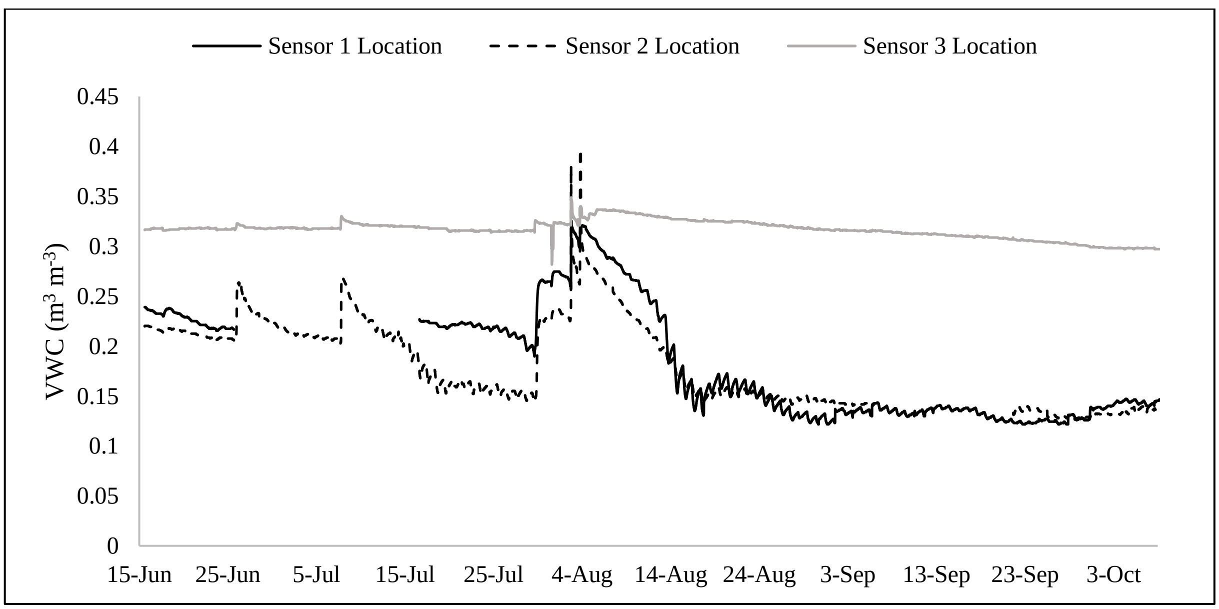

Figure D-8 Bulloch County CT Experimental Site Soil Moisture Graphs at 30 cm Depth

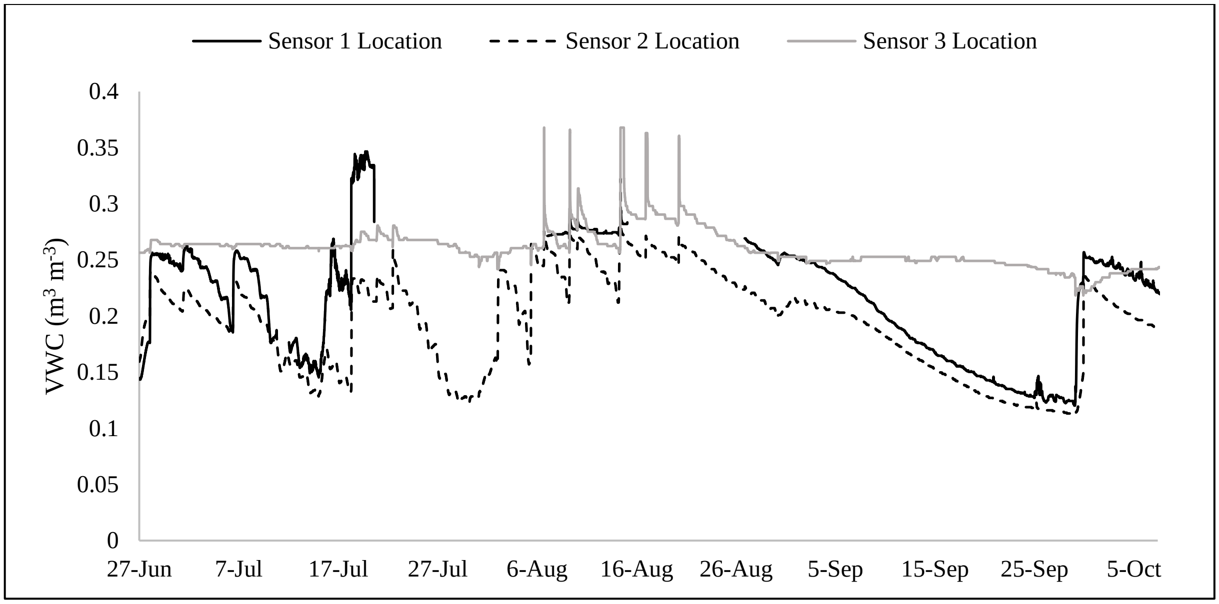

Figure D-9 Pulaski County ST Experimental Site Soil Moisture Graphs at 20 cm Depth

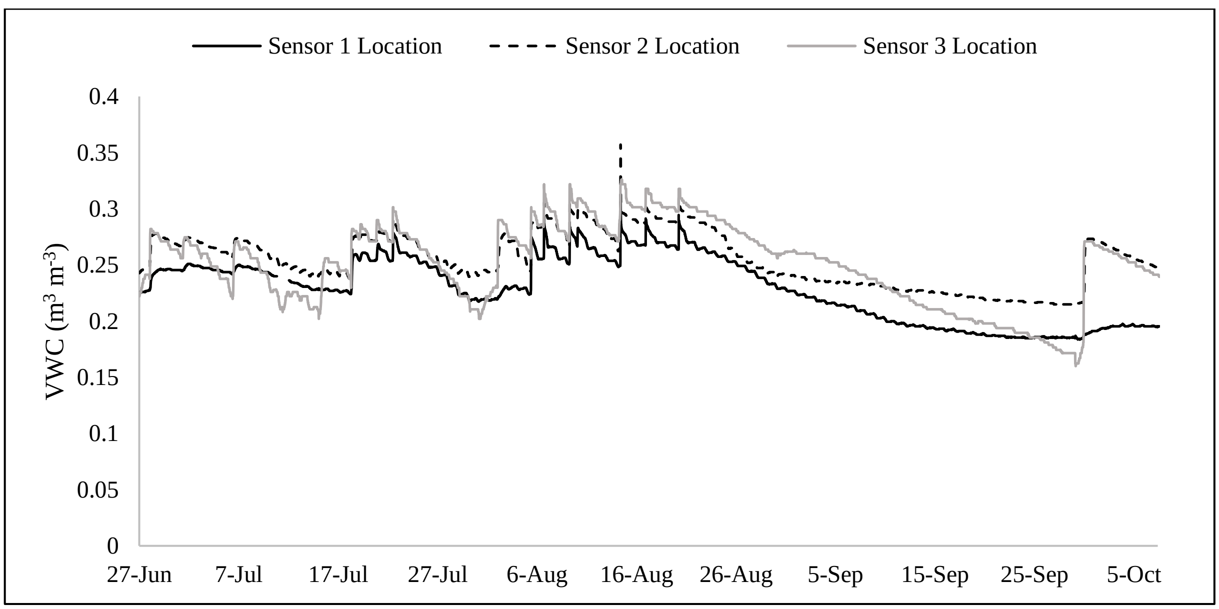

Figure D-10 Pulaski County ST Experimental Site Soil Moisture Graphs at 30 cm Depth

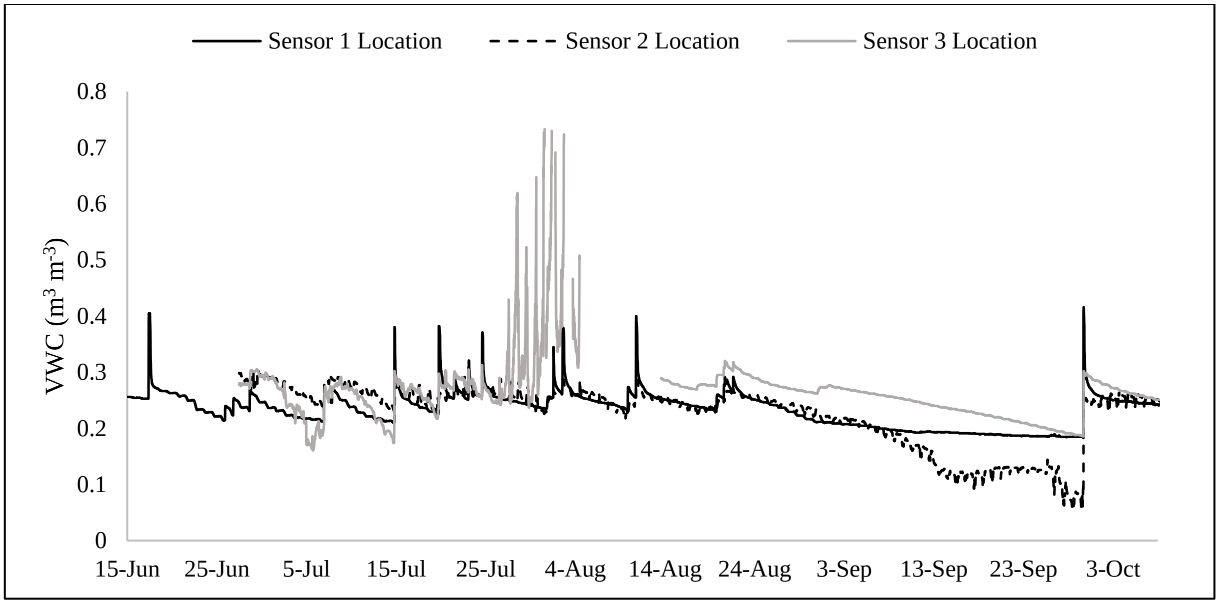

Figure D-11 Pulaski County CT Experimental Site Soil Moisture Graphs at 20 cm Depth

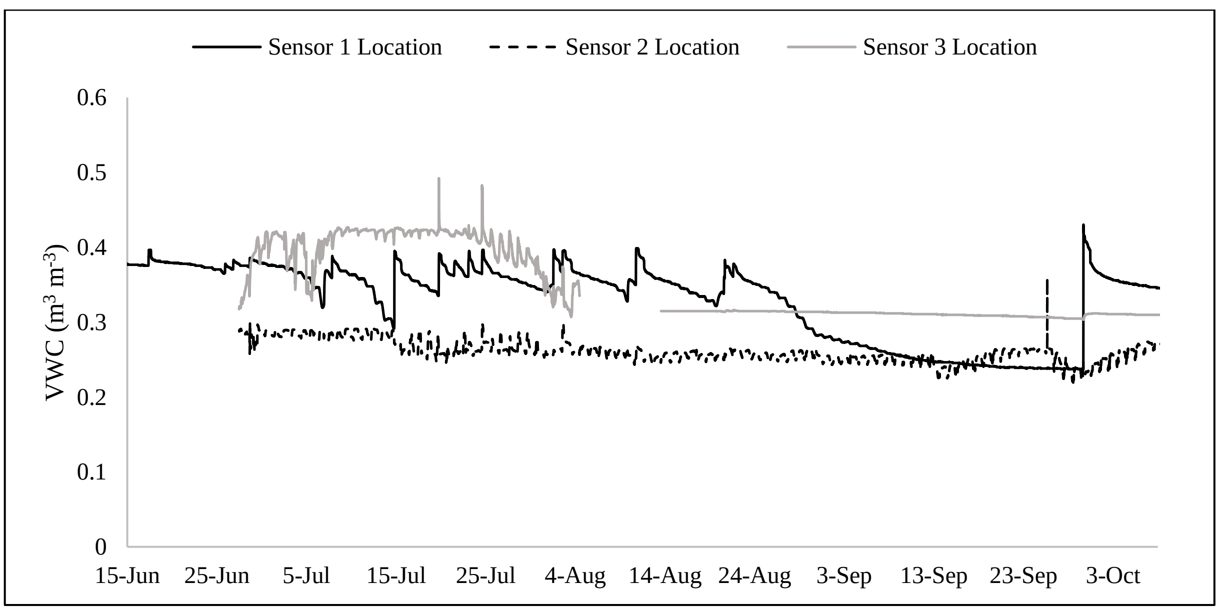

Figure D-12 Pulaski CT Experimental Site Soil Moisture Graphs at 30 cm Depth

APPENDIX E – BULK DENSITY AND POROSITY

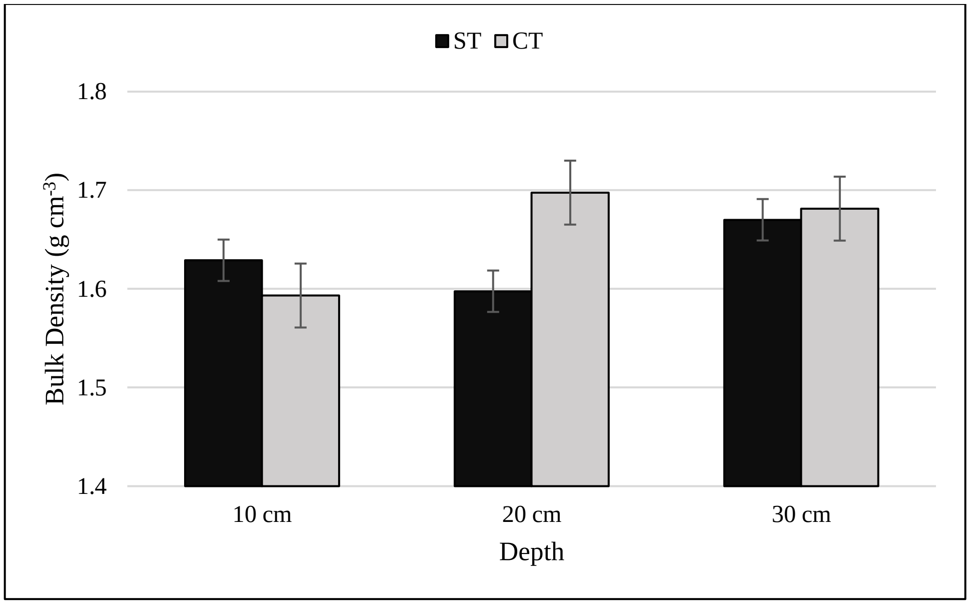

Figure E-1 Oconee County Experimental Site: Bulk Density Results at 10, 20, and 30 cm Depths

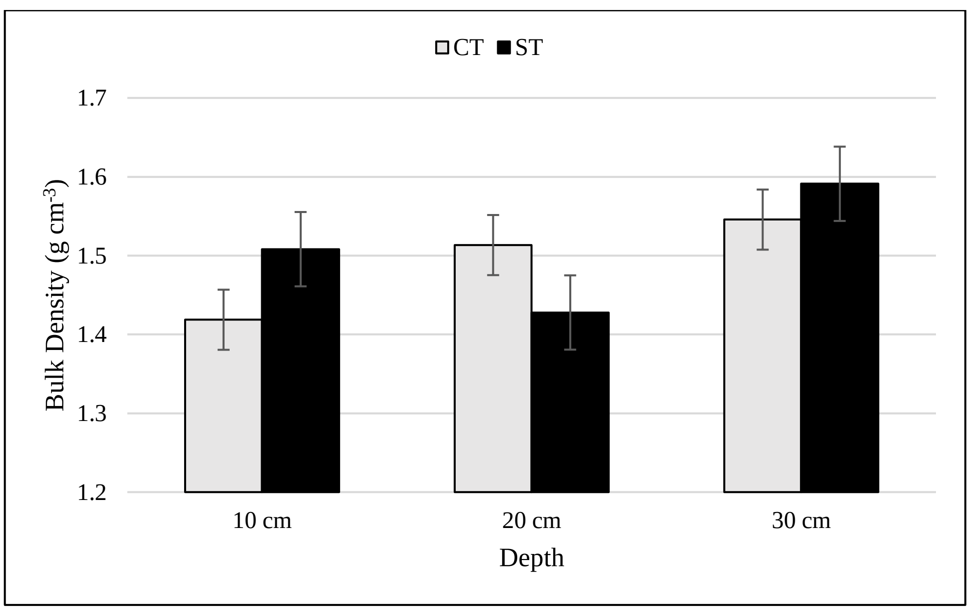

Figure E-2 Bulloch County Experimental Site: Bulk Density Results at 10, 20, and 30 cm Depths

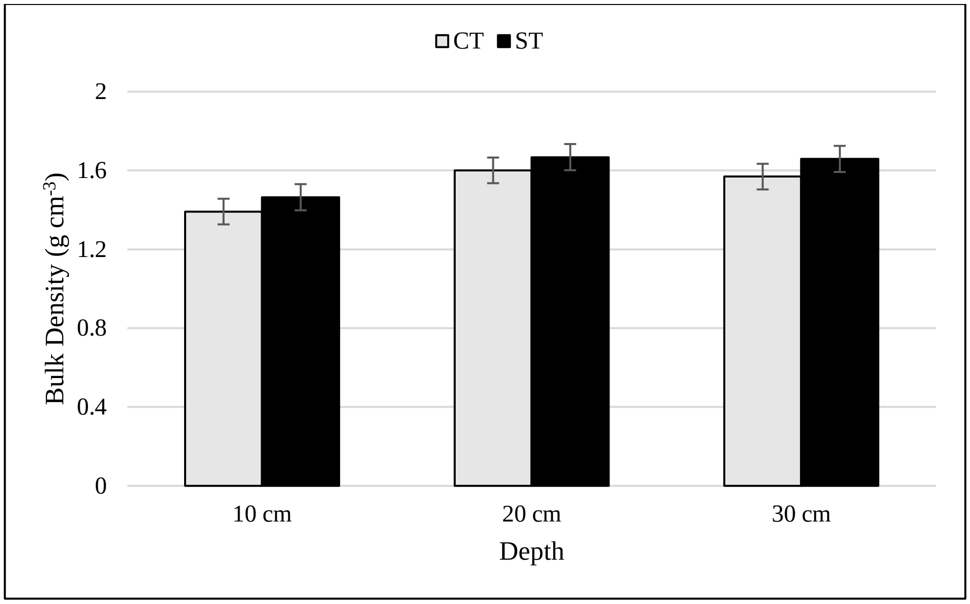

Figure E-3 Pulaski County Experimental Site: Bulk Density Results at 10, 20, and 30 cm Depths

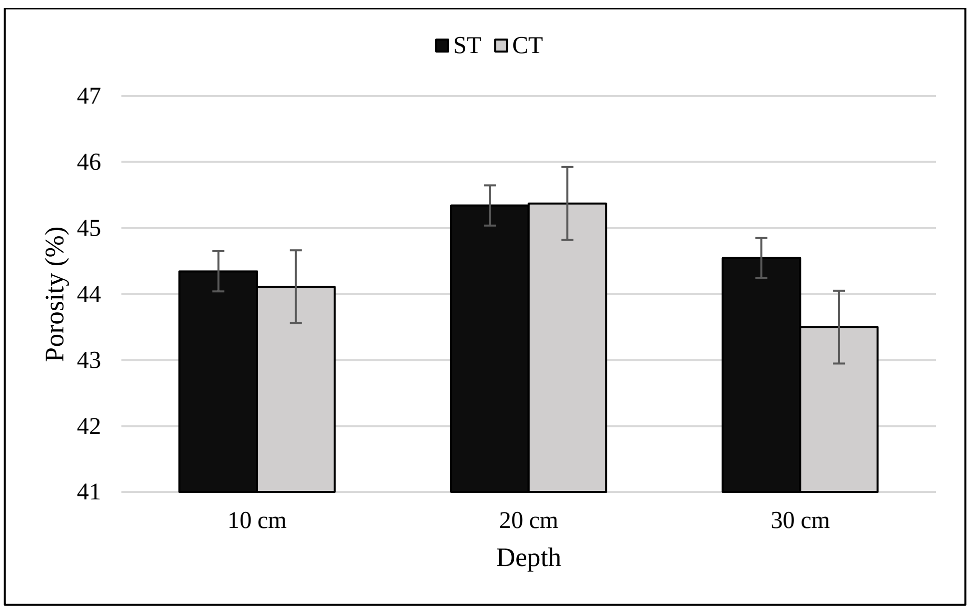

Figure E-4 Oconee County Experimental Site: Porosity Results at 10, 20, and 30 cm Depths

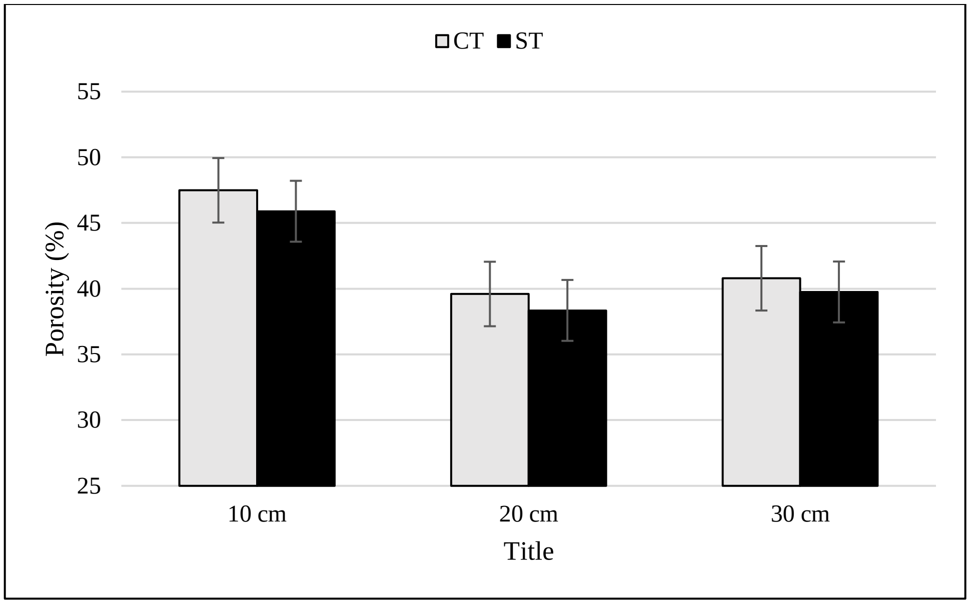

Figure E-5 Bulloch County Experimental Site: Porosity Results at 10, 20, and 30 cm Depths

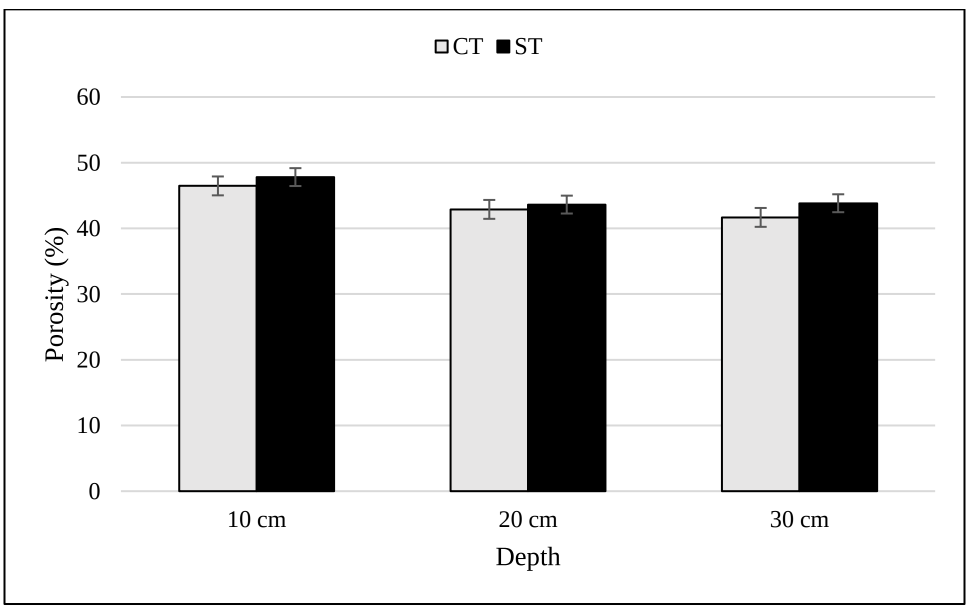

Figure E-6 Pulaski County Experimental Site: Porosity Results at 10, 20, and 30 cm Depths

APPENDIX F – VOLUMETRIC WATER CONTENT GRAPHS

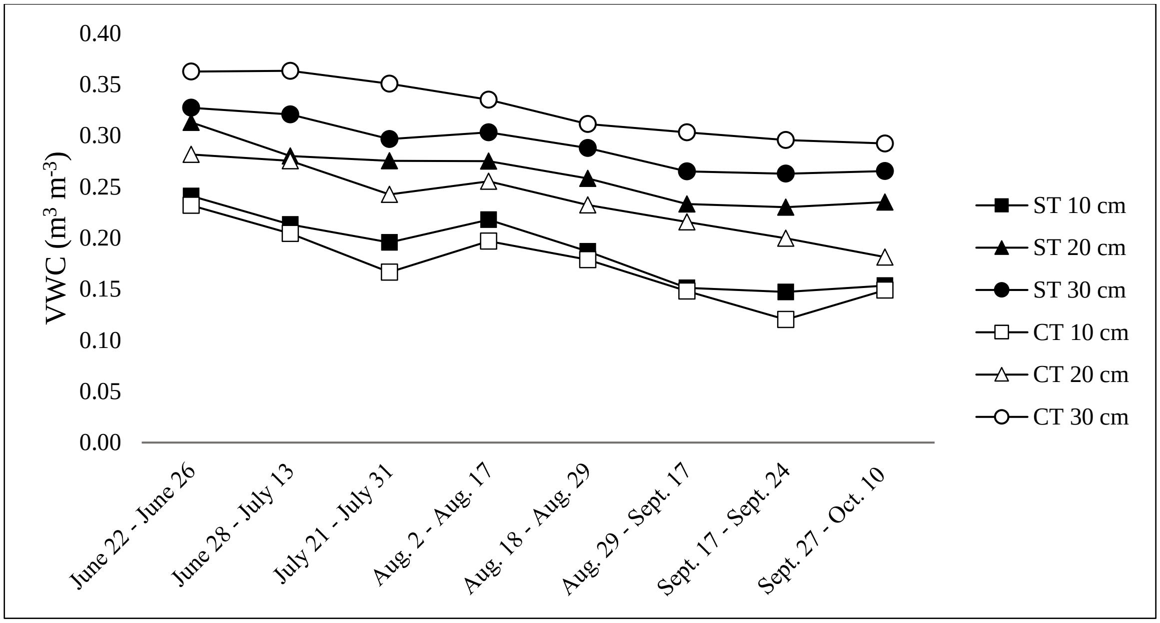

Figure F-1 Oconee County Experimental Sites: Average VWC per Event at 10, 20, and 30 cm

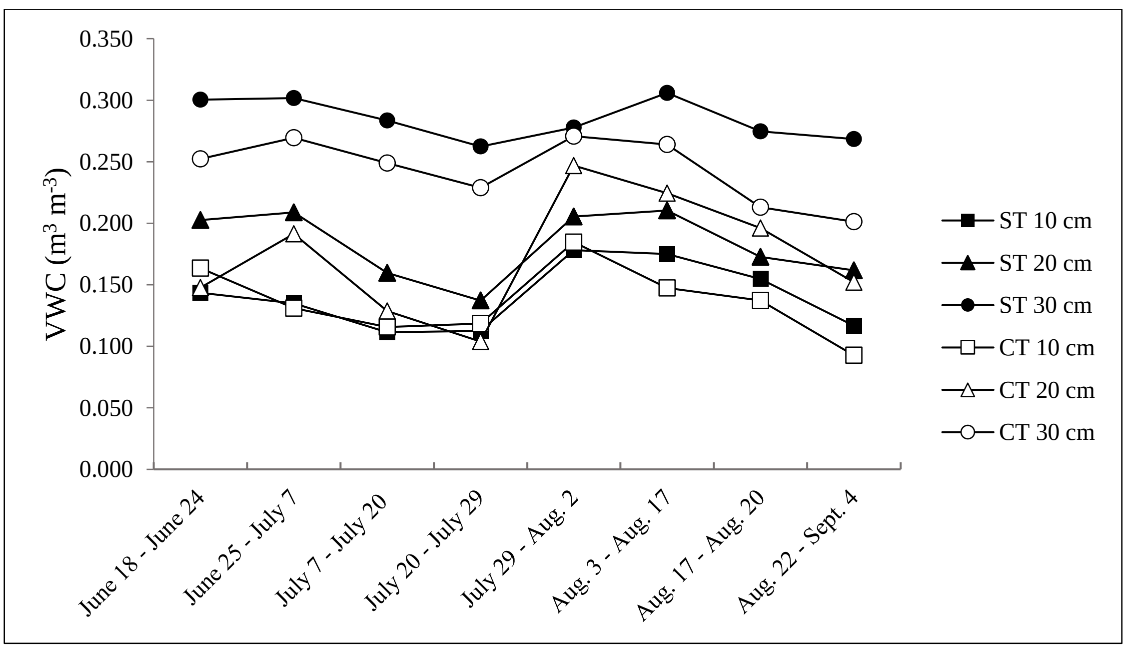

Figure F-2 Bulloch County Experimental Sites: Average VWC per Event at 10, 20, and 30 cm

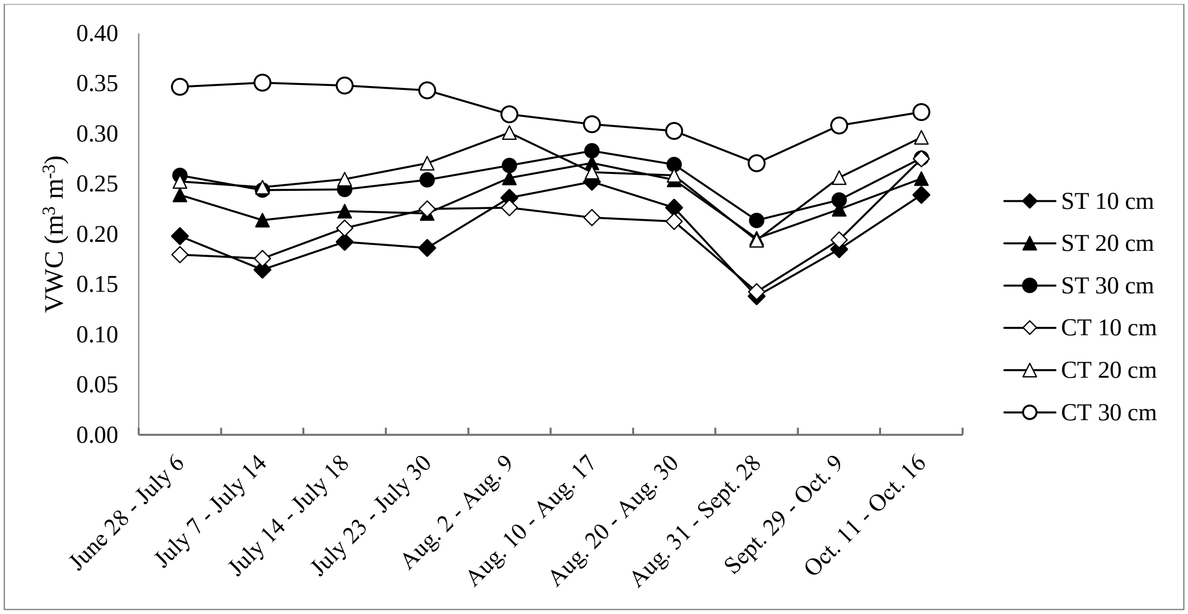

Figure F-3 Pulaski County Experimental Sites: Average VWC per Event at 10, 20, and 30 cm

APPENDIX G – RUNOFF GRAPHS

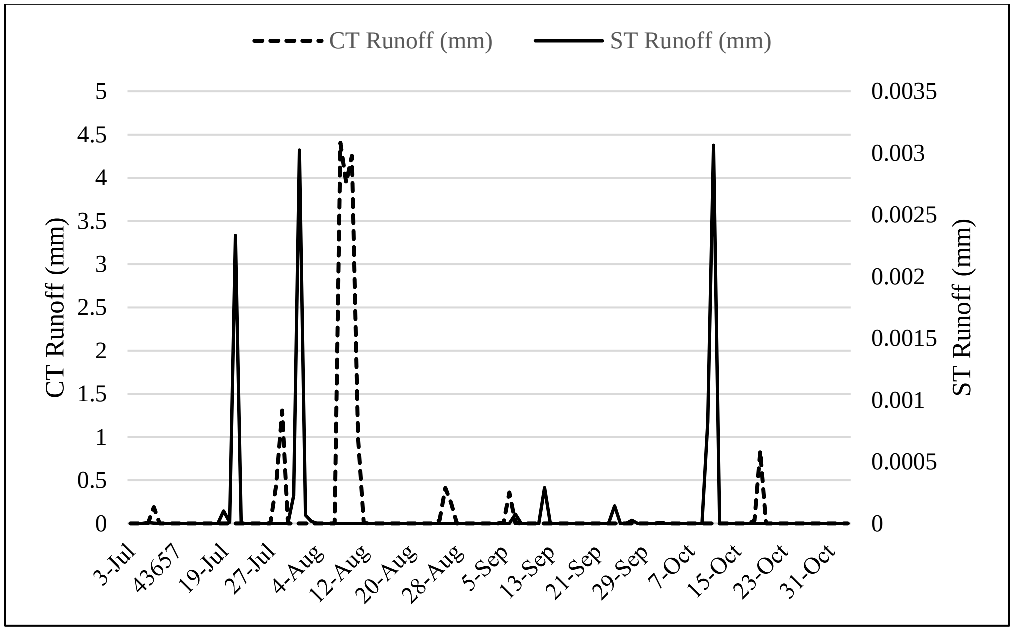

Figure G-1 Oconee County Experimental Sites Recorded Runoff for ST and CT Plotted with Different X-Axes

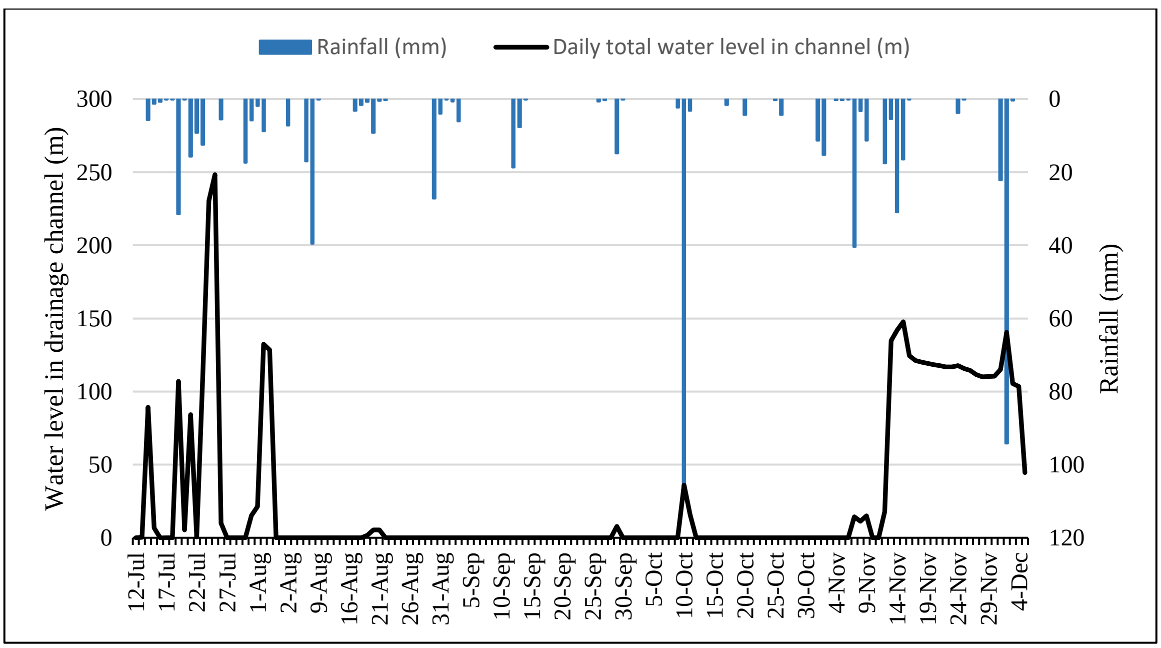

Figure G-2 Pulaski County CT Experimental Site Runoff Water Level in Channel and Rainfall from July 2018 to December 2018

APPENDIX H – PULASKI COUNTY CT EXPERIMENTAL SITE PHOTOGRAPHS

(a) Channel in October with indication of soil loss

(b) Channel in December with heavy soil erosion and excessive water loss off of field

Figure H-1 Pulaski County CT Experimental Site: Edge of Field Drainage Channel

(a) Drainage channel in October with damaged cotton lint on ground after Hurricane Michael

(b) Drainage Channel in December with nearly all sandy topsoil washed away and an intermittent stream through the field

Figure H-2 Pulaski County CT Experimental Site: Drainage Channel in Field (Viewing Towards Edge of Field Station)