LONG-TERM COVER CROP ANALYSIS IN THE COASTAL PLAINS CROP PRODUCTION REGION TO COMPARE COVER CROP TREATMENTS AND RETAINED IN-SEASON SOIL MOISTURE

by

MARY LOGAN TOSTENSON

(Under the Direction of Wesley M. Porter)

ABSTRACT

Cover crops, in conjunction with crop rotation and conservation tillage, have shown the potential to reduce erosion, increase soil organic matter, and better maintain in-season soil moisture. The main objective of this study was to evaluate three common cover crops/mixtures and determine their effects in a cotton, peanut, and corn rotation on biomass production, soil organic matter, soil moisture, and crop yield. The study site was located in southeast Georgia, and the treatments included a no cover crop control, a cereal rye monoculture, a cereal rye and crimson clover mixture, and a multiple species mixture. Results indicated that incorporating a cover crop into a production system increased soil moisture retention, and a positive relationship was discovered between cover crop biomass and soil organic matter. Year had an effect only on peanut yield compared within year, and cover crop treatment had an effect on corn yield in 2021 and peanut yield in 2022.

INDEX WORDS: Cover crops, cotton, peanut, corn, soil moisture sensors, soil moisture, soil moisture retention, soil organic matter, soil water tension

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DEDICATION

Mom, Dad, Lyle, and Lucas, thank you for always listening, encouraging, and supporting me, even when I have crazy ideas. Mom and Dad, I know for a fact that this degree would have not been possible without the encouragement and work ethic that you instilled in me at such a young age. I may have been oblivious at the time, but I now realize that there were some methods to your madness (and craziness at times). Also, thank you for the friendship and teamwork you generated between Lyle, Lucas, and me. Every day I have seen these parts of my childhood parallel to the type of student and colleague that I am. These are skills that are lacking in our society, and I would not possess them without each of you ensuring that they were fostered at a young age. Thank you for teaching me about learning, loyalty, and how to be patient and kind. I could not ask for better parents, and I hope you know how grateful I am for each of the qualities you have showed me in your own lives. These are far greater than any degree, award, or job I could ever achieve.

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LITERATURE REVIEW

Introduction to Integrating Soil Moisture Sensors, Cover Crops, and Tillage Practices

Rockström et al. (2009) stated that by 2050, 36% of the world population will face green and blue water shortages. Blue water is defined as water that meets hygienic, health, and economic requirements, including water used for irrigation practices. Green water is unfiltered rainwater that operates in the natural production of food and biomass (Falkenmark, 2013). Utilizing cover crops to capture green water and retain it in the soil profile and only applying blue water when necessary could pose many positive benefits. As a whole, the global population must work to build water resilience because of the constraints associated with expanding crop production hectares. In addition to land constraints, there is more potential for extreme weather conditions to occur, such as drought.

Soil Moisture Sensing Technologies

The stability associated with supporting an exponentially growing world population is heavily dependent upon production agriculture's ability to continue to increase crop yields while focusing on sustainable and cost-effective farming practices (Abioye et al., 2020; Falkenmark, 2013; Garg et al., 2016; Pereira, 2017). Although global crop yields have drastically increased over time through breeding efforts, management practices, and added inputs, the current yields available will not support the predicted population of 9.8

billion people in 2050 (UNDESA, 2017). The U.S. has done an incredible job of researching, implementing the research, and producing higher yields to assist in feeding and clothing the global population (Ray et al., 2012). Cotton (*Gossypium hirsutum* L.), peanut (*Arachis hypogaea* L.), and corn (*Zea mays* L.) are the staple row crops in the southeastern U.S. (USDA-NASS, 2022). According to statistics provided by the USDA, in the last 50 years the average yield for U.S. cotton, corn, and peanut has increased by 85%, 78%, and 82%, respectively. (USDA-NASS, 2022). In terms of total hectares in planted for production, Georgia ranks second in U.S. cotton production behind Texas, first in peanut produced hectares, and while Georgia does not have the climate and landscape to compete with midwestern states' corn production, it does still contribute many hectares to corn production (USDA-NASS, 2022).

Cotton, peanut, and corn are three major row crops produced in Georgia and the Coastal Plains region of the United States (USDA-NASS, 2019; USDA-NASS, 2022). The soil in this region is primarily composed of coarse-textured sand with very low levels of organic material and clay particles which is in direct relationship to the location of this land and historical records that prove it was once below sea level (Markewich et al., 1990). The soil structure makes water and nutrient retention and availability challenging and can negatively impact yields because of the fast infiltration rates and inability to hold moisture and elemental nutrients (Lamparter et al., 2006). Szydzik (2021) found that irrigated lands in Georgia increased by 30% (or 186,155 hectares) statewide over the past 12 years. In a 2012 financial study, the cost of irrigating along with the increased irrigated cotton yields found that it was financially beneficial to irrigate when an additional 144 kg ha^{-1} of cotton were produced if the added cost of irrigation was \$107.79 ha^{-1} and the lint price was at

\$0.36 kg^{-1} (Smith, 2012). Solely observing yield, rainfed cotton produces an average of only 840 kg ha^{-1}, whereas irrigated cotton produces an average of 1345 kg ha^{-1} (Georgia Cotton Production Guide, 2019). In wet years like 2020, which received 124-cm of rainfall versus 100-cm of rainfall received in 2019, rainfed cotton shows little yield difference to irrigated cotton. But in dry years, there can be up to an 897 kg ha^{-1} yield difference, but yield differences between 224 kg ha^{-1} and 448 kg ha^{-1} are most common (Georgia Cotton Production Guide, 2019). There is an extensive financial investment to incorporate irrigation into a production system, but the yield increase associated with irrigated crops allows for a greater net revenue (Sepaskhah and Ghahraman, 2004).

Along with applying irrigation, placing soil moisture sensors in production fields adds another layer of efficiency by providing data for irrigation management decisions. The data collected from soil moisture sensors can reduce irrigation, which saves money and water (Gonzalez-Alvarez et al., 2006). There are many different soil moisture sensors available to growers: gypsum blocks, tension meters, capacitance, volumetric, and neutron probes (Restuccia, 2021). All of these soil moisture sensors either measure soil water tension or volumetric water content to make irrigation decisions and to better understand the variability of soil water holding capacity (SWHC) throughout a field. Soil properties and variability are the main determinants for soil moisture sensor placement and the number of sensors placed in a field. The most efficient way of collecting data to determine placement and the number of sensors to use is to collect data on the field's soil electroconductivity (EC) and then using a software program, such as ArcMap or SMS, to delineate a high and a low soil EC zone to create a field map (Zazueta and Xin, 1994). This visual can then be used to determine the optimal number and the placement of sensors for that field.

Soil Moisture Sensors

Soil moisture sensors are physical probes used to collect soil moisture and are becoming a vital resource to combat water scarcity and promote efficient irrigation by continuously monitoring the soil moisture content in a field. Additionally, they play a key role in determining SWHC because they can measure, collect, and compile the necessary data in a manner that is easy to understand and use (Garg et al., 2016). Soil moisture is best defined as the volumetric water content, W, with $W(\%) = 100(V_w/V_s)$, where V_w is the total volume of water in the soil and V_s is the total volume of all soil components. Typical values of W range up to 60% because the porosity of most soils is between 40% and 60% (Eller and Denoth, 1996). By understanding soil moisture, SWHC, and the geographic location of the sensors, soil type, and plant-available water are also parameters that can be determined. For example, in the southeast region of Georgia, the clay concentration is low and sand and silt concentrations are high, meaning that SWHC and plant-available water are both relatively low and water quickly moves through the soil profile (DeTar, 2008). Soil moisture sensors in combination with soil structure identification can result in improving management practices to increase SWHC and plant-available water leading to greater WUE.

In order to collect accurate and necessary data from soil moisture sensors, accurate soil texture data is required. One way to achieve accurate data is using soil EC data to delineate high and low soil EC zones (Doerge et al., 1999; Gunzenhauser et al., 2016;

Hawkins et al., 2017). Once the high and low soil EC zones have been identified, the soil moisture probes can be placed in a field based on a soil EC zone map created in a software programming system, such as ArcMap or SMS. Although soil moisture sensors are placed by the soil texture zones, there are many different types of soil moisture sensors currently available. Tensiometers, also known as soil water tension (SWT) sensors, and capacitive soil moisture sensors are two examples of sensors that are commonly used in research and for irrigation management decisions. These two types of sensors use different strategies, but they work to achieve the same goal of understanding the moisture levels in the soil.

SWT sensors measure the physical force of holding water in the soil and use Centibars (kPa) of SWT. Evidence shows that the original design of tensiometers was proposed around 1908 that associated SWT with the capillary lifts of soil (Or, 2001). Early conventional tensiometers contained a water-filled reservoir that limited their ability to measure soil water pressures above 85 kPa. With newly designed tensiometers, a polymer solution took the place of water, and they are now able to measure SWT (or matric potential) between a range of 0 to 160 kPa (Bakker et al., 2007). In order for tensiometers to get readable data, the water tension in the soil has to be overcome. In wet conditions, the tensiometer is filled with water and brings the tensiometer closer to equilibrium (0 kPa) with the moisture in the surrounding soil. As soil conditions dry, water flows out of the tensiometer and creates tension that brings the tensiometer value away from equilibrium. Depending on the soil structure and type, the SWT will differ. Additionally, whenever the SWT is overcome, plants are able to move water into their root systems because of their capillary nature. Tensiometers that are wrapped by a porous stainless-steel cover where electrodes are embedded within a granular matrix, measure soil moisture by applying a current and measuring the amount of resistance present. The resistance of the current sent through the electrode differs depending on the amount of water present in the soil. Once the current is sent through the sensor, the resistance is correlated to kPa of SWT.

Capacitance soil moisture sensors measure dielectric permittivity (or constant) of the soil typically in the radio-frequency regime from 10 MHz up to several hundred MHz; the measurement quantity is the soil dielectric constant, which in dry soil normally ranges from 3 to 5 (Eller and Denoth, 1996). Furthermore, dielectric permittivity is a measure of the capacity of a non-conducting material to transmit electromagnetic waves or pulses, while capacitance can be defined as the ability of two conductors to store charge when a voltage is applied across them (Eller and Denoth, 1996). Factors that will influence dielectric permittivity (and in turn change SWHC) are water content, soil temperature, soil porosity and bulk density, mineral (2:1) clays, measurement frequency, and air gaps (Eller and Denoth, 1996; Matula et al., 2016). In-field calibration of dielectric soil moisture probes is sometimes necessary (Whalley et al. 2006).

Whenever real-time information is required to make irrigation decisions, each of the sensors placed in the field has a corresponding data logger placed alongside and connected to it. Data loggers collect the values from the soil moisture sensors, connect with cellular modems for a precise location, and provide data based on a present interval of data transmission for quick management decisions (Brinkhoff et al., 2017).

Irrigation and Irrigation Management Decisions

To account for the necessary crop yield increase produced on the same number of ha, irrigated land has expanded to consume over 70% of global freshwater and trends indicate that this percentage will continue to increase unless drastic changes in water management practices occur (Adeyemi et al., 2017; Fischer et al., 2007). Irrigation is incredibly important as irrigated crops account for an estimated 40% of the total agricultural output while producing twice the yield of non-irrigated crops (Fischer et al., 2007). If freshwater irrigation increases at the rate indicated, there will soon be a global shortage of freshwater (Adeyemi et al., 2017). Poor irrigation practices contribute to overall production inefficiency, and specifically, decrease a crop's water use efficiency (WUE) (Alcamo et al., 1997; Seckler et al., 1998). In terms of poor irrigation, over-irrigating can lead to harmful environmental effects, such as erosion, surface runoff, and deep percolation through the soil profile that causes leaching and potentially contaminating nearby water sources (Al-Karadsheh et al., 2002). Additionally, irrigating above the threshold could mean applied pesticides are not reaching their needed rain-fast period.

Applying less irrigation than the crop requires poses fewer overall environmental risks, but crop yields and quality can be reduced from lack of moisture, especially in hot, humid climates (Al-Karadsheh et al., 2002). Also, under-applying irrigation or lack of rainfall can also lead to loss and inefficient use of high cost crop inputs, such as fertilizers. Many fertilizers require penetration into the root zone of the crop for increased crop uptake, health, and yield. This can only be achieved through applying irrigation or rainwater after fertilization occurs. In situations where crops do not receive enough water (irrigation or rain), fertilizer may not be incorporated into the soil profile as quickly as needed, and yield potential decreases (Liu et al., 2021). To successfully combat the issues that are associated with freshwater irrigation, precision irrigation and sensing research efforts and techniques have increased among universities and private companies to provide tangible data that can be implemented on farm to prevent the predicted freshwater collapse. Precision irrigation optimizes water usage in a production system by focusing on crop yield and quality and minimizing adverse environmental impacts through the integration of information, communication, control, and prescriptive technologies (Abioye et al., 2020; Zacepins et al., 2012).

As stated in Cotton Incorporated's Cotton Irrigation Management for Humid Regions guide (Leib and Perry, 2012), integrating soil moisture sensors into irrigation decision-making will allow producers to monitor and determine plant-available water in the soil. This provides a specific threshold value or maximum allowable depletion of soil moisture, at which irrigation should be initiated. (Leib and Perry, 2012). Porter et al. (2020) evaluated the ideal trigger points for soil water tension (SWT) values. The trigger point is associated with a specific SWT value and once it hit that threshold, a uniform irrigation event occurred depending on the crop. Additionally, yield was collected to determine what the best trigger point was for peanut, cotton, and corn in the Coastal Plain region. For peanut, the ideal trigger point was found to be 40 kPa to achieve the most yield.

The addition of cover crops is beneficial to maximizing the soil moisture that is retained throughout the growing season. In the southeastern U.S., cover cropping has proven to increase soil moisture by as much as 10 percent (Farmaha, 2019). As cover crops are used for consecutive years and the soil organic matter (OM) increased, the SWHC and WUE are both increased, especially in sandy soils (Gentry and Snapp, 2008; SARE, 2007).

Cover Crops in the Southeast

Wallander et al. (2021), define the main purposes of cover crops as "to retain nutritious topsoil by slowing the rate of erosion, improving soil health, increasing SWHC, controlling weed pressure, and promoting biodiversity." Although the benefits of cover crops have been known; recent research, incentive programs, depleting soil nutrients, water scarcity, and high fertilizer prices have encouraged agriculturists to re-establish cover crops into their conventional farming practices. A once hesitant mindset of planting cover crops has been proven to shift by the 2017 United States Census of Agriculture indicating that cover crop usage has increased by 50 percent since the 2012 Census – from 4.2 million ha to 6.2 million ha (USDA-NASS, 2019).

Cover crop species and varieties differ depending on the region of the United States they inhabit and are classified by their taxonomic status (leguminous or non-leguminous) and/or growing season (winter vs. summer) (Antony, 2007). Additionally, a periodic table of cover crops created by the USDA ARS has been included for reference (USDA-ARS, 2018) (Figure 1). Not all cover crops used in the southeast were included on this chart.

Based on the 2012 USDA Plant Hardiness Zone Map, there are many different cover crop varieties that thrive in the Coastal Plain Region of Georgia (Zones 8 and 9) of the United States (USDA-ARS, 2012). These crops include cereal rye (*Secale cereale* L.), winter wheat (*Triticum aestivum* L.), crimson clover (*Trifolium incarnatum* L.), Persian clover (*Trifolium resupinatum* L.), black-seeded oats (*Avena sativa* L.), hairy vetch (*Vicia villosa* Roth), white vetch (*Vicia sativa* L.), forage kale (*Brassica oleracea* var. *sabellica* L.), tillage/cultivated radish (*Raphanus sativus* L.), yellow mustard (*Brassica hirta* Moench or *Sinapis alba* L.), rapeseed (or canola) (*Brassica napus* L.), annual ryegrass

(*Lolium multiflorum* Lam.), and winter triticale (hybrid of wheat and rye) (*Secale cereale* × *Triticum aestivum* or ×*Triticosecale* Wittm. ex A. Camus) (GBIF, 2023). One crucial difference to identify is that cereal rye and annual ryegrass are not the same species: cereal rye is a grain with similar growth characteristics to winter wheat and annual ryegrass is a cool-season grass. Although cereal rye and ryegrass verbiage cannot be used interchangeably because they are different, literature often compares their growth characteristics to one another to see how each of them perform in the same system. In the southeastern U. S., clover and rye are the two most utilized cover crops because of their ease of use, relatively low price, companionship with other cover crops, and known beneficial interactions with sandy loam soils. Clover and rye are the dominant cover crops in this region, but oats, vetch, kale, radish, mustard, rapeseed, and ryegrass can still be found in mixes for additional benefits. As planting season nears, cover crops may be terminated by chemical application, crimping, rolling, tillage, or cutting (SARE, 2007). In rare cases in the southeastern U.S., cover crops may be terminated during the later winter months if hard freezes occur.

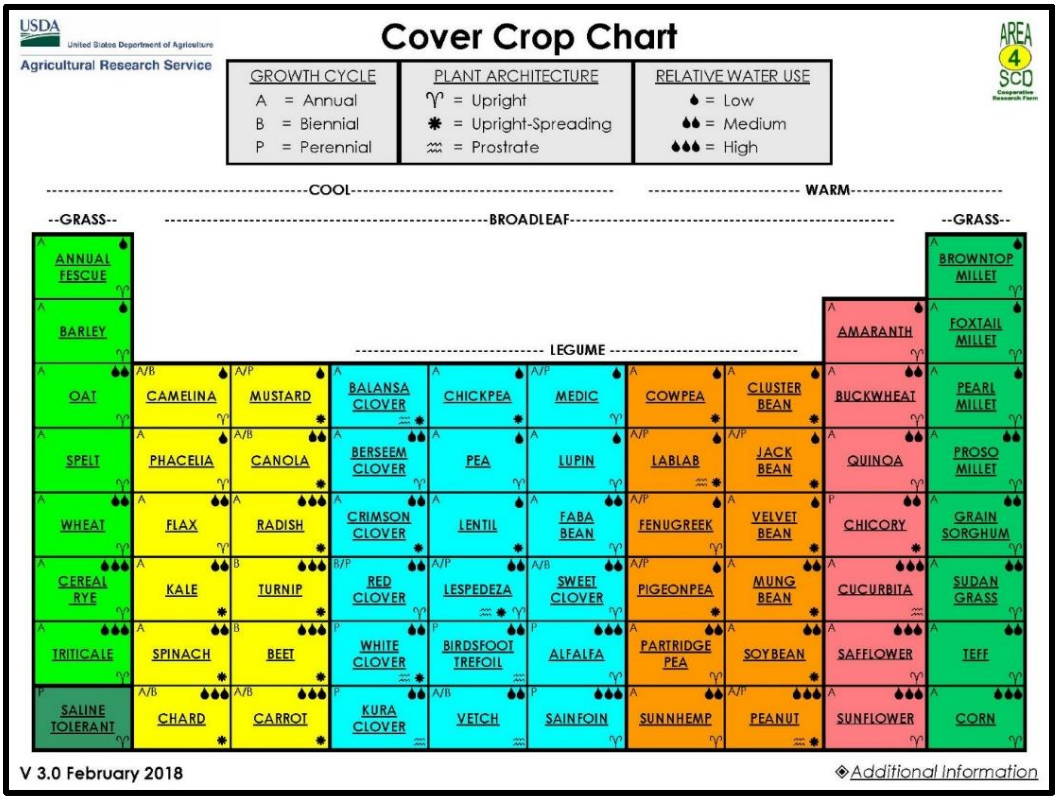

Figure 1. NRCS Cover Crop Chart to summarize the most commonly used species used as cover crops and the characteristics associated with them.

Cereal Rye

Cereal rye is known as the "workhorse" for small grain cover crops because of its vigorous growth, hardy establishment, and impressive performance in infertile, sandy soils (SARE, 2007). Cereal rye as a cover crop provides many benefits such as nutrient sequestration, erosion reduction, rotation versatility, addition and incorporation of OM, and pest suppression (SARE, 2007). There are four varieties on the market: 'Wrens Abruzzi' 'Winter Grazer', 'Elbon', and 'Bates' (USDA-NRCS, 2022). Wrens Abruzzi rye makes up the majority of cereal rye planted in the Coastal Plain region because of its long history in the area and the years spent on researching and developing this variety for the Coastal Plains climate at the Coastal Plains Research Center in Tifton, Georgia (Morey, 1970).

The root system associated with cereal rye may be the most important aspect of this cover crop. Although cereal rye does not have a long and extensive tap root, it does have fast growing, fibrous root system that can take up and hold ~28 to 56 kg ha^{-1} of unused nitrogen (N) in the soil, helping the system hold onto N rather than it being lost through nitrate leaching (SARE, 2007; UC Davis, 2022). Depending on the system or if cereal rye is planted early, it can take up and hold as much as 112 kg N ha^{-1}, and a portion of this can be passed to the next planted cash crop to offset some fertilizer applications and cost (Weil and Brady, 2017).

Cereal rye grows better in a soil with low clay content. Because of its ability to quickly establish itself, cereal rye has the potential to combat erosion associated with low clay content while increasing OM in the soil (Edwards et al., 1993). As cereal rye grows and produces more biomass, it also directly impacts weed and insect suppression by choking out many of the winter and spring weed seeds associated with these production systems (Przepiorkowski and Gorski, 1994). Cereal rye is naturally a great pest suppressor, giving it the ability to protect the entire crop production system (Wingard, 1995).

Crimson Clover

Following cereal rye, crimson clover is the second of the two main cover crops planted in the southeast. Crimson clover can be classified as a winter or summer annual legume which performs best in sandy loam soils (SARE, 2007; Teasdale, 1996). Crimson clover's largest benefit as a cover crop is the amount of early spring N it adds to the soil for corn and cotton. Its early spring N is derived from its early-fall robust growth that encourages more biomass and density for ground cover and is directly correlated with

SWHC (Varco et al., 1991). To measure cover crop biomass, water is removed from the material, and the dry matter (DM) is recorded (Scott et al., 1987). When planted as a winter annual cover crop, crimson clover can produce 3,922 to 6,165 kg DM ha^{-1} and can fix 78.5 to 168.1 kg N ha^{-1} by mid-May (SARE, 2007). 'AU Sunrise' and 'AU Robin' crimson clover varieties were both developed at Auburn University and are the most used clover varieties because of the specific breeding efforts to accommodate the Coastal Plains climate (Owsley et al., 2000). As found in an Alabama Experiment Station trial, crimson clover may need to be inoculated prior to growing if it has not been grown in the desired area before. Inoculation includes applying N-fixing bacteria (*Rhizobium leguminosarum* bv. *trifolii*) to crimson clover seed because in soils where clovers are not grown, N-fixing bacteria levels decrease (Adjei et al., 2006; Donnelly and Cope, Jr., 1961; Rachwal et al., 2016). If not inoculated, high phosphorus (P) and/or potassium (K) levels in the soils or acidic soils can shut down N fixation – the biggest reason for choosing to plant crimson clover as a cover crop (SARE, 2007). For this reason, proper inoculation is essential when planting crimson clover on new land.

Crimson clover's nectar-producing deep red blossoms are 1.3 to 2.5-cm long and attract many pollinators and create habitats for beneficial insects that play a part in combatting detrimental insect pests (UC Davis, 2022). Although crimson clover hosts many beneficial insects, it can also harbor insect pests such as corn earworm/cotton bollworm (*Helicoverpa zea*). With this in mind, it is imperative that crimson clover is treated and terminated two to three weeks prior to cash crop planting (Dabney et al., 2001).

Rye and Crimson Clover Mix

For a minimal and basic cover crop mix, cereal and crimson clover are top choices for southeastern growers because of their complementary properties and the economic value they provide. Cereal rye, a non-leguminous cover crop, performs best when planted with a legume companion crop so that as rye immobilizes N and reduces N leaching, the legume, crimson clover in this system, can fix N and more N will be immediately available for the succeeding cash crop (SARE, 2007).

Persian Clover

Persian clover is an annual, cool season, herbaceous legume that is capable of fixing N and providing a quick 'boost' to soil fertility. The growth habit is prostrate or semi-erect up to 1.2 m (Oregon State University, 2022). Many of Persian clover's growth characteristics are similar to those of crimson clover's, but it has not been as widely used in cover crop scenarios as crimson clover. Although Persian clover has not been used as widespread in cover crop mixtures, there is data that proves Persian clover's N addition success through intercropping. A study found that grass and cereal crops grown with Persian clover obtained 200 kg N ha^{-1} of needed fertilizer so that synthetic fertilizer could be reduced (Thompson and Stout, 1997). Persian clover can be used in a mixture, but there is not enough data specifically devoted to Persian clover to confidently plant this as a monoculture.

Black-Seeded Oats

Oats are a cool-season annual rotational cover crop in the southeastern U.S. that are quick to germinate to outcompete weeds. This cover grows upright at heights of about 1.2 m, and it thrives under cool, moist conditions on well-drained soils. The biomass oats produce contribute to their known ability to ‘smother’ weeds. Oats produce dry matter amounts of 2,242 to 4,483 kg DM ha^{-1} and typically incorporated in a cover crop mix for its great companionship qualities and boost in biomass production (Antony, 2007). In addition to weed suppression through biomass and allelopathic effects, oats take up excess soil nutrients and can improve the productivity of legumes when planted in mixtures. The cover’s fibrous root system also holds soil during cool-weather gaps in rotations, and the ground cover provides a mellow mulch before low-till or no-till crops. When time for spring planting, if oats have not been winterkilled by low temperatures, they can be terminated by herbicide application, tillage, mowers, or a roller crimper. The oats’ stage of growth and type of production system are the determining factors to decide when termination is necessary.

Hairy Vetch

Hairy vetch is a winter annual legume that is a superior N contributor in comparison to legume cover crops, and it is also a top biomass performer (Frye, 1986; Holderbaum et al., 1990). Multiple studies have been conducted to examine the amount of above ground dry matter and N produced by hairy vetch when planted in the fall and allowed to grow until crop-planting time the following spring. These studies found aboveground dry matter of hairy vetch yielded at 5.1, 4.6, 4.2, and 3.7 Mg ha^{-1} and contained 209, 153, 158, and

130 kg N ha^{-1}, respectively (Ebelhar et al., 1984; Elliot et al.,1987; Hargrove, 1986; Hoyt, 1987). Hairy vetch develops the majority of its shallow, sprawling root system in late fall and winter establishing vines up to 3.66 m (SARE, 2007). Overall, hairy vetch increases the availability of N to succeeding crops, increases soil OM, improves soil structure and water infiltration, decreases water runoff, reduces in-season soil surface temperature to decrease water loss through evaporation, improves weed control, increases soil productivity, and lowers the potential for spring nitrate leaching (Corak et al., 1991; Frye et al., 1988; Langdale et al., 1991).

Vetch

This cool-season annual legume is a hybrid vetch that is often utilized prior to cotton in the southeast. A research study completed in Tifton, GA funded by SARE found that minimally tilled crimson clover or ‘Cahaba’ vetch before cotton planting was successful in reducing fertilizer N up to 50 percent and insecticide inputs by 30 to 100 percent (SARE, 2007). Additionally, ‘Cahaba’ vetch can help suppress root-knot nematodes, but it can increase soil borne diseases.

Tillage Radish

Most of the radish varieties currently marketed for cover cropping (e.g., GroundHog radish™, Nitro radish, Sodbuster, and Biotill radish) are large rooted selections of daikon-type oilseed or forage radishes, but are not the product of formal breeding programs (Ngouajio and Mutch, 2004). The main focus of energy for radish is put towards their robust rooting ability and establishment. Their dense and quick growing roots provide soil cover and alleviate soil compaction, which are both strong assets in terms of SWHC and WUE; a radish root system can extend over 0.91 m and thicken to nearly 0.30 m in the span of 60 days (Chen and Weil, 2009). As discussed earlier, cereal rye residue decomposes slowly and continues to immobilize N for an extended period of time (Kremen, 2006). In contrast to cereal rye, radish quickly decomposes and releases N into the soil. While planning for crop establishment, radish's decomposing properties can provide a necessary boost of N and take the place of an early-season N fertilizer application (Weil and Kremen, 2007). Based on radish growth habits, this cover crop can produce approximately 7846 kg DM ha^{-1} of combined above and below ground dry matter (Gruver et al., 2019). Though this radish producers a greater amount of dry matter in comparison to other cover crops, it is highly decomposable so it will not contribute to increasing soil organic levels long term (Weil et al., 2009). Radish has only recently been viewed as a cover crop in addition to a vegetable crop, but it poses great potential to be utilized in specific cover crop mixes.

Forage Kale

Forage kale is a cool season annual broadleaf that has historically been used as a supplementary feed crop in forage grazing systems (Guillard et al., 1995). In recent years, forage kale has been incorporated into some southeastern U.S. cover crop mixes, especially under wetter conditions, because of its high N requirement and superb ability to uptake N to keep it from leaching (Wilson and Maley, 2006). When incorporated into a cover crop mix, forage kale is a great source for making useful green manure. Green manure takes cover cropping a step further by tilling the expired cover crop into the soil to later serve as mulch and soil amendment (Cherr et al., 2006).

Multiple cover crop species are available to farmers in the southeastern U.S., but determining what to use is sometimes confusing. The biggest factors to consider when choosing a cover crop are soil health, what cash crop will follow, and what is needed in that specific field. In addition to the biggest factors to consider in cover crop selection, tillage practices may help determine what cover crop to use. In a minimal or no-till system, it is important to choose a cover crop that can be planted into and allow the seed enough room to germinate. 'Bayou' Kale is a common variety used in southeastern cover crop mixes.

Mustard

Mustard is a cool-season broadleaf that has an upright and spreading plant architecture (SARE, 2007). In the southeast, mustard is typically used in mixes and the species used is 'white.' 'Yellow mustard' is sometimes used when referring to this cover crop species. It is important to be cautious when using mustard because of the allelopathic effects it could have on certain crops planted following it, such as soybean (*Glycine max* L.). On a positive note, the allelopathic effects often kill undesired weeds and help 'clean' problem fields.

Rapeseed (or Canola)

Rapeseed, also known as canola, is a cool-season biennial broadleaf. It is known for its ability scavenge N from the soil to produce biomass that effectively covers the soil. A common variety used in the southeast is 'Dwarf Essex' Rapeseed.

Annual Ryegrass

Annual ryegrass is a cool-season grass that is commonly recognized for its extensive root system to help prevent erosion, ability to capture N, increase of soil tilth and infiltration, and yield increases, especially in years of low summer rainfall (Pulmer et al., 2016). In comparison to cereal rye, annual ryegrass starts releasing N within a few of being terminated, where N may never be available for cash crops if not terminated at the proper time. 'Gulf' ryegrass variety is commonly used in the southeast.

Tillage Practices

As defined by Claassen et al. (2018), tillage practices can be split into two major sectors: conservation tillage and conventional tillage. Understanding the effects of tillage practices has become more common, therefore, the Soil Tillage Intensity Rating (STIR) system was created that associates a numerical index with the type and severity of disturbance caused by tillage practices. Conservation tillage can be further broken down to include no-till, strip-till, and mulch-till that have low STIR values in comparison to conventional tillage (Claassen et al., 2018). Conservational tillage was implemented as a system that retained at least 30 percent residue cover at planting (Allen and Fenster, 1986). Conservation tillage and cover cropping systems both work to build soil health, retain water and nutrients, and reduce runoff and erosion (Moore-Kucera, 2018). No-till systems plant directly into cover crops and provide no method of tilling prior to planting, strip-till systems till small strips large enough to plant seeds, and mulch-till systems till the soil with minimal disturbance (Claassen et al., 2018). Conventional tilling has a high STIR value as the methods associated with conventional management practices involve deep plowing and leaving fields fallow making them more prone to erosion and topsoil loss.

Conservation tillage and cover crop selection may be beneficial to the southeast if usage is expanded. A study conducted in 2007 concluded that when cotton was planted on highly weathered loamy sand soils, sediment losses were reduced using conservation tillage rather than conventional tillage (Truman et al., 2007). In addition to erosion reduction, conservation tillage enhances the benefits that cover crop provide by retaining the biomass on the soil surface rather than harrowing the DM into the soil profile (Bergtold et al., 2020). Brown et al. (1985) and Reiter (2020) successfully found that many of the cash crops common to the southeast, such as corn, peanut, and cotton, can be incorporated into a crop and cover crop rotation that improves yields, reduces pest and disease pressure, and improves soil health. Lal (1995) found that when cover crop residues are properly managed not only do they protect soil resources and enhance soil quality, but they also increase water conservation and availability. In a case study performed in Alabama, the grower witnessed a relationship between increase of soil OM and soil moisture retention (Mitchell and Buehring, 2020). This prior research studies provide evidence that there are opportunities for growth by incorporating cover crops into southeastern cropping systems, but tangible research is necessary to better understand cover crop selection and the amount of soil water retention that cover crop residues can provide to the cash crop months later.

Project Overview:

There were no studies found during the literature review that combined cover cropping, tillage practices, and soil moisture sensing to determine the combined effect they have on soil moisture retention in southeastern production agriculture. A study was conducted at University of Georgia's (UGA) Southeast Research and Education Center (SEREC) in Midville, Georgia that compared cover crop treatments, tillage practices, and soil moisture retention. Cover crops were first tested to determine if cover crops with reduced tillage compared to no cover with conventional tillage increased soil OM and crop yield by implementing cover crop treatments and replicated plots with single species and multiple species treatments. Then, cover crop treatments were tested to determine if in-season soil moisture was affected by implementing a cover crop treatment by evaluating if different cover crop treatments had impacts on in-season soil moisture retention in southeastern cropping systems. Finally, a case study was conducted on a production scale field to observe cover crop treatments on a larger scale, which evaluated the procedures from the primary (Chapters 2 and 3) research study in a different soil type and on a production scale in Georgia.

Hypotheses

- Southeast crop production stability increases with cover crop use and conservational tillage:
  - A multiple-species cover crop could be more diverse and beneficial than a monoculture.
  - Cover crops and conservational tillage can increase soil moisture retention.

Objectives

In order to thoroughly test the hypothesis of this study, the following objectives will be completed:

- Chapter 2:
    - Primary: to determine if cover crops with reduced tillage compared to no cover with conventional tillage increased soil OM and crop yield
        - Secondary: to determine if implemented cover crop treatments and replicated plots with single species vs. multiple species differed in development of soil OM and increase crop yield
- Chapter 3:
    - Primary: to determine if in-season soil moisture was affected by implementing a cover crop treatment
        - Secondary: to evaluate if different cover crop treatments had impacts on in-season soil moisture retention in southeastern cropping systems
- Chapter 4:
    - Primary: to implement a case study to evaluate the procedures from the primary (Chapters 2 and 3) research study in a different soil type and on a production scale in Georgia
        - Secondary: to evaluate the impacts the cover crop treatments had on cotton yield by collecting biomass and soil samples from different cover crop treatments and measuring soil moisture retention using capacitance soil moisture probes

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CHAPTER 2

COVER CROP EFFECTS ON GEORGIA CROP PRODUCTION

Introduction

Cover crops are planted to improve soil fertility, soil quality, water infiltration, and wildlife habitat, while also managing weeds, pests, and diseases (Claassen et al., 2018). Data collected for the 2017 Census of Agriculture reported a 15% increase of farms incorporating cover crops since the last census in 2012. The 2017 census data also indicated the amount of cover cropped hectares in the United States increased by 50% climbing from 4,160,500 hectares in 2012 to 6,228,400 hectares in 2017 (USDA-NASS, 2019). In comparison within the United States, Georgia is currently ranked 13th in cover crops hectares planted with 15 to 25% of available cropland planted in cover crops as seen in Figure 2 (USDA-NASS, 2019). It is also important to consider that there are some cover cropped hectares that are not represented in the censuses' final numbers due to the fact that reported hectares in the census do not include land that is accounted for in the USDA's Conservation Reserve Program (CRP). In this program, erosion prone land is removed from production for 10 to 15 years to improve conservation practices. The Wetland Reserve Program (WRP), Farmable Wetland Program (FWP), and Conservation Reserve Enhancement Program (CREP) programs are included in the CRP. Nonetheless, there is room for improvement to increase cover crop hectares in Georgia and similar climates.

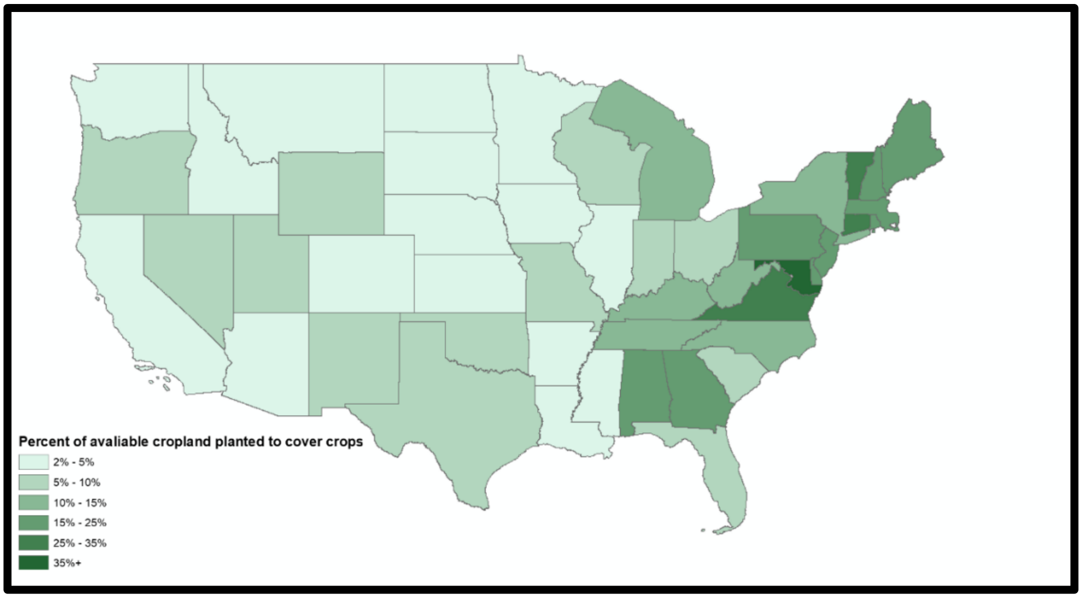

Figure 2. Percentage of available cropland planted to cover crop based on 2017 USDA Census of Agriculture (USDA-NASS, 2019).

Between the 2012 and 2017 Census of Agriculture, the amount of overall intensive tillage hectares declined by 24%. In place of intensive tillage, reduced tillage hectares increased by 28% and no tillage hectares increased by 8% (USDA-NASS, 2019). Conservation tillage practices include no-till, strip till, and reduced/mulch-till (Claassen et al., 2018). According to the USDA, conservation tillage and cover cropping may be viewed as complementary to one another because of their combined effect on soil health and productivity (Claassen et al., 2018). Conservation tillage is a system that leaves enough crop residue on the soil surface after planting to provide at least 30% soil cover (Balkcom et al., 2007). Conservation tillage provide benefits such as: reduction in soil erosion, decreased labor and energy input, increased availability of water for crop production, and improvement in soil quality. When cover crops are added to a conservation tillage system, additional benefits are: cover crop residues increase soil organic matter (OM), aid in weed control, improve soil structure, increase infiltration, protect the soil surface, add carbon into the soil through strong root systems, and effectively dissipate raindrop energy

(Balkcom et al., 2007). Conservation tillage systems rely on the biomass from crops and cover crops to protect the soil surface throughout the year. In order to constantly have the soil surface covered, a cover crop dry matter (DM) biomass is recommended of at least 4500 kg DM ha^{-1} in addition to the crop residue left on the soil surface after harvest (Balkcom et al., 2007). As cover crops and their root systems work to improve soil physical properties, there is greater water infiltration in the soil, greater aggregate stability (or tilth), less surface sealing, and greater soil porosity (Baumhardt and Lascano, 1996; Bruce et al., 1992; Dabney et al., 2001; Delgado et al., 2021).

Although there are many known long-term benefits for cover cropping and the potential contribution to greater yields, some studies indicate that cover cropping may also contribute to reduced yields (Delgado and Gantzer, 2015; Essah et al., 2012; Kaspar and Bakker, 2015; SARE, 2007; Thorup-Kristensen and Rasmussen, 2015; Unger and Vigil, 1998). Yield reductions caused by planting cover crops are predominantly caused by increased immobilization, water competition in dry areas, cooler soil surface and oxygen competition (Qin et al., 2021). Additionally, corn and cotton yields can be further reduced when a non-leguminous species of cover crop is planted prior and is not terminated early enough, which enhances competition for resources (Qin et al., 2021). Additional nitrogen (N) fertilization may be required for the subsequent cash crop to minimize yield loss (Burke et al., 2022; Wagger, 1989). Because of possible yield reduction, there are hesitations from producers to incorporate cover crops into their farming operations. However, using the four Rs of cover crops and management could help reduce the risk of decreasing the yields of the following crop (Delgado and Gantzer, 2015). The 4 Rs include: the *right* cover crop or cover crop mixture, the *right* time to plant and kill (or harvest) the cover crop, the *right* cover crop management practices, and the *right* location. When the 4 Rs are not used, yield has the potential to decrease because crop residue that has high amounts of carbon (C) can reduce the availability of N to the following cash crop. Cover crops with high C to N ratios can contribute to immobilization of N for the subsequent crop, which can reduce water availability in the soil profile, and in semi-arid and arid systems has the potential to cause yield reductions of the subsequent crop (Kessavalou and Walters, 1997; Wagger and Mengel, 1988).

Over the last decade, government agencies have allocated specific funding that provides financial incentives for producers to incorporate and increase cover crop hectares in their operations. The most recent program is The Pandemic Cover Crop Program (PCCP), offered by USDA's Risk Management Agency (RMA). This program works to reduce producers' overall premium bills and helps them maintain their cover crop systems (USDA-RMA, 2022). It is funded by the Federal Crop Insurance Corporation, which is managed by the USDA's RMA (USDA-RMA, 2022). Additionally, the funding includes educational components to teach producers how to successfully manage a cover crop while still maintaining a desirable crop yield.

The main objective of this study was to determine if cover crops with reduced tillage compared to no cover with conventional tillage increased soil OM and yields. The main objective was met by addressing the following secondary objective: evaluating if a single cover crop species worked as well as a two-species or a multiple-species mixture by comparing a no cover crop (control), a 'Wrens Abruzzi' rye (*Secale cereale* L.) monoculture, a 'Wrens Abruzzi' rye and 'Auburn University (AU) Robin' crimson clover

(*Trifolium incarnatum* L.) mixture, and a multiple-species mixture where the species differed depending on the year and the cash crop that followed.

Materials and Methods

For the duration of this 6-yr study, the same irrigated field located at the University of Georgia's (UGA) Southeast Research and Education Center (SEREC) in Midville, Georgia was utilized. The soil types in this field are sand, loamy sand, and sandy loam (USDA-NRCS, 2022). The field is 1.21 hectares and had a corn (*Zea mays* L.), peanut (*Arachis hypogaea* L.), cotton (*Gossypium hirsutum* L.) rotation. Corn was planted in 2018 and 2021, peanuts were planted in 2019 and 2022, and cotton was planted in 2020. Cotton will be planted in 2023 for the final year of the study. There was a total of 16 treatment plots in a Randomized Complete Block Design (RCBD) with four replications of four treatments (Figure 3). The species included in the mix were dependent upon what cash crop followed the cover. In addition to taking the cash crop into consideration, the species included in the mix were based on the same or a similar mix to what growers in the area planted. In the 2018 season, a five species mix of 'AU Robin' crimson clover, 'Cosaque' black-seeded oats (*Avena sativa* L.), tillage/cultivated radish (*Raphanus sativus* L.), 'Cahaba' white vetch (*Vicia sativa* L.), and 'Bayou' forage kale (*Brassica oleracea* var. *sabellica* L.) was used. In 2019, 2020, and 2021, a 'Dixie' crimson clover (*Trifolium incarnatum* L.), 'Cosaque' black-seeded oats, tillage/cultivated radish, 'Cahaba' white vetch, 'Shield' yellow mustard (*Brassica hirta* Moench or *Sinapis alba* L.) and 'Bayou' forage kale mixture was used. In 2022, a 'Cosaque' black-seeded oats, 'AU Sunrise' crimson clover (*Trifolium incarnatum* L.), 'Cahaba' white vetch, tillage/cultivated radish, ‘Dwarf Essex’ rapeseed (*Brassica napus* L.), and ‘Bayou’ forage kale mixture was used. During 2023, a ‘Cosaque’ black-seeded oats, ‘Gulf’ annual ryegrass (*Lolium multiflorum* Lam.), ‘Dixie’ crimson clover, Persian clover (*Trifolium resupinatum* L.), ‘Cahaba’ white vetch, and ‘Bayou’ forage kale mixture was used. These treatments were determined based on the typical cover crops used in southeast Georgia (Sapp, P., personal communication, August 24th, 2017).

In all years of the study, the cover crop treatments were planted using a three-point hitch lift interval Great Plains (Great Plains Manufacturing, Salina, KS) seed drill. The drill spacing comes stock with 19-cm spacing for rows, but 38-cm spacing was used to plant the cover by blocking every other drill cup. This was done to create a furrow for strip till machinery and the planter to work in the 38-cm furrow. The plots were 12 rows wide on 91-cm spacing and 122-m long. The seeding rates for each year are listed in Table 1.

Table 1. Cover crop seeding mixtures and rates for 2018 through 2023 seasons.

	Treatment		
	Cereal Rye	Rye & ‘Dixie’ Crimson Clover	‘AU Robin’ Crimson Clover, ‘Cosaque’ Oats, Tillage Radish, ‘Cahaba’ Vetch & ‘Bayou’ Kale
2018	78.4	67.3 + 11.2	5.60 + 39.2 + 1.12 + 3.36 + 1.12
			‘Dixie’ Crimson Clover, ‘Cosaque’ Oats, Tillage Radish, ‘Cahaba’ Vetch, Yellow Mustard & ‘Bayou’ Kale
2019	78.4	67.3 + 11.2	5.60 + 39.2 + 1.12 + 3.36 + 1.12 + 1.12
2020	78.4	67.3 + 11.2	5.60 + 39.2 + 1.12 + 3.36 + 1.12 + 1.12
2021	78.4	67.3 + 11.2	5.60 + 39.2 + 1.12 + 3.36 + 1.12 + 1.12
			‘Cosaque’ Oats, ‘AU Sunrise’ Crimson Clover, ‘Cahaba’ Vetch, Tillage Radish, ‘Dwarf Essex’ Rapeseed & ‘Bayou’ Kale
2022	78.4	67.3 + 11.2	39.2 + 5.6 + 2.24 + 1.12 + 1.12 + 1.12
			‘Cosaque’ Oats, ‘Gulf’ Annual Ryegrass, ‘Dixie’ Crimson Clover, Persian Clover, ‘Cahaba’ Vetch & ‘Bayou’ Kale
2023	78.4	67.3 + 11.2	33.6 + 5.60 + 3.36 + 2.24 + 1.12 +1.12

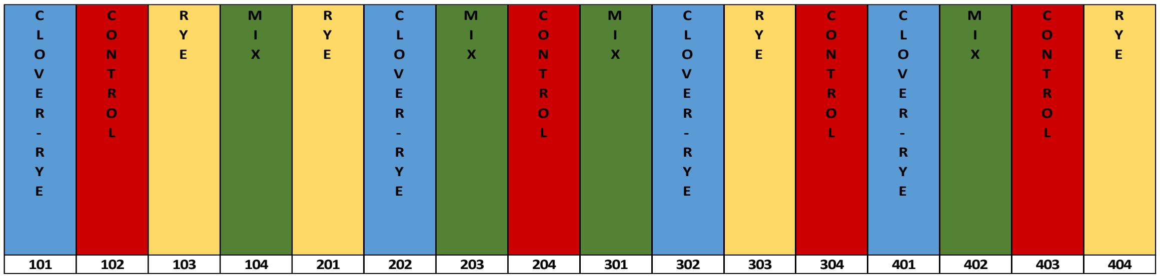

Figure 3. Plot design for a cover crop study located in Midville, GA.

To determine the potential effects that cover crop treatments had on Coastal Plain crop production systems, soil and biomass samples were collected. Prior to 2022, the sampling methods for both soil and biomass were collected by UGA Extension agents based on visual and some scientific standards because of lack of personnel and funding. A more intensive adaptation of The UGA Extension's handbook recommended procedure for soil and biomass sample collections were employed for the 2022 season to reduce potential bias and collection errors, while increasing the accuracy of the trial's results (UGA Extension, 2011). In order to ensure a baseline of the results from the soil samples was present each year soil was sampled, the samples collected in 2022 included the previous years' soil sampling locations with additional soil sampling points.

Boundary lines for the field exterior and for the plots were created using a John Deere Gator (Deere and Company, Moline, IL), which was all-terrain vehicle (ATV) equipped with autosteer, Global Navigation Satellite System (GNSS) GPS technology, and a John Deere Generation 4 monitor. The boundary lines collected were saved as a shape file and were used in GIS software.

For simplicity, Table 2 is provided and contains important dates for each growing season the study into a condensed version and can be used for reference throughout chapters two and three.

Table 2. Important dates for each growing season condensed into one easily readable table. ‘Pre-Harvest Prep Date’ was the date cotton was defoliated or when peanuts were dug.

Crop Year	Crop	Cover Crop Plant Date	Cover Crop Sample Date	Cover Crop Termination Date	Crop Plant Date	Pre-Harvest Preparation Date	Crop Harvest Date
2018	Corn	10/26/17	4/10/18	4/12/18	4/11/18	-	8/24/18
2019	Peanut	10/19/18	4/8/19	4/11/19	5/10/19	10/5/19	10/10/19
2020	Cotton	10/25/19	4/15/20	4/15/20	5/22/20	10/2/20	10/23/20
2021	Corn	11/9/20	3/22/21	3/24/21	4/9/21	-	9/7/21
2022	Peanut	10/26/21	3/26/22	4/15/22	5/17/22	10/24/22	11/2/22
2023	Cotton	11/10/22	-	-	-	-	-

Biomass Sampling

The materials used for biomass sampling were a 1-m by 1-m PVC square, 24 brown paper bags,18 woven plastic mesh bags, handheld shears, four 19-L buckets, a scale, a Trimble Nomad 900 (Trimble Inc., Westminster, CO) handheld GPS system with shapefiles of field boundaries and collection points, and a plot map created in ArcMap™.

Throughout the entire 6 yrs of the study, biomass samples were collected using the guidelines from the UGA’s Cover Crop Biomass Sampling Handbook (Gaskin et al., 2019). Sampling locations remained consistent within each treatment, but beginning in 2022, bigger and greater amounts of biomass samples were collected. The UGA Cover Crop Biomass Sampling Handbook is aimed for producer and Extension agent use more so than scientific research, so in 2022 and 2023, the biomass sampling procedure was revised based on materials and methods from similar studies (Andrews et al., 2010; Gaskin et al., 2019; USDA-NRCS, 2018). The alterations included: a 1-m by 1-m PVC square used for samples rather than a 2.0 by 2.5 ft U-shaped quadrant and using a forced air dryer rather than the drying methods suggested (sun dry or microwave method).

ArcGIS's ArcMap 10.8.1 software program (ESRI, Redlands, California), was used to display a satellite image of the field and import boundaries lines of the plots. The field was divided horizontally (from East to West) to determine biomass collection points from the North and South ends of the field (Figure 4). This was done because of the topography and increased sandy soil in the northern portion of the field. The sample location points were then uploaded to a Trimble Nomad 900 handheld GPS system. The Trimble Nomad handheld GPS was used in-field to locate the pre-determined sampling points. Two samples from each cover crop plot were collected. The number of samples was determined by the samples needed for the area of the cover crop plots as stated in Cover Crop Biomass Sampling (Gaskin et al., 2019). To ensure location accuracy, the exact sample coordinates were also recorded on the day of sampling (Figure 5). No biomass samples were collected from the control plots because plots were chemically terminated and disc tilled. A total of 24 samples were collected, weighed, dried, and weighed again. The samples were dried using a forced air drier at 48°C for 6 d and were rotated and flipped in the drier on the third day.

Figure 4. Cover crop treatment plot outlines with an East/West dividing line to delineate the field into a North and South region for the 2018-2023 cover crop study located in Midville, GA.

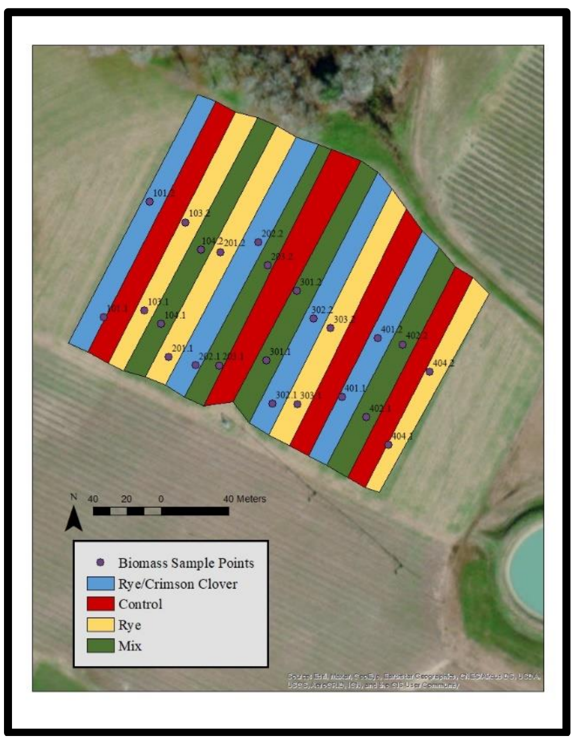

Figure 5. Cover crop biomass sampling points created in ArcGIS for the 2018-2023 cover crop study located in Midville, GA.

The biomass sampling procedure began by creating a field boundary and sampling points in ArcMap™. The field boundary and sampling points were uploaded onto the handheld GPS to locate the biomass sampling point in field (Figure 6).

Figure 6. A Trimble Nomad handheld GPS was used to locate biomass (and soil) sampling points.

At each sampling point, a 1-m by 1-m PVC square was thrown at random within the sampling area to eliminate bias of choosing an area that may have been denser or sparser in cover crop. This was referred to as the subsample. After the PVC square was thrown and the subsample was determined, all plant material within the quadrant was clipped at 2.5-cm from ground level using shears and put into a 19-L bucket to be carried out of the field and weighed (Figure 7).

Figure 7. Biomass collected using shears, a 1-m by 1-m PVC square, and a bucket. After being cut, the sample was placed into the bucket and transported to the scale to record the 'fresh' weight.

The bucket weight was tared and the subsamples from the 24 biomass sampling points were weighed using a scale. This weight was recorded as the 'field' or 'fresh' weight. The subsamples were placed into the forced air dryer, left for 6 d and were rotated and flipped on day three (Figure 8). Dry matter was recorded using the same scale. As soon as biomass samples were collected, cover crop treatments were terminated. Approximately 30 d following cover crop termination, the cash crop was planted except in the first year of the study. In 2018, the cover crop chemical burndown was applied with starter fertilizer the day after the cash crop was planted. This method proved to be challenging and was not used in following years. All treatments, including the control, were chemically sprayed by SEREC staff using the recommended rate of glyphosate herbicide to terminate cover crop treatments (UGA Extension, 2018).

Figure 8. Collected biomass samples in the forced air drier for 5 d at 48℃.

Soil Sampling

Following the biomass sample collection and cover crop termination, soil samples were collected from the same locations as the biomass samples. Soil samples were collected in 2018, 2020, and 2022. The procedure of sampling was based on UGA's soil sampling guidelines outlined in the UGA Extension Soil Test Handbook (UGA Extension, 2011). In both 2018 and 2020, 16 soil samples were collected prior to corn being planted. One sample from each plot was collected in efforts to demonstrate the potential changes in the soil over the span of the first half of this study. Similar to biomass, the soil sampling procedure was more intensive during 2022 to improve scientific reasoning and methodology of this study. In 2022, soil sampling points were determined following the biomass sampling procedure of two samples collected per treatment at both the North and South locations of the field. These sample location points were uploaded and navigated in the field using the handheld GPS system. The exact sample coordinates were recorded on the day of sampling using the handheld GPS system. Two soil samples from every plot were collected including the control with no cover for a total of 32 soil samples. In all years that soil was sampled, the samples were sent to the UGA's Agricultural and Environmental Services Laboratories located in Athens, GA and were analyzed for a Mehlich I routine nutrient analysis test, a texture analysis, and an OM analysis. In the routine nutrient analysis, pH, lime buffering capacity, phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), zinc (Zn), and manganese (Mn) level levels were provided.

The materials used for the soil sample collection were a soil probe marked at the desired depth of sample collection (approximately 20-cm), brown paper soil sampling bags, a 19-L bucket, a small hand trowel to mix and bag samples, a Trimble Nomad Handheld GPS with shapefiles of field boundaries and collection points, and a plot map that was created in ArcMap™. The soil sampling procedure began by preparing a field boundary and sampling points that were created in ArcMap™. These points were uploaded into the handheld GPS to locate the soil sampling points in field (Figure 9). At each sampling point, eight to ten soil cores were collected at a 20 to 22-cm depth using a soil probe (Figure 10).

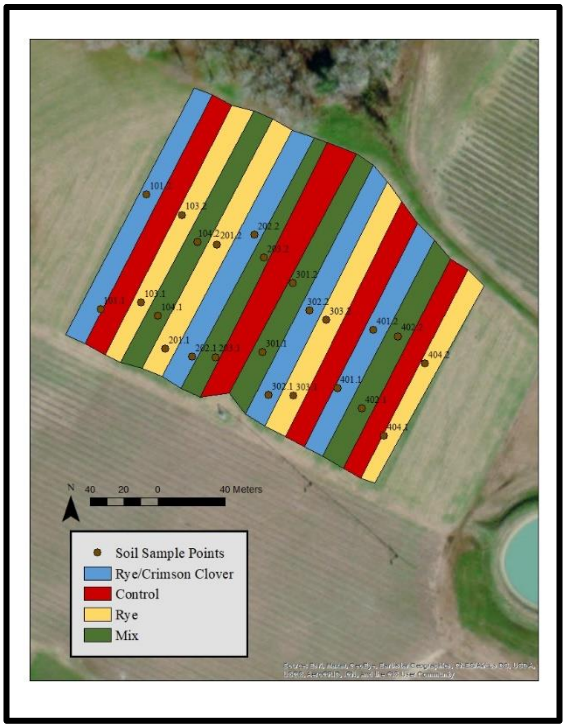

Figure 9. Soil sampling points created in ArcGIS for the 2018-2023 cover crop study located in Midville, GA.

Figure 10. Soil cores taken at 20 to 22-cm depth after cover crop termination.

Cash Crop Management

Prior to planting the cash crop, a four-row KMC (Kelley Manufacturing Company, Tifton, GA) strip-till implement was pulled by a 180 hp tractor to prepare the soil for planting. The strip-till implement was equipped with wide rollers to help roll (or push) the cover crop down while creating the furrow. This furrow is where the cash crop seed was planted. All crops in this study were planted using a four-row hydraulic drive John Deere 7300 Max Emerge planter. In 2018 and 2021, ‘Croplan (CG) 5678’ (WinField United, Arden Hills, MN) corn variety was planted. In 2019 and 2022, ‘Georgia-06G’ peanut was planted, and in 2021, ‘Deltapine (DP) 1646’ (Bayer Crop Sciences) cotton was planted. The field was equipped with an electric pump, two tower overhead pivot for irrigation. Irrigation scheduling was based off of the UGA Checkbook Method (UGA Extension, 2022). The nutrient and irrigation management decisions were made and completed by the SEREC staff. At the end of the season, yield data were collected from the four middle rows of each plot. The harvested area of each plot was hand measured using a surveyor’s measuring wheel each year of the study. The grain weigh wagon used for the corn harvest and the boll buggy used for the peanut and cotton harvest were calibrated and certified annually by a local scale company prior to harvest. The weigh wagon and boll buggy were both equipped with load cells and a digital readout monitor. Corn was harvested using a Case IH 1640 (CNH Industrial America, Sturtevant, WI) four-row combine and grain was dumped into a grain weigh cart. Peanuts were harvested using a KMC 3350 four-row combine and dumped into the boll buggy. Cotton was harvested using a John Deere 9965 four-row picker, and seed cotton was dumped into the boll buggy. Peanut yield was determined by harvested field weight. Cotton yield from individual plots were not sent to the gin to determine final lint yield turnout, therefore the harvest seed cotton yield was used to determine final yield for each plot (Raper et al., 2000). For corn, the moisture was adjusted to the standard 15.5% (Mulvaney and Devkota, 2020). For peanut, the moisture was adjusted to the University of Florida’s determined standard moisture of 10.5% (Mulvaney and Devkota, 2020). All tractors were equipped with RTK GPS systems to ensure accuracy. The previous year's GPS field maps were used and the cover crop, strip-till furrow, and the crop would shift either 46-cm to the left or to the right. This was done to ensure the furrows would be different every year to maintain soil structure. Table 3 highlights important dates and materials for the entirety of this study.

Table 3. Plant dates, plant population, and harvest date for each crop and year.

Crop	Year	Variety	Plant Date	Plant Population	Harvest Date
Corn	2018	CG 5678	4/11/18	32,500 seed per ha	8/34/18
Peanut	2019	GA-06G	5/10/19	20 seed per m	10/10/19
Cotton	2020	DP 1646	5/22/20	36,300 seed per ha	10/23/20
Corn	2021	CG 5678	4/9/21	34,00 seed per ha	9/7/21
Peanut	2022	GA-06G	5/17/22	20 seed per m	11/2/22

Results and Discussion

The biomass and soil sample collection years coincided with the cash crop planting year. For example, the cover crops were planted for the first year in 2017 prior to corn being planted, but the collected cover crop biomass samples, soil samples, and yield all were displayed as 2018 because this is when the final data were collected. Results for 2018, 2019, 2020, 2021, and 2022 were used in the results analysis, but a stronger emphasis was put on the results from 2022 as the scientific components of data collection were improved during this year.

Statistical analysis: Cover crop biomass and crop yields were analyzed using JMP® Pro Version 16.0 (SAS Institute Inc., Cary, NC). Graphs utilized to display data in the following sections were created using Excel (Microsoft Corporation, 2018). Single factor Analysis of Variable (ANOVA) tests were completed in JMP Pro, which were used to understand the mean separation and standard error (SE) to determine if the results were significant. P-values were determined in this test. Tukey's honest significance test was performed on the data in JMP to determine where significant differences occurred. An alpha level of 0.05 ($\alpha = 0.05$) was used in all analyses.

Biomass Results and Discussion

Cover crop biomass data was first analyzed by year, where significant differences only occurred in the rye and mix treatments, but not in the rye/crimson clover treatment. Because of these significant differences, the data was further analyzed by year within treatment and not pooled.

Cover Crop Treatment Biomass Compared by Year:

The ANOVA test indicated that when compared across years, there were no differences in biomass observed in the rye/crimson clover treatment ($p = 0.0749$) (Figure 11a), but it did indicate that there were differences in the rye treatment ($p<0.0001$) (Figure 11b) and the mix treatment ($p<0.0001$) (Figure 11c).

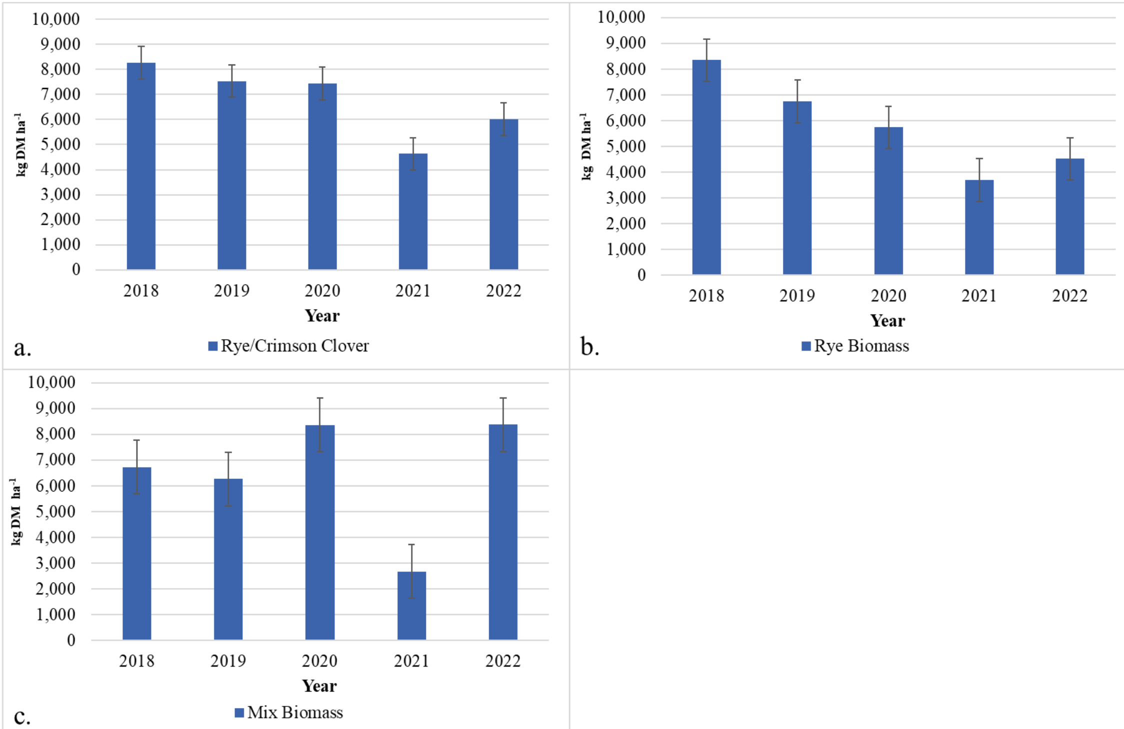

Figure 11. Cover crop biomass averages compared among years (kg DM ha^{-1}). 11a) represents the rye/crimson clover treatment, 11b) represents the rye treatment and 11c) represents the mix treatment. Error bars indicate one standard error above and below the mean.

Cover Crop Biomass Compared by Treatment:

Following the initial statistical analysis where individual treatments were compared across all years, a statistical analysis was completed where biomass weights for individual treatments were compared within year. There were no differences in 2018 (p=0.1720) (Figure 12a) or 2019 (p=0.3130) (Figure 12b), but there were differences in 2020 (p=0.0059) (Figure 12c), 2021 (p=0.0482) (Figure 12d), and 2022 (p=0.0482) (Figure 12e). In 2020, the mix treatment produced greater biomass than rye. In 2021, differences occurred between the rye/crimson clover treatment and the mix treatment. And, in 2022, differences occurred between the rye treatment and the mix treatment.

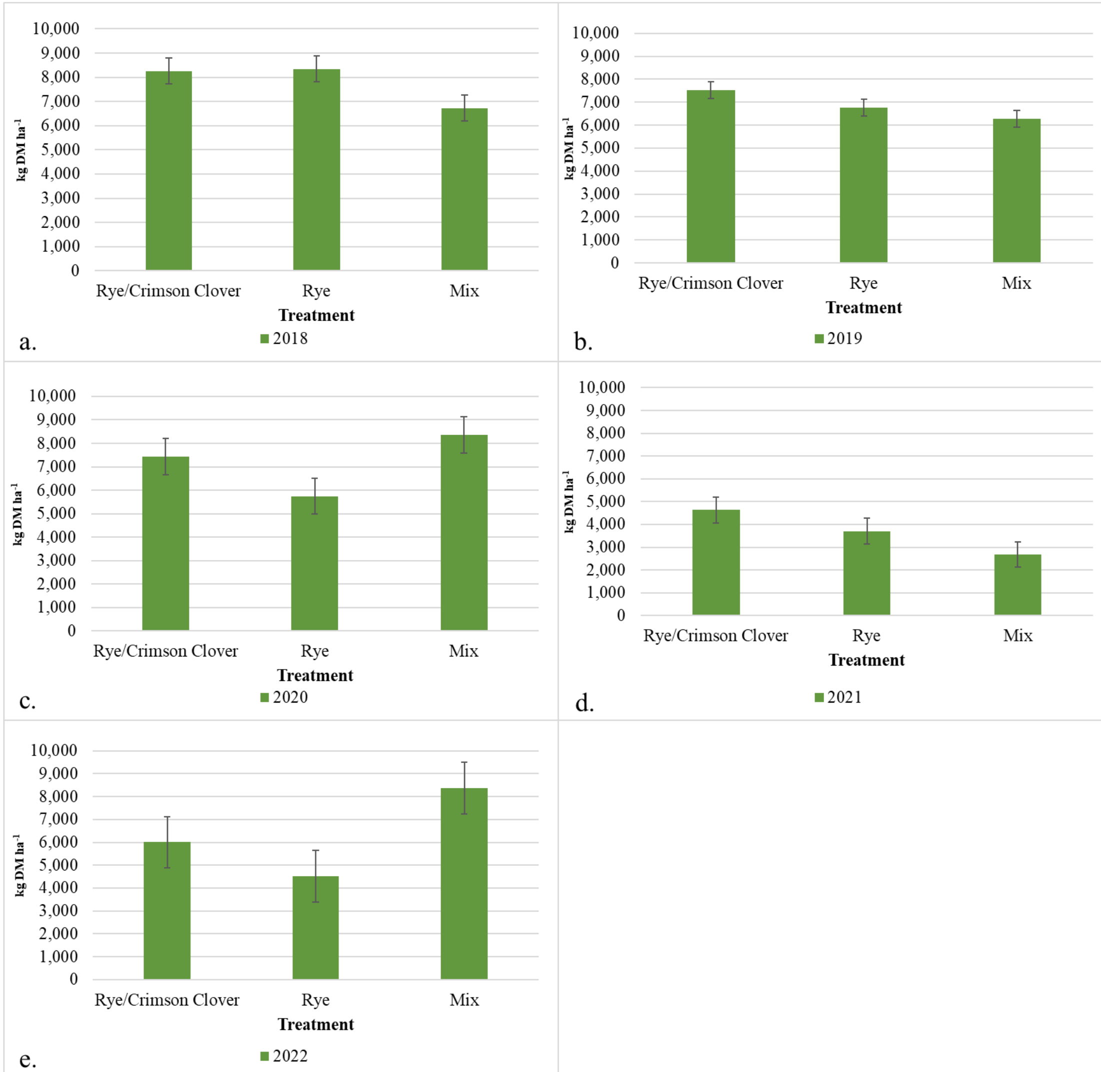

Figure 12. Cover crop biomass averages compared among treatments (kg DM ha^{-1}). 12a) represents 2018 cover crop treatments, 12b) represents 2019 cover crop treatments, 12c) represents 2020 cover crop treatments, 12d) represents 2021 cover crop treatments and 12e) represents 2022 cover crop treatments. Error bars indicate one standard error above and below the mean.

Results from the biomass collected indicate that year had an effect on the amount of biomass developed for each treatment. The statistical analysis of the biomass sample weights for each year excluded the conventional treatment because no cover crop was planted, developed or collected from those plots. The biomass from the rye and mix treatments were statistically different by year while the rye/crimson clover was not thus, all data were analyzed by year independently. The rye monoculture did not have any differences, but the other two treatments did, which could lead to the assumption that year had an effect only on the cover crop biomass from treatments that were two or more species. Additionally, crop harvest data and cover crop harvest date have been shown to be more impactful to species and their associated growth habits used in this study other than rye. When cover crop biomass was evaluated across treatments within each year, 2020, 2021, and 2022 were the only years when difference occurred between treatments.

Biomass differences that were observed in both analyses, within treatment by year and within year by treatment, were attributed to several factors. The cover crop growing season in 2018 was 168 days, 2019 was 173 days, 2020 was 175 days, 2021 was 132 days, and 2022 was 153 days. The overall biomass for each treatment in 2021 was less than the biomass produced in any other year, which was indicative that the shorter growing season impacted the amount of biomass present. 2020 had the longest growing season, but it did not produce more biomass in each treatment every year. As previous research states, the longer the cover crop growing season was, the more biomass produced (Miller et al., 2022; Tubaña et al., 2020; USDA-NRCS, 2018). Along with season length, temperature impacted biomass production (especially during germination). The average temperature in Celsius for each cover crop growing (~middle of October through middle of April) season between 2018 and 2020, respectively was: 11.8, 12.3, 13.4, 10.8, and 12.3. In addition to the short growing season, 2021 had the lowest average temperature which contributed to a lower amount of overall biomass produced. Cover crop species have different minimum temperature for germination and optimum growth, and the mix species, especially was impacted when the temperature went below these thresholds. Finally, rainfall was the final contributor to biomass production. The cumulative rainfall amounts in cm during the cover crop growing seasons (~middle of October through middle of April) in 2018 through 2022, respectively were 51, 53, 88, 50, and 32-cm. The most rainfall during the cover crop growing season occurred in 2020 and the least amount occurred in 2022. To remove some bias, the pivot irrigated the cover crops to initiate germination, but depending on when rainfall occurred after germination, there were impacts on the biomass produced.

Soil Sample Results and Discussion

Soil samples were collected during 2018, 2020, and 2022. The main purpose of soil sampling was to compare nutrient and soil OM levels throughout the entirety of this study. Multiple studies have shown that soil OM values and the benefits associated with increased OM should improve the longer cover crops are incorporated into a production system. (Boquet et al., 2004; DeLaune, 2019; Fageria et al., 2005; Johnson et al., 2021; Simoes et al., 2009). The soil sampling strategy was intensified in 2022 and Figure 9 can be used for reference to visually understand where the soil samples were collected. All soil OM results were averaged by cover crop treatment for comparison of soil OM over time (Table 4). Table 5 indicates that soil OM present in the soil increased over the 5-yr of this study. When soil OM in 2018 was compared to 2022, the mix treatment produced the highest level of an increase followed by rye/crimson clover, then rye, and then the conventionally tilled control treatment (Table 5). The rye/crimson clover treatment produced the most cumulative biomass (33,866 kg DM ha^{-1}) when biomass was combined from 2018 through 2022., followed by the mix treatment (32,420 kg DM ha^{-1}) and then the rye treatment (29,073 kg DM ha^{-1}). These results indicate that when more biomass was present, the change in soil OM increased.

Table 4. Soil OM for each cover crop treatment in 2018, 2020, and 2022.

	2018		2020		2022	
Treatment	**Avg. OM (%)**	**Std Dev.**	**Avg. OM (%)**	**Std Dev.**	**Avg. OM (%)**	**Std Dev.**
Control	0.53	0.09	0.60	0.07	0.62	0.22
Rye/Crimson Clover	0.55	0.06	0.66	0.29	0.96	0.54
Rye	0.59	0.15	0.59	0.12	0.87	0.40
Mix	0.57	0.06	0.61	0.13	0.99	0.50

Table 5. Difference in soil OM for each cover crop treatment.

2018, 2020, and 2022 Soil OM Compared by Treatment			
	Difference in OM (%)		
Treatment	**2018 - 2020**	**2020 – 2022**	**2018 - 2022**
Control	0.06	0.02	0.08
Rye/Crimson Clover	0.11	0.30	0.41
Rye	-0.01	0.28	0.28
Mix	0.03	0.39	0.42

Soil sample results indicated that when cover crops biomass was increased because the growing season contained more days, soil OM increased, even in sandy loam soils. Similarly, other research has found that an increase in biomass produced from cover crops also increases the soil OM present (Steenwerth and Belina, 2008; USDA-NRCS, 2018). When the change in soil OM was compared between 2018 and 2022, the mix treatment had the greatest change in OM followed by the rye/crimson clover mix, and then the rye monoculture. Contrary to many beliefs about a multiple species mix producing the most biomass and increasing OM the most, a rye and rye/crimson clover mixture has the ability to incorporate two different types of root systems that can also increase density, while in multiple species mix, it is difficult for all of the species to perform at their highest level since they are competing with each other.

The rye and crimson clover mix were comprised of two species that each had very different decomposition rates. According to Wann (2011), the rate of decomposition of cover crop residues is dependent upon the chemical composition of the residue and decomposition is performed as a biological process. When residues possess large concentrations of nutrients that benefit the soil microorganisms, the rate of decomposition increases. The process of decomposition favors easily-digestible simple sugars and amino acids, such as the ones found in crimson clover. In contrast, rye is predominantly composed of lignin, which is not easily-digestible thus microbial degradation of rye is much slower than crimson clover (Wann, 2011). Additionally, residues with large C (carbon):N ratios decompose slower than residues with smaller C:N ratios. Rye's C:N ratio is greater than 20, whereas crimson clover's C:N ratio is typically less than 20 (Wann, 2011).

Crimson clover starts its decomposition shortly following termination and quickly provides nutrients and OM to the soil, where rye's decomposition period is much longer and does not quickly release nutrients. The multiple species mix did not consistently provide as much biomass and was comprised of many cover crops that either had thick rooting systems or decayed too quickly causing soil OM to not improve as quickly and as consistently as the rye and crimson clover mix.

Yield Results and Discussion

Yield from the 5 yrs of the study were analyzed similar to the biomass treatments, but the control (conventionally tilled fallow plots) was also considered in the yield analysis. First, crop yields of the same crop for each cover crop treatment was compared by year. Then, a secondary analysis was completed to compare crop yield by cover crop treatment.

Crop Yield Compared within Cover Crop Treatment by Year:

Corn (2018 compared to 2021)

When yield was compared by the two corn growing years (2018 and 2021) within each cover crop treatment, there were no differences in the yield produced (Figure 13).

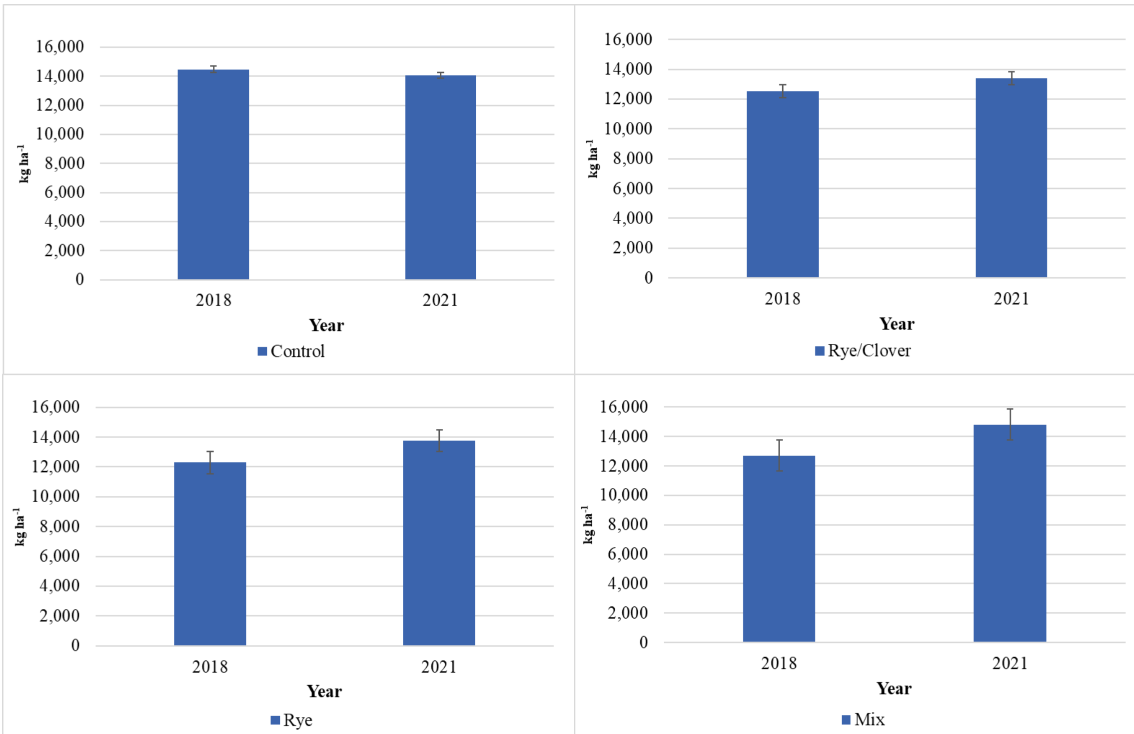

Figure 13. Corn yield (kg ha^{-1}) compared between years. 13a) represents the control treatment, 13b) represents the rye/crimson clover treatment, 13c) represents the rye treatment and 13d) represents the mix treatment. Error bars indicate one standard error above and below the mean.

Peanut (2019 compared to 2022)

When yield was compared by the two peanut growing years (2019 and 2022) within each cover crop treatment, there were differences in the yield produced for all treatments: control, rye/crimson clover, rye, and mix (Figure 14). Yields in all treatments from the 2019 season were greater than those from the 2022 season. A disease analysis was not conducted.

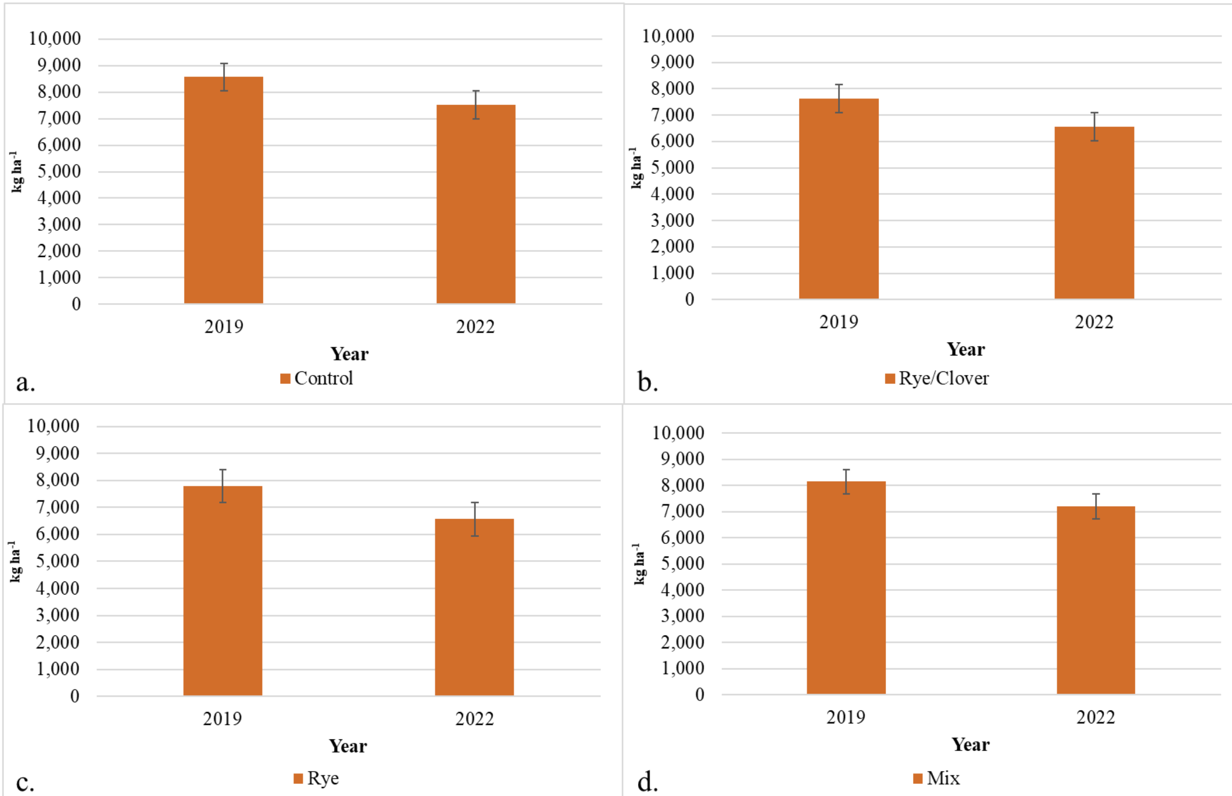

Figure 14. Peanut yield (kg ha^{-1}) compared between years. 14a) represents the control treatment, 14b) represents the rye/crimson clover treatment, 14c) represents the rye treatment and 14d) represents the mix treatment. Error bars indicate one standard error above and below the mean.

Crop Yield Compared by Cover Crop Treatment:

All yield data were compared by cover crop treatment within an individual year to determine if treatment had an effect on yield (Figure 15). When yield was compared by treatment within each year, there were no differences in yield among treatments in 2018 (p=0.7083) (Figure 15a), 2019 (p=0.1063) (Figure 15b), or 2020 (p=0.1016) (Figure 15c), but there were differences in 2021 (p=0.0275) (Figure 15d) and 2022 (p=0.0002) (Figure 15e). In 2021, the only difference occurred between the rye/clover and the mix treatment (p=0.0207). This difference could have occurred because of the growth habits of rye versus the mix treatment. Studies have shown that corn planted after rye does not provide as many benefits as would a cover crop that fixes and makes N available to corn (Basche et al., 2015; Martinez-Feria et al., 2016; Quinn et al., 2019). In 2022, differences occurred between the rye and control treatment (p=0.0005), the rye and control treatments (p=0.0006), the rye/crimson clover and mix treatments (p=0.0132), and the rye and mix treatments (p=0.0146).

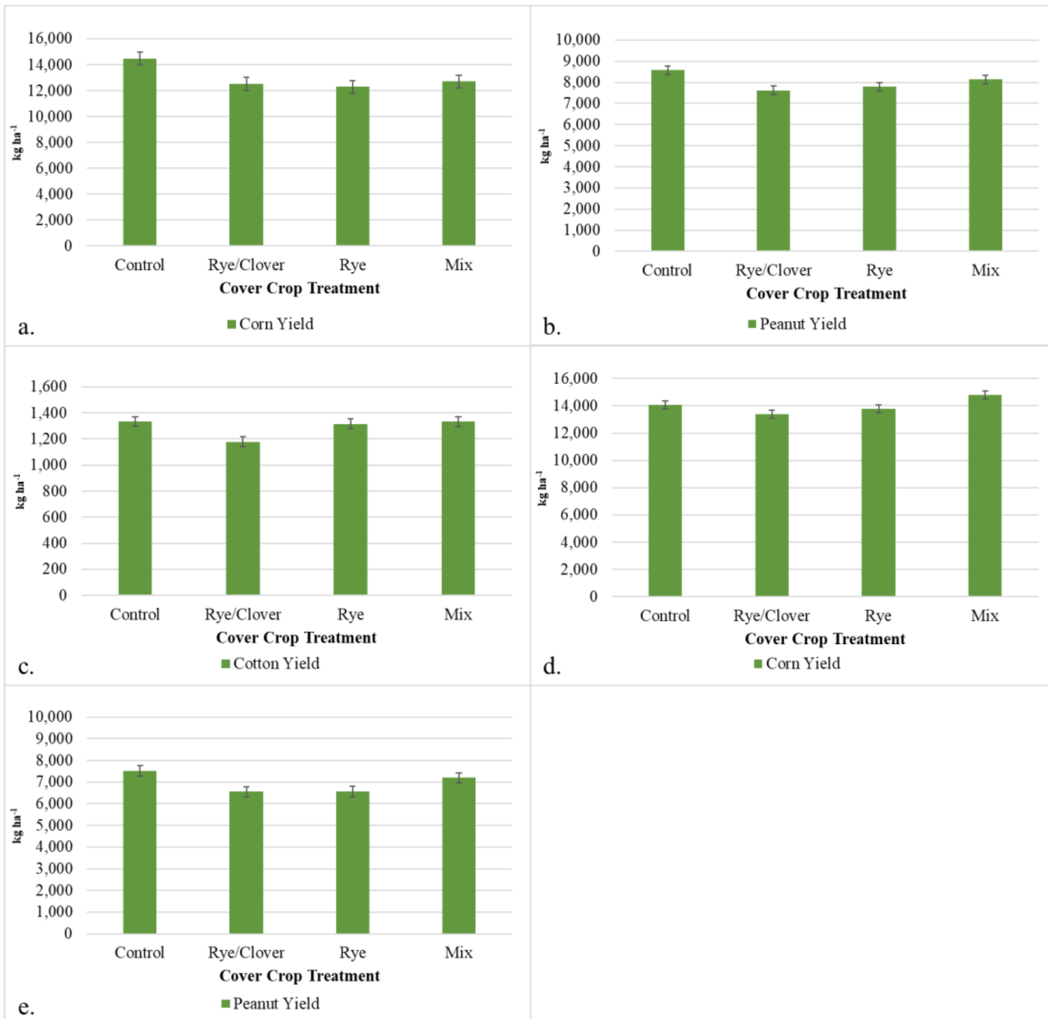

Figure 15. Crop yield (kg ha^{-1}) compared among cover crop treatments. 15a) represents 2018 corn yield, 15b) represents 2019 peanut yield, 15c) represents 2020 cotton yield, 15d) represents 2021 corn yield and 15e) represents 2022 peanut yield. Error bars indicate one standard error above and below the mean.

Previous research evaluated the relationship between cover crops and cash crop yield. Some studies found that yield was improved when cover crops were added, (Badon et al., 2021; Chalise et al., 2019; Chu et al., 2017; Miguez and Bollero, 2005), whereas others observed no difference in yield (Wortman et al., 2012). And, Wann (2011) reported that overall production efficiency could be improved by implementing a cover crop regime. Some studies found that the addition of cover crops resulted in yield reduction (Reddy, 2001; Sanchez et al., 2019). Upon further investigation, Daryanto et al. (2018) found that positive yield responses were associated primarily with leguminous cover species and proper nitrogen application in the subsequent cash crop (Daryanto et al., 2018).

In this study, the resulting yield showed that there were no differences between the corn yields in 2018. But, the peanut yield comparison provided different results. In all treatments, the 2022 peanut yield was less than the peanut yield in 2019. This change indicated that year had an effect on peanut yield, and could be from numerous factors such as rainfall amount, rainfall distribution, disease, temperature, sun intensity, or biomass production. Greater soil moisture levels because of more biomass present causing more soil moisture to be retained could have impacted the seed's ability to germinate causing a reduction in yield. Whenever crop yields were compared by cover crop treatments within an individual year, the resulting statistical analysis for 2021 corn and 2022 peanut indicated that yield reductions occurred whenever a cover crop was implemented. It is important to evaluate where the differences occurred in 2021 and 2022 because there was only one difference between corn yields collected from cover crop treatments in 2021 and four differences among peanut yields collected from cover crop treatments in 2022. Overall, there were more years without differences in crop yields than there with differences.

Conclusions

The main objective of this study was to determine if cover crops with reduced tillage compared to no cover with conventional tillage increased soil OM and yields. Based on the biomass, soil samples, and yield collected over the course of this study, the best cover crop treatment to implement in a southeastern production system would depend on the main goal of a farming operation and a financial analysis to determine the most affordable option. If the goal was to greatly reduce erosion by producing the most biomass and increasing the soil OM, then a rye/crimson clover treatment would be the best option based on these results. If high yields were the most important component of a farming operation, especially when first implementing cover crops, then a rye/crimson clover or multiple species mix would be the best option. Additionally, the cash crop that would be planted following the cover crop could make an impactful difference in the decision of what cover to plant or what species to include in a multiple species mix. Overall, the rye/crimson clover treatment provided biomass, increased soil OM, and cash crop yields were maintained at levels that were not different than the control in all years except for 2022. A separate cost/benefit financial analysis would need to be conducted to understand the full economic impact on net revenue for a grower. This analysis would need to consider things such as: cover crop seed cost, irrigation events, nutrient management, and additional equipment needed.

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CHAPTER 3

COVER CROP EFFECTS ON SOIL MOISTURE

Introduction

In Field to Market's 2021 National Indicator Report, it is stated that agriculture is the single largest water consumer in the U.S., causing increased sensitivity to changes in weather/climate and to depletion of groundwater resources (Marshall et al., 2015; Moore et al., 2015). Without proper water management and future planning, the southeast U.S. could become susceptible to water shortages as drought continues to expand and intensify. Following U.S. trends, the number of irrigated hectares in Georgia have increased. Between 2008 and 2020, Georgia statewide corn irrigation increased by 115% (58,000 ha), peanut irrigation increased by 100% (85,000 ha), and cotton irrigation increased by 94% (107,000 ha) (Szydzik, 2021). Specifically, irrigated cropland hectares in the Chattahoochee-Flint River basin, which is located in the southwestern and major row crop producing part of Georgia has increased by approximately 65,000 ha between 2008 and 2020. In total, over 25,000 farm irrigation permits have been issued statewide, but the southwestern part of the state comprises the most permits for agricultural irrigation (Szydzik, 2021). Because of the high volume and demand for irrigation and approximate location to Alabama and Florida, the water use in this area of Georgia causes stress and tension beyond its state borders (Painter, 2019).

On average, the southeast receives 127-cm of rainfall annually, but rainfall distribution is generally not synchronized with peak crop water requirements and often occurs in the winter months (UGA Extension, 2023). Therefore, supplemental in-season irrigation is necessary to achieve yield potential. Porter et al. (2019) performed research to determine if irrigation events could be decreased in efforts to better manage water resources by determining corn, peanut, and cotton water use curves (WUC) (Figures 16, 17 and 18). Understanding these WUC has led to better management of water resources through applying irrigation events appropriate to crop growth stage needs. In the study, soil moisture tensiometers were used to detect fluctuations in soil moisture that correlated with the crops' water usage at different physiological stages. The peak of each curve represents the growth stages that require the most water and where yield will be impacted the most if the crop does not receive adequate moisture. These curves are beneficial when making on farm management decisions, and aid in making informed irrigation and water use decisions. Irrigation decisions, also known as irrigation scheduling, historically have been made by a variety of methods ranging from calendar dates, plant growth stages, crop condition, or other past research methodologies, all ranging in their effectiveness. A popular method in Georgia is utilizing the UGA Extension Checkbook method (UGA Extension, 2022). The checkbook method determines irrigation events based off of historical average evapotranspiration of a crop growth stage, local rainfall, and prior irrigation applied to the field, but Porter et al.'s (2019) recent research proves that this method could be over-irrigating or recommending irrigation events to occur that do not coincide with the crop's WUC.

Figure 16. Corn water use curve (Porter et al., 2019).

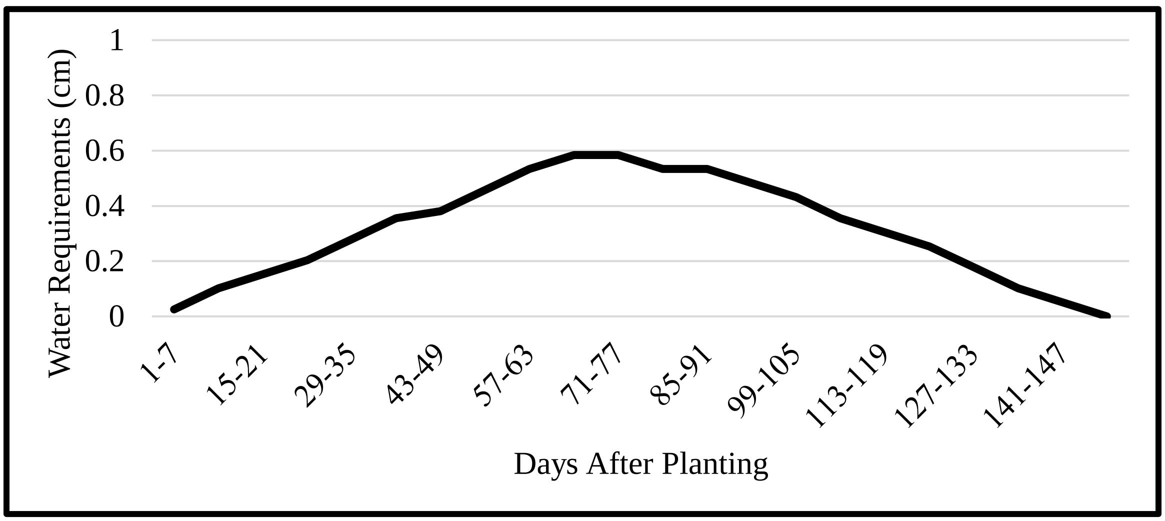

Figure 17. Peanut water use curve (Porter et al., 2019).

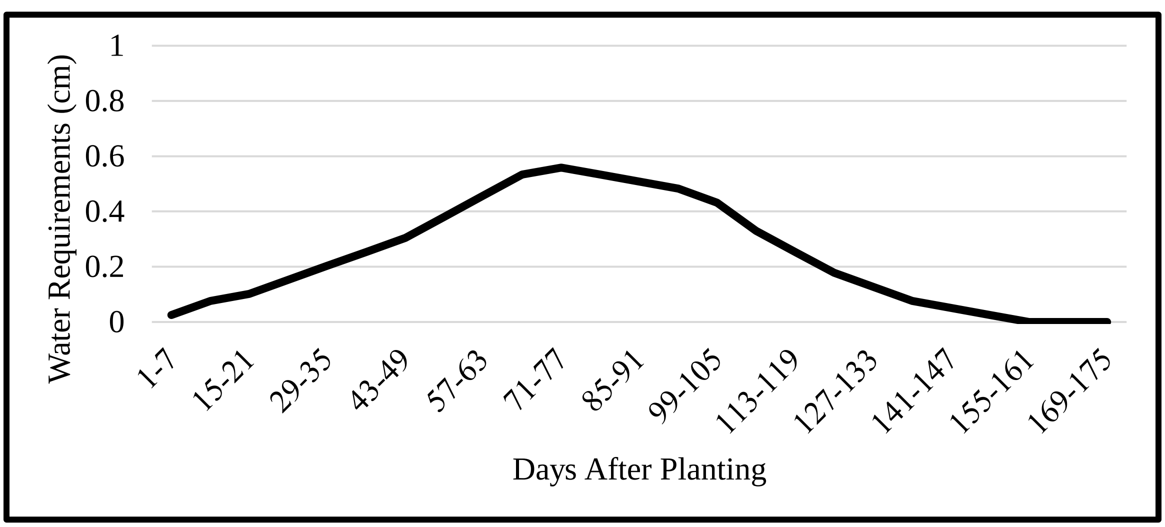

Figure 18. Cotton water use curve (Porter et al., 2019).

The majority of current farm management practices, specifically conventional tillage and winter fallow fields in the southeast reduce water permeability and create surface runoff. Most rainfall in this region occurs in the winter and spring months making soil extremely vulnerable to top soil runoff and erosion when a root system is not in place (Claassen et al., 2018). The primary southeastern soil type is sandy loam, which has an infiltration rate of 10 to 15 mm per hour (Cornell University, 2010). Soil type and infiltration rates in the southeast are conducive to rainwater movement through the soil profile, but the bare soil is unable to effectively capture and retain heavy rainfall events with current management practices, so runoff and erosion are common results. Incorporating cover crops into these systems could help capture and retain rainfall by providing root systems in the off-season and increased soil OM in the crop season, but growers are often hesitant to incorporate a cover crop prior to a cash crop being planted if soil moisture recharge does not occur between cover crop termination and cash crop planting (Vann et al., 2018). The necessity of research to understand how cover cropping effects soil moisture retention has become increasingly apparent as the issues of water scarcity, soil health, and sustainability arise.

To expand on the preliminary objective and to address the overall objective of the study, cover crop soil moisture research was conducted. This main objective of this study was to determine if different cover crop monocultures versus mixtures had impacts on in-season soil moisture in southeastern cropping systems. The same field and treatments were used in this portion of the study as mentioned in Chapter 2.

Materials and Methods

Prior to the 2022 season, soil moisture sensors were installed and used, but the methodology of sensor placement was based upon soil sample collection location and visual field differences. From 2018-2021, 12 soil moisture probes were installed (Figure 19). The same probes were used in 2022, but an additional 12 probes were included for a total of 24 probes placed in the field. Two probes were placed in plots 102, 103, 201, 202, 203, 301, 302, 303, 304, 401, 402, and 403 (Figure 3). Each probe had two WaterMark (Irrometer Company, Inc., Riverside, CA) tensiometer sensors and were installed at the depths of 20 and 40-cm. Probes were assembled by using two sensors, 19 mm (¾") PVC pipe sections, PVC primer and glue, 19 mm (¾") PVC threaded adaptors (both male and female ends), standard 19 mm (¾") PVC tees, Deutsch connection plugs and terminal pins (TE Connectivity, Berwyn, PA), rubber electrical tubing, heat shrink wrap, and stainless-steel t-shaped handles with double eared pinch clamps TIG welded in the middle and top of the handle for structural support. The sensors were connected to Trellis (Trellis, Inc., Peachtree Corners, GA) (2018-2021) and REALM5 (2022) telemetry that collected real-time soil moisture data throughout the seasons.

Figure 19. Soil moisture probe with two WaterMark soil moisture tensiometric sensors installed at 20 and 40-cm depths.

In 2022, the methodology of this study was adapted to better fit a scientific approach for soil moisture data collection. To determine sensor placement, soil EC was collected on May 12th, 2022 after cover crop termination but prior to peanut planting (Figure 20). A Veris 3100 (Veris Technologies, Salina, KS) was connected to the ATV mentioned in Chapter 2 to collect soil EC data (Figure 21). Soil EC measures the ability of soil to conduct or attenuate electrical current and is expressed as milli-Siemens per m(mS/m) or as deci-Siemens per m (dS/m) (Hawkins, et al., 2017). Historically, soil EC has been used to measure soil salinity, but research discovered that soil EC can expose differences in soil physical properties, such as texture (USDA-NRCS, 2011). In addition to EC collection, the soil samples that were collected for the cover crop biomass portion of this study (Chapter 2) were used to ensure that the reported soil EC matched the soil type. The contact method of measuring soil EC was used. The energized sending disc electrodes transmitted an electrical signal that penetrated the soil and soil EC was determined from the amount of interruption between the transmitting and receiving electrode discs (Figure 22). Mid-range (0 to 60-cm) EC was collected because of the rooting depths and growth habits of the crops used in this study. The initial A-B line was set along the field edge and 6.1-m wide swaths were used to collect soil EC throughout the field in a serpentine pattern. As the ATV moved through the field, a laptop connected to the Veris showed the progress of data collection (Figure 20). On the day of collection, the field boundary was also created by driving the ATV around the edge of the study field.

Figure 20. Soil EC data collection on May 12th, 2022 with the field boundary displayed on the laptop.

Figure 21. Four-disc Veris 3100 connected to ATV.

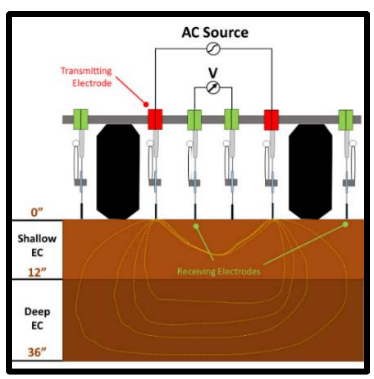

Figure 22. Schematic drawing of contact style soil EC sensor with six discs that measured shallow (0 to 30.5-cm inches) and deep (0 to 91.4-cm) soil volumes (Hawkins, et al., 2017).

Once soil EC was collected, the data were evaluated in the USDA's Management Zone Analysis (MZA) tool to determine the optimum number of management zones that best fit this field "using a fuzzy c-means unsupervised clustering algorithm" (Fridgen et al., 2003). The soil EC management zones determined the optimum placement area for soil moisture sensors across cover crop treatments that would capture all soil moisture variability present. Three management zones were determined to be the best fit. To delineate the soil EC zones, ArcMap was used (Figure 23). The soil EC data, the field boundary, and the background field image were imported. As shown in Figure 23, the highest EC zone was displayed in green, followed by yellow, and then red. These varying levels were determined by selecting '3 zones' and using 'Natural Breaks' in ArcMap. Soil EC data was collected in 2018, 2021 and 2022, but there were no differences in the EC values or number of management zones, therefore only one map was used and displayed.

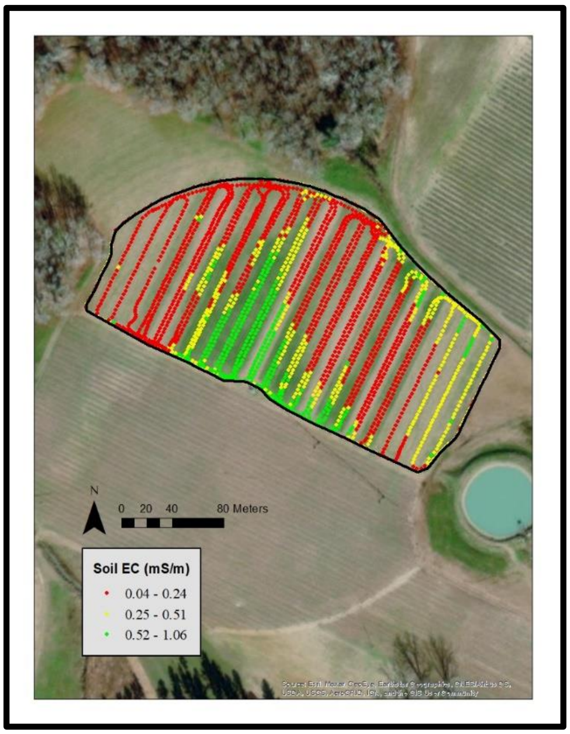

Figure 23. 2021 Soil EC data for cover crop study field in Midville, GA.

For better visualization, the EC data was interpolated and overlaid onto the cover crop treatments in ArcMap to create Figure 24. The zones were made transparent and delineated by using thick lines colored based on the soil EC zone. Additionally, this soil

EC map only displays the data collection area of the field, rather than the entire field soil EC as seen in Figure 23.

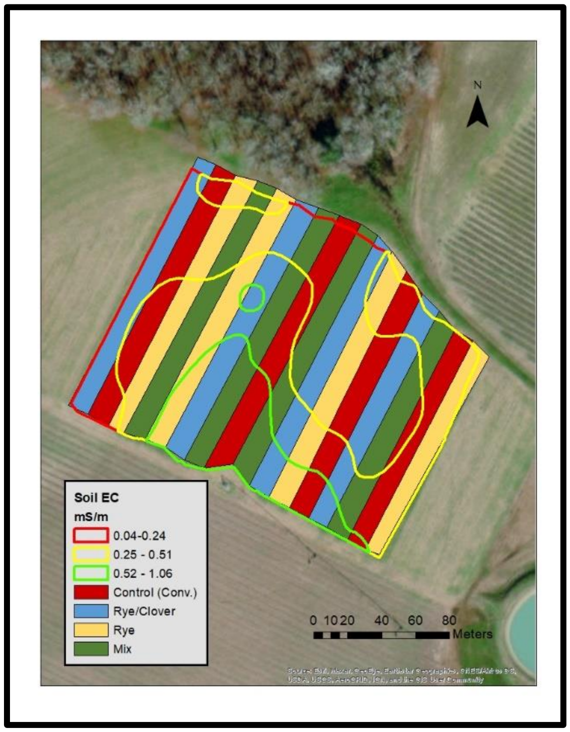

Figure 24. Soil EC zones hollowed out in ArcMap with cover crop treatments.

Once it was determined three management zones were the ideal number for this field, soil moisture sensor probe placements were established with the ‘Draw’ tool in ArcMap. Circles where probes would be placed were drawn, to generate georeferenced points for sensor installation. A total of 24 sensors were used in this study – eight soil moisture sensor probes were placed into each of the three EC zones. To ensure accurate data collection and to avoid prior connectivity issues that occurred in 2020 and 2021, one probe was placed in two replications of each treatment (Figure 25).

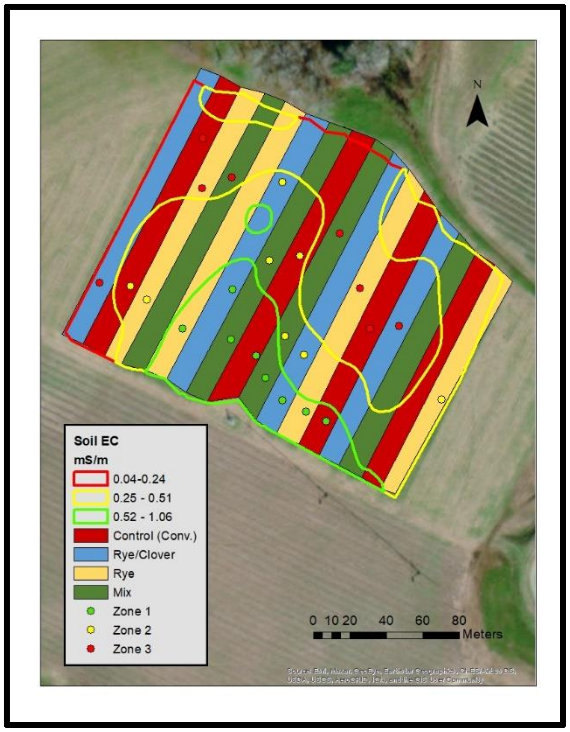

Figure 25. Soil moisture sensors placed in each EC zone and two replications of each treatment.

Prior to the day of installation, the map of probe placement was imported to a handheld GPS (Figure 6) to easily and accurately locate each point in field. Following the Irrometer recommended installation, all of the probes were soaked in a bucket of water for at least 24 hr (Figure 26). This process ensured that each sensor was fully saturated and at a stable baseline reading of 0.0 kPa. Each sensor was tested using WaterMark's propriety digital soil moisture meter that connected to the sensor wiring and displayed the current sensor reading in kPa. All sensors displayed a satisfactory baseline reading prior to installation.

Figure 26. Soil moisture probes that were soaked in water to properly calibrate prior to installation.

To install each probe and data logger pole, a gas-powered auger with a 4-cm diameter bit was used to drill two holes side by side within the planted rows. The hole in which the soil moisture probe was placed was drilled 44-cm deep so that the middle of the bottom probe would measure soil moisture at 40-cm and the top sensor would measure soil moisture at 20-cm. The data logger hole depth was drilled until the plug connection port was near the top of the soil bed. The depth of this hole was approximately 60-cm. Once the holes were drilled, the soaked two-probe sensor was placed into the 44-cm deep hole and was surrounded with a soil and water slurry mixture (Figure 27). The mixture consisted of approximately equal amounts of sifted soil from the area of where the sensor was installed (Figure 28).

Figure 27. Soil moisture probe after it was installed, surrounded by the soil slurry, and connected to the data logger pole.

Figure 28. Mixture of equal parts sifted soil and water to create a slurry for soil moisture probe installation.

The data logger PVC poles were placed into the holes that were drilled for them and were surrounded by soil (not slurry). After all soil moisture probes and data logger poles were installed, the plugs were connected to one another and the data logger was placed onto the PVC pole and wires with clamped pins were inserted into the '1' and '2' slots on the data logger (Figure 29). Batteries in the data logger were checked, and the data collection started. The soil moisture probe installation process was completed on June 1st,

2022. At the time of installation, the peanut crop was 15 days old. After installation, the data were available in real-time on REALM's website and were monitored daily to ensure that no connectivity or data logging issues occurred.

Figure 29. Data logger on the PVC pole connected by wiring to read the soil moisture sensor data connected to it.

The soil moisture content was determined by tensiometer sensors that measured the soil water tension (SWT) values in kPa (or dB). In contrast to prior years, a new telemetry system was used to track soil moisture data. The data from the soil moisture sensors were logged by REALM Flexes (REALM, Lincoln, NE) (Figure 30) and was sent to the user via the in-field REALM base station. The base station was equipped with cellular data sending capability, so the user was able to view the real-time soil moisture within the REALMFive user webpage.

Figure 30. REALM data logger that prior to being connected to its PVC pole and wires.

Soil moisture data were averaged daily utilizing a developed code in Python program (Python Software Foundation, Beaverton, OR). This code was written to take in an Excel CSV file containing columns with a date, and sensor readings from the two depths mentioned. The code grouped data using the date of collection as the commonality and performed an averaging function on each of the sensor depths. The code was then able to compile the newly computed data, and generated an Excel file to be used in further data analysis.

Although the REALM data loggers were capable of real-time soil moisture data collection, due to previous years inconsistent data, and to remove any potential performance biases, the UGA Checkbook method was utilized for making irrigation decisions during each season.

After the probes were constructed, PVC poles were made for wire safety, and data loggers placed during data collection. The data logger PVC poles were made from PVC pipe, PVC connection pieces, PVC primer and glue, Deutsch male terminal pins, female Deutsch plugs, plastic conduit, red and green wiring, and heat shrink wrap. Poles were installed in crop rows, as the probes were built at a height of 1 m tall to allow for in season farming operations to be uninterrupted. All connections, plugs and wires were encased in conduit or heat shrink tubing as to reduce environmental damage or data interruptions.

Results and Discussion

Statistical analysis: Cover crop biomass and crop yields were analyzed using JMP® Pro Version 16.0 (SAS Institute Inc., Cary, NC). Graphs utilized to display data in the following sections were created using Excel (Microsoft Corporation, 2018). Single factor Analysis of Variable (ANOVA) tests were completed in JMP Pro, which were used to understand the mean separation and standard error (SE) to determine if the results were significant. P-values were determined in this test. Tukey's honest significance test was performed on the data in JMP to determine where significant differences occurred. An alpha level of 0.05 ($\alpha = 0.05$) was used in all analyses. Soil moisture graphs were not able to be statistically analyzed.

Soil Moisture Trends Results and Discussion

Data from 2020 and 2021 were compromised due to telemetry issues, therefore they were unable to be used to compare cover crop treatment trends. The soil moisture content was determined by tensiometer sensors that measure the soil water tension (SWT) values in kPa (or dB) was displayed in 2022 within the REALMFive user webpage (Figure 31). The 2018 and 2019 data were available online in a similar web interface. The graphs represented in Figures 32, 33 and 34 display the soil water tension data from 2018, 2019, and 2022 respectively.

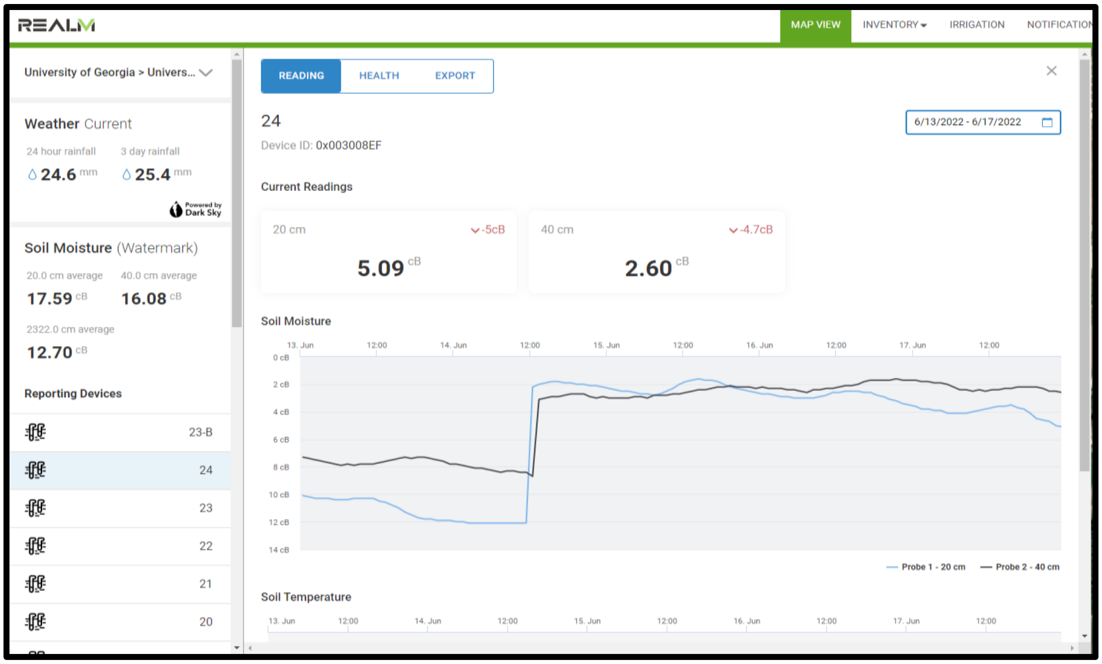

Figure 31. 2022 soil moisture data that was logged and graphed into REALM's website to display soil moisture data.

Corn was grown in 2018 and peanuts were grown in 2019 and 2022. In 2018, the rye and crimson clover treatment retained water the best throughout the season, which can be attributed to the rye seeding reduction so that crimson clover could be incorporated into the mix (Figure 32). Wann (2011) explained that crimson clover is primarily composed of simple sugars and amino acids, which leads to a faster decomposition rate in comparison to rye. These same components create a 'sponge-like' effect in crimson clover's residue making it able to retain moisture. Additionally, the rye/crimson clover mix retained moisture better when planted together because of the different root systems. Crimson clover has a tap root system and rye has a fibrous root system. With both of these present in the mixture, soil moisture retention was improved when compared to the rye monoculture. The other three treatments trended similarly but there was no distinct separation or differences in how these treatments retained moisture in the soil profile. In 2019, the treatments trended similarly but more distinct differences occurred in the amount of moisture that was present. Again, the rye and clover treatment retained soil moisture the most consistently throughout the season (Figure 33). The rye treatment retained moisture best at certain points of the growing season, but there were more inconsistencies throughout the season causing the trend line to shift upwards and downwards more drastically than the rye and clover treatment. The 2022 soil moisture data separated a bit differently than in 2018 and 2019 (Figure 34). By observing the graph, the mix and rye plus crimson clover treatments retained water the best. All treatments trended the same and reacted to irrigation and rainfall events in the same way.

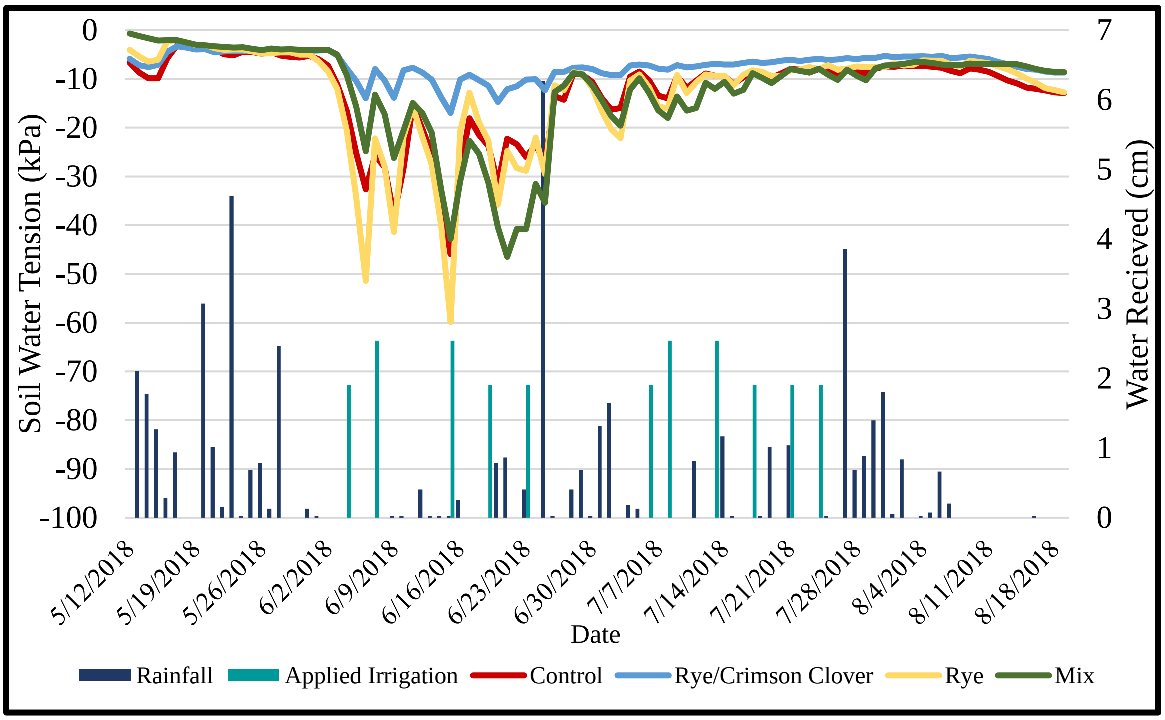

Figure 32. Cover crop treatment soil moisture trends throughout the 2018 corn growing season. The primary (left margin) y-axis relates to SWT of cover crop treatments, and the secondary (right margin) y-axis relates to amounts of rainfall and applied irrigation.

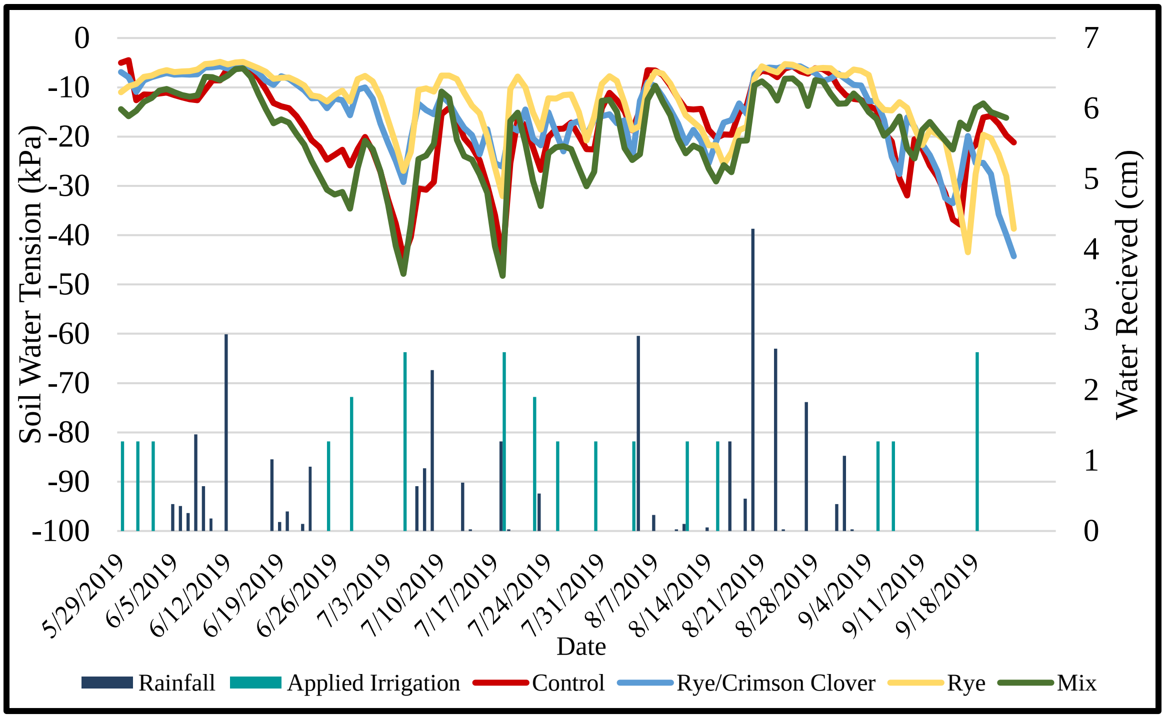

Figure 33. Cover crop treatment soil moisture trends throughout the 2019 peanut growing season. The primary (left margin) y-axis relates to SWT of cover crop treatments, and the secondary (right margin) y-axis relates to amounts of rainfall and applied irrigation.

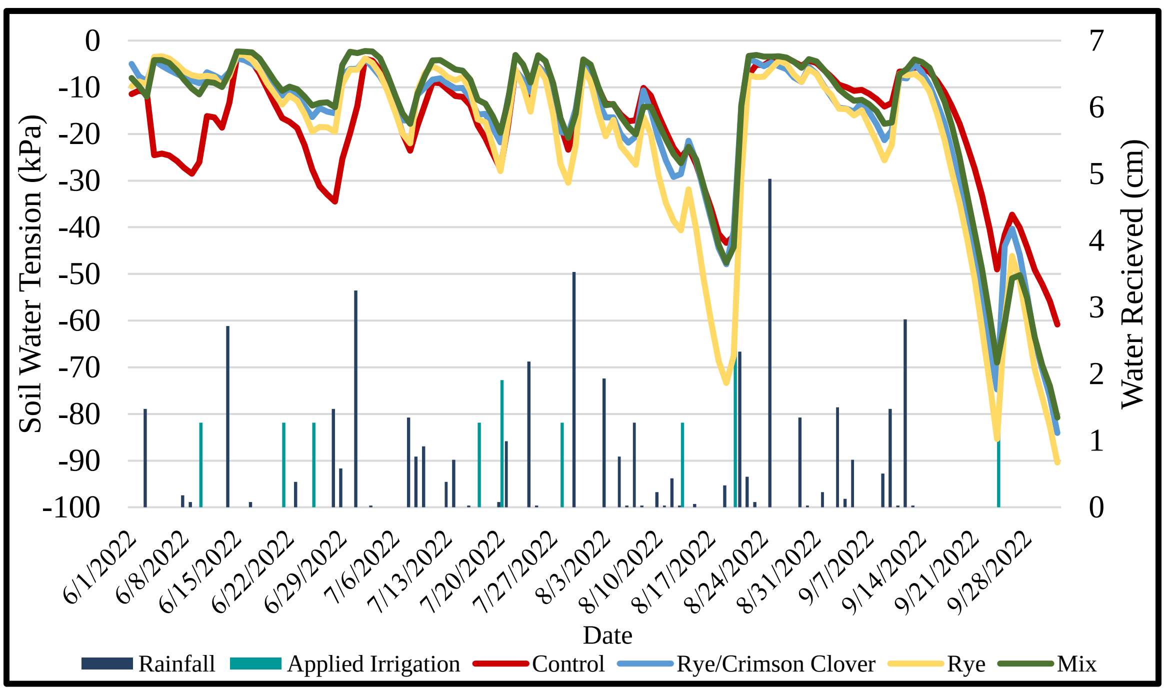

Figure 34. Cover crop treatment soil moisture trends throughout the 2022 peanut growing season. The primary (left margin) y-axis relates to SWT of cover crop treatments, and the secondary (right margin) y-axis relates to amounts of rainfall and applied irrigation.

Biomass Results and Discussion

When soil moisture was compared to the amount of dry matter (DM) biomass developed, a relationship was identified. In 2018, the rye treatment produced the most biomass, but the rye/crimson clover treatment retained the most moisture (Figures 32, 35a, and 36a). This could be due to fact that 2018 was the first year the study was conducted. In 2019, the rye/crimson clover treatments produced the most biomass and retained the most moisture (Figures 33, 35a, and 36b), and in 2022, the mix treatment produced the most biomass and retained the most moisture (Figures 34, 35a, and 36e).

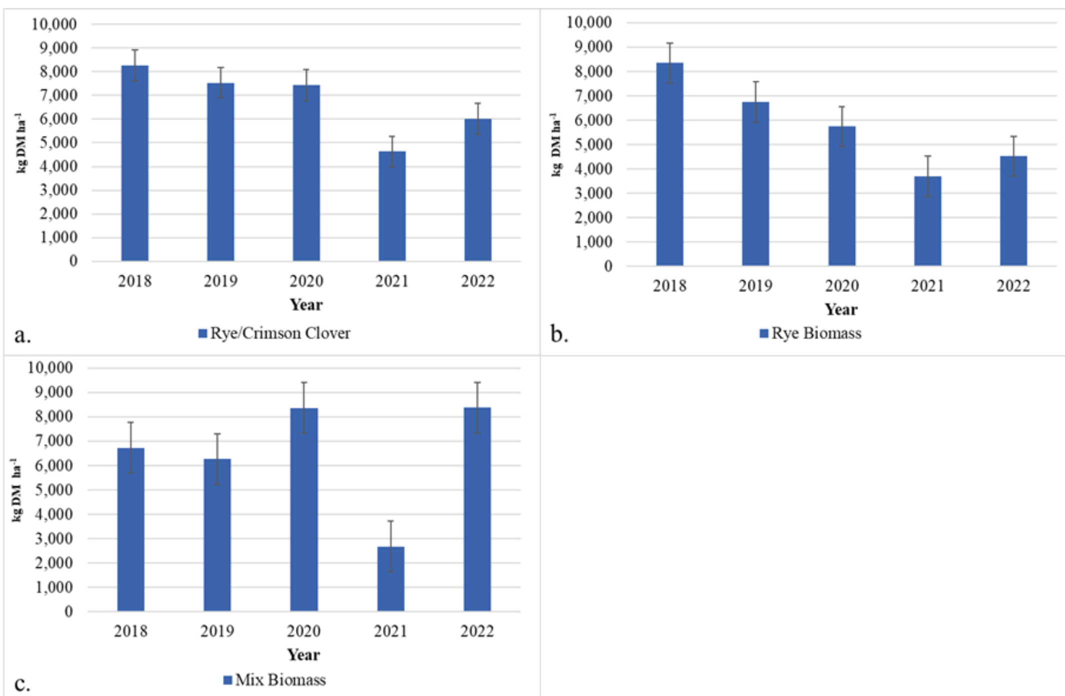

Figure 35. Cover crop biomass averages compared among years (kg DM ha^{-1}). Cover crop biomass averages compared across years (kg DM ha^{-1}). 35a) represents the rye/crimson clover treatment, 35b) represents the rye treatment and 35c) represents the mix treatment. Error bars indicate one standard error above and below the mean.

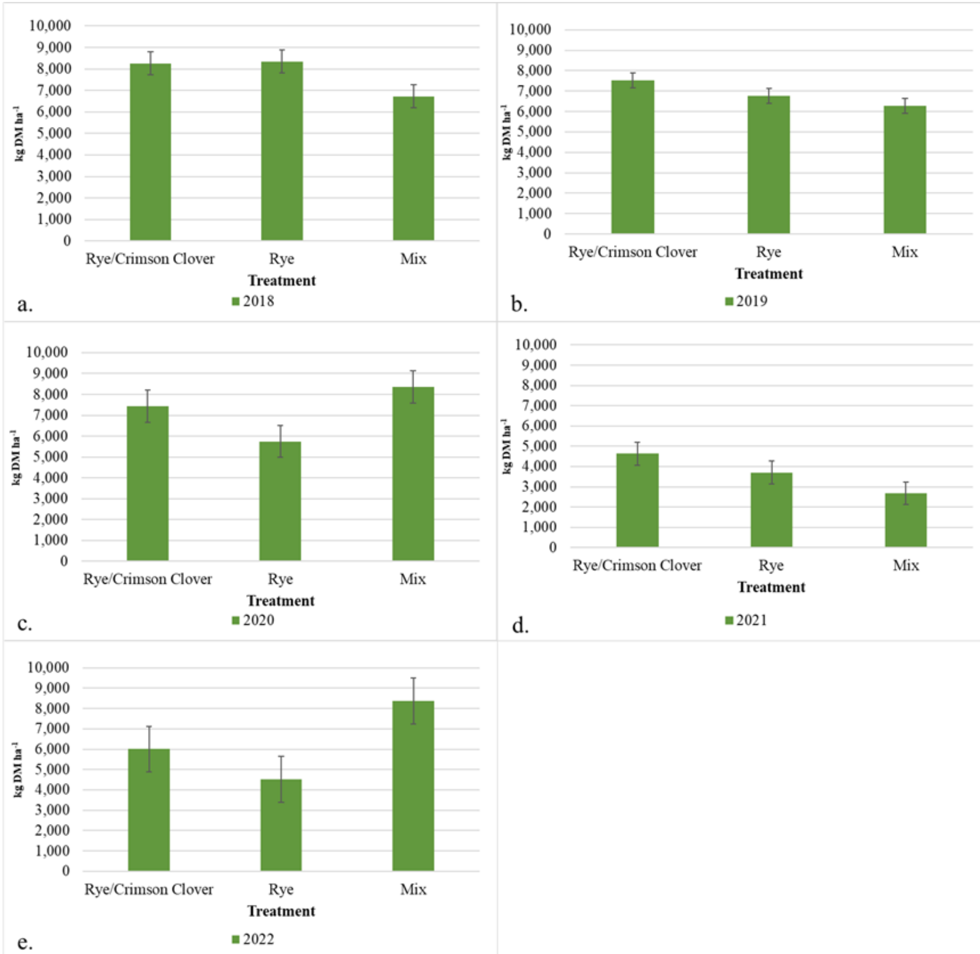

Figure 36. Cover crop biomass averages compared among treatments (kg DM ha^{-1}). 36a) represents 2018 cover crop treatments, 36b) represents 2019 cover crop treatments, 36c) represents 2020 cover crop treatments, 36d) represents 2021 cover crop treatments and 36e) represents 2022 cover crop treatments. Error bars indicate one standard error above and below the mean.

Yield Results and Discussion

The relationship among cover crop biomass, yield, and soil moisture were less evident than the relationship identified between soil moisture and biomass. In all years, the control treatment, which was conventionally tilled and did not have a cover crop planted, produced the largest crop yield (Figures 37a, 38a, and 39a-e). If the control yields were excluded in this analysis, the mix treatment produced the greatest yields in all years (Figures 37d, 38d, and 39a-e). But, this treatment did not produce the most biomass or retain the most moisture in 2018 or 2019 (Figures 32 and 33). Again, this lack of relationship could have been due to the fact that the study was in its first year, as often times it takes multiple years of cover cropping to observe the full effects they have on a production system. In 2022, there was evidence that supports that the mix treatment was the optimal cover because it produced the most biomass, produced the greatest yield (aside from the control), and retained the most moisture throughout the season. Additionally, the soil OM increased by 0.42% between 2018 and 2022 in the mix treatment, which was the largest change in comparison to the other cover crop treatments.

The length of the cover crop growing season, rainfall amount and distribution during the cover crop growing season, and the temperature during the cover crop growing season all impacted the amount of biomass produced, which impacted the soil moisture retained in the cash crop growing season. Overall, more cover crop biomass provided more soil moisture retention because the OM was increased, and the cover crop material helped fill the porous soil, but cover crop species did impact soil moisture retention as observed in 2022.

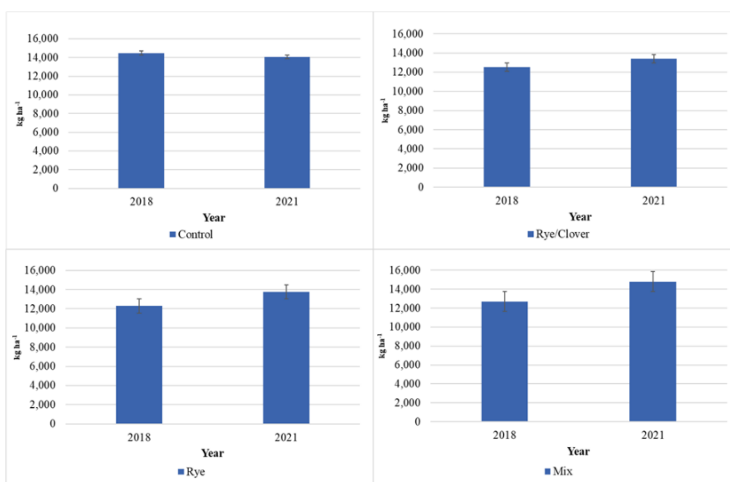

Figure 37. Corn yield (kg ha^{-1}) compared between years. 37a) represents the control treatment, 37b) represents the rye/crimson clover treatment, 37c) represents the rye treatment and 37d) represents the mix treatment. Error bars indicate one standard error above and below the mean.

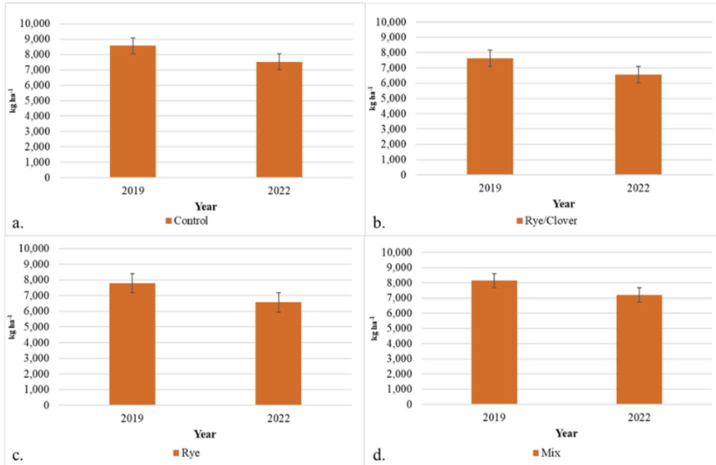

Figure 38. Peanut yield (kg ha^{-1}) compared between years. 38a) represents the control treatment, 38b) represents the rye/crimson clover treatment, 38c) represents the rye treatment and 38d) represents the mix treatment. Error bars indicate one standard error above and below the mean.

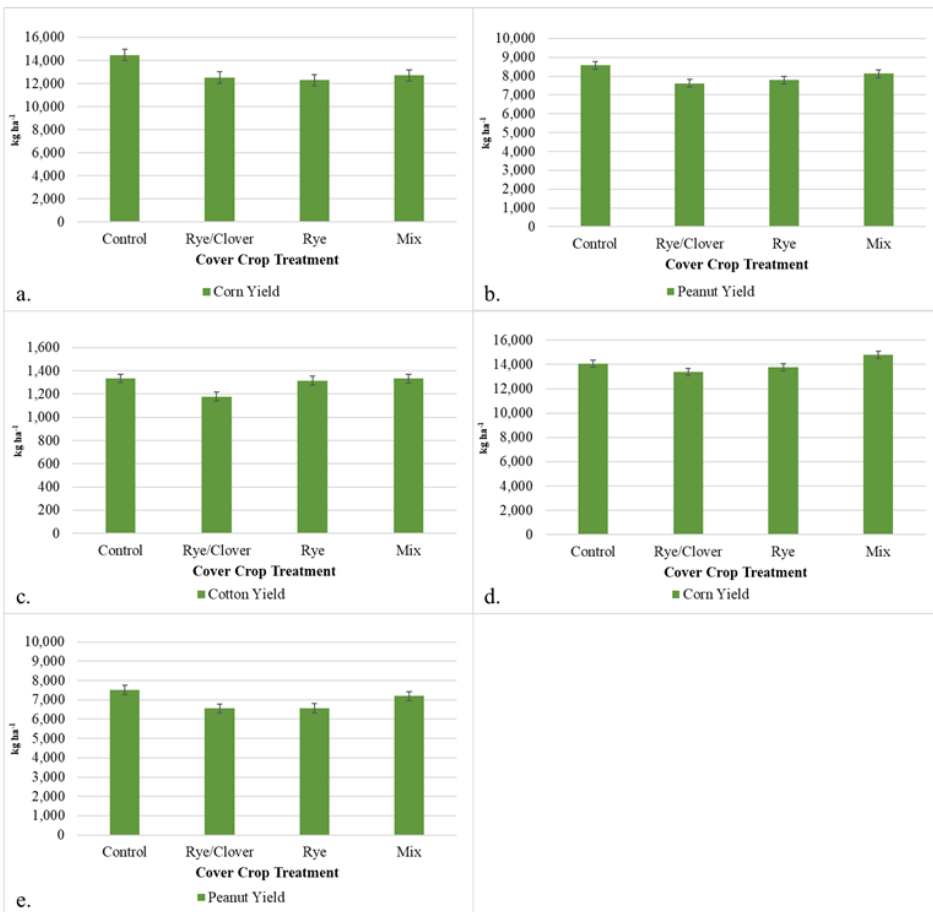

Figure 39. Crop yield (kg ha^{-1}) compared among cover crop treatments. 39a) represents 2018 corn yield, 39b) represents 2019 peanut yield, 39c) represents 2020 cotton yield, 39d) represents 2021 corn yield and 39e) represents 2022 peanut yield. Error bars indicate one standard error above and below the mean.

Conclusions

As a case study, confident scientific conclusions could now be drawn. Based solely on observation, it seemed that cover crops had an effect on soil moisture retained in the upper soil profile. Future research could continue using this data to construct an analysis of cover crops' ability to lengthen time between irrigation events. Trigger point irrigation research has been conducted for several years and measured by the yield of the crop to determine the threshold in which a crop can withstand between irrigation events and still have a desirable yield and economic outcome. Not only is it important that water may be retained in the soil profile for longer amounts of time, but it is also important that the initial infiltration of the soil allows the water to move into the soil profile, rather than experiencing major runoff events that are often observed on southeastern soils. Currently, there are many different types of irrigation decision making tools and web platforms that integrate water use curves, historical evapotranspiration data, weather, growing degree days and crop type. These are often inaccurate, especially in comparison with soil moisture sensors. Additional research that focuses on a financial analysis could also help cover crop and soil moisture sensing adoption rates in the southeast.

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CHAPTER 4

CASE STUDY: ON-FARM COVER CROP AND SOIL MOISTURE STUDY

Introduction

The USDA-NRCS identified that healthier soils reduced environmental damage and benefited farmers (Claassen et al., 2018). Specifically, the research identified that the adoption of soil health practices improved rainfall infiltration rates and soil water-holding capacity, reduced environmental damage due to decreasing sediment, nutrient, and pesticide runoff while reducing the risk of low crop yields by increasing drought resilience (Karlen et al., 1994; Moebius-Clune et al., 2008; Rawls et al., 2003). To reap the benefits of improved soil health, cover crop and conservation tillage practices must be implemented (Claassen et al., 2018). Four basic principles were identified to help farmers manage for soil health by protecting and ‘feeding’ the soil: keep the soil covered (protect), reduce soil disturbance (protect), keep living roots in the soil (feed), and diversify using rotations and cover crops (feed) (Moore-Kucera, 2018; USDA-NRCS, 2017).

The primary objective of the on-farm case study was to examine and compare the findings with those from a randomized complete block design 6-yr cover crop study located in Midville, GA. The case study field location was in the Southwest region of the state, which provided a different perspective. The primary objective was met by collecting biomass samples for different cover crop treatments, installing capacitance soil moisture sensors to monitor soil moisture retention across treatments during the cash crop growing season, and evaluate the impacts the cover crop treatments had on cotton (*Gossypium hirsutum* L.) yield.

Materials and Methods

A 2-yr study beginning in 2021 and ending in 2022 was conducted in Terrell County, GA to evaluate different cover crop treatment responses when planted across a large number of hectares. The field utilized was irrigated by overhead pivot irrigation and was 28-ha. The field was divided into sections from the North to South end of the field. Each of the sections were four 7-ha strips (Figure 40) and had a different cover crop treatment planted into each strip. The treatments included: an 'Elbon' cereal rye (*Secale cereale* L.) monoculture, a 'Dixie' crimson clover (*Trifolium incarnatum* L.) monoculture, a 'Wrens Abruzzi' cereal rye (*Secale cereale* L.) and 'AU Merit' hairy vetch (*Vicia villosa* Roth) mixture, and a multiple species mixture. In 2021, the multiple species mixture was a blend of 'Wrens Abruzzi 'cereal rye, 'Cosaque' black-seeded oats (*Avena sativa* L.), 'AU Merit' hairy vetch, and 'Dixie' crimson clover (Table 6), and in 2022, the multiple species mixture was a blend of 'Wrens Abruzzi' cereal rye, winter triticale (hybrid of wheat and rye) (*Secale cereale* × *Triticum aestivum* or ×*Triticosecale* Wittm. ex A.Camus), 'Villana' hairy vetch (*Vicia villosa* Roth), and 'Dixie' crimson clover (Table 6) (GBIF, 2023). The rye monoculture acted as the 'control' in this study because cereal rye was the most commonly utilized cover crop in this region of the state (McAllister, S., personal communication, August 20th, 2020). Important dates from the 2021 and 2022 seasons are listed in Table 7.

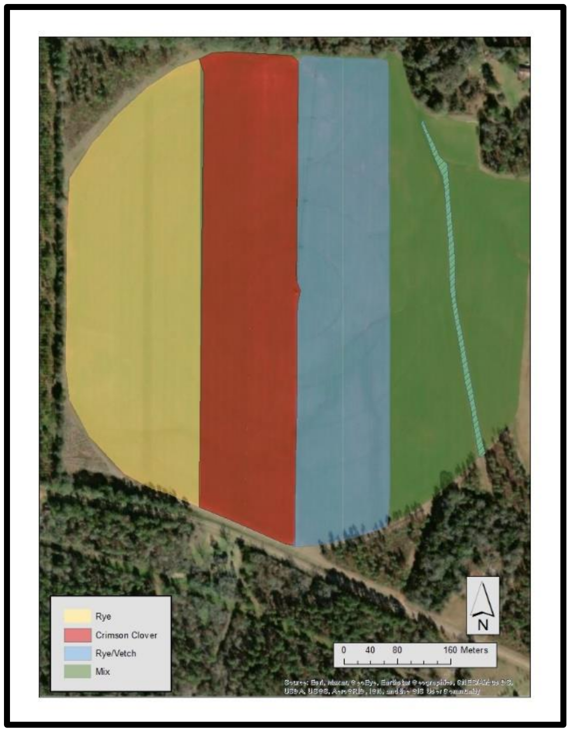

Figure 40. 2021 Terrell County cover crop treatments displayed in ArcMap.

Table 6. 2021 and 2022 cover crop treatments and seeding rates.

Year	Cover Crop Treatments			
2021	Rye	Crimson Clover	Rye & Vetch	Rye, Oats, Vetch & Crimson Clover
Rate (kg ha^{-1})	30	8.2	16 + 3.5	9.0 + 6.8 + 2 + 2.5
2022	Rye	Crimson Clover	Rye & Vetch	Rye, Triticale, Vetch & Crimson Clover
Rate (kg ha^{-1})	30	8.2	16 + 3.5	9.0 + 6.8 + 2 + 2.5

Table 7. Important dates the 2021 and 2022 growing seasons.

Crop Year	Cover Crop Plant Date	Cover Crop Sample Date	Cover Crop Termination Date	Plant Date	Defoliation	Harvest Date
2021	11/01/20	4/5/21	4/7/21	5/11/21	10/11/21	11/1/21
2022	11/10/21	4/12/22	4/12/22	5/14/22	10/08/21	10/28/22

Cover Crop Management and Biomass Sampling

Cover crop treatments were planted on November 1st, 2020 using a John Deere grain drill implement with 19-cm row spacing. The grain drill was also equipped with small seed attachment for the crimson clover seed (Figure 41). The 2021 cover crop seeding rates and species are listed in Table 6. When the cover crop treatments were approximately two weeks pre-termination stage, one biomass sample was collected from each treatment for a total of four biomass samples in 2021. The sampling methods and procedure directly followed the sampling method in UGA's Cover Crop Biomass Sampling Handbook (Gaskin et al., 2019). A 0.61-m by 0.76-m U-shaped PVC template was used to determine the area to cut for each sample (Gaskin et al., 2019). Once the samples were collected, they were air dried outdoors using the sun-dried method (Gaskin et al., 2019).

Figure 41. John Deere cover crop drill with additional clover box utilized to plant cover crop treatments.

Cover crop treatments were terminated on April 7th, 2021, using the same equipment and methodology. In 2021, the cover crop treatments were first rolled using an 11-m wide field cultipacker (Landoll Co., LLC, Marysville, KS) then the cover crop treatments were sprayed with recommended rates of dicamba and glyphosate as a burndown herbicide application (UGA Extension, 2018). A CaseIH sprayer with a 27.5-m width was used to apply all spray applications. Following the chemical burndown and to prepare for cotton planting, each of the treatments were strip-tilled and then cultipacked again using a 12-row ‘Ripper-Stripper’ (Unverferth Manufacturing Co., Inc., Kalida, OH) implement that was equipped with strip-till shanks to create the future seed bed as well as cultipacker wheels to press down the terminated cover crop (Figure 42). The implement was connected to a tractor that was equipped with 370 hp (Figure 43). Cotton was planted on May 11th, 2021 using a 260 hp tractor connected to a 12-row John Deere MaxEmerge XP planter (Figure 44).

Figure 42. 12-row strip-till and cultipacker implement that was used to create the seed bed and push the terminated cover crop down.

Figure 43. Tractor connected to strip-till and cultipacker implement. Image was taken during field preparation.

Figure 44. MaxEmerge XP planter connected to tractor.

In 2022, the study treatments were reversed in-field location. Figure 45 represents the map view of the field. Cover crop treatments were planted on November 10th, 2021 using the same grain drill mentioned above and the planting rates are listed in Table 6.

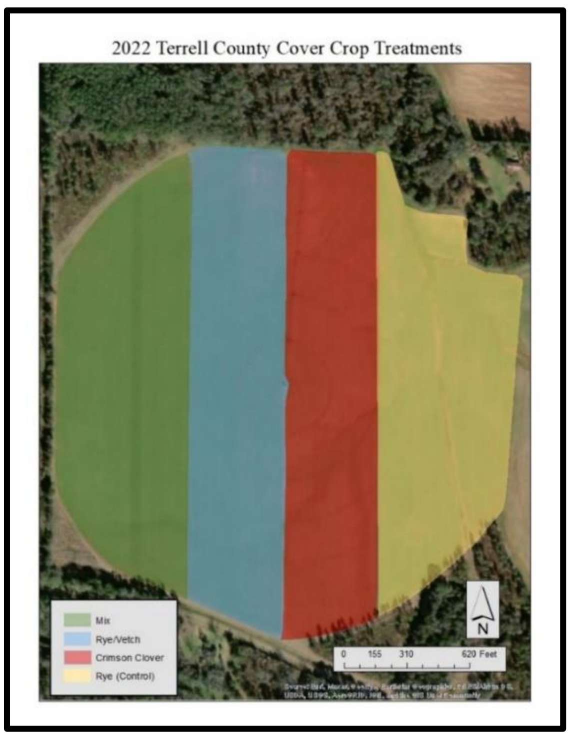

Figure 45. 2022 Terrell County cover crop treatments displayed in ArcMap.

The materials used for biomass sampling were a 1.0-m by 1.0-m PVC square, 16 brown paper bags, 10 woven plastic mesh bags, handheld shears, two 19-L buckets, a scale, and a Trimble Nomad Handheld GPS with shapefiles of field boundaries and collection points, and a plot map created in ArcMap™ (Figures 6, 7 and 8). Biomass samples were collected in 2022 using a modified method of the UGA's Cover Crop Biomass Sampling Handbook (Gaskin et al., 2019). The modified biomass sampling method that was utilized in this portion of the study was based on scientific studies, rather than a production focused biomass sampling guide (Andrews et al., 2010; Gaskin et al., 2019; USDA-NRCS, 2018). The alterations included: a 1-m by 1-m PVC square used for samples rather than using a 0.61-m by 0.76-m a U-shaped quadrat and using a forced air dryer rather than the drying methods suggested (sun dry or microwave method). Four samples from each treatment were collected: two samples from the North end of the field and two samples from the South end of the field for a total of 16 samples (Figure 46). The sampling points were determined in ArcMap™ prior to collecting the samples to ensure that enough samples were collected for each treatment based on UGA's Cover Crop Biomass Sampling Handbook (Gaskin, et al., 2019). On the day of sampling, the points were re-recorded using the handheld GPS to ensure accuracy. Biomass samples were weighed individually utilizing a scale to record the initial in-field weight. Then, the samples were forced air dried for 6 d at 48°C and were rotated and flipped in the drier on day three. The cover crop dry matter (DM) weight was recorded once the sample was dried, and the weights were compared.

Cover crop termination was slightly different in 2022 than in 2021. The cover crop treatments were not first rolled and then chemically terminated because the additional trip across the field did not provide any benefit and proved during 2021 to be an unnecessary trip across the field. To maximize efficiency, cover crops treatments were only terminated utilizing a burndown herbicide application of recommended rates of dicamba and glyphosate. A month after the cover crop was terminated, each of the treatments were strip-tilled and then cultipacked. The planter followed the strip-till and cultipacker implement, and cotton was planted on May 11th, 2022. The same equipment was utilized for cover crop termination, crop preparation, and planting that was used in 2021 (Figures 42, 43 and 44). In both years, Deltapine 2038 cotton was planted at a targeted plant population of 12,140 plants ha^{-1}.

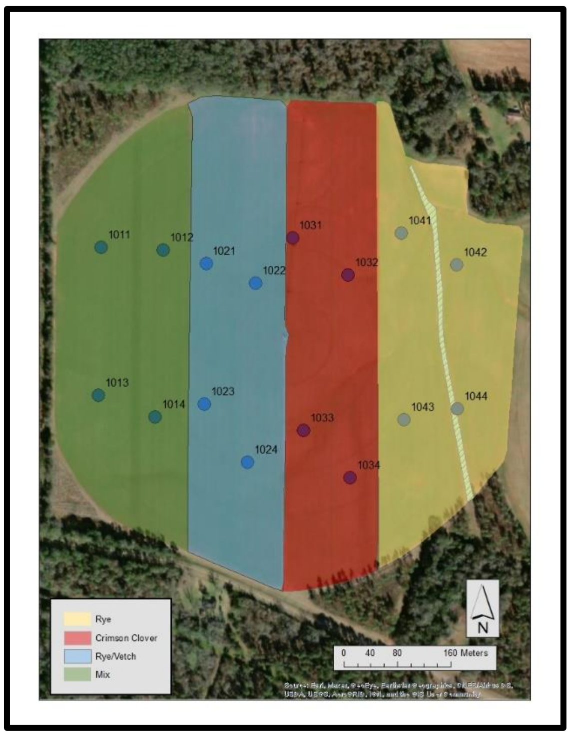

Figure 46. Cover crop biomass sampling points displayed in ArcMap.

Soil Sampling and Soil EC Collection

Soil EC was not collected in 2021, and soil sampling was performed by the grower's crop consultant and was only utilized for nutrient management decisions. This consultant's procedure of sampling was based on UGA's soil sampling guidelines outlined in the UGA Extension Soil Test Handbook (UGA Extension, 2011). Access to the results from these data were limited.

In 2022, after biomass samples were collected and the cover crop was terminated, soil EC data was collected. Soil EC was collected and was used to determine the locations for the 2022 soil moisture sensor. A Veris 3100 was connected to the ATV to collect the EC data at a mid-range of 0 to 60-cm deep (Figure 21). The initial A-B line was set along the field edge and 6.1-m wide swaths were used to collect EC throughout the field in a serpentine pattern. As the ATV moved through the field, a laptop connected to the Veris showed the progress of data collection (Figure 20). On the day of collection, the field boundary was also created by driving the ATV around the edge of the study field. Once soil EC was collected, the data were evaluated in the USDA's Management Zone Analysis (MZA) tool to determine the number of management zones that best fit this field "using a fuzzy c-means unsupervised clustering algorithm" (Fridgen et al., 2003). The management zones determined the optimum placement area for soil moisture sensors across cover crop treatments that would capture all soil moisture variability present. Two management zones were determined to be the best fit. To visually delineate the soil EC zones, ArcMap was used. The soil EC data, the field boundary, and the background field image were imported. As shown in Figure 47, the greater EC zone (6.45-15.16 dS/m) was displayed in green and the lesser (0.76-6.44 dS/m) in red. These varying levels were determined by selecting '2 zones' and using 'Natural Breaks' in ArcMap.

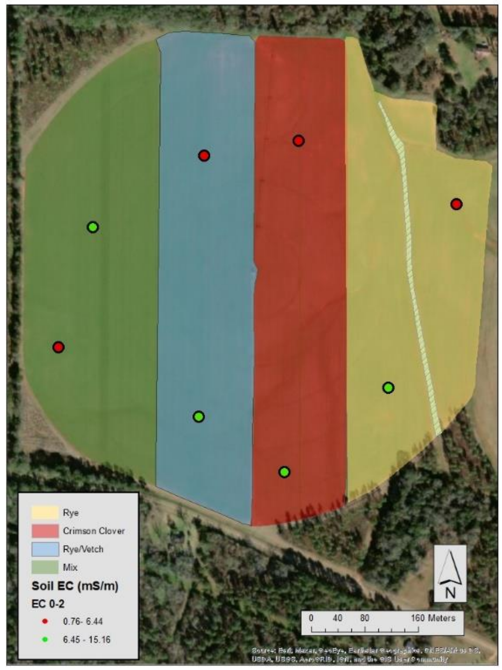

Figure 47. Terrell County sensor placement based on two soil EC zones.

Soil samples were collected following soil EC data collection from the same locations as the biomass samples (Figure 46). The only year soil sampling occurred specifically for this study was in 2022. In 2022, a total of 16 soil samples were collected and the procedure followed UGA Extension's recommended soil sampling procedure (UGA Extension, 2011). These sample location points were uploaded and navigated to in the field using the handheld GPS system. The exact sample coordinates were recorded on the day of sampling using the handheld GPS system. The soil samples were sent to the UGA's Agricultural and Environmental Services Laboratories located in Athens, GA and were analyzed for a Mehlich I routine nutrient analysis test, a texture analysis, and a soil organic matter (OM) analysis. In the routine nutrient analysis, pH, lime buffering capacity, phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), zinc (Zn), and manganese (Mn) level levels were provided.

The materials used for the soil sample collection were a soil probe marked at the desired depth of sample collection (approximately 20-cm), 16 brown paper soil sampling bags, a 19-L bucket, a small hand trowel to mix and bag samples, a Trimble Nomad Handheld GPS with shapefiles of field boundaries and collection points, and a plot map that was created in ArcMap™. The soil sampling procedure began by preparing a field boundary and sampling points that were created in ArcMap™. These points were uploaded into the handheld GPS to locate the soil sampling points in field. At each sampling point, eight to ten soil cores were collected at a 20 to 22-cm depth using a soil probe. All soil cores were mixed in a bucket prior to putting them in the soil sample bag to ensure that the sample was representative of the area.

Soil Moisture Monitoring

During the 2021 growing season, four AgSense capacitance soil moisture sensors equipped with real-time data loggers were placed into one of each of the treatments. The sensor placement methodology was based on the farmer's understanding of his field and was not scientifically based. Soil EC was used as the parameter to delineate soil moisture sensor placement. The collected EC data were evaluated in the USDA's Management Zone Analysis (MZA) tool to determine the number of management zones that best fit this field and to determine optimum placement for soil moisture sensors. The MZA tool suggested two management zones – one in the areas of high EC and one in the areas of low EC. Two AquaCheck (AquaCheck USA, Perry, IA) capacitance probes were placed into each treatment (Figure 47). One sensor was in the high EC zone and one was in the low EC zone. These sensors were not equipped with real-time data logging capability. The

AquaCheck probes were checked and data was collected using a hand-held device with Bluetooth capabilities to transfer the data points collected by the soil moisture probes every 2-3 wk. The data were removed and uploaded to an Excel spreadsheet to determine the soil moisture levels in the treatments over time. An additional four AgSense capacitance probes were placed in the field because the grower wanted to use real-time sensors to make irrigation decisions. The placement of these four soil moisture sensors were determined by recreating soil EC maps that had three management zones, so that a mid-level EC zone would be present. One sensor was placed in each cover cop treatment in the mid-EC zone. There were total of 12 soil moisture sensors in the field during the 2022 season. All soil moisture sensors that were placed in-field were used to evaluate soil moisture because all probes were capacitance and the additional four sensors that the grower utilized were placed in the mid-level EC zone, which gave an additional level of data.

Prior to the day of installation, the map of probe placement was exported onto a handheld GPS. On the day of installation, the GPS points were located, and soil moisture sensors were installed in row with the cotton plants. To install each probe, a round metal pole with a bolt was hammered into the soil using a metal mallet to create a space for the probe to slide into (Figure 48). Once the hole was created, the soil moisture probe was placed into the hole and nearby soil was utilized to tightly pack the probe into place (Figure 49). Then, a water container was placed directly over the soil moisture probe and the soil was saturated for approximately 30 minutes (Figure 50). This procedure was used to field calibrate the probe and prepared it for future soil moisture data collection.

Figure 48. Soil moisture probe hole created using metal pole, bolt, and metal mallet.

Figure 49. Soil moisture slid into the hole that was created by hammering the piece of metal pipe.

Figure 50. Soil moisture probe saturated for approximately 30 mins after installation.

The soil moisture content was determined by volumetric water content sensors that required biweekly data collection by using a handheld 'shuttle' device that would connect by Bluetooth to the sensor and transfer the collected soil moisture data with corresponding dates (Figure 51). Each soil moisture probe collected data at 20, 40, and 60-cm. The shuttle was then connected to a computer and the logged data points were uploaded to MyAgBuddy website where the soil moisture complex code was decoded. In MyAgBuddy, the soil moisture data were graphically displayed, and the logged data were available for export. The data collected was exported in a .csv file, and soil moisture data were averaged daily utilizing a developed code in Python program (Python Software Foundation, Beaverton, OR). This determined the average daily soil moisture and graphically place the soil moisture trends.

Figure 51. Soil moisture probe and handheld shuttle used to transfer soil moisture data from probe to handheld device and eventually to the computer.

During the cash crop growing season, the grower only irrigated when necessary, but all treatments received the same amount of irrigation. In 2021, the grower irrigated a total of 3.8-cm, and in 2022, the grower irrigated a total of 12.7-cm. The field was equipped with a six-tower center pivot.

Cotton was harvested by treatment on November 1st, 2021, and October 28th, 2022, using a 6-row John Deere cotton basket picker. The picker was not equipped with a yield monitor, so an in-field scale was utilized to obtain field weights and final yields were calculated using a 40% lint turnout.

Results and Discussion

Data were not analyzed statistically because the study was performed on-farm and the treatments were not replicated. Though not statistically analyzed, numerical and visual trends were observed.

Table 8. Terrell County cover crop treatment biomass (kg DM ha^{-1}) for 2021 and 2022.

2021		2022
Treatment	Biomass Weight (kg DM ha^{-1})	
Rye	4,877	4,253
Crimson Clover	3,542	3,685
Rye/Vetch	7,168	4,252
Mix	7,737	3,289

When 2021 and 2022 treatment biomass weights were compared, there were only observations made about the biomass collected since a statistical analysis could not be conducted. Additionally, the biomass samples collected in 2022 provided a more accurate representation of biomass present because of the number of samples and the improved sampling procedure. The length of the cover crop growing seasons did not differ, therefore the conclusion can be drawn that collecting multiple samples is necessary for a representative amount of in-field biomass.

The soil samples from the 2022 collection indicated that the primary soil type in this field was a sandy clay loam (USDA-NRCS, 2022). The field of this study had soil that contained more clay material, which has better soil moisture retention properties than soils with higher sand content. Table 9 displays the collected soil OM averaged for each treatment from the 16 soil samples collected. As observed in Table 9, the mix treatment had the greatest soil OM. There were multiple species that decayed at different rates providing the opportunity for OM to be present in the soil for longer periods of time and at different rates than monocultures or two species mixtures.

Table 9. Terrell County 2022 soil OM.

Plot and Sample Location	Soil OM (%)
Rye	2.75
Rye/Vetch	3.06
Crimson Clover	2.43
Mix	3.61

All soil moisture data in this chapter are represented by volumetric water content (VWC), and the axes for Figures 52 and 53 are positive. Thus, the greater the value of the moisture trendline, the better the treatment retained soil moisture. Soil moisture data were collected in 2021 from a total of eight sensors that were placed in the field based on the grower’s knowledge. From the data mentioned in Table 8, the mix treatment produced the greatest biomass, and based on the soil moisture trends in Figure 52, the mix treatment retained the most moisture throughout the season.

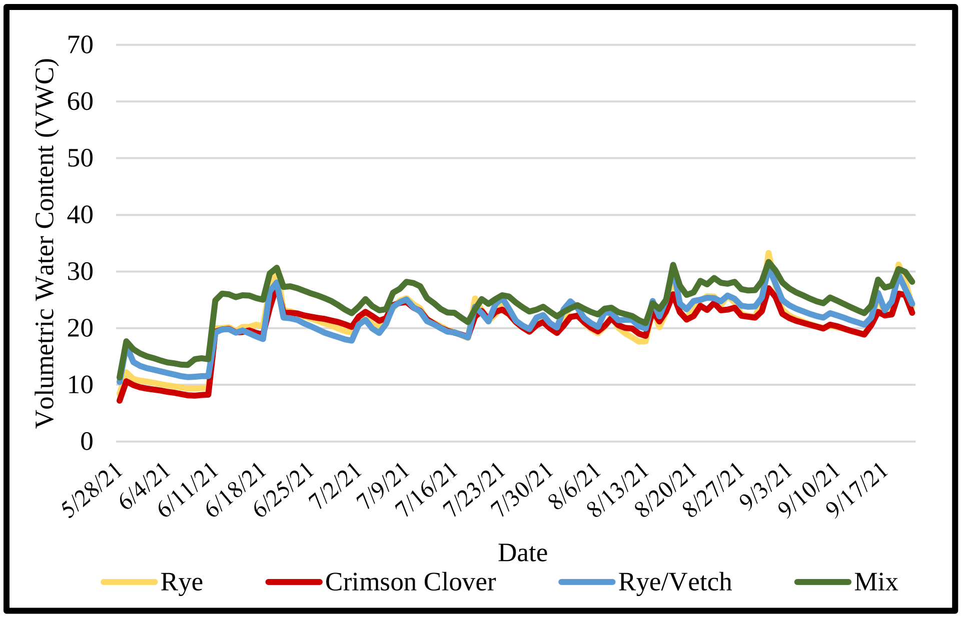

Figure 52. 2021 averaged soil moisture for eight probes at three reading depths for each cover crop treatment. The primary (left margin) y-axis relates to VWC of cover crop treatments.

The 2022 soil moisture trends indicated that the rye treatment retained moisture the best throughout the season (Figure 53). Similar to 2021, the treatment that produced the greatest level of biomass also retained the most moisture. In 2022, the rye treatment produced the greatest biomass. Although it was only by a small amount, a relationship was present 2 yrs in a row. When soil OM was also evaluated, the mix treatment had the greatest OM content, and the rye treatment had the second to lowest. This occurred because of the species present in the mix and the rye/vetch treatment in comparison to the rye monoculture. The mix treatment had species that decayed quickly and ones that decayed at a slower rate, and the vetch in the rye/vetch treatment quickly decayed upon termination, where the rye was slower to decay. Both of these treatments had greater OM that the rye monoculture because species were present that had different decaying rates. Whereas, the rye monoculture decayed at a very slow rate causing it to have more biomass present on top of the soil for a longer period of time rather than being incorporated early on after termination. Cover crop growth habits determined the amount of OM present as well as biomass and soil moisture retention.

The treatment location in field had impact on the biomass produced, as well. As previously stated, the treatment locations reversed in 2021 and in 2022, and the treatment that produced the most biomass was located in the left most part of the field. This could have been due to different topography of the field, different soil type levels, nutrient management, or wildlife pressure.

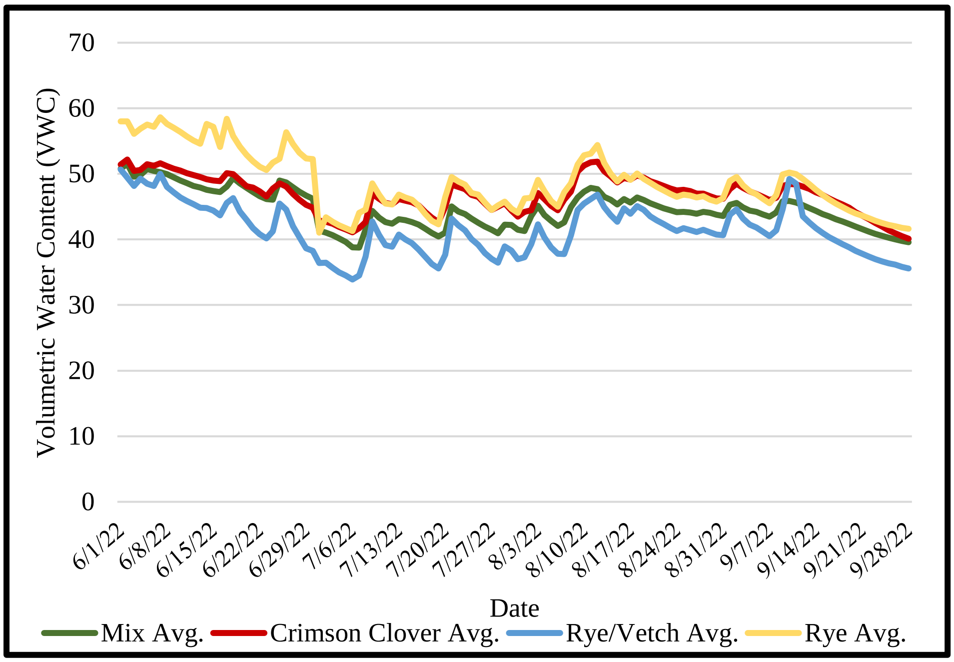

Figure 53. 2022 averaged soil moisture for eight probes at three reading depths for each cover crop treatment. The primary (left margin) y-axis relates to VWC of cover crop treatments.

Yield data for 2021 and 2022 were calculated by the grower and Extension agent based on a 40% lint turnout. Yield data collected from the 2021 and 2022 growing season are listed in Table 10. In previous chapters, cotton yield was determined by utilizing seed cotton yield. In 2021, the mix treatment produced the most cotton among the treatments (Table 10).

Table 10. 2021 and 2022 cotton lint yield data categorized by treatment.

Treatment	Yield (kg ha^{-1})	
	2021	2022
Rye	1,564	1,719
Crimson Clover	1,485	1,587
Rye/Vetch	1,406	1,798
Mix	1,577	1,961

The 2022 yield data indicated that the mix treatment produced the greatest yielding cotton crop in comparison to all other treatments. As previously mentioned, the rye treatment produced the most biomass in 2022 and retained moisture the best throughout the growing season. This can be attributed to the growth habits of rye and that rye had a slower release rate but occurs for a longer period of time compared to the other treatments with more species present. Other residues were able to contribute more N for the cotton crop than the rye treatment did because of their ability to release N quicker and over less time. The mix treatment produced the greatest yield because of the four species that decayed at different rates and that provide necessary nutrients throughout the growing season. Also, the thick stems and root systems on some of the mix treatment's species improved soil infiltration in a soil that was greater clay content, and therefore, more compact than a soil with a greater sand content. This relationship provided aeration and root channels that the cash crop was able to use, establish itself, and produce a greater yielding crop.

Conclusions

Since only one season of scientific data were collected, this study needs additional years of data collected but relationships were observed between biomass produced, soil OM, soil moisture retention, and yield. Although there was not one certain cover crop treatment to recommend for all operations based solely on the 2022 data for a sandy clay loam soil, there were distinct characteristics that could help a grower make a final decision. But, if the grower’s goal was to produce large amounts of biomass and retain soil moisture, these data suggest a rye monoculture would be the best fit. With all of these conclusions, it is imperative that data be collected in the future and determine how that data compares.

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CHAPTER 5

CONCLUSIONS AND FUTURE WORKS

Conclusions

In conclusion, this project supports the hypothesis that including different cover crop monocultures and mixtures into Coastal Plains production systems impacts yield in corn, peanut, and cotton, above ground biomass produced, soil organic matter (OM) and soil moisture levels. This study indicates that there was a relationship between cover crop growth habits, biomass production, soil OM, and soil moisture retention, which has further expanded the understanding of cover crops and their necessity in a production system. Previous studies support that when cover crops are implemented, yield reductions follow. The results from this study disagree, and found that the crop yield in the control treatment did not produce a greater yield than the yield collected from the cover crop treatments.

Additionally, the amount of cover crop biomass produced in each year heavily depended upon the length of the growing season, temperature, and rainfall. The average biomass for each treatment in 2021 was less than the biomass produced in any other year, which was indicative that the shorter growing season impacted the amount of biomass present. The mix treatment at the primary study location and the case study location both had the greatest levels of soil OM.

In years where the cover crop had a longer period of time to grow, both the biomass and soil OM collected were greater, as well as soil moisture measurements indicating a greater sustained saturation throughout the growing season. When considering water use and management practices, soil moisture probes are an essential management tool, especially as water shortages occur throughout the U.S. and world. Water conservation and stewardship is a critical factor in agriculture, and many academic programs around the world are now dedicated to improving the ways that farmers utilize and steward their water resources. Many cover crop benefits have been evaluated prior to this study, but none looked at the specific relationship between water retention and cover crop implementation. This study was able to identify trends in the soil moisture retention of the various cover crop treatments in comparison to a fallow, conventionally tilled soil. Overall, a multiple species mix had the best soil moisture retention.

The case study research results do not provide enough scientific components or a statistical analysis, therefore the study must only be viewed as an anecdotal study and scientifically confident conclusions cannot be drawn.

Future Works

This project was a 6-yr study from 2018-2023. The 2023 growing season will conclude the project with the planting of a cotton crop. During this season, biomass, soil moisture, soil OM, soil nutrients, and yield will all be measured using the procedures outlined in this paper. Additional work in the future may focus on variable rate irrigation methods, trigger point irrigation timing compared across treatments, implementing a complete randomized block design study with cover crop treatments compared to a control in other areas of the state, and continuing to implement on-farm trials throughout the state that have multiple replications so that they can be statistically analyzed.