Cover Crop Effects on Insect Dynamics in Cropping Systems of the Southeastern U.S.

by

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ABSTRACT

Evidence suggests winter cover crops could be useful for augmenting conservation biological control of insect pests in southeastern row crop systems. Management decisions such as selection of cover crop species and irrigation management can potentially influence insect populations, since cover crop species may vary in their ability to attract and sustain complexes of natural enemies. Research is needed to understand the effect of various winter cover crop mixtures on the in-field insect dynamics in Alabama soybean (*Glycine max*), peanut (*Arachis hypogea*), and cotton (*Gossypium hirsutum*) production systems. A study was established at the Tennessee Valley Research and Extension Center (Belle Mina, AL) and the Wiregrass Research and Extension Center (Headland, AL) to assess the effect of crimson clover (*Trifolium incarnatum*), cereal rye (*Secale cereale*), and forage radish (*Raphanus sativus*) cover crops on pest and beneficial insect presence. All cover crops were fall planted and chemically terminated at least two to three weeks prior to cash crop planting. Insect presence was recorded using sweep nets, beat sheets, and visual observations of damage in cash crops. Results showed that crimson clover and radish-clover cover crops can increase beneficial insects such as big eyed bugs (*Geocoris punctipes*) and lady beetles (Coccinellidae) in north AL. Clover-containing cover crops were also preferable to winter fallow for harboring greater numbers of beneficials in south AL. Rye, clover, and radish-clover cover crops all generally harbored more pest insects than fallow and radish monocultures. Crimson clover cover crops can increase numbers of three cornered alfalfa hoppers (*Spissistilus festinus*) and bean leaf beetles (*Cerotoma trifurcata*), while tarnished plant bug (*Lygus lineolaris*) pests seem to prefer radish-clover bicultures. Winter cover crops are unlikely to enhance beneficial insect persistence during soybean or peanut growing seasons if terminated two to three weeks ahead of cash crop planting. Cover crops had weak

impacts on beneficial insects during the cotton growing season in north AL, while rye residue promoted beneficial insect persistence in south AL cotton better than radish cover crops. Soybeans planted into rye-radish-clover mixture residue may benefit from lower amounts of bean leaf beetle pests during the growing season. Center pivot irrigation may increase populations of certain peanut pests such as spotted cucumber beetles (*Diabrotica undecimpunctata*) and three cornered alfalfa hoppers. Crimson clover cover crops may increase the presence of grasshoppers (Acrididae) and leafhoppers (Cicadellidae) early in the cotton growing season in north AL. While cover crops like crimson clover may attract greater numbers of beneficial and pest insects during the cover crop growing season, they have minimal influence on insect populations during the cash crop growing season in Alabama row crop production systems.

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LIST OF ABBREVIATIONS

TVREC	Tennessee Valley Research and Extension Center, Belle Mina, AL
WREC	Wiregrass Research and Extension Center, Headland, AL
TPB	Tarnished plant bug
BLB	Bean leaf beetle
TCAH	Three cornered alfalfa hopper
BSB	Brown stinkbug
BMSB	Brown marmorated stinkbug
SGSB	Southern green stinkbug
RSB	Rice stinkbug
GH	Grasshopper
CSB	Clover stem borer
CB	Cucumber beetle
GCW	Green clover worm
FAW	Fall armyworm
CBW	Cotton bollworm
TBW	Tobacco budworm
YSAW	Yellow striped armyworm
LB	Lady beetle
BEB	Big eyed bug
FA	Fire ant
SSB	Spined soldier bug
HF	Hoverfly
GLW	Green lacewing
BW	Braconid wasp
TF	Tachinid fly

I. LITERATURE REVIEW

Introduction

Humans rely upon cropland soils for the provision of several critical services such as food, fiber, and fuel (Lal, 2008; Franzleubbers, 2010). Unfortunately, the world loses more than 10 million hectares of soil annually due to poor management, erosion, and salinization (Derpsch, 2003). The long-term use of unsustainable land management practices, especially in the southeastern United States, has left large swathes of agricultural soils in a degraded state (Lal, 2004). The farmers who cultivated the nation's ground in the 1800s and early 1900s could have never predicted the widespread loss of fertility and structural integrity that their erosive practices would one day have across the southern Coastal Plain and Piedmont regions (Triplett and Dick, 2008). The Coastal Plain is a humid region, naturally dominated by highly-weathered, coarse-textured Ultisols with poor water and nutrient holding capacities (Shaw et al. 2002; Schomberg et al., 2006). These soils have historically been planted to cotton (*Gossypium hirsutum*), corn (*Zea mays*), and peanuts (*Arachis hypogea*) managed with conventional tillage, which over time has led to large losses of fertile topsoil and the development of compacted subsoil layers. Similarly, the Piedmont region now harbors some of the most highly eroded soils in the entire country. This area is characterized by an abundance of low activity kaolinitic clay and has far greater topographical variation than the relatively flat Coastal Plain. With an average topsoil loss depth of 17.8 cm, some fields in the Piedmont have developed gullies so large that farmers are now incapable of planting crops in eroded areas (Trimble, 1974). The poor condition of America's arable land during the Dust Bowl prompted the USDA to form the Soil Erosion Service (SES) in the 1930's to perform erosion surveys and promote management practices to prevent soil erosion. The formation of the SES, renamed the Natural Resource Conservation Service in 1994, has led to more widespread adoption of soil conservation practices today.

Conservation Systems in the Southeast

Crop yields in the Southeast are often limited by the soil's historic degradation and inherent lack of organic matter, which can exacerbate other issues related to low soil pH and nutrient holding ability (Franzluebbers, 2010). By implementing conservation practices such as reduced tillage and cover cropping, farmers can increase their soil organic matter (SOM), which leads to improvement in many other soil health parameters (Edwards et al., 1992; Causarano et al., 2008). Conservation agriculture systems aim to increase SOM by keeping the soil surface covered with semi-permanent mulch or residue from organic materials like cover crops (Derpsch, 2003). Cover crops are plants grown to cover the soil surface during times when fields would otherwise be left bare and fallow (Dabney et al. 2001). The most commonly planted cover crops in the Southeast are winter annual cereals (Poaceae), legumes (Fabaceae), and brassicas (Brassicaceae) (Schomberg et al., 2007; USDA-SARE, 2017). Utilizing cover crops with high biomass accumulation potential can be an effective tactic to raise the productivity of conservation cropping systems in the Southeast, as high-residue cover crops have been shown to improve the biological, chemical, and physical properties of the soil (Langdale et al., 1990; Schomberg et al., 2008). Properly managed cover crop residue can help decrease erosion, improve aggregation, increase water infiltration, conserve moisture, and build soil carbon (C) and nitrogen (N) levels (Castro and Logan, 1991; Franzleubbers et al., 1995; Causarano et al., 2008). Residue aids in mitigating the erosion of surface sediments by intercepting rainfall impacts, which lowers the volume and speed of water that will eventually run off the field (Dabney et al., 2001). Increased additions of C and N promote higher soil quality, which raises the production potential of the entire cropping system (Bauer and Black, 1994). The practice of planting winter cover crops to improve factors such as soil quality, soil moisture retention, and weed suppression has become increasingly popular in recent years (USDA NASS, 2012). However, attaining these goals on a national scale requires an awareness of the financial barriers and geographical limitations of cover crops (Hamilton et al. 2017). Today, federal and state agriculture departments seeking to increase cover cropped acreage offer incentive programs to offset some of the input costs for farmers interested in using cover crops (Mirsky et al., 2009).

Conservation Tillage

Conventional tillage negatively impacts soil quality by leaving fields vulnerable to degrading forces of rain, wind, and heat (Derpsch, 1998). When conventional tillage is used for emergency weed control or to enhance C and N mineralization, it also breaks up soil aggregates which diminishes soil structure (Cambardella and Elliott, 1993; Derpsch, 2003). Conventional tillage also often has the unintended effect of destroying or dispersing most of the beneficial insects present in the field (Phatak and Diaz-Perez, 2007). Additionally, intensive tillage can deplete SOM levels substantially over time, which has pushed many farmers in the Southeast to implement conservation tillage practices. Conservation tillage is generally defined as any practice that leaves behind over 30% of residue cover on the soil surface. The most widely used types of conservation tillage include no-till, mulch-till, and strip-till (USEPA, 2018). No-till is the planting of cash crops into undisturbed soil, while mulch-till includes any non-inversion tillage (e.g., chiseling) that leaves behind more than 30 percent of surface residues (CTIC, 2001). Many southern farmers use coulters or in-row subsoilers to carry out strip-tillage, a soil conservation method which leaves behind a 15 – 30 cm wide undisturbed inter-row area (Schomberg et al. 2006). Strip-tillage is desirable because it reduces erosion and water losses, increases soil temperatures for better seed germination, and can increase crop yields compared to conventionally tilled systems (Busscher et al. 2003; Kaspar et al. 1990; Lascano et al. 1994). Converting to a conservation cropping system requires widespread management changes, because altering components in an incomplete manner will render the system inefficient (Derpsch, 2003). For example, if a farmer plants a field with winter cover crops and later conventionally tills the field, they will miss out on the erosion reduction and moisture conservation offered by undisturbed residue.

Cover Crop Systems

Tillage practices have significant impacts on conservation cropping systems, but cover crops play an important role as well. In a 25-year cotton study, researchers found that a hairy vetch (*Vicia villosa*) cover crop improved SOM, porosity, aggregate size, permeability, and cash crop yield - even when it was conventionally tilled (Patrick et al., 1957). When used in conjunction with cover crops, conservation tillage allows for the greatest quantity of residue to endure on the soil surface for the longest amount of time. The majority of data shows that using conservation tillage with cover crops increases the positive effects on the soil, especially on parameters like C sequestration and organic matter accumulation (Causarano et al., 2008; Franzluebbers, 2010). Cover crops can also improve soil aggregation by promoting glomalin-producing mycorrhizal fungi populations (Galvez et al., 1995; Wright et al., 1999). Mycorrhizal fungi help crops take up more water and nutrients, but fields need actively growing cover crop roots and minimal soil disturbance to maximize these benefits. In addition to soil health benefits, studies have also observed greater weed suppression with cover crops when the residue is not managed with tillage (Blum et al., 1997). Field improvements gained from switching to a conservation tillage system with a well-planned cover crop rotation can improve profitability over traditional systems (Sorrenson, 1984; Derpsch, et al., 1991). Farmers in Paraguay, for example, were able to significantly improve their corn and cotton yields by switching to a no-till green manure cover crop system for a 4 year period (Florentín et al., 2001; Derpsch, 2003).

While there are many benefits of cover crops, potential challenges should also be considered in order to maximize the economic productivity of a cropping system. Surface residue can be an obstacle for the planter and may result in poor cash crop seed to soil contact, especially for high biomass cover crops (Grisso et al., 1984). Annual cover crops may also contribute to the weed seed bank if they are terminated after reproductive maturity, which could complicate management for farmers who only want to try cover crops for one growing season (Landis et al., 2000). Cover crops can also harbor diseases that impact cash crops, and corn crops planted directly after a cereal rye cover crop may experience greater issues with seedling diseases such as *Pythium spp.* (Robertson et al., 2016). Southeastern farmers interested in cover crop implementation must consider all impacts of introducing cover crops species into their agroecosystems on logistics, procedures, and crop management goals. Due to the myriad of potential impacts cover crops may have, proper selection to meet production goals is critical.

Small Grain Cover Crops

Several winter annual grass cover crop species are available for farmers to select from, including cereal rye (*Secale cereale*), oats (*Avena sativa*), wheat (Triticum aestivum), and triticale (*x Triticosecale*). Cereal rye is frequently planted as a cover crop in the U.S. for its ability to survive harsh winters, produce high biomass, and resist degradation (Wilkins and Bellinder, 1996). In the Southeast, rye establishes early and matures rapidly, which simplifies the timing component of integrating it into an existing crop rotation (Stoskopf, 1985). Farmers in the

Coastal Plain region planting into sandy or acidic ground can still easily establish a small grain cover crop with relatively low seed costs (SARE, 2007). A stand of high-biomass, mature small grain plants can serve many purposes, including better water infiltration, reduced evaporation, and suppression of weeds (Decker et al., 1994). They can improve nutrient cycling within a cropping system by acting as a sink for additional N and P provided by poultry-litter applications (Mirsky et al., 2009). The large fibrous root systems of small grains take up anywhere from 28 to 112 kg N ha^{-1}, which may be used by the following crop as the residue breaks down (SARE, 2007). Small grains can immobilize N immediately following termination, but the fate of N is impacted greatly by cover crop combinations and termination practices. If small grains are terminated before maturity and paired with a legume cover crop like hairy vetch, they will be less likely to immobilize N (SARE, 2007). Complete termination of a rye cover crop is essential because permitting growth to continue can deplete soil moisture levels, especially during spring planting periods with little rainfall (Liebl et al., 1992; Mirsky et al, 2009).

Legume Cover Crops

Winter annual legumes are frequently used as cover crops. Legumes provide N to the soil through symbiotic association with *Rhizobium,* a genus of bacteria which can fix atmospheric N_2 and convert the N into plant-available forms (Bowman et al., 2000). Crimson clover (*Trifolium incarnatum*) is a popular legume for livestock grazing, but it is also a highly valuable cover crop, green manure, and weed suppressor (SARE, 2007; Bowman et al., 2000). This cover crop prefers well drained sandy loam soil and grows best during cool, wet conditions. Crimson clover typically performs well in mixtures with other legume and grass cover crops, and reseeding cultivars can give fields a long-term source of natural fertility. Crimson clover accumulates N later into the spring, and the residue can contribute anywhere from 80 to 170 kg N ha^{-1} to the following cash crop during the first 4 weeks after termination (Wilson and Hargrove, 1986; Schomberg et al., 2006; Dabney et al., 2001). The low C:N ratio of crimson clover residue does make it susceptible to rapid degradation, but its ability to quickly accumulate biomass in the fall can provide an option for farmers who manage systems with short rotation windows, which is often the case with cash crops like cotton (SARE, 2007). In the warm climate of the Southeast, crimson clover rarely winterkills, so biomass production levels may range from 4,000 to 6,000 kg ha^{-1} (Bowman et al., 2000; SARE, 2007). Studies in Mississippi suggest that crimson clover can outperform other legumes such as hairy vetch, berseem clover (*Trifolium alexandrinum*), and winter peas (*Pisum sativum*) in terms of biomass production (Varco et al., 1991). The consistent performance of crimson clover across a wide range of soil types and climates make it an ideal legume cover crop for the Southeast. Crimson clover and other legumes also provide abundant habitat and nectar resources for helpful insect pollinators (SARE, 2007).

Brassica Cover Crops

Brassica cover crops can provide benefits in many agricultural production systems, including tree fruits, vegetables, and row crop systems. The ability of cover crops such as Daikon radish (*Raphanus sativus*) to reduce erosion, sequester nutrients, and suppress pest levels has increased interest in including brassica species in southern crop rotations (SARE, 2007). If the planting date is optimal, brassica cover crops can produce over 9,000 kg ha^{-1} of biomass, and its large lobed leaves cover up to 80% of the soil surface, shading out weeds and reducing erosion by intercepting most rainfall before it impacts the ground (Haramoto and Gallandt, 2004). Nitrogen accumulation is positively correlated with biomass production, so a dense stand of Daikon radishes can accumulate up to 160 kg N ha^{-1}, some of which may be available to the following cash crop (Ngouajio and Mutch, 2004). Additionally, brassica species produce glucosinolate compounds which can be toxic to certain harmful bacteria, fungi, insects, and nematodes (Matthiessen et al., 2006). Farmers planting brassica cover crops for their pest fumigant properties will have greater success if the residue is mechanically incorporated into the soil, so no-till management may be less preferable in this case. Radishes may winterkill if temperatures dip below approximately 4°C, but the plants will quickly decompose and leave behind macropores in the seed bed for better water infiltration. The large fleshy taproot of the plant can alleviate some compaction in the upper portion of the soil profile (Williams et al., 2004).

Cover Crop Benefits and Challenges

Cover crops can give farmers a wide range of benefits, but some benefits are more reliable and predictable than others. Based on cover crop selection, both primary and secondary production goals may be attainable. Primary goals are generally related to soil health benefits, while secondary goals pertain to improving management of other components of the cropping system. For example, having large quantities of cereal rye surface residue reliably protects the soil from eroding, lowers evaporative losses of water, and raises organic matter levels over time (Derpsch, 2001). Similarly, well inoculated legume cover crops often contribute N to the following crop, so improving soil fertility and lowering fertilizer costs are primary benefits that farmers are likely to achieve (Bowman et al., 2000). These primary goals will remain consistent for a number of different soil types and cropping systems, but for secondary goals, the benefits may be more variable. Based on the level of pest pressure in the area, cover crops have potential to assist growers with preventing weed germination, lowering pest populations, and reducing chemical inputs. Multiple studies have reported weed suppression with high-biomass cover crops following termination (Price et al., 2008; Price et al., 2016), and flowering cover crops can raise beneficial insect abundance (Putnam et al., 1983; Barnes et al., 1987; Bugg and Van Horn, 1998). Promoting populations of beneficial predatory species can also help enhance environmental stewardship by minimizing reliance on pesticides, which consequently reduces chemical exposure and mitigates groundwater contamination (R. L. Bugg, 1991). Despite these positive findings, secondary improvements can be sporadic and are often perceived as less reliable. Further research is necessary to provide a broader perspective on how cover crops can benefit row crop producers in the Southeast.

Conservation Tillage Effects on Insect Dynamics

Some growers have used tillage as a pest management strategy because mechanical disruption of the soil causes high insect mortality and disturbs pest habitats. However, fields under no-till management experience less erosion and greater soil moisture conservation than conventional tillage systems, and some research has even shown no-till systems may be less susceptible to insect pest outbreaks. Not only has no-tillage been shown to increase total arthropod presence and species diversity, it can preserve populations of predators like spiders during periods of drought stress (Blumberg and Crossley, 1983). Cover crop systems with minimal soil disturbance can help bolster beneficial arthropod populations in a variety of ways, such as: 1) providing reproductive sites, 2) providing alternate prey/hosts, or 3) protecting from inclement weather. For example, beneficial ground nesting wasps can be preserved by utilizing conservation tillage but would likely be killed by conventional tillage (House and Alzugaray, 1989). A cover crop trial on a Nebraska corn (*Zea mays*) farm found that ground beetle (Carabidae), a soil-dwelling predator, populations were substantially higher in conservation tillage plots with a wheatgrass (*Thinopyrum intermedium*) cover crop compared to tilled fallow plots. The increased presence of predatory Carabidae reduced third instar populations of western corn rootworm (*Diabrotica virgifera)* pests, which in turn lowered root damage ratings in the corn crop (McMechan et al., 2017). Reichert et al. (1990) found grass hay mulches can also increase the presence of certain beneficials such as spiders. In southern row crop fields managed under conservation tillage for many years, shelter availability may improve conservation biological control of Heliothine pests such as tobacco budworm (*Helicoverpa zea*; TBW). When fields are managed with conservation tillage to preserve shelter and habitat for beneficial fire ants (*Solenopsis invicta;* FA), it promotes higher rates of predation upon TBW and cotton bollworm (CBW) eggs (McCutheon et al. 1994). These findings are backed by other studies which found conservation tillage cotton plots with crimson clover and rye residue contained significantly greater numbers of aphidophagous FA than fallow, conventionally tilled cotton plots (Tillman et al., 2004).

Cover Crop Effects on Pest and Beneficial Insect Populations

Cover Crop-Insect Community Dynamics

Beneficial arthropods are usually categorized as predators or parasitoids, and both serve important biological control purposes in the environment. Predators are considered generalists and will take advantage of a wide range of food sources, while parasitoids are generally specialists and often seek one species of prey. Predators kill other insects through direct consumption, while parasitoids usually spend their larval stage inside a host insect, resulting in death of the host insect (Phatak, 2007). The original definition of biological control refers to using agents such as parasitoids, predators, or pathogens to maintain pest populations at lower levels than if agents were not present (Altieri et al., 1997). For southern conservation cropping systems, the question remains: Can cover crop implementation positively affect biological control by promoting naturally occurring predator/parasitoid populations? Cover crops can influence both pest and beneficial insect numbers in the field and can impact farms negatively if they provide habitat or food sources for large quantities of pests and attract very few beneficial insects. Effects of cover crops on insect populations are influenced greatly by species complexes, natural processes, and management practices (Lewis et al., 1997; Dabney et al., 2001). The success of cover crops to increase beneficial insect abundance and persistence relies on the quality and quantity of winter cover crops, the presence of extrafloral pollen sources, and the extent to which cash crop insecticide applications negatively impact natural enemy populations (Wissinger, 1997; Wratten et al., 1995). Conservation biological control, in this context, involves using cover crops to manipulate the environment to promote survival, reproduction, and predatory effectiveness of natural enemies (Landis et al., 2000). For insect pest management, biocontrol should aid in suppressing pest populations below levels that cause economic loss and reduce reliance on chemical pest control measures.

Insect pests cause damage to cash crops through feeding and disease transmission, but they can be controlled by their natural enemies in well-balanced crop production ecosystems. Beneficial insect complexes must be large enough that pest populations are regulated at low levels for the system to be balanced. Research has demonstrated that introducing conservation practices can improve pest management services within an agroecosystem by promoting diverse communities of beneficial insects (Rabb et al., 1974; Blumberg and Crossley, 1983). Cover crops eliminate long fallow periods and provide food and habitat for insects in crop ecosystems. Cover crop residue can provide shelter for ground dwelling predators, while flower nectar offers a supplemental food source for various generalist beneficial insects (Phatak, 2007). The ephemeral nature of conventional cropping systems often results in inhospitable field conditions for insects during fallow periods, which is not optimal for overwintering of beneficial predators (Wissinger

1997). Furthermore, low levels of heterogeneity and frequent disturbances (e.g., pesticide applications, traffic through fields, tillage) common to conventionally managed row crop systems can create fewer desirable habitats for natural enemies (Gurr et al. 2016), especially in annual monoculture cropping systems where the establishment rate and pest-reducing ability of beneficial insects is lower than in more balanced systems (Landis et al. 2000). Research is needed to determine how to better promote beneficial insect persistence after cover crop termination. Successfully using cover crops for conservation of beneficial insects depends on ecosystem properties, the crop, and pest complexes targeted.

Each generation of insects needs food, water, and harborage to survive, and the disruption of these resources can reduce survival or increase migration from an area. Diversity of insect communities has been a cornerstone for measuring ecosystem health, but the benefit of natural enemy diversity for pest suppression to prevent economic losses is debated. It remains unclear if increasing beneficial insect diversity should be the primary goal when seeking to augment conservation biological control. Some biological control programs have demonstrated effective control by introducing very few natural enemies that are effective at reducing primary pests (Myers et al. 1989), while others claim crop pests are best regulated by a varied community of beneficials (Losey and Denno, 1998). A meta-analysis found that groups of three introduced beneficial insects provided successful biological control only 32% of the time, whereas just one species achieved the same goal 68% of the time (Myers et al. 1989). The effects of intraguild predation and behavioral interference among cyclically colonizing insects can both contribute to the detriment of conservation biological control (Wissinger, 1997). Intraguild predation occurs when one beneficial predatory species consumes another, whereas behavioral interference involves one species reducing the ability of another to capture prey (Jonsson et al. 2017). For example, high numbers of large-bodied predators such as ground beetles (Carabidae) may reduce pest control through intraguild predation. In addition to the number of beneficial insect species present, the duration of habitat availability may have a large impact on biological control efficacy. Winter cover crops terminated prior to cash crop planting may still promote beneficial insect presence but will likely be incapable of competing with systems which have permanent habitat reservoirs established for cyclical predator colonization. For natural predators to be effective in typical southern crop rotations, they must be able to thrive in the annual cover crop habitat and also re-colonize fields at the beginning of the summer growing period (Wissinger, 1997).

The level of pest suppression by natural enemies in a cropping system is also influenced by mechanisms such as resource partitioning and positive selection effects (Jonsson et al. 2017). Resource partitioning involves natural predators feeding on different life stages of the same pest, which reduces instances of detrimental intraguild predation. Positive selection, on the other hand, relates to increasing natural predator diversity to raise the likelihood that an exceptionally effective beneficial species will be present. In this case, increasing natural predator diversity is advantageous for cultivating dependable biological control because similar species help maintain functional redundancy within the predator community. For example, if one beneficial insect population is reduced, another functionally equivalent (redundant) species may help preserve prey suppression over time by replacing the lost functions of the reduced group (Jonsson et al. 2017). Managing farms for increased landscape and insect community diversity may enhance certain agricultural processes, but some researchers argue functional trait diversity is superior for predicting ecosystem functioning (Gagic et al. 2015). The abundance of different functional traits such as foraging mode, diet breadth, and microhabitat use may contribute to biological control more than species diversity and abundance alone.

Cover crop monocultures and mixtures, if terminated improperly, could potentially cause large scale dispersion of pests to the cash crop. Consequently, effective pest control via natural predators is likely more achievable in small-scale heterogeneous cropping systems rather than large-scale homogeneous cropping systems (Bianchi et al. 2006). Managing ecosystem properties for conservation of natural enemies has yielded conflicting results, indicating there is no one size fits all approach. By not entirely terminating cover crops and allowing them to grow as intercrops, the cropping system may become more stressed. Studies have found limited benefits or even negative effects when cover crops are grown as intercrops to augment natural enemy populations (Landis et al., 2000). Specifically, benefits gained from increased natural predator activity in intercropping systems may be outweighed by lower yields from the cash crop competing with the cover crop for water and nutrients (Dempster, 1969; Reeves, 1994;Unger and Vigil, 1998).

Small Grain Cover Crops and Insect Populations

Small grain cover crops can provide several valuable benefits to the soil, but their effects on insect populations have been both positive and negative (Decker et al., 1994). Cereal rye can sustain large populations of pestiferous bird-cherry oat aphids (*Rhopalosiphum padi L.*) in the early spring, which can lure in predatory lady beetles (Coccinellidae*;* LB). Aphid abundance patterns usually reflect LB attendance and reproduction on rye cover crops, whether grown in monocultures or in mixtures (Bugg et al. 1991). While rye can increase LB numbers by providing prey, other studies compared different cover crop mixtures for presence of big eyed bugs (Geocoridae; BEB) in a cantaloupe (*Cucumis melo* L.) field and found less promising results (Bugg et al. 1990). The rye monoculture plot harbored particularly low numbers of BEB compared to subterranean clover, indicating the pollen and nectar provided by the clover has stronger impacts on BEB than the habitat provided by rye (Bugg et al. 1990). Fields inhabited by smaller predatory species are superior at controlling pests like aphids because intraguild predation occurs less frequently (Rusch et al., 2015). Soil-dwelling rove beetles (Staphyliniidae) can effectively control aphids in Swedish barley production systems, reducing yield losses from aphid damage by 23% (Ostman et al. 2003). The resources a cover crop provides, usually food resources or harborage, determine the eventual impact on insect dynamics.

Legume Cover Crops and Insect Populations

Legume species offer great promise as cover crops for conservation biological control because they can serve as insectaries for beneficial insects such as those in the families Geocoridae, Ichneumonidae, and Braconidae (Bugg et al. 1990; Bugg et al. 1989; Bugg and Ellis, 1990). However, some studies have reported concerning findings regarding legume cover crops and insect pests. If a legume cover crop, such as crimson clover, is unable to attract sufficient numbers of beneficial insects, it could harbor detrimental amounts of cotton pests such as cutworms (*Agrotis spp.)*, TBW, and tarnished plant bugs (*Lygus lineolaris;* TPB) (Stadelbacher, 1981; Snodgrass et al., 1984; Dabney et al., 2001). Laboratory choice tests revealed TPB prefer the reproductive portions of crimson clover over hybrid vetch or subterranean clover (Bugg et al. 1990b). Various clover cover crop species can also attract high numbers of spider mites and thrips (Boucher and Plotkin, 2012). For legumes managed as a living mulch, springtime pest monitoring is crucial when cover crops are senescing or drought-stressed because two-spotted spider mites (*Tetranychus urticae*) may disperse to associated cash crops and inhibit their early growth stages (Tedders et al., 1984). These insect pests can typically be avoided in conservation cropping systems by applying insecticides at planting or by terminating the legume three to four weeks before planting the cash crop (Leonard et al., 1994; Dabney et al., 2001). Nevertheless, there are multiple documented success stories in which legume cover crops improved beneficial insect activity and conservation biological control. A study conducted in South Carolina found a crimson clover cover crop encouraged greater parasitism of both TBW and CBW larvae present in the clover (McCutheon et al. 1994). Various species of Braconidae (*Cardiochiles nigriceps*, *Meteorus autographae*, and *Microplitis croceipes*) parasitized TBW and CBW 66% and 33%, respectively. This study reported a strong correlation between the presence of crimson clover and greater populations of several beneficial insects, including lacewings (*Chrysopa spp*.) and LB in the early spring, and spiders and BEB later when the clover began to mature. Reichert et al. (1990) found high densities of spiders can reduce cash crop damage, but also significantly lower the amount of prey available to other predators. Big eyed bugs have also been observed in great abundance during late spring on other legumes such as arrowleaf clover (*T. vesiculosum*), berseem clover (*T. alexandrium*), and subterranean clover (*T. subterraneum*) (Bugg et al. 1990). On winter legume cover crops such as these, BEB likely subsist on a variety of pest species, including spider mites (Tetranychidae), collembola, thrips (Thysanoptera), aphids, and TPB.

The dynamics of some insect species within a legume cover crop system are more complex. For example, Thysanoptera on the inflorescences of crimson clover may be perceived as pests, but the role they play with other arthropods in an agronomic system is multifaceted. Some thrips (Thysanopteran) species commonly cause damage to cash crop leaves in early growth stages, but they feed on Tetranychidae eggs and serve as a food source for beneficial BEB and LB (Bugg, R. L. 1991). Aphids are similar because while they cause direct feeding damage and can transmit diseases to the cash crop, they are frequently preyed upon by various predatory beneficials. Many legume species, including crimson clover, are potentially susceptible to late winter/early spring aphid infestations. However, a study in southern Georgia found clover cover crops can afford alternate prey such as thrips or aphids without incurring major damage, and still harbor helpful species like the convergent lady beetle (*Hippodamia convergens*) and seven-spotted lady beetle (*Coccinella septempunctata*). Researchers in this study also reported particularly high densities of hover flies (Syrphidae) in crimson clover plots, providing further evidence of its ability to provide resources which support beneficials (Bugg et al. 1992) The morphology of clover plants naturally provides great habitat for beneficials, but the nectar resources they produce are important as well. Specifically, crimson clover cover crops have stronger impacts on short-tongued beneficials such as Syrphidae compared to plants like Lacy phacelia (*Phacelia tanacetifolia*), because the corollas on clover inflorescences are not as deep and therefore do not inhibit nectar access (Landis et al. 2000).

Brassica Cover Crops and Insect Populations

Unfortunately, research focused on evaluating brassica cover crop effects on insect complexes is lacking. *Brassicaceae* often possess varying levels of pest-repelling glucosinolate compounds but can still become infested with green peach aphids (*Myzus persicue*) or turnip aphids (*Hyuduphis erysimi*) (Bugg et al. 1991; SARE, 2007). The present knowledge gap regarding brassicas and insects provides reasonable justification for further inquiry into whether pest attendance on brassicas will worsen pest issues in cash crops.

Cover Crop Mixtures and Insect Populations

Cover crop mixtures may be desired to provide diverse benefits to the soil. For example, consider a cover crop mixture containing a small grain, legume, and brassica species. The small grain produces significant biomass, which helps prevent soil erosion and increase SOM. The legume provides a source of plant-available N, while brassicas have deep taproots that can scavenge for nutrients deeper in the soil profile. Growing a diverse array of cover crop vegetation may also help to increase insect habitat variation and support higher numbers of beneficials (SARE, 2007). Small grains establish rapidly and may provide resources for insects earlier in the growing season. Winter annual legumes are slower to establish and produce less biomass than rye but provide food and refuge for beneficial insects (Tillman et al. 2004). Different developmental speeds for these two cover crops suggests their maturity stages could overlap, and thus extend the amount of time beneficials would be attracted to additional pollen and nectar resources. Research has demonstrated farms lacking diversity in the form of later-maturing host plants may predispose pests such as spider mites to rapidly migrate to the cash crop (Bugg, R. L. 1991). Bugg et al. (1990a) showed hairy vetch/ryegrass cover crop bicultures can remain green longer than clover monocultures and attract large amounts of beneficial BEB. Other research in Georgia has shown bicultures of hairy vetch and cereal rye can increase LB populations in orchard systems (Bugg et al. 1991a). Other studies have demonstrated certain predators such as spiders may be largely unaffected by the presence of multiple plant species, so further research is necessary to determine the effects of cover crop mixtures on specific beneficial insects in southeastern cropping systems (Snodgrass et al. 1989). A cotton study in Tift County, Georgia found cover crop mixtures were preferable for augmenting insect complexes (Tillman et al. 2004). The most common pest species collected via sweep net in the study were: aphids, TPB, stink bugs (*Halyomorpha halys*), and Heliothines such as TBW and CBW. The Heliothine pests exceeded the economic threshold for cotton more often in the fallow control plots than plots with a rye and crimson clover mixture (Tillman et al. 2004). The primary beneficial predators found in cover crops and cotton throughout the study were BEB, insidious flower bugs (*Orius insidiosus*), FA, and aphidophagous LB. In both years, the legume cover crop mixture (Hairy vetch, balansa clover, crimson clover) harbored significantly higher numbers of both BEB and insidious flower bugs compared to the rye monoculture treatment. Results also indicated the legume cover crop mix provided more suitable springtime habitat for LB than the rye monoculture (Tillman et al. 2004). In addition to boosting beneficial insect populations, the legume mixture and crimson clover plots also both produced significantly higher cotton yields compared to the control plot. Southeastern farmers considering planting a cover crop mixture should actively scout their fields to attain a better understanding of which specific pests are causing the greatest amount of crop damage.

Secondary Cover Crop Impacts on Insect Populations

Soil properties such as organic matter content and microbial populations are affected by cover crops, and therefore may potentially impact insect communities. For example, adding organic matter with cover crop residue and reducing tillage both play key roles in improving soil health and minimizing how vulnerable a crop is to pest damage. Research in Georgia has shown that cotton grown in soil with higher biological activity has better natural resistance against insect pests than cotton grown on poorly structured, low fertility soil (Phatak, 2007). Maintaining soil health with cover crops can influence pest suppression by stimulating microbial competition in the soil, preserving alternative prey populations, and reducing crop water stress. When soil aggregates are undisturbed, cover crops raise soil microbial biomass and enzyme activity levels

(Mendes et al., 1999). Soils with an upper layer of decomposing cover crop residue can stimulate fungal and bacterial populations that parasitize other organisms which would be antagonistic to the cash crop. In addition to microbes, biologically active soils with higher organic matter (OM) levels are exceptional at supporting complex food webs that preserve predatory insect populations in an area (Magdoff and van Es, 2000). An increase in soil dwelling detritivores (Collembola) in high OM soils has been shown to increase the number of above ground generalist predators, including Carabidae spp. and spiders (Settle et al. 1996). Beneficial Carabidae spp. and spiders can respond more quickly to insect pest outbreaks if they are already present and feeding on alternative populations of soil mesofauna (Purvis and Curry, 1984; Bilde et al. 2000). Finally, adequate amounts of cover crop residue can reduce evapotranspiration at the soil surface which improves the cash crop's ability to persist against insect damage and still produce high yields. Good soil moisture maintenance is critical because water stress restricts protein synthesis and increases soluble N concentrations which can make foliage more attractive to pests (Waring and Cobb, 1991).

Cover Crop Nitrogen Contributions and Insect Pest Effects

The amount of N a cover crop can take up from the soil depends on several factors, including species, planting date, termination time, and climate (Gallaher, 1977; Groffman et al., 1987; Staver and Brinsfield, 1998). Similarly, the rate of N release from cover crops after termination will vary according to growth stage, management, and lignin/cellulose content (Muller et al., 1988; Bowen et al., 1993). Grain cover crops like cereal rye generally produce high C:N ratio (>35) residue, which can cause N immobilization and reduce the speed of N release (Pink et al., 1948). Conversely, legume cover crops typically have low C:N ratios (<20) and can lessen the amount of N fertilizer needed for the following cash crop (Touchton et al., 1982; Ebelhar et al., 1984). To raise the efficiency of production, cover crop N release needs to be synchronized with cash crop demand. Cotton, for instance, experiences peak N demand 11-12 weeks after planting and can therefore make good use of slowly-available cover crop N in no-till systems (Ebelhar, 1990; Oosterhuis, 1990).

Nitrogen is certainly a vital plant macronutrient, but excessive N fertilizer applications actually reduce cash crop insect resistance by increasing cellular N concentrations, protein synthesis, and lush vegetative growth (Altieri, et al., 2012). The combination of high plant N levels and excessive vegetative growth can raise insect pest and fungal pathogen numbers (Birkhofer et al., 2008). For example, higher free N levels in plant sap following urea applications can stimulate more frequent outbreaks of pests like whiteflies and aphids (Altieri & Rosset, 1996). In sandy soils with naturally low levels of available N, winter legumes can be implemented as a valuable N source without providing an oversupply. Touchton et al. (1984) found cotton grown after a crimson clover cover crop actually had higher yields when no additional fertilizer was applied compared to cotton that received an additional 34 kg N ha^{-1}. Though more research is needed in this area, it stands to reason that using legume cover crop residue as a natural slow release N source could potentially provide greater tolerance to insect damage because it releases N more gradually throughout the growing season.

Cover Crop Effects on Insecticide Applications

Maintaining a healthy relationship between the above and below ground components of an agroecosystem can reduce input costs from insecticide applications through improved cash crop pest resistance and natural enemy proliferation (Yardim and Edwards, 2003). Therefore, farmers could lessen their reliance on chemical insect pest control methods by utilizing conservation tillage and cover crops. For example, Georgia farmers participating in a cotton/peanut rotation study reduced their insecticide costs by $49-$99/ha compared to similar conventionally managed systems. Insecticide costs decreased substantially in cover-cropped fields because many key pests were less problematic, including: thrips, CBW, TBW, fall armyworms (*Spogoptera frugiperda*), aphids, and whiteflies (*Aleyrodidae spp*.). In addition to cotton and peanut farmers, several Georgia vegetable producers who grew cucumbers (*Cucumis sativus*), squash (*Cucurbita spp*.), and peppers (*Capsicum annuum*) and used cover crops in their rotations were able to reduce their insecticide sprays compared to vegetable systems with no cover crops (Phatak, 2007).

While insecticides may briefly lower pest populations, they can cause considerable harm to existing beneficial insect complexes (Blumberg and Crossley, 1983). Choosing to spray insect growth regulators instead of more broad-spectrum insecticides can help preserve larger beneficial insect populations (Gurr et al., 2016). In conservation cropping systems, broad-spectrum insecticides should be avoided because they tend to destabilize the agricultural ecosystem. Establishing heterogeneous fields with sufficient refuge can minimize negative effects of pesticides on natural predators by promoting pesticide avoidance behavior (Wissinger, 1997). Using restorative management practices to minimize beneficial insect exposure to pesticides enhances the health and productivity of the entire cropping system, with the added benefit of reducing farm input costs.

Research Objectives

To encourage more producers to implement cover crops and biodiversity as viable pest management strategies, researchers should develop protocols which are both economical and practical. Protocols should be dynamic, and account for different grower's region-specific target pests and soil health concerns. Species present in a beneficial/pest insect complex may vary depending on: Where the farm is located, what the next cash crop will be, and the availability of nearby habitat. Cotton, peanut, and soybean fields that growers are responsible for managing are quite complex, so focusing solely on conservation biological control with cover crops may not be the best approach. Enhancing biodiversity and natural enemies without sacrificing cash crop yield should be the overarching goal, with an additional focus on promoting effective ecosystem services through proper vegetation management.

Converting to a system with cover crops and conservation tillage introduces uncertainty regarding whether these management changes will have positive or negative effects throughout the agricultural environment (Hubbard et al., 2012). Specifically concerning cover crop effects on insect dynamics, farmers may have an array of inquiries on how management practices could impact their fields. Several research topics must be examined to assess the effects of cover crops on insect populations, including: 1) cover crop species impacts on beneficial insect presence 2) cover crop species effects on insect pest presence, 3) cover crop surface residue impacts on insect populations, and 4) interaction of cover crops and irrigation management on insect populations. It is critical to provide credible answers to these questions for a variety of common Alabama row crop systems, including cotton, peanut, and soybean. Frequently assessing pest and beneficial insect populations and quantifying the presence of different insect species could provide growers with more knowledge needed to make management decisions when converting to a no-till system with cover crops.

II. COVER CROP EFFECTS ON INSECT DYNAMICS IN CROPPING SYSTEMS OF THE SOUTHEASTERN U.S.

INTRODUCTION

Unsustainable land management practices in the southeastern United States have left large portions of agricultural soils in a degraded state (Lal, 2004). Crop yields in this region are often limited by the soil's inherently low organic matter, pH, and nutrient holding capacity (Franzluebbers, 2010). Utilizing conservation practices such as reduced tillage and cover cropping can help farmers improve several soil health parameters (Edwards et al., 1992; Causarano et al., 2008). Based on pest pressure levels, cover crops could also assist growers with lowering insect pest populations through conservation biological control. Conservation biological control involves using cover crops to enhance the survival, reproduction, and predatory effectiveness of natural enemies (Landis et al., 2000). The effects of cover crops on insect populations are influenced greatly by species complexes, natural processes, and management practices (Lewis et al., 1997; Dabney et al., 2001). Cover crops can influence both pest and beneficial insects in the field and can impact farms negatively if they provide resources for large quantities of pests while attracting very few beneficials. For insect pest management, biocontrol should aid in reducing pest populations below levels that cause economic loss and lower reliance on chemical pest control measures. Frequently assessing pest and beneficial insect populations and quantifying the presence of different insect species could provide growers with more knowledge needed to make management decisions when converting to a no-till system with cover crops.

MATERIALS AND METHODS

Experimental Design

Cover crop trials were established in the fall of 2018 and 2019 at the Tennessee Valley Research and Extension Center (TVREC) in Belle Mina, AL (34°41’22.4”N 86°53’01.7”W) and at the Wiregrass Research and Extension Center (WREC) in Headland, AL (31°30’N, 85°17’W). The TVREC cover crops were planted into a Dewey silt loam soil (fine, kaolinitic, thermic Typic Paleudult), while the WREC cover crops were planted into a Lucy loamy sand (loamy, kaolinitic, thermic Arenic Kandiudult). The field where plots were established at TVREC had been under no-till management for 20 years, whereas the WREC field had previously been managed with conventional tillage.

Trials were arranged in a randomized complete block design with 8 different cover crop treatments replicated four times in both irrigated and dryland conditions. Cover crops did not receive any center pivot irrigation, but the cash crops (soybean, peanut, and cotton) following the cover crops did. Irrigation treatments were spatially isolated at each location and therefore were not part of the randomized complete block design. Cover crop treatments included monocultures and mixture combinations of ‘Wrens Abruzzi’ cereal rye, ‘Dixie’ crimson clover, and ‘Sodbuster’ radishes. All treatments were evaluated against winter fallow control plots. Seeding rates for the cover crop treatments are presented in Table 1. The TVREC plots were 10.67 m long by 8.16 m wide, while the WREC plots were 10.67 m long by 7.32 m wide. In 2018, cover crops were planted in 19 cm rows with a Great Plains 3P606NT drill on 19 Oct. 2018 at TVREC and a Great Plains 1205NT on 19 Nov. 2018 at WREC. In 2019, cover crops were planted in 19 cm rows on 5 Nov. 2019 at TVREC and on 18 Nov. 2019 at WREC.

Before termination, cover crop biomass samples were taken to determine if there was a correlation between above ground biomass and pest or beneficial insect abundance. Biomass was collected by placing a 0.25 m^2 quadrat in two random spots within the plot and clipping all the above ground plant material. Samples were then oven-dried for at least 48 hours at 60° C and placed on a scale to determine dry biomass weight.

All major field operation dates are located in Table 2. Cover crop treatments were terminated at both locations at least two weeks prior to spring cash crop planting. At TVREC a herbicide mix of 2.24 kg/ha of Roundup PowerMax and 1.12 kg/ha of Sterling Blue (Dicamba) was sprayed on 4-16-2020. Cover crops at WREC only were rolled with a KMC rip/strip at termination in addition to a herbicide spray of 2.34 L/ha Glyphosate + 1.75 L/ha Prowl (Pendimethalin) + 0.14 kg/ha Valor (Flumioxazin). The TVREC plots remained exclusively no-till, while the WREC plots were in-row subsoiled with the KMC rip/strip before planting. Prior to this experiment, Deltapine 1646 B2XF cotton was grown at both locations in the summer of 2018. In 2019, Asgrow 55X7 soybeans were planted in 76 cm rows at TVREC on 22 May, 2019 and FloRun 331 peanuts were planted in 91 cm rows at WREC on 20 May, 2019. In 2020, Deltapine1646 cotton was planted in 102 cm rows at TVREC on 2 May, 2020 and in 91 cm rows at WREC on 28 May, 2020.

During the 2019 summer growing season, insect feeding damage on cash crops was sufficient to trigger insecticide applications. Soybeans at TVREC were sprayed with the group 3 pyrethroid GrizzlyToo (Lambda-cyhalothrin) at 0.14 kg/ha on 13 Aug. 2019 (Table 2). At WREC, peanuts were sprayed with 0.56 kg/ha Intrepid (Methoxyfenozide), a group 18 insect growth regulator, + 0.28 kg/ha of Interlock placement agent on 21 Aug. 2019. The TCAH was the most abundant pest in peanut plots prior to spraying, and visual observations of peanut showed significant defoliation, especially in dryland plots. During the 2020 growing season at WREC, cotton pinhead square assessments and internal boll damage ratings showed damage in dryland cotton plots was sufficient to trigger an insecticide application. The WREC dryland cotton was sprayed with 0.42 kg/ha of Bifenthrin on 8 Aug. 2020 (Table 2).

Insect Sampling

Insects were sampled once from cover crops in late April prior to termination, at which point all plants had reached reproductive maturity. During the 2019 summer growing season, soybean and peanut plots were sampled bi-weekly from 25 June 2019 to 11 Sept. 2019. During the 2020 summer growing season, cotton plots were sampled bi-weekly from 25 June 2020 to 3 Sept. 2020. Sweep net samples were used to assess the presence of different beneficial and pest insect species in each plot throughout the soybean and peanut growing seasons (Rudd et al., 1977). A total of 10 sweeps were taken down rows two and seven of each cover crop, soybean, and peanut plot, immediately placed into sealed bags and later refrigerated. Sweep net samples were also taken from cotton plots until plants began blooming with a total of 25 sweeps per plot. After bloom, insects were counted in cotton using a drop cloth for the remainder of the growing season. Pest and beneficial insects were identified in the field using beat sheet samples across 6 row feet of each cotton plot. All insect species were organized into family groups and categorized as either pest or beneficial.

The presence of thrips was assessed in all cash crops during the 2019 and 2020 growing seasons. Visual thrips counts were conducted for this experiment because other techniques such as plant washing are far more time consuming and produce similar total thrips numbers (Parajulee et al., 2006). In 2019, the TVREC soybean plots were sampled at the V3 stage in early June using a beat-bag method of 10 plants per plot. The WREC peanut plots were sampled by clipping terminal leaflets off of 10 young plants per plot and placing them into ethanol vials. Thrips from TVREC were counted against a contrasting white background with a hand-lens, while the WREC thrips were counted in petri dishes under a dissecting microscope. In 2020 at both locations, cotton plants were scouted for thrips using a beat-bag method at the 3-4 true leaf stage and evaluated for damage on a 1-5 scale. No cotton plants at WREC had a damage rating greater than two, and 94% of cotton plants at TVREC were rated 2 or less. Since very little damage was observed, damage ratings were not investigated further.

Cover crop biomass and insect data was analyzed using the GLIMMIX procedure in SAS. Statistical differences were determined using Tukey's HSD test at $\alpha=0.10$, and the Poisson distribution, which has been used in numerous experiments involving biological counts, was utilized to normalize insect count data (Kuno, 1991). Treatment, irrigation, year, and the interactions between the three variables were treated as fixed effects, and replication (block) was treated as a random effect.

RESULTS AND DISCUSSION

Cover Crop Biomass

Cover crop biomass was evaluated for monocultures and mixture treatments according to location. At TVREC, cover crop treatment affected biomass production according to year (Table 3). In 2019, clover produced higher biomass than rye and radish monocultures, and no mixture produced more biomass than clover as a single species. These findings are similar to those observed by Ranells and Wagner (1997), in which legume monocultures produced similar biomass to grass/legume mixtures. In 2020, there were no differences in biomass production for various cover crop treatments, but biomass was overall lower in 2020 compared to 2019. The later planting date in the fall of 2019 at TVREC may be partially responsible for the overall decreased biomass at TVREC in 2020 compared to 2019, as planting date has been reported to influence cover crop biomass production. For example, a study in South Carolina showed small grain cover crops planted in November produce significantly less biomass than those planted in October (Bauer & Reeves, 1999). Ruis et al. (2019) also found that cover crops with longer growing seasons often produce more biomass than those with short seasons, which can contribute to highly variable biomass production levels in warm, humid Southeastern fields. The radish monoculture was the least favorable in terms of biomass production at TVREC. Across 2019 and 2020 growing seasons, the radish monoculture produced 2.4 to 3.4 times less biomass than all other cover crops. This is likely the result of increased winter-kill of radishes at TVREC. Radishes are considered less winter hardy than rye and crimson clover, and it has been previously reported that radish winter-kill when temperatures drop below 4°C for multiple days (Chen et al, 2014).

Year did not interact with cover crop treatment to affect biomass at WREC. However, there was an overall effect of cover crop treatment at this location. Cover crop mixtures tended to perform better than monocultures at the WREC location. For example, all mixtures containing clover had greater biomass than clover or radish monocultures. Additionally, the radish-clover mixture had greater biomass than all monocultures, including rye. This was somewhat unexpected, since other studies have shown winter grains such as cereal rye can produce more biomass than eight species mixtures of legumes, brassicas, and other grasses (Finney et al. 2016). In a review of 27 studies to compare cover crop biomass production in monocultures versus mixtures, it was observed that biomass production was not different for mixtures compared to monocultures in >70% of comparisons (Florence and McGuire, 2020). In the same study, monocultures had greater biomass than mixtures in 18% of comparisons.

Overall, differences in cover crop biomass production differed according to year and location. At WREC, the location in the Coastal Plain, cover crop mixtures tended to produce greater biomass than monocultures. At TVREC, results were more variable. In the first year, clover performed better than other monocultures, while in the second year, there were no differences between treatments. Cover crop growth is influenced by a variety of factors including soil type, planting date, soil moisture at planting, climate, and species being planted. It is important to consider each of these factors when deciding the appropriate cover crop for row crop production systems. Other factors, such as nectar or pollen production, may be important to consider when cover crops are being used to attract beneficial insect populations.

Insect Dynamics in Cover Crops

Beneficial Insects at TVREC

Insect populations were counted in cover crops directly prior to termination to assess differences among cover crop treatment, irrigation, and year (Table 4). At TVREC there was a significant cover crop treatment × irrigation × year interaction for beneficial insects (Table 4). Beneficial insect complexes in cover crops at TVREC were primarily comprised of LB, BEB, hoverflies (Syrphidae; HF), spiders, braconid wasps (Braconidae; BW), and bees (Apidae; Table 5). At TVREC in 2019, previously irrigated crimson clover plots contained more beneficial insects than all other previously irrigated treatments, except for the rye monoculture (Table 6). Dryland clover monoculture plots also had larger beneficial insect populations than every other dryland treatment, except for the radish-clover biculture (Table 6). At TVREC in 2019, clover monoculture plots produced significantly more biomass than radish plots, which may in part explain the drastic difference in beneficial numbers between the two treatments (Table 3 and Table 7). Crimson clover has increased beneficial insect numbers in previous research (Bugg et al., 1992), though these results may be inconsistent from year to year. At TVREC in 2020, clover monoculture plots did not stand out to the same degree, as both previously irrigated and exclusively dryland crimson clover plots contained similar numbers of beneficial insects to the fallow control plots (Table 6). Crimson clover produced 63% less biomass in 2020, so the overall reduction in habitat availability may explain why beneficial numbers were greater in 2019 (Table 3). Radish-clover plots had higher numbers of beneficials than fallow, radish, and rye-radish plots during both years of the study, so certain cover crop bicultures may be preferable to monocultures for increasing beneficial presence. Bugg et al. (1990a) also determined that cover crop bicultures were preferable to clover monocultures for harboring beneficial insects such as BEB. At TVREC, rye-radish-clover mixture plots typically did not increase beneficial insect presence compared to monoculture, biculture, or fallow treatments in either previously irrigated or exclusively dryland conditions (Table 6), indicating that this three-species cover crop mixture may not be advantageous for further increasing populations of beneficial insects.

In addition to the cover crop treatment × irrigation × and year effect on beneficial insect populations, there was also an overall cover crop treatment × year effect at TVREC (Table 4). At TVREC in 2019, crimson clover plots had the most beneficial insects while fallow and radish plots had the least (Table 7). Table 7 represents beneficial insect totals pooled across both previously irrigated and exclusively dryland plots. In 2020, crimson clover and radish-clover plots had more total beneficials than every other treatment (Table 7), primarily consisting of LB and BEB species. Crimson clover and radish-clover cover crop bicultures held greater amounts of beneficial LB than radish monocultures during both site years at TVREC (Table 8). Similarly, crimson clover and radish-clover cover crop bicultures held more beneficial BEB than cereal rye and radish cover crop monocultures in some instances (Table 8). A study by McCutcheon et al. (1994) also determined that crimson clover cover crops can increase the number of BEB and LB in the field. Cereal rye and Daikon radish cover crops seem to lack the ability to increase beneficial BEB numbers, likely due to the relative lack of extrafloral resources compared to clover. Tillman et al. (2004) found that cereal rye cover crop monocultures generally do not increase the amount of BEB in the field. Lady beetle populations in rye plots were greater than in fallow plots at TVREC in 2019 (Table 8). Bugg et al. (1991) also found that cereal rye cover crops can promote large LB populations, especially when rye provides extra prey resources in the form of aphids. While summer irrigation did not affect total numbers of beneficial insects collected in cover crops at TVREC, exclusively dryland plots did have larger BEB populations in 2019 (Table 8). It is interesting that rye-radish-clover cover crop mixtures did not attract greater amounts of beneficial insects than rye monocultures or fallow plots during either year of the study, despite the diverse array of resources that may be provided by a three-species cover crop (Table 7).

Year to year comparisons of insect totals revealed that beneficial insect numbers in TVREC cover crops were 19% greater in 2019 than in 2020 (data not shown). In the current study, despite cover crops being planted in the same location for multiple years, beneficial insect populations did not increase from 2019 to 2020. Ephemeral legume, grass, and brassica cover crop habitats likely do not provide resources consistently enough to build greater populations of beneficial insects over time.

Beneficial Insects at WREC

Three-way and two-way interactions between cover crop treatment, year, and irrigation were not significant at WREC; however, beneficial insect totals were influenced by both treatment and irrigation across both site years (Table 9). The most abundant beneficial insects at WREC were LB, HF, BEB, spiders, damsel bugs (Nabidae; DB), and assassin bugs (Reduviidae; AB) (Table 5). Cover crop plots in fields that had previously been irrigated held larger amounts of beneficial insects. It is unclear why irrigation during the previous cash crop growing season would impact beneficial numbers during the cover crop growing season. However, Perfect et al. (1986) claims there may be an association between insect population establishment on host plants and the presence of favorable moisture levels. Summer irrigation could be contributing to the reproductive success of certain insects in southeastern cover cropping systems. Radish-clover plots at WREC harbored more beneficials than fallow and rye monoculture plots (Table 9). These findings are similar to those observed at TVREC and are corroborated by previous research by Wissinger (1997) which determined fallow field conditions do not provide ample resources for overwintering beneficials. High biomass production in WREC 2019 radish-clover plots also likely contributed to increased numbers of beneficials compared to rye monoculture plots (Table 3 and Table 7). At WREC, during both site years, there were no effects of cover crop treatment on any specific beneficial insect species. Despite the lack of cover crop treatments effects, LB populations were greater in previously irrigated plots compared to exclusively dryland plots in 2020 (Table 10). The differences in soil type and climate between TVREC and WREC may partially explain the varied effects of summer irrigation on beneficial insect populations in the spring.

Correlations of Insect Populations with Cover Crop Biomass

Cover crop biomass may impact insect communities because it can serve as a measurement of plant resources available to them. There was a moderate correlation between beneficial insect numbers and cover crop biomass at both locations in 2019, but not in 2020 (Table 11). Lower cover crop biomass production in 2020 (Table 3) was likely responsible for the lack of a correlation with beneficial insect populations in the second year of the study (Table 11). The effects of cover crop biomass on pest populations was less consistent than it was with beneficial populations. Pest insect numbers had a moderate correlation with cover crop biomass levels at TVREC in 2020, but not in 2019. Pest insect numbers had a moderate correlation with cover crop biomass levels at WREC in 2019, but not in 2020.

Pest Insects at TVREC

There was an interactive effect of cover crop treatment × irrigation × year for total pest insect counts at TVREC (Table 4). Pest insect complexes at TVREC were primarily comprised of aphids, TPB, bean leaf beetles (Chrysomelidae; BLB), three cornered alfalfa hoppers (*Spissisilus festinus*; TCAH), brown stinkbugs (Pentatomidae; BSB), and clover stem borers (*Languria mozardi*; CSB) (Table 5). At TVREC in 2019, radish cover crop monocultures in previously irrigated plots had fewer total pest insects than previously irrigated cereal rye and rye-radish plots, whereas dryland radish plots had fewer total pest insects than every other treatment except for the fallow control (Table 6). It seems radish cover crop monocultures generally harbor very low pest insect populations, but especially so in exclusively dryland conditions. Dryland radish cover crops in north Alabama which accumulate very little biomass will likely lack sufficient habitat to attract pest insects into the field. Previously irrigated rye monoculture plots at TVREC in 2020 had more total pest insects than every other treatment except for radish-clover, whereas pest insect populations in the 2020 dryland rye monocultures were not different than the fallow control (Table 6). These results suggest insect pest populations can be quite variable in rye cover crops and are potentially influenced by irrigation management during the cash crop growing season. Most clover-containing treatments contained greater amounts of pest insects than non-clover-containing treatments in 2020. At TVREC in 2020, dryland radish-clover plots had more total pest insects than all other treatments, except for rye-clover and the clover monoculture. However, TVREC 2020 previously irrigated radish-clover plots only had more pest insects than previously irrigated fallow, radish, and rye-radish plots (Table 6). These results indicate radish-clover and other clover-containing cover crops can attract particularly high numbers of pest insects in dryland fields. In both years of the study, previously irrigated rye-radish-clover mixtures did not have more pest insects than previously irrigated radish monocultures at TVREC. However, dryland rye-radish-clover mixture plots did have more total pest insects than radish monocultures in 2019 (Table 6). Perhaps insect pests are drawn to the varied habitat and greater biomass offered by the cover crop mixture in the absence of summer irrigation.

In addition to the three-way interaction between cover crop treatment, irrigation, and year, cover crop treatment × year and irrigation × year interactions both affected pest insects at TVREC (Table 4). Summer irrigation had variable effects on pest insect populations in cover crops (Table 12). In 2019, TVREC dryland plots had greater pest populations than previously irrigated plots, while previously irrigated plots had greater total pest insect numbers than dryland plots at TVREC in 2020. It is unclear why irrigation during the cash crop growing season impacted pest populations differently according to year. When examining the effects that cover crop treatments had on pests according to year, fallow and radish monoculture plots harbored the fewest total pest insects at TVREC in 2019, while cereal rye monocultures had more total pest insects than the rye-radish-clover mixture, fallow, and radish monocultures. The magnitude of difference in pest insect numbers between rye and radish at TVREC in 2019 was considerable, as the rye plots harbored more than 12 times as many total pests as the radish plots. In 2020, radish-clover plots had greater total pest numbers than every treatment except clover and rye monocultures, with total pest counts over four times greater in radish-clover compared to fallow and radish monoculture plots. Clover, rye, and rye-radish-clover cover crop mixtures all had more total pests than radish monoculture plots (Table 12). The low biomass of radishes may partially explain reduced pest populations in the radish monoculture treatment, due to a lack of resources available for insects. Clover, rye, and rye-radish-clover cover crop mixtures all had more total pests than radish monoculture plots (Table 12). Crimson clover and radish-clover cover crop bicultures contained high total pest numbers in both northern and southern AL. Planting a mono or biculture containing crimson clover has the potential to attract an array of pests in Alabama; primarily: TPB, BLB, CSB, TCAH, GH, and aphids. TVREC 2019 fallow and radish plots both had fewer aphids than crimson clover monocultures (Table 8). Aphids were present in greater numbers in previously irrigated plots compared to exclusively dryland plots in 2020 at TVREC (Table 8). Favorable moisture availability may increase the presence of some sucking insect pests such as aphids. At TVREC in 2020, fallow, radish, and rye-radish plots also had substantially lower aphid populations than rye and rye-clover plots (Table 8). These data suggest brassica cover crops and winter weeds tend to attract very few aphids, while cereal rye and crimson clover cover crop monocultures are both susceptible to aphid infestations. Other researchers have also observed cereal rye containing very large populations of aphids (Bugg et al. 1991). At TVREC in 2019, cereal rye monocultures also had high numbers of rice stinkbug (*Oebalus pugnax;* RSB) pests, but very few TPB, radish-clover cover crop bicultures contained the most TPB (Table 8).

Previous research has demonstrated that TPB can be highly abundant on various other cool-season cover crops including mustard species and hairy vetch (*Vicia villosa*) due to availability of extrafloral nectaries which promote survival of Lygus nymphs (Bugg et al., 1991). In 2020, radish-clover and crimson clover plots had larger BLB populations than fallow, rye, radish, and rye-radish plots. Radish-clover bicultures also contained more CSB than every other treatment. At TVREC in 2020, crimson clover monocultures had more TCAH than every treatment, except for radish-clover.

Pest Insects at WREC

Similar to TVREC, cover crop treatment × year and irrigation × year affected pest insect populations at WREC (Table 4). The most abundant pests at WREC were grasshoppers (Acrididae; GH), TPB, aphids, cucumber beetles (Chrysomelidae; CB), TCAH, and RSB (Table 5). Cover crop treatment only affected pest insects at WREC in the spring of 2019, while summer irrigation impacted pests both years (Table 12). At WREC in 2019, crimson clover and radish-clover cover crop bicultures had the most pest insects, while rye and rye-radish had the least (Table 12). At WREC in 2019, rye-radish-clover cover crop mixtures did not harbor more pest insects than fallow control plots (Table 12). The tendency of rye cover crop monocultures to harbor aphids may be regionally driven because very few aphids were present in rye at WREC compared to TVREC (data not shown). Tarnished plant bugs at WREC followed similar trends to TPB at TVREC, with crimson clover and radish-clover containing more TPB than cereal rye and rye-radish bicultures (Table 10). Previous research by Tillman et al. (2004) also determined that TPB are often present in greater abundance in legume cover crops than rye cover crops. At WREC in the spring of 2019, GH were also more abundant in radish-clover and clover plots than all other treatments, with rye-radish having the fewest total GH (Table 10). Elsayed (1998) determined grasshoppers (*Euprepocnemis plorans*) prefer to consume clover crops such as *Trifolium alexandrinum* more than lupin (*Lupinus termis*) and horsebean (*Vicia faba*), indicating GH may prefer specific cover crop vegetation for feeding. Previous research has not determined whether GH have preference for clovers compared to small grain and brassica cover crops. The strong cover crop treatment differences in 2019 were largely due to GH's preference for crimson clover, but this was not the case in 2020. In 2020, GH populations were essentially evenly distributed across all treatments at WREC (Table 10), indicating that the basic presence of a winter vegetative habitat can attract GH pests to south Alabama fields in the spring. The inconsistent effects of summer irrigation on pest populations at TVREC were also observed at WREC. At WREC in 2019, previously irrigated plots had more total pest insects than the dryland plots, while WREC 2020 dryland plots had more total pests than previously irrigated plots (Table 12). In addition to its variable impacts on pest totals, summer irrigation had contradictory effects on GH and TPB at WREC. Grasshopper populations were smaller in exclusively dryland plots at WREC in 2019 and greater in dryland plots in 2020 (Table 10). Tarnished plant bugs were unaffected by irrigation in 2019, but more abundant in previously irrigated plots at WREC in 2020 (Table 10). Residual effects of summer irrigation may promote greater populations of certain pest insects in south AL cover crops.

There was no significant correlation between pest insects and cover crop biomass production at either location (Table 11). TVREC cover crops harbored more pest insects overall in 2020 than in 2019. At WREC, pest insects were more abundant in 2019 than 2020, likely due to lower biomass production in 2020. Despite the pest results at WREC, it appears that pest insects are more adept at cyclically colonizing ephemeral cover crop habitats than beneficial insects, particularly in north AL.

Insect dynamics in cash crops

Soybean

Bi-weekly insect samples were taken from both irrigated and dryland soybean plots after cover crop termination during the 2019 cash crop growing season at TVREC. Beneficial insect populations were not affected by cover crop treatment during any of the soybean sampling dates, but there were some mild effects on pest insects later in August. Center pivot irrigation only affected total beneficial insect counts at 15 WAP, as more beneficials were observed in irrigated soybeans plots than dryland plots (Figure 1). The soybean beneficial insect complex was mostly comprised of spiders, BEB, tachinid flies (Tachinidae; TF), spined soldier bugs (*Podisus maculiventris;* SSB), and LB. Beneficial insect totals collected at 13 WAP were substantially smaller than totals collected at 11 WAP regardless of cover crop treatment, indicating that the lambda-cyhalothrin insecticide application at 12 WAP was detrimental to total beneficial insect abundance (Figure 1). Research conducted by Blumberg and Crossley (1983) also found that insecticide sprays can harm beneficial insect populations in the field. Decreased beneficial insect numbers at 13 WAP likely contributed to the greater pest insect populations observed in irrigated soybean plots after the lambda-cyhalothrin spray (Figure 2).

Thrips population assessments two weeks after soybean planting revealed thrips were impacted by irrigation and the interaction between cover crop treatment and irrigation. Dryland soybean plots had greater thrips numbers than irrigated plots overall (data not shown). It has been previously observed that overhead irrigation can also reduce thrips populations (Palumbo et al., 2002). There were no statistical differences in thrips populations among cover crop treatments in irrigated soybeans, but dryland soybeans did experience differing amounts of thrips with respect to cover crop treatment. For soybeans following radish and fallow treatments, larger thrips populations were observed compared to soybeans following rye, rye-clover, and rye-radish-clover treatments (Figure 3). The absence of any surface residue in fallow plots and low cover crop biomass production levels in radish monoculture plots likely contributed to higher levels of thrips. Research has shown rye cover crop residue can lower thrip infestations in leguminous cash crops such as peanut, so it may be having a similar effect in soybean (Olson et al. 2006). Lack of residue ensures soil moisture will be depleted more quickly and can cause soybeans to experience greater drought stress, which could contribute to the increased thrips numbers in dryland soybeans.

The presence of cover crop residue, whether from a monoculture or mixture, does not appear to have strong effects on total pest insect abundance after spring termination in Alabama soybean systems. The soybean pest insect complex was primarily comprised of BLB, TCAH, green clover worms (*Hypena scabra;* GCW), GH, BSB, and CSB. No cover crop treatment differences were observed early in the soybean growing season, but pest insect abundance did differ with respect to cover crop treatment at 13 and 15 weeks after planting (WAP), however, none of the treatments were different from the fallow control plots (Table 13). At 13 WAP, soybean plots with rye-radish residue contained more total pests than soybeans with rye-radish-clover and rye-clover biculture residue. At 15 WAP, soybean plots with radish residue had more pests than the rye-radish-clover mixture and radish-clover plots (Table 13). Even though cover crop residue did not strongly influence total soybean pest numbers, it did have a slight impact on certain pest species. Bean leaf beetle populations differed with respect to cover crop treatment at 5 and 13 WAP, but all treatments were statistically similar to fallow control plots (Table 14). Soybean plots with radish-clover and crimson clover residue held larger amounts of BLB pests than plots with rye-radish-clover residue at 5 WAP, while at 13 WAP soybean plots with rye-clover and rye-radish-clover mixture residue had low numbers of BLB (Table 14). Previous research by Jeffords et al. (1983) stated early-season problems with BLBs usually occur in areas with extensive overwintering habitat, which would have certainly been provided by the clover cover crop plots. Though BLB differences were not observed in cover crops at TVREC in 2019, BLB were greater in clover and radish-clover plots than rye and radish monoculture plots in 2020 (Table 8). There seems to be a slight trend of 3-way mixture residue reducing BLB populations compared to cover crop monoculture residue in north AL soybean systems.

Results from the first sampling date, taken 5 WAP, revealed that the presence of irrigation significantly affected total pest insect populations. Dryland soybean plots had greater total pest insect numbers than irrigated plots at 5 WAP across all cover crop treatments (Figure 2). Despite pest counts being greater in dryland soybean plots, irrigated plots had higher numbers of TCAH at 5 WAP (Figure 4). Total pest counts were unaffected by treatment or irrigation at 7 and 11 WAP. At 9 WAP, the effects of irrigation reversed, as larger total pest quantities were observed in irrigated plots instead of dryland plots (Figure 2). This trend continued for the final 2 sampling dates as well. At 13 and 15 WAP, irrigated soybean plots had significantly larger amounts of pest insects (Figure 2). At 13 WAP irrigated plots contained nearly twice as many total pests as dryland plots, and at 15 WAP irrigated plots had more than twice as many pests (Table 13). Irrigation may lead to more vegetative growth and cooler micro-climates within the crop, which could be responsible for greater pest attendance. On the final 3 sampling dates (11, 13, and 15 WAP), irrigated plots had more BLB pests (Figure 5). Kogan et al. 1980 claims BLB frequently cause economically significant defoliation on soybeans in the southern United States. Alabama farmers growing irrigated soybeans should scout their fields frequently and thoroughly for late season insect pests such as BLB, because the magnitude of difference in pest presence compared to dryland beans is substantial. The lambda-cyhalothrin insecticide application at 12 WAP led to total pest decreases in dryland plots, but not irrigated plots. The spray was effective at decreasing TCAH populations, but it did not decrease BLB populations (Figure 4 and Figure 5). Previous research in the Mississippi Delta region has shown pyrethroid insecticides are not always effective at controlling BLB in soybeans (Musser et al. 2012).

Peanut

During the 2019 peanut growing season at WREC, bi-weekly insect samples revealed that irrigation sometimes affected beneficial insect populations but cover crop treatment did not affect the presence of beneficial insects. The peanut beneficial insect complex was primarily comprised of spiders, damsel bugs (Nabidae), FA, BEB, and minute pirate bugs (*Orius insidiosus*). On the first peanut sampling date at 5 WAP, beneficials were unaffected by cover crop treatment or irrigation (Figure 6). At 7 WAP, beneficial insect populations were greater in irrigated plots. This was the only time during the peanut growing season where beneficials were impacted by irrigation. The methoxyfenozide insecticide spray adversely affected beneficial insect numbers, as total beneficial counts decreased numerically in both irrigated and dryland plots after the insect growth regulator was applied.

Thrips populations did not differ with respect to treatment or irrigation when they were assessed in peanut plots at 2 WAP. Cover crop treatment did not impact insect pest totals in peanut plots, but pest totals were greater in irrigated peanuts on half of the sampling dates (i.e., 7, 13, and 15 WAP) (Figure 7). The peanut pest insect complex was primarily comprised of TCAH, GH, CB, GCW, and leafhoppers (Cicadellidae; LH). Cucumber beetle populations were greater in irrigated plots on half of the sampling dates (7, 11, and 13 WAP), while TCAH were greater in irrigated plots at 13 and 15 WAP (Figure 8 and Figure 9). These results suggest south AL peanut farmers can incorporate cover crops into their rotations without worsening pest problems, as long as cover crops are terminated two to three weeks ahead of cash crop planting. However, peanuts grown under center pivot irrigation may need to be scouted more frequently for CB and TCAH. The methoxyfenozide insecticide application at 13 WAP was effective against caterpillar pests (data not shown) but did not substantially decrease total pest insect populations. In fact, total pest insect abundance was greater after the application (Figure 7). Cucumber beetle populations were reduced after the spray, but TCAH populations were actually greater (Figure 8 and Figure 9).

Cotton

During the 2020 cotton growing season at TVREC and WREC, bi-weekly insect samples were taken from both irrigated and dryland cotton plots after cover crop termination. Winter cover crops did not appear to have a strong impact on beneficial insect persistence in north AL cotton fields when terminated two to three weeks before planting. Fire ant populations were numerically greatest in cotton plots with rye-radish-clover residue at 8 WAP, but not statistically different from the fallow control plots (data not shown). From 10 WAP and onward at TVREC, none of the cover crop treatments were different from the fallow control plots in terms of total beneficial insect presence. While cover crops had little influence on the cotton beneficial insect complex at TVREC, dryland cotton plots contained more total beneficial insects than irrigated plots on 4/5 sampling dates (Figure 10). The 3rd sampling date at 12 WAP was the only time when total beneficial counts were unaffected by the presence of irrigation at TVREC. Center pivot irrigation may adversely affect beneficial FA activity in north AL cotton fields, as FA populations were greater in dryland cotton plots on 3/5 sampling dates (10, 14, & 16 WAP) (Figure 11). Fire ants can play a stronger predatory role in cotton systems rather than soybean, because the dense trichomes on soybean stems hinder foliage feeding (Styrsky, 2006). Cotton bollworms were observed in irrigated cotton plots at TVREC but not in dryland plots, indicating FA predation of CBW may be more frequent in dryland cotton (data not shown).

The ability of cover crop residue to promote beneficial insect persistence may have regional and temporal limitations. During the 2020 growing season at WREC, beneficial insect totals were greater in cotton following a cereal rye cover crop compared to cotton following a radish cover crop at both 10 and 12 WAP (Table 15). The slowly-decomposing residue provided by the rye cover crop may have created a favorable habitat for beneficial insects such as FA, which were the most abundant beneficials in WREC cotton. A study by Ali et al. (1986) found that FA populations were greater in Louisiana sugar cane fields with high amounts of surface residue cover, which may explain why cotton plots following a radish cover crop held fewer FA. By 14 WAP, cover crop treatment no longer impacted total beneficial insect counts in WREC cotton. After 14 weeks, cereal rye cover crop residue has likely degraded to the point that it is no longer harboring extra numbers of beneficial FA in south AL cotton fields. While center pivot irrigation negatively impacted FA numbers in north AL cotton, it appears to have the opposite effect on FA in south AL. On 3/5 sampling dates (8, 12, & 14 WAP), irrigated cotton plots contained more FA than dryland plots at WREC (Figure 12). Irrigated cotton plots also had higher total beneficial insect counts on 2/5 sampling dates (8 & 12 WAP) (Figure 13). Ali et al. (1986) claims that sandy soils typically have lower moisture levels than clayey soils, which could increase the risk of FA colony desiccation. Sandier soils at WREC may benefit more in terms of moisture conservation from cereal rye cover crop monocultures than more clayey soils at TVREC. Sandy soils lose water very quickly, so cover crop residue conserving moisture may assist fire ants in maintaining their nests.

The presence of cover crop residue and irrigation had no effect on thrips populations in TVREC cotton plots at 4 WAP. At WREC, thrips population assessments at 3 WAP revealed while cover crop residue had no effect, irrigated cotton plots did have more thrips (1.14 thrips per plant) than dryland cotton (0.73 thrips per plant). On the first sweep net sampling date (8 WAP) at TVREC when cotton was at the 4-5 true leaf stage, cover crop residue significantly impacted total pest numbers. At TVREC, cotton following a radish-clover cover crop harbored more total pest insects than rye-radish-clover, rye, rye-radish, and fallow control treatments, and cotton following clover had higher total pest insects than cotton following rye (Table 16). Cover crop residue which contains crimson clover appears to enhance pest insect persistence in north AL cotton fields early in the growing season. Host-free periods typically serve as a hinderance to insect population development, and cropping systems which include winter cover crops have inherently shorter host-free periods than fields which remain fallow in the winter. (Perfect et al. 1986). Crimson clover cover crops may increase the carryover of certain pests if the time period from termination to cash crop planting is too short. Specifically, GH and LH were both affected by cover crop treatment at 8 WAP (Table 17). At TVREC, cotton plots with radish-clover and rye-clover biculture residue both had greater amounts of LH than fallow and rye monoculture plots at 8 WAP (Table 17). Additionally, cotton plots with crimson clover residue had more total GH than rye-radish biculture plots, but neither were statistically different from the fallow control. At 10 WAP, TVREC cotton plots with rye-clover residue had greater total pest populations than the fallow, cereal rye, and rye-radish-clover plots (Table 16). On the final three sampling dates at TVREC (12, 14, and 16 WAP), pest populations were unaffected by the presence of different cover crop residue. By 12 WAP clover, radish, and rye cover crop residue may be sufficiently degraded so as to not promote higher pest populations in north AL cotton fields. Irrigated cotton plots at TVREC had higher total pest insect counts at 8 WAP (Table 16). When examining the effect of irrigation on specific insect populations, TVREC dryland cotton contained more GH at 8 WAP, while irrigated cotton contained more LH (Table 17). Irrigated TVREC cotton plots also had greater pest populations at 16 WAP (Figure 14). Square retention and boll damage assessments also revealed no strong effects of cover crop residue or irrigation on the number of dead/missing pinhead squares at 12 WAP or the number of damaged cotton bolls at 14 WAP.

Similar to TVREC, few cover crop treatment effects were observed on insect populations at WREC during the cotton growing season. Winter cover crops did not affect pest insect totals collected at any sampling date. On the first sweep net sampling date (6 WAP) at WREC when the cotton was at the 4 true leaf stage, the presence of irrigation significantly impacted total pest and beneficial numbers but cover crop treatment did not (Figure 15 and Figure 13). On the first sampling date, irrigated cotton plots had more pest insects while dryland plots had more beneficial insects. Irrigated cotton plots at WREC also contained more pest insects at 8WAP (Figure 15). After 8 WAP, total pest insect counts remained unaffected by irrigation for the duration of the season at WREC (Figure 15). Center pivot irrigation stabilizes water and temperature levels within a cropping system and can increase both crop growth and humidity levels within the canopy (Rosenburg, 1974). Other studies have found the amount of CBW larvae, for example, can be correlated with moisture levels in terminal cotton shoots (Fletcher, 1941). Cotton pinhead square assessments at 10 WAP revealed dryland (1.76 missing squares/plant) plots were missing substantially more squares than irrigated (0.64 missing squares/plant) plots at WREC (Data not shown). The high rate of square-shedding in dryland cotton plots was likely due to water stress and not an insect infestation. Boll damage assessments at 12 WAP were not statistically significant, but internal damage ratings were above threshold so an insecticide spray was triggered in dryland WREC cotton plots.

CONCLUSIONS

Cover crop species can vary greatly in their ability to attract pest and beneficial insects. Crimson clover and radish-clover cover crops have demonstrated the ability to attract high numbers of beneficial insects like BEB and LB. Rye and radish cover crop monocultures are less likely to increase presence of beneficial insects. Rye, clover, and radish-clover cover crops often harbor more pest insects than fallow fields and radish monocultures. Radish cover crop monocultures seem to attract very few pest or beneficial insects. The presence of crimson clover in a cover crop mixture can increase the presence of several pests, such as aphids, BLB, CSB, and TCAH, during the cover crop growing season in north AL. In south AL, GH infestations can be severe in crimson clover and radish-clover cover crops. North AL rye cover crop monocultures are susceptible to aphid and RSB infestations but attract very few TPB. Tarnished plant bugs appear to have a marked preference for radish-clover bicultures, whether grown in north or south AL. The use of center pivot irrigation on summer cash crops may have varying effects on pest insect abundance in cover crops. High biomass production may be important for cover crops to provide sufficient habitat and resources to increase beneficial insect numbers. Beneficial insect populations did not increase from 2019 to 2020, which may be an effect of ephemeral legume, grass, and brassica cover crop habitats not providing resources consistently enough to build greater populations of beneficial insects over time. Pest insect totals were greater in the 2nd year of the study, so they may be using the short-lived habitat more efficiently than beneficial insects.

Winter cover crop residue is unlikely to enhance beneficial insect persistence in north AL soybean systems when cover crops are terminated two to three weeks ahead of soybean planting. Similarly, center pivot irrigation seems to have very little impact on beneficial populations in soybean fields. Dryland soybeans following a cereal rye or rye-clover biculture cover crop may experience reduced thrips infestations compared to soybeans sown into fallow fields. Cover crops terminated at least two weeks prior to soybean planting have weak impacts on pest insect persistence as well. Soybeans planted into rye-radish-clover mixture residue may benefit from lower amounts of BLB pests. Summer irrigation can increase BLB numbers in north AL soybean fields, so regular scouting is essential.

Cover crop residue and center pivot irrigation have weak effects on beneficial and pest insect populations in south AL peanut fields. Southeastern farmers can likely rotate peanuts with cover crops and not exacerbate insect pest issues. Center pivot irrigation may increase populations of certain peanut pests such as CB and TCAH.

The effects of cover crop residue and center pivot irrigation on cotton insect dynamics differed substantially with respect to region. Cover crops had weak impacts on beneficials in north AL cotton, while cereal rye cover crop residue promoted beneficial insect persistence better than radish residue in south AL cotton. Dryland cotton fields in north AL may have more active communities of beneficial fire ants compared to irrigated cotton fields. The impact of irrigation on FA in cotton may be a function of soil type, as the sandier soils at WREC consistently harbored more FA when under the pivot. Cover crop residue is unlikely to worsen thrips infestations in AL cotton fields, but irrigation may increase thrips abundance in the southern portion of the state. Cover crop residue which contains crimson clover may increase the presence of GH and LH early in the north AL cotton growing season. Irrigation may increase pest insect populations early in the south AL cotton growing season.

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TABLES

Table 1. Cover crop seeding rates.

Treatment	Seeding rate		
	Rye	Crimson clover	Radish
	$kg\ ha^{-1}$		
Rye	100	-	-
Radish	-	-	9
Clover	-	22	-
Rye-radish	50	-	9
Rye-clover	50	22	-
Radish-clover	-	22	9
Rye-radish-clover	34	11	4

Table 2. Field operation dates for the Tennessee Valley Research and Extension Center (TVREC) in Belle Mina, AL and the Wiregrass Research and Extension Center (WREC) in Headland, AL.

In-Field Operations				
	TVREC		WREC	
Season	† 2018/2019	†† 2019/2020	‡ 2018/2019	†† 2019/2020
Cover crop planting	10/19/2018	11/05/2019	11/19/2018	11/18/2019
Cover crop termination	04/23/2019	04/16/2020	04/22/2019	04/27/2020
Cash crop planting	05/22/2019	05/02/2020	05/20/2019	05/28/2020
Pesticide applications	08/13/2019	N/A	08/21/2019	08/18/2020
Cash crop harvest	10/1/2019	10/7/2020	10/24/2019	TBD

† Soybean

‡ Peanut

†† Cotton

Table 3. Cover crop biomass production by location and year for the Tennessee Valley Research and Extension Center (TVREC) in Belle Mina, AL and the Wiregrass Research and Extension Center (WREC) in Headland, AL.

	Cover Crop Biomass					
Location	TVREC			WREC		
Year	2019	2020	Mean	2019	2020	Mean
Treatment	——— kg ha^{-1} ———					
	$P = 0.0006$	$P = 0.0006$	$P < 0.0001$	$P = 0.1084$	$P = 0.1084$	$P = 0.0030$
Fallow	-	-	-	-	-	-
Rye	3585 b†	2276 a	2931 a	3820 abc	2145 a	2162 bc
Radish	995 c	1456 a	1225 b	2880 bc	1883 a	1923 c
Clover	5093 a	1885 a	3489 a	4250 abc	1677 a	2100 c
Rye-radish	3671 ab	2107 a	2890 a	2010 c	2137 a	2420 abc
Rye-clover	5396 a	2877 a	4136 a	9330 a	2273 a	3776 ab
Radish-clover	3960 ab	2109 a	3035 a	6600 ab	1809 a	3811 a
Rye-radish-clover	4723 a	2714 a	3747 a	6280 ab	2576 a	3091 abc

†Means followed by a different letter within a column for the main effect (i.e., cover crop treatment) are statistically different at the α = 0.10 significance level.

Table 4. Summary of analysis of variance for cover crop treatment, irrigation, and year for beneficial and pest insect totals collected in cover crops at the Tennessee Valley Research and Extension Center (TVREC) in Belle Mina, AL and the Wiregrass Research and Extension Center (WREC) in Headland, AL.

Source of Variance	df	TVREC		WREC	
		Beneficials	Pests	Beneficials	Pests
		Pr > F			
Cover Crop (CC)	7	<0.0001	<0.0001	0.0006	<0.0001
Irrigation (I)	1	0.1497	0.0422	0.0253	0.0001
Year (Y)	1	0.0025	<0.0001	0.0478	<0.0001
CC x I	7	0.2459	<0.0001	0.0736	0.0135
CC x Y	7	<0.0001	<0.0001	0.2709	<0.0001
I x Y	1	0.3143	<0.0001	0.5393	<0.0001
CC x I x Y	7	0.0010	0.0166	0.2815	0.1377

Table 5. The total number of pest and beneficial insects counted in all cover crop treatments prior to termination at the Tennessee Valley Research and Extension Center (TVREC) in Belle Mina, AL and the Wiregrass Research and Extension Center (WREC) in Headland, AL ranked in descending order.

Location	TVREC				WREC			
Year	2019		2020		2019		2020	
Insect Category	*Pest*	*Beneficial*	*Pest*	*Beneficial*	*Pest*	*Beneficial*	*Pest*	*Beneficial*
	Aphids (205)	LB (246)	Aphids (494)	LB (58)	GH (849)	HF (117)	GH (521)	LB (41)
	RSB (186)	BEB (53)	BLB (89)	BEB (43)	TPB (134)	LB (38)	TPB (92)	BEB (32)
	TPB (103)	HF (27)	CSB (68)	HF (37)	Aphids (59)	BEB (20)	Aphids (34)	Spiders (27)
	BLB (39)	Spiders (14)	TCAH (54)	Spiders (36)	CB (58)	Spiders (20)	TCAH (18)	DB (21)
	BSB (24)	Bees (13)	TPB (26)	BW (22)	RSB (55)	Bees (13)	BSB (9)	Assassin Bugs (19)
	TCAH (14)	GLW (12)	Snails (22)	TF (22)	BSB (15)	GLW (1)	Burrower Bugs (9)	TF (17)
	GH (11)	SSB (4)	BSB (12)	GLW (5)	TCAH (12)		CB (8)	HF (11)
	Bill Bugs (4)		GH (12)	Bees (2)	SGSG (6)		RSB (4)	BW (7)
	CB (3)		CB (6)	SSB (2)	Black Cutworms (4)		GCW (4)	SSB (2)
	Harlequin Bugs (3)		RSB (2)	DB (1)	GCW (3)		SGSB (4)	
	SGSB (2)		Harlequin Bugs (1)		FAW (3)		YSAW (1)	
	BMSB (1)		SGSB (1)		YSAW (2)			
	CSB (1)				BLB (1)			
	FAW (1)							
	GCW (1)							

All abbreviations are listed on page 12.

Table 6. Three-way interaction between cover crop treatment, irrigation, and year for the mean number of beneficial and pest insects collected in cover crops at the Tennessee Valley Research and Extension Center (TVREC) in Belle Mina, AL.

		Treatment	Fallow	Rye	Radish	Clover	Rye-radish	Rye-clover	Radish-clover	Rye-radish-clover
		Beneficial insect totals								
		Insects per 10 sweeps								
Year	2019	Irrigated	0.22 h†	2.14 bcdef	0.92 fgh	2.82 ab	1.50 efgh	1.87 cdefgh	1.91 cdefgh	1.39 efgh
		Dryland	0.56 gh	1.70 cdefgh	0.41 h	2.93 a	1.18 fgh	1.66 defgh	2.62 abc	2.05 bcdefgh
	2020	Irrigated	0.81 fgh	0.69 gh	1.25 fgh	1.75 cdefgh	0.56 gh	0.69 gh	2.42 abcde	1.45 efgh
		Dryland	1.66 defgh	0.56 gh	1.39 efgh	2.55 abcd	0.81 fgh	1.39 efgh	1.91 cdefgh	1.25 fgh
		Pest insect totals								
Year	2019	Irrigated	1.17 kl	2.42 cdefghi	0.69 l	1.91 ghijkl	2.25 efghijk	1.79 hijkl	2.04 fghijkl	1.50 ijkl
		Dryland	1.09 kl	2.97 bcde	0.81 l	3.02 bcd	2.93 bcde	3.02 bcd	2.62 bcdefgh	2.78 bcdef
	2020	Irrigated	1.94 ghijkl	3.54 a	2.04 fghijkl	2.95 bcde	1.87 ghijkl	2.81 bcdef	3.08 abc	2.44 cdefghi
		Dryland	1.44 ijkl	2.08 fghikl	1.25 jkl	2.97 bcde	1.50 ijkl	2.70 bcdefg	3.11 ab	2.37 defghi

† Means followed by a different letter for each main effect (i.e., irrigation, cover crop treatment, and year) are statistically different at the α = 0.10 significance level.

Table 7. Mean number of beneficial insects collected in cover crops during the 2019 and 2020 growing seasons at the Tennessee Valley Research and Extension Center (TVREC) in Belle Mina, AL.

Year	2019	2020
Location	TVREC	
Treatment	Total Beneficials	
	———Insects per 10 sweeps———	
	P <0.0001	*P <0.0001*
Fallow	0.39 d†	1.23 b
Rye	1.92 bc	0.63 b
Radish	0.66 d	1.32 b
Clover	2.87 a	2.15 a
Rye-radish	1.34 cd	0.69 b
Rye-clover	1.77 bc	1.04 b
Radish-clover	2.27 b	2.17 a
Rye-radish-clover	1.72 cd	1.35 b

† Means followed by a different letter within a column for the main effect (i.e., cover crop treatment) are statistically different at the $\alpha = 0.10$ significance level

Table 8. Mean number of tarnished plant bugs (TPB), aphids, bean leaf beetles (BLB), rice stinkbugs (RSB), clover stem borers (CSB), lady beetles (LB), and big eyed bugs (BEB) collected in cover crop treatments during the 2019 and 2020 growing seasons at the Tennessee Valley Research and Extension Center (TVREC) in Belle Mina, AL.

Year	2019					
Treatment	Pests				Beneficials	
	Insects per 10 sweeps					
	TPB	Aphids	BLB	RSB	LB	BEB
	P = 0.6597	*P <0.0001*	*P = 0.0910*	*P = 0.5527*	*P = 0.4656*	*P = 0.0818*
Irrigated	0.79 a[†]	0.09 b	0.17 b	2.14 a	1.34 a	0.24 b
Dryland	0.87 a	1.54 a	0.55 a	2.50 a	1.23 a	0.62 a
	P = 0.0001	*P = 0.0022*	*P = 0.100*	*P <0.0001*	*P <0.0001*	*P = 0.0036*
Fallow	0.62 bc	0 b	0 a	0 c	0.22 e	0.11 b
Rye	0.11 c	1.09 ab	0 a	2.29 a	1.67 bc	0 b
Radish	0.48 bc	0 b	0 a	0.06 c	0.40 de	0 b
Clover	1.37 ab	1.53 a	0.83 a	0 c	2.56 a	1.28 a
Rye-radish	0.60 bc	1.06 ab	0 a	2.09 a	0.75 de	0 b
Rye-clover	0.97 abc	1.09 ab	0.57 a	1.44 b	1.35 cd	0.81 ab
Radish-clover	1.67 a	1.01 ab	0.91 a	0 c	2.01 b	0.80 ab
Rye-radish-clover	0.80 bc	0.92 ab	0.55 a	1.22 b	1.35 cd	0.45 ab

Year	2020					
Treatment	Pests				Beneficials	
	Insects per 10 sweeps					
	TCAH	Aphids	BLB	CSB	LB	BEB
	P = 0.6322	*P <0.0001*	*P = 0.4981*	*P = 0.2603*	*P = 0.3851*	*P = 0.9391*
Irrigated	0.39 a[†]	2.28 a	0.57 a	0.53 a	0.36 a	0.34 a
Dryland	0.49 a	1.63 b	0.71 a	0.98 a	0.55 a	0.32 a
	P <0.0001	*P <0.0001*	*P <0.0001*	*P <0.0001*	*P = 0.0004*	*P = 0.0011*
Fallow	0 b	1.52 cd	0 c	0 b	0.80 ab	0 b
Rye	0 b	2.73 a	0.11 bc	0 b	0 b	0 b
Radish	0 b	1.37 d	0.27 bc	0 b	0 b	0 b
Clover	1.52 a	2.10 bc	1.42 a	0.98 b	1.29 a	1.03 ab
Rye-radish	0 b	1.53 cd	0 c	0 b	0 b	0 b
Rye-clover	0.41 b	2.38 ab	1.18 ab	0.51 b	0 b	0.20 ab
Radish-clover	1.05 ab	1.92 bcd	1.47 a	1.86 a	1.21 a	1.26 a
Rye-radish-clover	0.55 b	2.01 bc	0.68 abc	0.19 b	0.31 ab	0.31 ab

[†] Means followed by a different letter within a column for each main effect (i.e., irrigation and cover crop treatment) are statistically different at the α = 0.10 significance level. The 2019 cash crop was soybean, the 2020 cash crop was cotton.

Table 9. Mean number of beneficial insects collected in cover crops at the Wiregrass Research and Extension Center (WREC) in Headland, AL.

Location	WREC
Treatment	Total Beneficials
	P = 0.0253
Irrigated	1.41 a†
Dryland	1.19 b
	P = 0.0006
Fallow	0.68 c
Rye	1.16 bc
Radish	1.35 ab
Clover	1.35 ab
Rye-radish	1.29 abc
Rye-clover	1.33 ab
Radish-clover	1.68 a
Rye-radish-clover	1.59 ab

† Means followed by a different letter for each main effect (i.e., irrigation and cover crop treatment) are statistically different at the $\alpha = 0.10$ significance level.

Table 10. Mean number of tarnished plant bugs (TPB), grasshoppers (GH), and lady beetles (LB) collected in cover crops during the 2019 and 2020 growing seasons at the Wiregrass Research and Extension Center (WREC) in Headland, AL.

Year	2019		
Treatment	Pests		Beneficials
	———Insects per 10 sweeps———		
	TPB	GH	LB
	P = 0.5654	*P = 0.0309*	*P = 0.6891*
Irrigated	1.08 a†	2.43 a	0.45 a
Dryland	0.99 a	2.21 b	0.36 a
	P = 0.0034	*P <0.0001*	*P = 0.2968*
Fallow	1.08 ab	2.43 c	0 a
Rye	0.26 b	1.37 e	0.31 a
Radish	1.29 ab	1.97 d	0.46 a
Clover	1.53 a	3.27 a	0.91 a
Rye-radish	0.61 b	0.78 e	0 a
Rye-clover	0.92 ab	2.93 b	0.69 a
Radish-clover	1.51 a	3.41 a	0.57 a
Rye-radish-clover	0.94 ab	2.40 c	0.31 a
Year	2020		
Treatment	Pests		Beneficials
	———Insects per 10 sweeps———		
	TPB	GH	LB
	P = 0.0608	*P <0.0001*	*P = 0.0698*
Irrigated	0.99 a†	1.55 b	0.65 a
Dryland	0.67 b	2.48 a	0.27 b
	P = 0.5991	*P = 0.3638*	*P = 0.9195*
Fallow	1.11 a	1.89 a	0.11 a
Rye	0.55 a	1.77 a	0.69 a
Radish	1.07 a	2.02 a	0.35 a
Clover	0.68 a	2.22 a	0.46 a
Rye-radish	0.96 a	2.03 a	0.55 a
Rye-clover	0.74 a	1.99 a	0.39 a
Radish-clover	0.91 a	2.16 a	0.61 a
Rye-radish-clover	0.65 a	2.04 a	0.52 a

† Means followed by a different letter within a column for each main effect (i.e., irrigation and cover crop treatment) are statistically different at the α = 0.10 significance level.

Table 11. Cover crop biomass correlations with beneficial and pest insects collected in the spring of 2019 and 2020 at the Tennessee Valley Research and Extension Center (TVREC) in Belle Mina, AL and the Wiregrass Research and Extension Center (WREC) in Headland, AL.

Cover Crop Biomass Insect Correlations			
Location	Year	Total Beneficials	Total Pests
		R	
TVREC	2019	*P = 0.0034* 0.3844	*P = 0.9286* 0.01255
	2020	*P = 0.7548* 0.0427	*P = 0.0218* 0.3059
WREC	2019	*P = 0.0213* 0.3071	*P = 0.0758* 0.2392
	2020	*P = 0.1551* 0.1925	*P = 0.2107* 0.1192

Table 12. Mean number of pest insects collected in cover crops during the 2019 and 2020 growing seasons at the Tennessee Valley Research and Extension Center (TVREC) in Belle Mina, AL and the Wiregrass Research and Extension Center (WREC) in Headland, AL.

Year	2019	
Location	TVREC	WREC
Treatment	Total Pests	
	——Insects per 10 sweeps——	
	P <0.0001	*P <0.0001*
Irrigated	1.72 b†	2.83 a
Dryland	2.41 a	2.66 b
	P <0.0001	*P <0.0001*
Fallow	1.14 c	2.69 cd
Rye	2.69 a	1.80 e
Radish	0.75 c	2.46 d
Clover	2.46 ab	3.57 a
Rye-radish	2.59 ab	1.71 e
Rye-clover	2.40 ab	3.19 b
Radish-clover	2.33 ab	3.69 a
Rye-radish-clover	2.14 b	2.87 c
Year	2020	
Location	TVREC	WREC
Treatment	Total Pests	
	——Insects per 10 sweeps——	
	P <0.0001	*P <0.0001*
Irrigated	2.58 a†	2.08 b
Dryland	2.17 b	2.66 a
	P <0.0001	*P <0.0001*
Fallow	1.69 d	2.29 a
Rye	2.79 ab	2.07 a
Radish	1.64 d	2.39 a
Clover	2.95 ab	2.52 a
Rye-radish	1.68 d	2.46 a
Rye-clover	2.75 bc	2.34 a
Radish-clover	3.09 a	2.50 a
Rye-radish-clover	2.39 c	2.38 a

† Means followed by a different letter within a column for each main effect (i.e., irrigation and cover crop treatment) are statistically different at the α = 0.10 significance level.

Table 13. Mean number of pest insects collected at 13 and 15 weeks after planting (WAP) during the 2019 soybean growing season at the Tennessee Valley Research and Extension Center (TVREC) in Belle Mina, AL.

Treatment	Total Pests	
	——Insects per 10 sweeps——	
	13WAP	15 WAP
	P <0.0001	*P <0.0001*
Irrigated	2.95 a†	2.66 a
Dryland	2.35 b	1.86 b
	P = 0.0242	*P = 0.0247*
Fallow	2.78 ab	2.31 ab
Rye	2.71 ab	2.35 ab
Radish	2.59 ab	2.61 a
Clover	2.84 ab	2.24 ab
Rye-radish	2.86 a	2.27 ab
Rye-clover	2.40 b	2.22 ab
Radish-clover	2.68 ab	1.99 b
Rye-radish-clover	2.46 b	2.17 b

† Means followed by a different letter within a column for each main effect (i.e., irrigation and cover crop treatment) are statistically different at the α = 0.10 significance level.

Table 14. Mean number of bean leaf beetles (BLB) collected at 5 and 13 weeks after planting (WAP) during the 2019 soybean growing season at the Tennessee Valley Research and Extension Center (TVREC) in Belle Mina, AL.

Treatment	Total Pests	
	—BLB per 10 sweeps—	
	5 WAP *P = 0.0060*	13 WAP *P = 0.0025*
Fallow	1.01 ab†	2.48 a
Rye	0.35 ab	2.44 a
Radish	0.85 ab	2.31 ab
Clover	1.31 a	2.43 a
Rye-radish	0.31 ab	2.45 a
Rye-clover	0.75 ab	1.82 b
Radish-clover	1.32 a	2.33 ab
Rye-radish-clover	0.11 b	1.89 b

† Means followed by a different letter within a column for the main effect (i.e., cover crop treatment) are statistically different at the $\alpha = 0.10$ significance level.

Table 15. Mean number of beneficial insects collected at 10 and 12 weeks after planting (WAP) during the 2020 cotton growing season at the Wiregrass Research and Extension Center (WREC) in Headland, AL.

Treatment	Total Beneficials	
	—Insects per 6 row ft—	
	10 WAP	12 WAP
	P = 0.3935	*P = <0.0001*
Irrigated	1.98 a†	2.67 a
Dryland	1.88 a	2.33 b
	P = 0.0008	*P = 0.0010*
Fallow	2.10 abc	2.18 c
Rye	2.26 ab	2.81 a
Radish	1.37 d	2.27 bc
Clover	1.81 bcd	2.43 abc
Rye-radish	2.33 a	2.57 abc
Rye-clover	1.65 cd	2.39 bc
Radish-clover	1.97 abcd	2.68 ab
Rye-radish-clover	1.94 abcd	2.69 ab

† Means followed by a different letter within a column for the main effects (i.e., cover crop treatment and irrigation) are statistically different at the α = 0.10 significance level.

Table 16. Mean number of pest insects collected at 8 and 10 weeks after planting (WAP) during the 2020 cotton growing season at the Tennessee Valley Research and Extension Center (TVREC) in Belle Mina, AL.

Treatment	Total Pests	
	—Insects per 25 sweeps—	
	8 WAP	10 WAP
	P = 0.0078	*P = 0.8927*
Irrigated	2.81 a†	1.94 a
Dryland	2.63 b	1.93 a
	P = 0.0004	*P = 0.0096*
Fallow	2.61 bc	1.61 b
Rye	2.55 c	1.43 b
Radish	2.74 abc	1.91 ab
Clover	2.94 ab	1.89 ab
Rye-radish	2.47 c	1.80 ab
Rye-clover	2.78 abc	2.3 a
Radish-clover	3.04 a	1.65 b
Rye-radish-clover	2.67 bc	1.58 b

† Means followed by a different letter within a column for each main effect (i.e., irrigation and cover crop treatment) are statistically different at the α = 0.10 significance level.

Table 17. Mean number of grasshoppers (GH) and leafhoppers (LH) collected at 8 weeks after planting during the 2020 cotton growing season at the Tennessee Valley Research and Extension Center (TVREC) in Belle Mina, AL.

Treatment	Pests	
	——Insects per 25 sweeps——	
	GH	LH
	P = <0.0001	*P = <0.0001*
Irrigated	1.25 b†	2.25 a
Dryland	1.83 a	1.49 b
	P = 0.0147	*P = <0.0001*
Fallow	1.35 ab	1.49 cd
Rye	1.74 ab	1.36 d
Radish	1.71 ab	1.86 bcd
Clover	1.93 a	2.01 abc
Rye-radish	1.01 b	1.88 abcd
Rye-clover	1.34 ab	2.24 ab
Radish-clover	1.76 ab	2.40 a
Rye-radish-clover	1.49 ab	1.74 bcd

† Means followed by a different letter within a column for each main effect (i.e., irrigation and cover crop treatment) are statistically different at the α = 0.10 significance level.

FIGURES

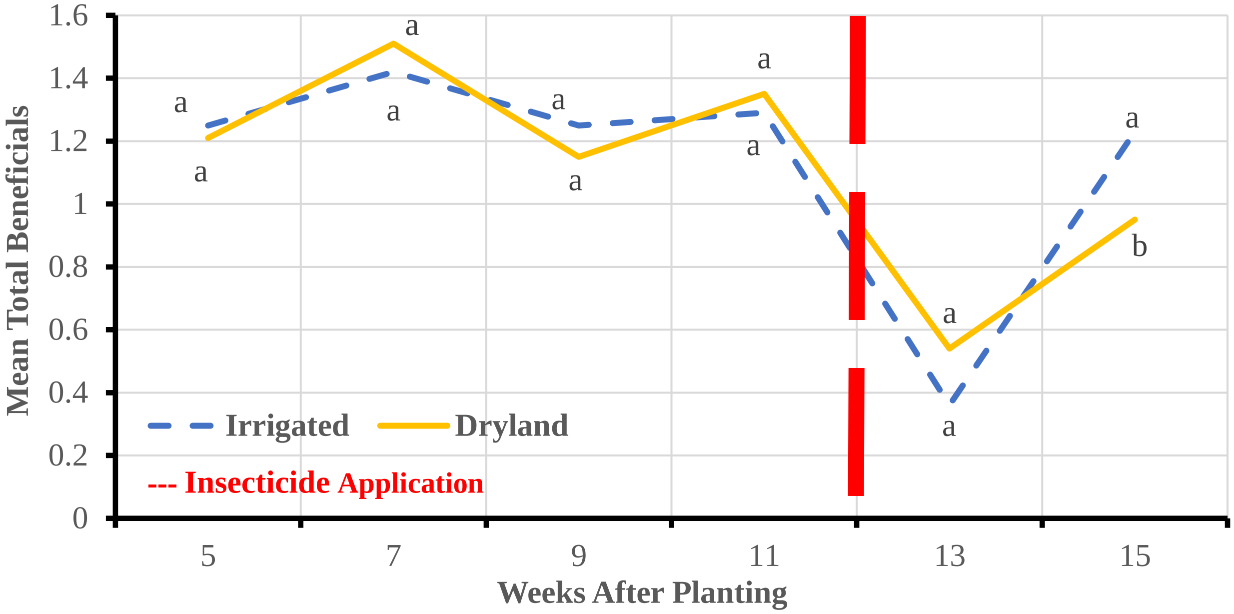

Figure 1. Irrigation and Lambda-cyhalothrin insecticide effects on beneficial insect totals collected in soybeans across all cover crop treatments at the Tennessee Valley Research and Extension Center in Belle Mina, AL during the 2019 growing season. Means followed by a different letter for the main effect (i.e. irrigation) are statistically different at the α = 0.10 significance level.

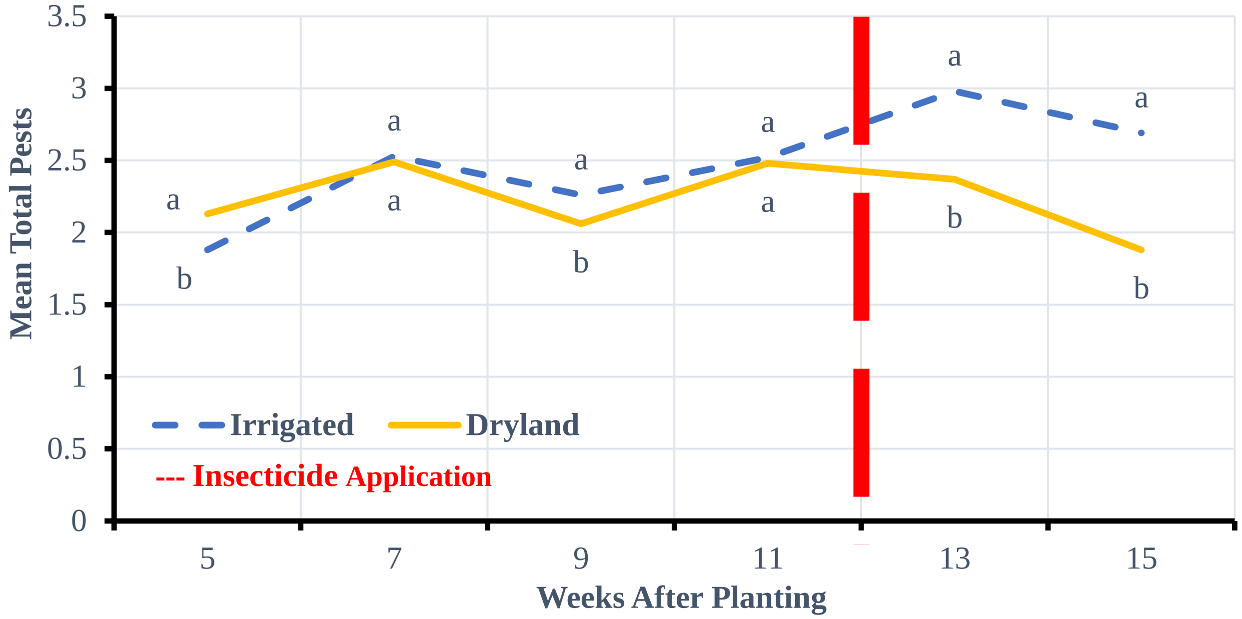

Figure 2. Irrigation and Lambda-cyhalothrin insecticide effects on pest insect totals collected in soybeans across all cover crop treatments at the Tennessee Valley Research and Extension Center in Belle Mina, AL during the 2019 growing season. Means followed by a different letter for the main effect (i.e. irrigation) are statistically different at the α = 0.10 significance level.

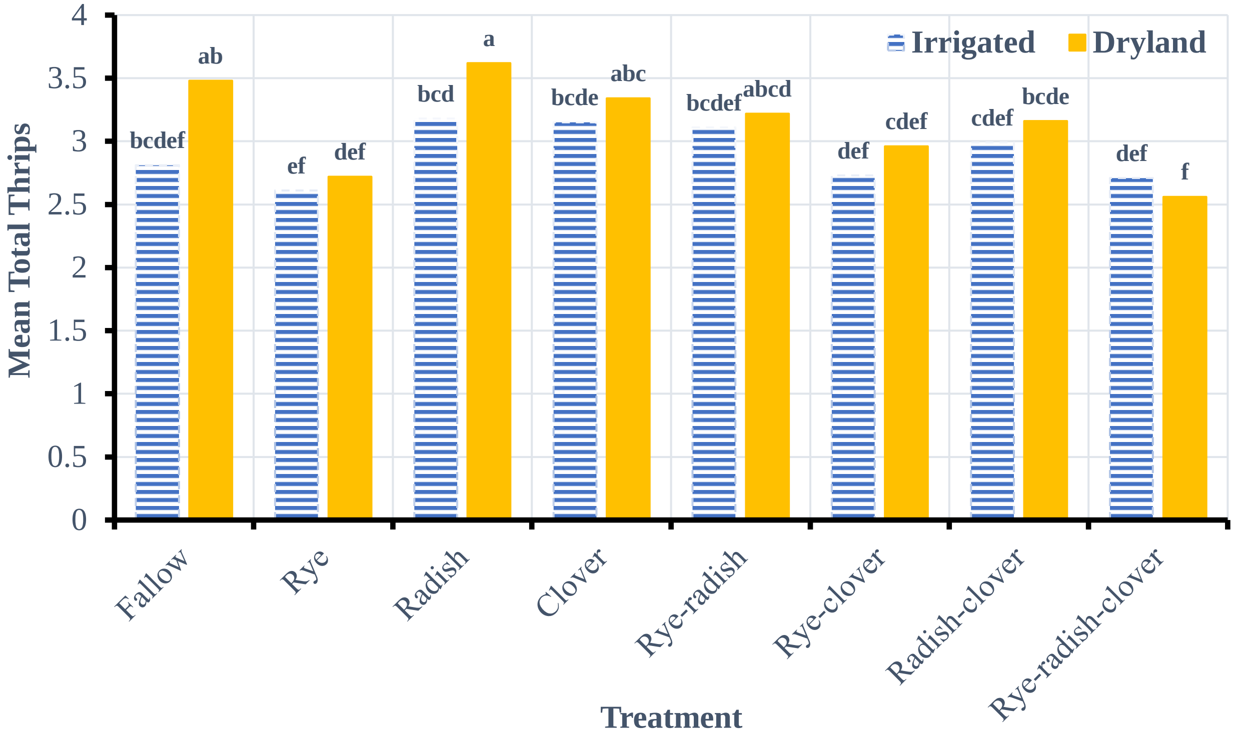

Figure 3. Interaction between cover crop treatment and irrigation management on the mean number of thrips collected in soybeans at the Tennessee Valley Research and Extension Center in Belle Mina, AL in 2019. Means followed by a different letter for each main effect (i.e., irrigation and cover crop treatment) are statistically different at the α = 0.10 significance level.

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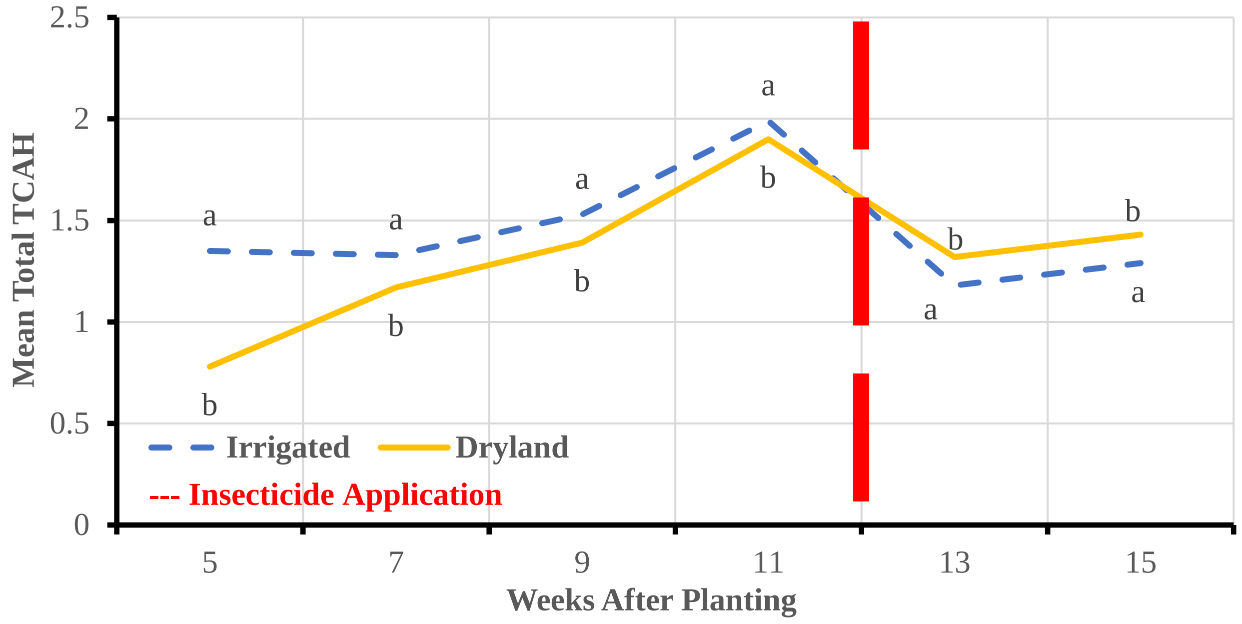

Figure 4. Irrigation and Lambda-cyhalothrin insecticide effects on three cornered alfalfa hoppers (TCAH) collected in soybeans across all cover crop treatments at the Tennessee Valley Research and Extension Center in Belle Mina, AL during the 2019 growing season. Means followed by a different letter for the main effect (i.e. irrigation) are statistically different at the α = 0.10 significance level.

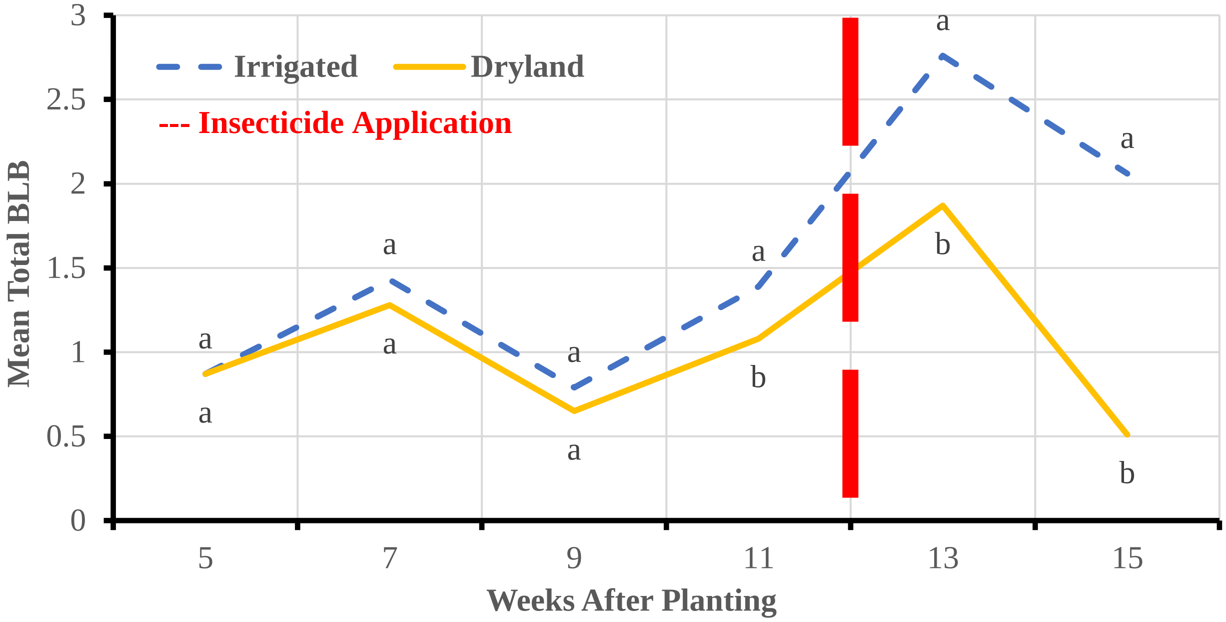

Figure 5. Irrigation and Lambda-cyhalothrin insecticide effects on bean leaf beetle (BLB) totals collected in soybeans across all cover crop treatments at the Tennessee Valley Research and Extension Center in Belle Mina, AL during the 2019 growing season. Means followed by a different letter for the main effect (i.e., irrigation) are statistically different at the α = 0.10 significance level.

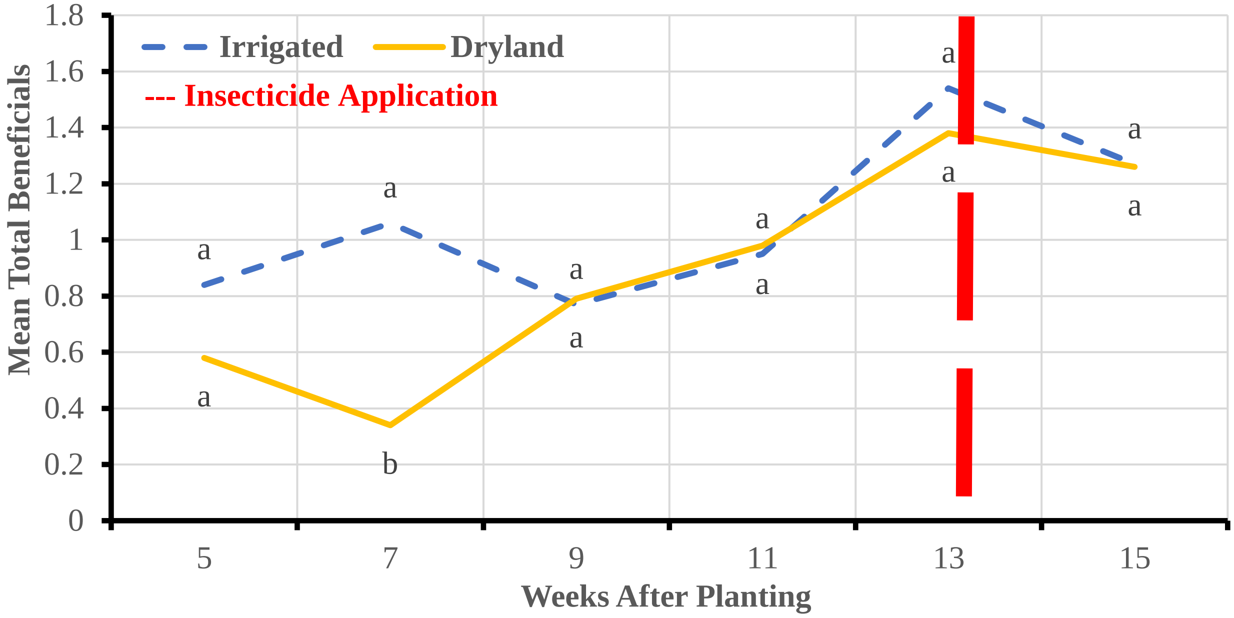

Figure 6. Irrigation and Methoxyfenozide insecticide effects on beneficial insect totals collected in peanuts across all cover crop treatments at the Wiregrass Research and Extension Center in Headland, AL during the 2019 growing season. Means followed by a different letter for the main effect (i.e. irrigation) are statistically different at the α = 0.10 significance level.

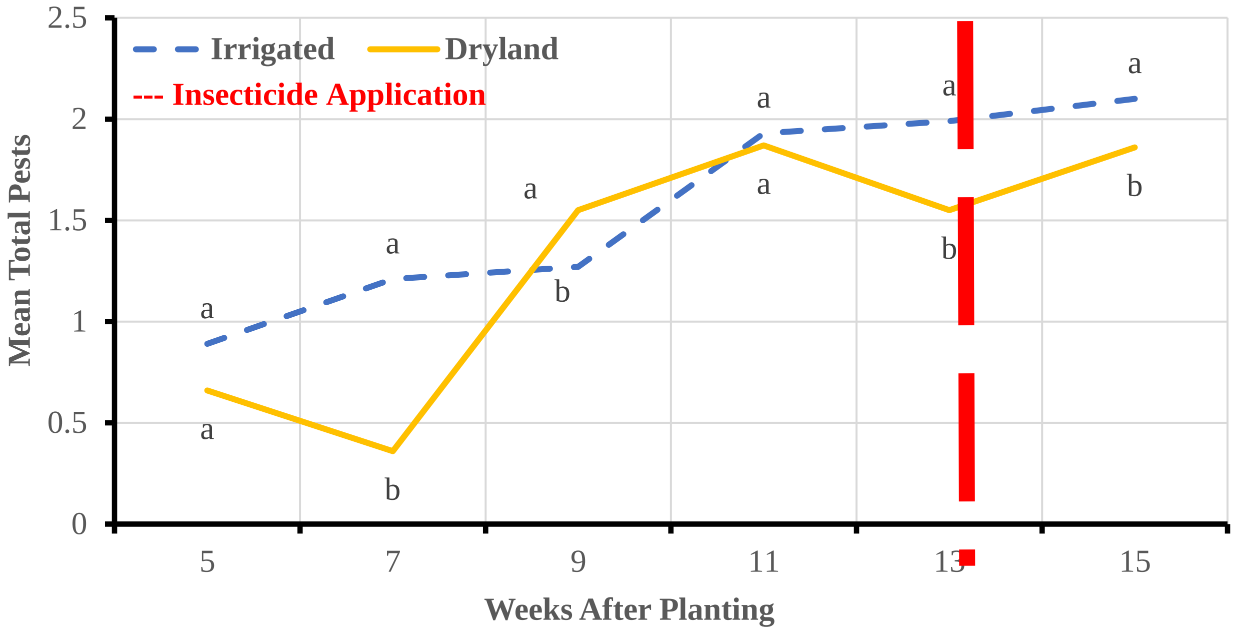

Figure 7. Irrigation and Methoxyfenozide insecticide effects on pest insect totals collected in peanuts across all cover crop treatments at the Wiregrass Research and Extension Center in Headland, AL during the 2019 growing season. Means followed by a different letter for the main effect (i.e. irrigation) are statistically different at the α = 0.10 significance level.

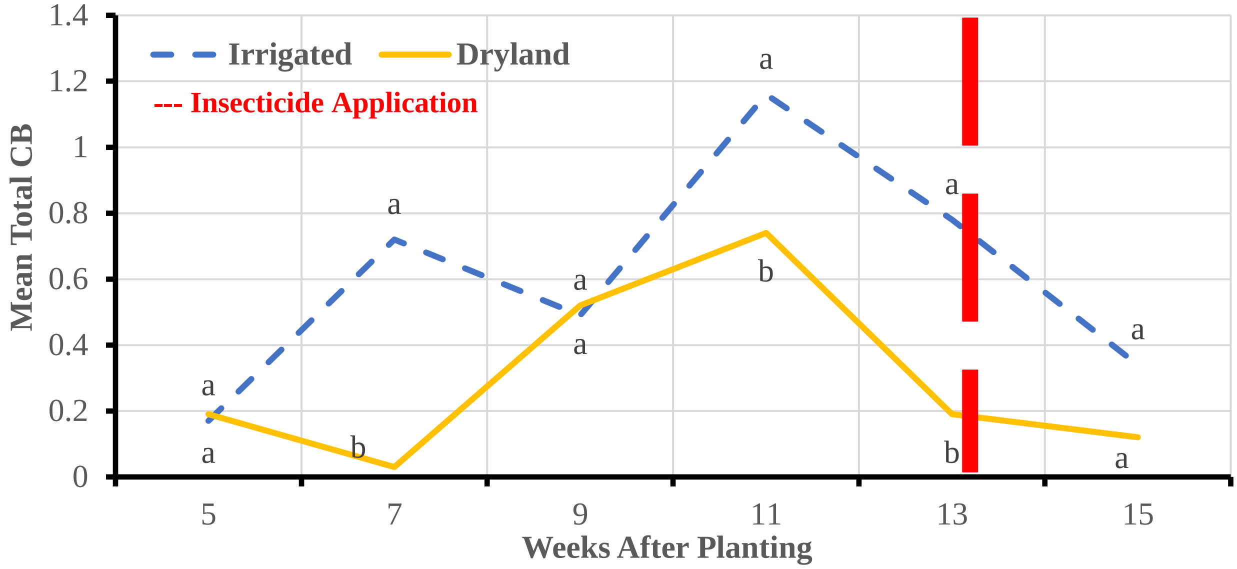

Figure 8. Irrigation and Methoxyfenozide insecticide effects on cucumber beetles (CB) collected in peanuts across all cover crop treatments at the Wiregrass Research and Extension Center in Headland, AL during the 2019 growing season. Means followed by a different letter for the main effect (i.e. irrigation) are statistically different at the α = 0.10 significance level.

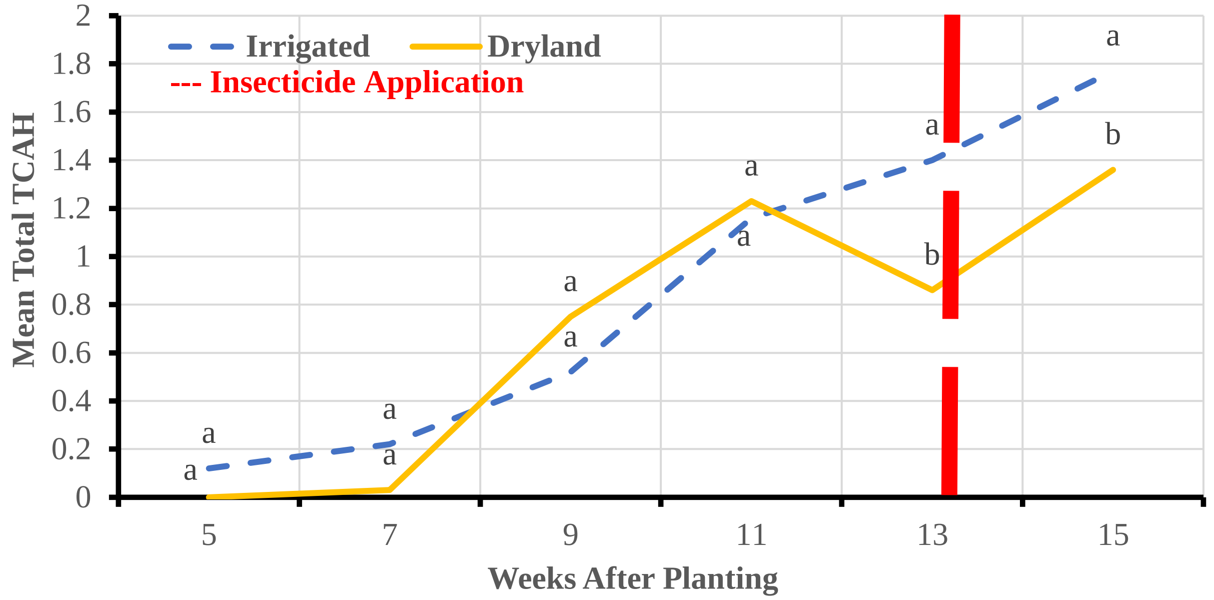

Figure 9. Irrigation and Methoxyfenozide insecticide effects on three cornered alfalfa hoppers (TCAH) collected in peanuts across all cover crop treatments at the Wiregrass Research and Extension Center in Headland, AL during the 2019 growing season. Means followed by a different letter for the main effect (i.e. irrigation) are statistically different at the α = 0.10 significance level.

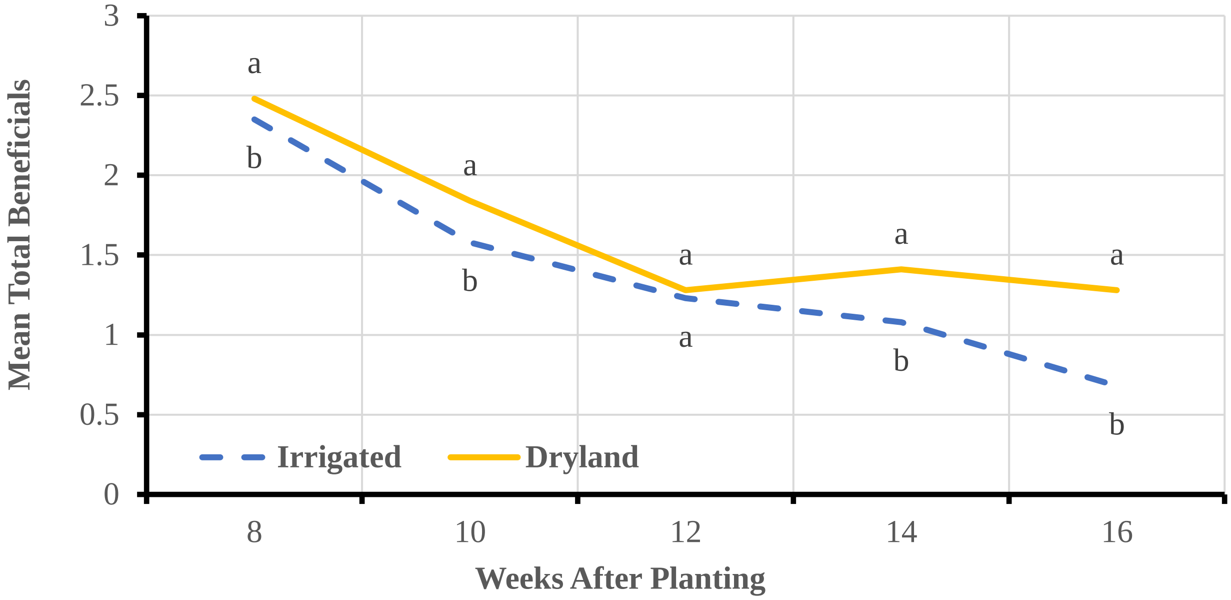

Figure 10. Irrigation effects on beneficial insect totals collected in cotton across all cover crop treatments at the Tennessee Valley Research and Extension Center in Belle Mina, AL during the 2020 growing season. Means followed by a different letter for the main effect (i.e., irrigation) are statistically different at the α = 0.10 significance level.

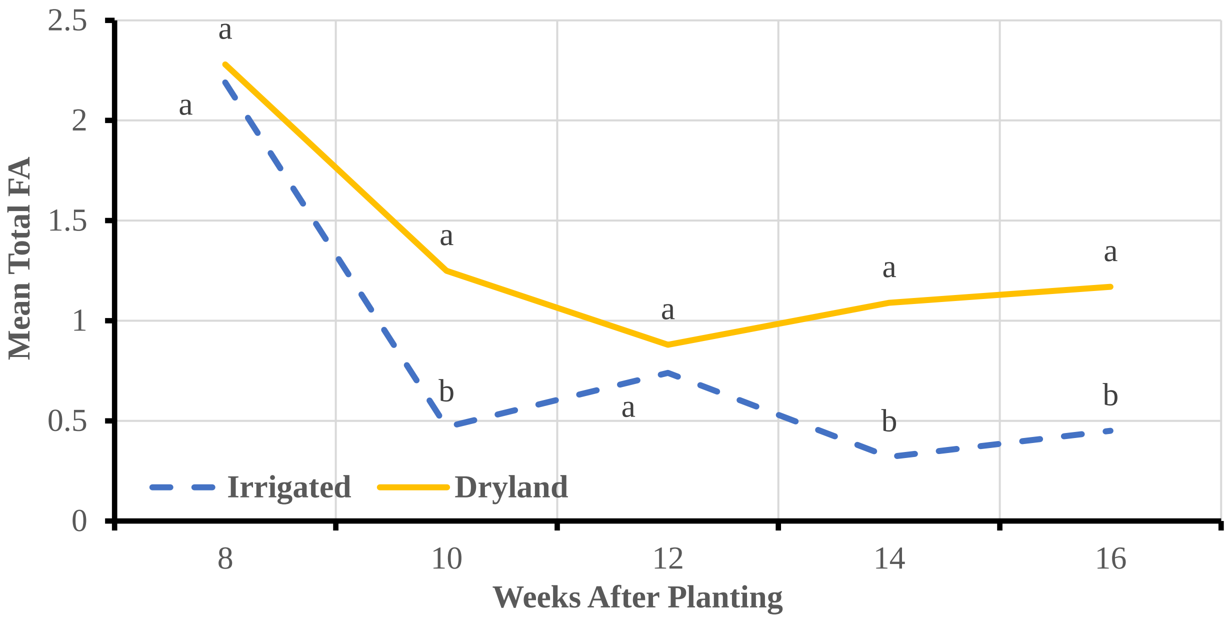

Figure 11. Irrigation effects on fire ants (FA) collected in cotton across all cover crop treatments at the Tennessee Valley Research and Extension Center in Belle Mina, AL during the 2020 growing season. Means followed by a different letter for the main effect (i.e., irrigation) are statistically different at the α = 0.10 significance level.

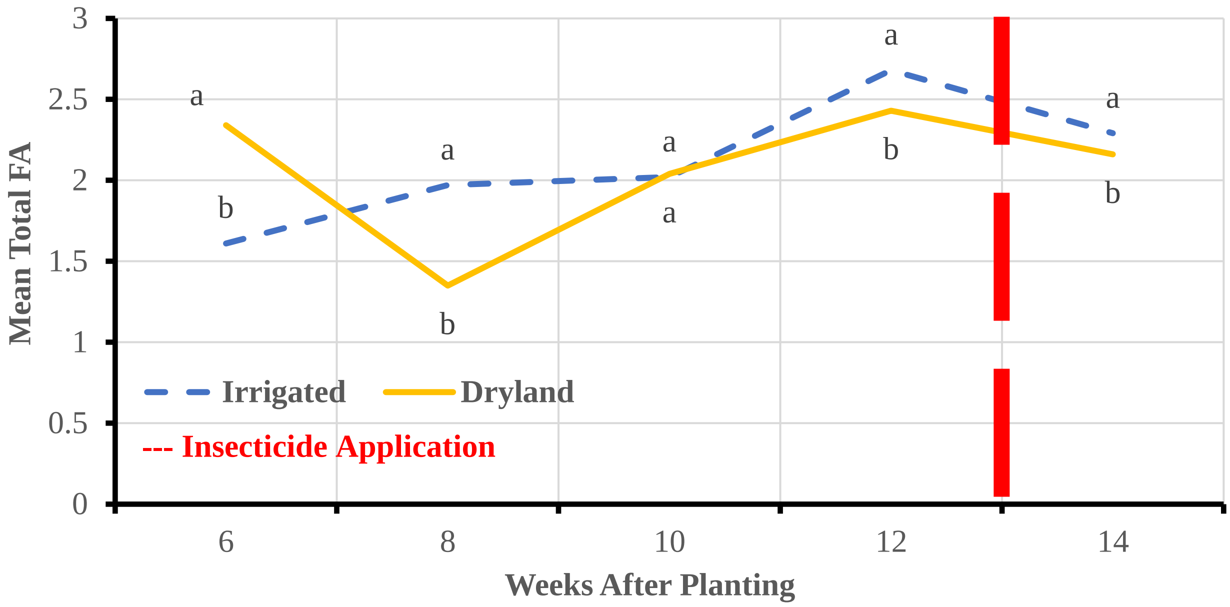

Figure 12. Irrigation and Bifenthrin insecticide effects on fire ants (FA) collected in cotton across all cover crop treatments at the Wiregrass Research and Extension Center in Headland, AL during the 2020 growing season. Means followed by a different letter for the main effect (i.e., irrigation) are statistically different at the α = 0.10 significance level.

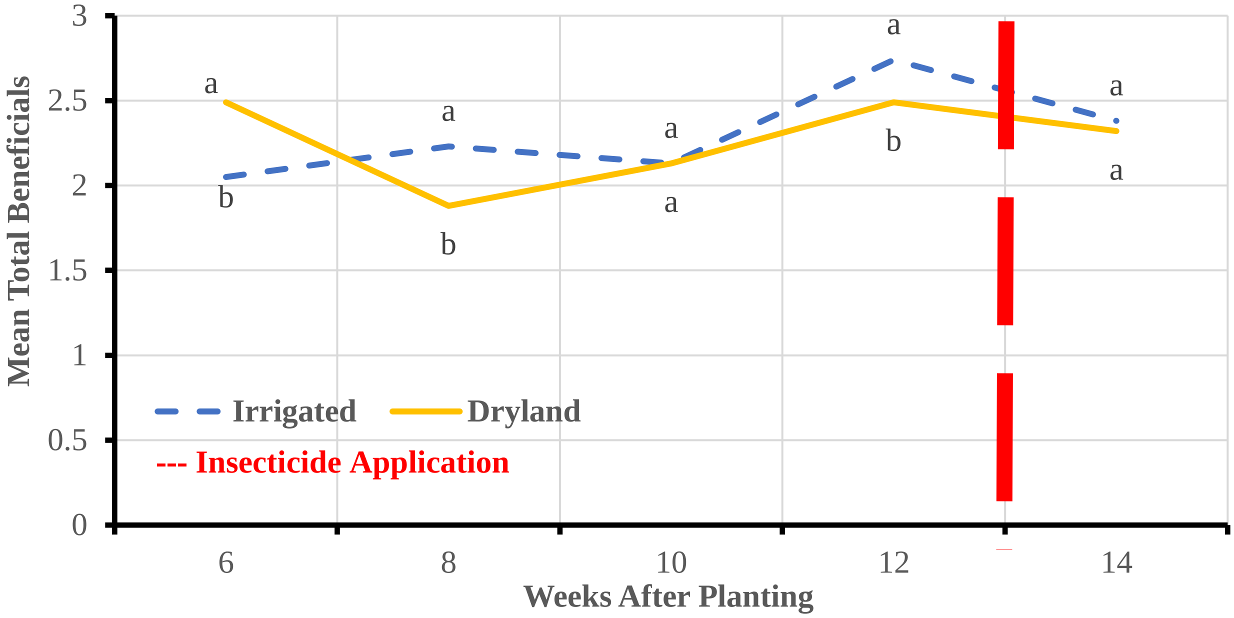

Figure 13. Irrigation and Bifenthrin insecticide effects on beneficial insect total collected in cotton across all cover crop treatments at the Wiregrass Research and Extension Center in Headland, AL during the 2020 growing season. Means followed by a different letter for the main effect (i.e., irrigation) are statistically different at the α = 0.10 significance level. Note: Insecticide was only applied to dryland plots.

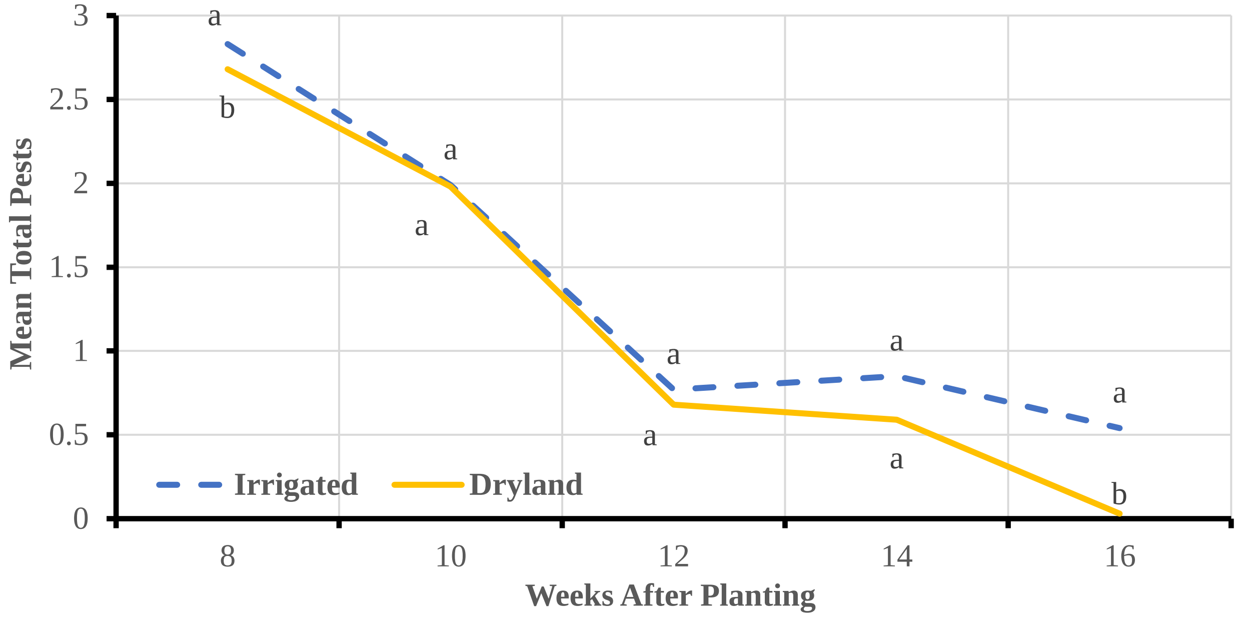

Figure 14. Irrigation effects on pest insect totals collected in cotton across all cover crop treatments at the Tennessee Valley Research and Extension Center in Belle Mina, AL during the 2020 growing season. Means followed by a different letter for the main effect (i.e., irrigation) are statistically different at the α = 0.10 significance level.

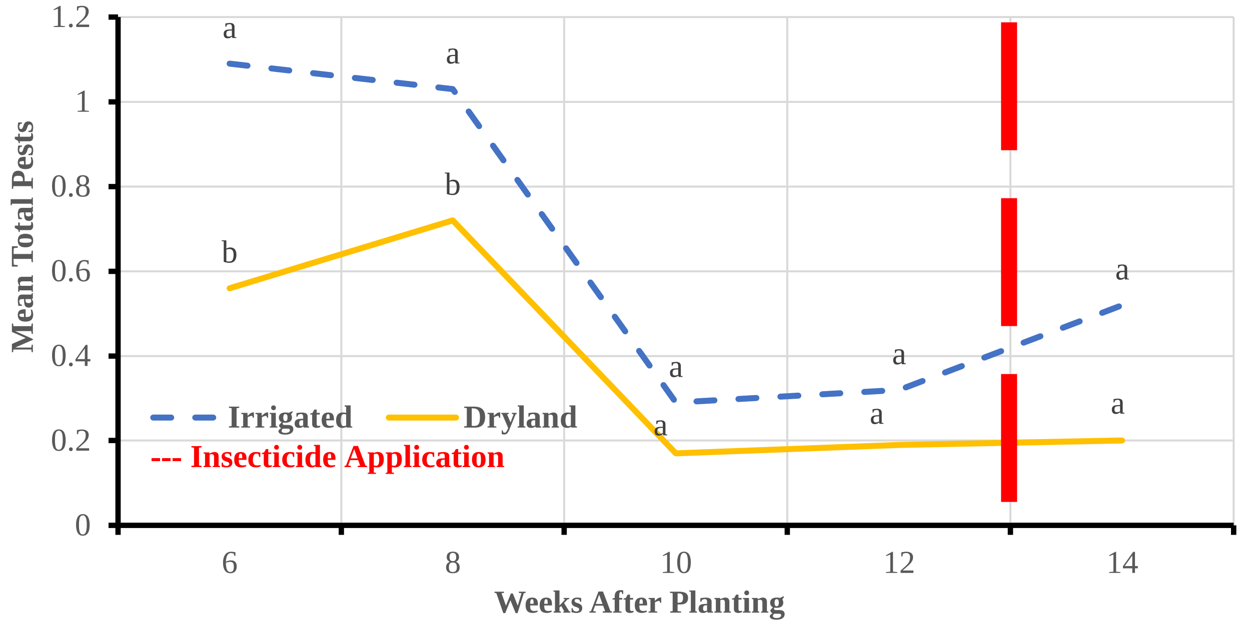

Figure 15. Irrigation and Bifenthrin insecticide effects on pest insect totals collected in cotton across all cover crop treatments at the Wiregrass Research and Extension Center in Headland, AL during the 2020 growing season. Means followed by a different letter for the main effect (i.e., irrigation) are statistically different at the α = 0.10 significance level. Note: Insecticide was only applied to dryland plots.

APPENDIX

Irrigation dates for cash crops at the Tennessee Valley Research and Extension Center (TVREC) in Belle Mina, AL and the Wiregrass Research and Extension Center (WREC) in Headland, AL.

	Irrigation			
	TVREC		WREC	
Season	† 2019	†† 2020	‡ 2019	†† 2020
Irrigation Dates	7/30	7/10	7/1	7/20
	8/2	7/20	8/14	7/27
	8/6	7/25	9/3	8/6
	8/12	7/30	-	-
	8/19	8/3	-	-
	8/22	8/11	-	-
	9/5	8/15	-	-

All cash crops at TVREC received 0.60” of water per irrigation event, while cash crops at WREC received 1.0” of water per irrigation event.

† Soybean

‡ Peanut

†† Cotton