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Winter Cover Crop Mixes: Effects on Strip-tilled Plasticulture and No-till Watermelon Production in Arkansas

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Winter Cover Crop Mixes: Effects on Strip-tilled Plasticulture and No-till Watermelon Production in Arkansas

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Abstract

Watermelon, *Citrullus lanatus* (Thunb.) Matsum. & Nakai, producers in Arkansas grow watermelons in either plasticulture or bare-ground systems. Both systems can benefit from the use of winter cover crops for weed control and to supply nitrogen (N) to the watermelon crop. Currently, the use of cover crops in watermelon production in AR is mostly limited to either cereal rye (*Secale cereale* L.) or winter wheat (*Triticum aestivum* L). The objective of this research is to evaluate the potential benefits of growing a mix of a legume and grass cover crops before watermelon production in both a strip-till plasticulture and a no-till roller crimped system. Specifically, we compared the following winter cover crop treatments: Austrian winter pea (*Pisum sativum* L. ssp. *arvense*), crimson clover (*Trifolium incarnatum* L.), mustard (*Brassica cretica),* black-seeded oats *(Avena sativa* L.), cereal rye, winter wheat, and mixed combinations of Austrian winter pea + black-seeded oats, Austrian winter pea + cereal rye, Austrian winter pea + winter wheat, black-seeded oats + crimson clover, black-seeded oats + Austrian winter pea + mustard. These cover crops were compared to a fallow ground control with preemergence herbicide applied at transplant. The test to evaluate a plasticulture system was conducted in Hope, AR from 2017-2019, and the test in no-plastic cover, no-till system was conducted in Kibler, AR from 2017-2020. 'Jubilee' watermelon was planted in both locations. Data collected included: cover crop biomass ($kg{\cdot}ha^{-1}$), winter weed biomass ($kg{\cdot}ha^{-1}$), cover crop C to N ratio and N content ($kg{\cdot}ha^{-1}$), petiole nitrate-N, summer weed biomass ($kg{\cdot}ha^{-1}$), and watermelon yield and fruit quality. Overall, a mix of cereal rye + Austrian winter pea is a suitable choice for a strip-till plasticulture system or for a no-till roller-crimped system. In both production systems the mix of cereal rye + Austrian winter pea produced consistent amounts of cover crop biomass, occasionally increased watermelon petiole nitrate-N content, had summer weed suppression

similar to a preemergence herbicide in the early season, and resulted in numerically higher watermelon yields. Arkansas farmers should avoid growing winter wheat as a cover crop for watermelon production because winter wheat could reduce yields in both no-till and strip-till systems.

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Chapter 1. Introduction and Literature Review

Watermelon Crop Economic Status

Watermelon, *Citrullus lanatus* (Thunb.) Matsum. & Nakai, has become a major cash crop throughout the world. The modern watermelon, is a warm-season annual cucurbit crop derived from an African native species (*C. lanatus* subsp. lanatus var. caffer (Schrad.) Mansf. (Wasylikowa et al., 2004). Seeds from native watermelon plants have been found throughout ancient African civilizations with harvests recorded in Egypt dating back 5,000 years. Today watermelons are cultivated on large scale to meet consumer demand for the fruit. From 2010 through 2015, the United States averaged 52,292 hectares of fresh market watermelon production (USDA NASS, 2018). Watermelons are a high-value specialty crop with US farmers averaging about $14,636 gross sales per hectare in 2018 (USDA NASS, 2018). Arkansas accounted for an average 0.8% of the total US production from 2016-2018 (USDA-AMS, 2020). States with the largest production for 2016-2018 were, Georgia (18.0%), Florida (17.9%), California (13.8%,) Texas (11.8%,) and Indiana (10.6%) (USDA-AMS, 2020). The US continues to be a net importer of watermelons with about 37% of fruit in the marketplace being imported, of which Mexico supplies 83% of total imported volumes (Perez and Ferreira, 2018).

According to USDA NASS (2017), Arkansas farmers grew over 737 hectares of watermelons in 2017, of which 717 hectares were for fresh market. Some of the watermelon cultivars that are recommended for production in Arkansas include ‘Crimson Sweet’, ‘Jubilee II’, ‘Star Brite’, ‘Sweet Favorite’, ‘Shiny Boy’, ‘Yellow Baby’, ‘Triple Crown’, and ‘Moon and Stars’ (Andersen, 2011). The cultivar ‘Jubilee II’ is a seeded, diploid cultivar with an estimated 90 days to maturity, it is also resistant to diseases anthracnose and fusarium wilt 1 (Andersen, 2011).

When accounting for other Cucurbitaceae crops, such as summer squash (*Cucurbita pepo* L.), and pumpkins (*Cucurbita pepo* L.), cucumbers (*Cucumis sativus* L.), muskmelon, (*Cucumis melo* L.), honeydew melons, (*Cucumis melo* L.), and cantaloupes (*Cucumis melo* L.), a total of 1,189 hectares of cucurbit crops are grown in Arkansas (USDA NASS, 2017).

Plasticulture Watermelon Production Systems

Watermelons are ideally planted in sandy-loam, well-drained, and organic-matter-rich soils (Anderson, 2011). When planting direct-seeded and transplanted watermelons, the soil temperature needs to be a minimum of 16.7 ℃ with no risk of future frost. Days to maturity of watermelon varies from 70 to 130 days (Anderson, 2011).

Plasticulture production, which involves forming a raised bed covered with black plastic mulch overlaying drip irrigation is a common method of production for watermelons in the Southeast. A typical raised plastic bed is 10 to 15 cm tall and 76 cm wide (Lamont, 1993). Black plastic mulch has been in use for specialty crops since the 1960s. Some adoption of biodegradable plastic mulch has been implemented but is not currently widely adopted. Polyethylene plastic mulch is used in a plasticulture system for many reasons, including early and consistent warming of the beds, moisture retention, and weed suppression (Lamont, 1993). The black plastic mulch can warm the soil underneath by 2.8 ℃ at 5 cm and 1.7 ℃ higher at 10 cm compared to the respective depths in bare ground soil (Lamont, 1993) Plastic mulch in conjunction with drip irrigation has been shown to reduce moisture evaporation from the soil and reduce irrigation water use (Hanlon and Hochmuth, 1989). Significantly greater and earlier yields have been reported when watermelons are grown on black plastic mulch beds compared to bare ground (Soltani et at., 1995).

Some limiting factors for plasticulture systems are the cost of the plastic material and for its disposal. The majority of commercially grown vegetables utilize polyethylene mulch and this usage totals approximately 130 million kg of plastic per year in the United States (Shogren and Hochmuth, 2004). Removal of the plastic requires labor and expenses estimated at $250 per hectare (Shogren and Hochmuth, 2004). Proper disposal of polyethylene mulch is an issue since recycling is difficult due to soil and debris in the plastic which landfills may not accept or for which they charge a tipping fee (Lamont, 2005). These fees have increased $1.37 per metric ton each year on average in the U.S., and as a result much of the plastic is disposed of by burning or burying on the farmer's property (Lamont, 1993; Shogren and Hochmuth, 2004); NSWMA, 2012).

Watermelon Crop Nutrient Requirement

Nitrogen is an essential macronutrient required as a component of amino acids, a component of nucleic acids, and also a component of chlorophyll. When insufficient amounts of nitrogen are available, plants may have stunted growth, yellowing of leaves, and a loss in fruit production. (Glass, 2010; Pilbeam 2011). Potassium is also a macronutrient which is associated with transport of water and carbohydrates in the plant, and enzymatic activity including adenosine triphosphate production, and regulation of stomatal function. Potassium deficiency may result in stunted growth and reduced fruit production (Clarkson and Hanson, 1980; Wang and Wei-Hua, 2013).

Recommended season-long fertilizer rates for watermelon include 130 $kg \cdot ha^{-1}$ of nitrogen and 110 $kg \cdot ha^{-1}$ of potassium (Hartz and Hochmuth, 1996). Application is recommended to be distributed via weekly fertigation throughout the growing season with the rate based on stage of crop development. (Kemble et al., 2021). Drip irrigation can be used to supply the necessary fertilizer, via fertigation, which lowers the overall fertilizer application rate and minimizes the effect on the environment. Fertigation allows for more consistent and controlled fertilizer applications directly to plant, rather than heavy fertilizer applications preplant and in-season side dress (Hartz and Hochmuth, 1996).

Watermelon Petiole Nutrient Sampling

Soil testing as a means to predict nitrogen fertility in-season is limited because nutrients are mobile in the soil; thus, availability may fluctuate due to rainfall or irrigation (Hochmuth, 1994b.) Plants low in nitrogen may not have visual symptoms that indicate a deficiency; therefore, a nutrient sample to monitor plant nitrogen status is useful to prevent reduced plant growth and low fruit yield (Hochmuth et al., 2018). Measurement of the nutrient content of watermelon petioles at critical phenological points in the growing season is used to determine if sufficient levels of key nutrients are being provided by the in-season fertility program. Nutrient guidelines for optimum yield and fruit quality of watermelon have been established for nitrate and potassium content in the petiole sap ($mg \cdot liter^{-1}$) based on the developmental stage of the plant (Hochmuth, 1994a). Analysis of the plant tissue directly measures what nutrients the plant is taking up but the most accurate and definitive results from this method require whole leaf or dried petiole samples to be analyzed in a lab via digestion, which can be time consuming and expensive (Hochmuth, 1994a). The use of a Cardy meter (Horiba, Kyota, Japan), a hand-held ion-specific electrode, can provide an immediate, accurate reading in the field of plant petiole sap. To use the Cardy meter a representative sample of approximately 20 recently mature leaves with the leaf blade removed so only the petiole remains should be collected for extraction of the petiole sap by physical compression (Hochmuth, 1994b).

Watermelon Pest Management

Weeds

Weeds contribute to yield loss in watermelon production if they are not controlled in the first several weeks following transplant (Mitchem et al., 1997). According to Terry et al. (1997), the vining nature and slow growth of watermelons can make weed control difficult.

Yellow (*Cyperus esculentus* L.) and purple nutsedge (*Cyperus rotundus* L.) are, perennial tuber-forming monocots, which can be major weed problems in watermelon productions in the Southeast. These weed species have been shown to cause 10% yield loss in transplanted watermelon even at low densities (2 plants/ m^2) (Buker et al., 2003). Yellow and purple nutsedge reproduce and spread through tubers which may be dispersed by tillage and use of machinery across different fields (Ransom et al., 2009). Yellow nutsedge can be very pervasive when grown in well-irrigated nitrogen-rich soil. One yellow nutsedge tuber can produce 1,700 to 3,000 new shoots and 19,000 to 20,000 additional tubers in one year (Ransom et al., 2009). Yellow nutsedge can penetrate through black plastic mulch demonstrating that an infested field cannot be controlled exclusively by black plastic mulch (Webster, 2005). Neither yellow nor purple nutsedge can be controlled by graminicides. The use of a cereal rye cover crop mat alone cannot suppress yellow nutsedge for the entirety of the season, however, the cover crop mat in conjunction with the pre- and post-applied herbicides can improve weed control (Monday et a., 2015).

Palmer amaranth (*Amaranthus palmeri* S. Watson), also known as carelessweed or pigweed, is an annual broadleaf which can be particularly problematic in watermelon production due to its growth pattern. Palmer amaranth can grow 5-8 cm in a day and reach heights of 1.8-2.4 m tall (USDA-NRCS, 2017). The rapid growth can quickly shade out and compete for resources with watermelon plants. Palmer amaranth has been reported to produce 1,800,000 seeds from a single plant (Smith et al., 2012). To reduce yield losses to less than 10% of average yield, watermelon plots must be maintained weed-free from smooth amaranth (*Amaranthus hybridus* L.) for at least three weeks after seeding (Terry et al., 1997).

Other summer weeds that may become problematic throughout the watermelon growing season include: common purslane (*Portulaca oleracea* L.), carpetweed (*Mollugo verticillata* L.), barnyardgrass (*Echinochloa crus-galli* L.), goosegrass (*Eleusine indica* (L.), large (hairy) crabgrass (*Digitaria sanguinalis* L.), broadleaf signalgrass [*Urochloa platyphylla* (Munro ex C. Wright], dallisgrass (*Paspalum dilatatum* Poir), eclipta (*Eclipta prostrata* L.), path rush (Juncus tenuis), redroot pigweed (*Amaranthus retroflexus* L.), and purple nutsedge (*Cyperus rotundus* L.).

Weed Control

In Arkansas 95% of fields utilize herbicide for weed control in watermelon production (Andersen and Spradley, 2003). A limited number of herbicides are labeled for watermelon production, making weed control difficult when control methods rely exclusively on herbicides. Herbicides available for post-emergent weed control in watermelons are limited to graminicides, growers must select a preemergent herbicide with a minimum residual weed control of 18 days after transplant to prevent yield loss due to weed pressure (Bertucci et al., 2018). Annual grasses, such as barnyardgrass and goosegrass can be effectively controlled by ethalfluralin, sethoxydim, clethodim, and bensulide, however, neither yellow nutsedge (*Cyperus esculentus* L.) nor purple nutsedge can be controlled effectively in season during watermelon production (Johnson et al., 2002). Tillage is also a significant means for weed control in watermelon, and is often accomplished via hand hoeing in the rows before vines cover the row middles (Bertucci et al., 2019).

Diseases

Plant disease can negatively impact watermelon plant health and fruit production, reducing yield or marketability. Diseases that affect watermelons in Arkansas include anthracnose (*Colletotrichum orbiculare*) and other fruit belly rots caused by the fungus fungi *Pythium aphanidermatum* or *Sclerotium rolfsii*, damping off caused by fungal species *Pythium* spp., *Sclerotinia*, and *Phytophthora* in cool, wet soils or *Rhizoctonia solani*, fusarium wilt (*Fusarium oxysporum*), and *Sclerotium rolfsii* in warm dry conditions, and gummy stem blight (*Stagonosporopsis cucurbitacearum, Stagonosporopsis citrulli, and Stagonosporopsis caricae)*. Many of these diseases often occur when the watermelon fruit or vines are in contact with soil. Cultural practices that reduce soil contact by vines and fruit like the use of black plastic or a cover crop mat may reduce plant exposure to soil-borne microorganisms responsible for disease. However, high disease pressure in the Southeast requires the use of fungicides to produce high-quality fruit.

Anthracnose is fungal disease caused by *Colletotrichum orbiculare* which commonly occurs during periods of extended rain and warm weather. Both the leaves and fruit may be affected by the disease and infected leaves and vines may lead to plant death. Fruit damaged by Anthracnose is unmarketable due to small round lesions, which eventually leak and rot (Damicone and Brandenberger, 2020). Southern blight fungus *Sclerotium rolfsii,* causes a water lesion on the fruit which spreads and becomes surrounded by profuse growth of white mycelium. The blight occurs with rainfall and high temperatures. Prevention of belly rots is by planting on plastic mulch to keep fruit off soil and planting in well-drained soils (Boyhan et al., 2017).

Damping-off is caused by fungal pathogens *Pythium spp, and Rhizoctonia solani* and can be troublesome for both direct-seeded and newly transplanted watermelons (Hodges, 2003). Symptoms of damping-off in young seedlings is wilting even when soil is adequately moist, brown discoloration of roots, or a lesion on the stem at soil level that eventually girdles the plant and causes death (Hodges, 2003). Pythium is often problematic on watermelon during cool (10-20C°) wet springs when the soil moisture is 50% or greater that causes plant stress and opens the plants up to infection by the fungus (Hodges, 2003). Excess nitrogen may also increase the outbreak of pythium (Hodges, 2003). Pythium can be controlled with the fungicide mefenoxam (Ridomil Gold).

Rhizoctonia fungus reproduces more efficiently during warm dry weather but often infects plants during cool wet times when the plant is not growing rapidly, similar to pythium (Hodges, 2003). Rhizoctonia may have a reduced inoculum when a grass cover crop is incorporated into the soil, whereas a legume such as clover my increase the inoculum (Hodges, 2003).

Watermelon Fruit Disorders

Blossom-End Rot

Blossom-end rot (BER) is a disorder of many fruit and vegetable crops that begins with a browning and shriveling of the blossom-end of the fruit opposite the side attached to the stem. The BER allows an opening for further microbial colonization in the wound which often results in a large, soft black spot on the fruit. Early research on tomatoes indicated the cause of BER to be a nutritional disorder related to a shortage of calcium in the plant (Lyon et al., 1942). Joy and Hudelson (2005) discuss how irregular patterns of soil moisture, from fully saturated soil to dry soil, can reduce plant transpiration rates which effects calcium uptake via active transpiration to the fruits. Other factors that may impact transpiration rates such as high humidity and heat lowers the rate of transpiration which effects calcium uptake by the plant. Excessive fertilizer may also increase BER as plants are induced to greater vegetative growth, which limits the amount of calcium available for fruits (Joy and Hudelson, 2005). When low rates of calcium are applied to tomatoes lower fruit numbers, lower levels of calcium in the leaf and fruit tissue, and a higher incidence of BER have been observed (Mestre et al., 2012). Calcium is a key component of enzyme activity, which in short supply results in an increase of lipid peroxidation and visual symptoms of cell wall break-down associated BER (Mestre et al., 2012). Excessive applications of nutrients (nitrogen, phosphorus, potassium, and micronutrients) can also lead to higher incidences of BER symptomology (77% of the time compared to 8.7% when grown with normal fertilizer application rates) due to interference with the plant's ability to transport calcium to the fruit (Suzuki et al., 2003).

Sun Scald

Sun scald results in a white or yellow mark on the top of the watermelon after exposure to excess solar radiation and heat, which dehydrates the rind (Munné-Bosch and Vincent, 2019). Sun scald may occur in healthy plants; however, it is most common under conditions of poor plant health where reduced foliage cover does not provide shade to the watermelon fruit. The application of some pesticides may cause sunburn damage to the fruit surface as well, such as fungicides containing chlorothalonil (Egel and Maynard, 2015).

Cover Crops

A cover crop is any non-cash crop grown for its potential effect on the soil, or subsequent cash crops (UC-SARE, 2017). Some of the benefits of cover crops are reduced fertilizer costs, reduced reliance on herbicides, enhanced soil health through increased infiltration, reduced soil compaction, increased of organic matter, enhanced nutrient cycling, reduced soil erosion, and conservation of soil moisture (Clark, 2007). Major types of cover crops include grasses, legumes, and brassicas.

Cover crops have a long history of use in agriculture. Cover crops were used by the Romans and Greeks for their effect on increasing crop yields (USDA-NRCS, 2015). Xenophon a writer living in areas around the Mediterranean from 434 to 355 B.C. discusses green plants, not gone to seed, plowed into the soil with similar results to manure to strengthen the soil to increase crop yields (Wedderbuan and Collingwood, 1976). Ancient writers living in present day China discussed how farmers plowed in legumes grown for two months to increase future crop production, with results similar to rotted farm manure (Pieters, 1927). Cover crops were an important part of agriculture prior to the ubiquitous use of synthetic fertilizers in the 1950s (USDA NRCS, 2010). The term cover crop in the United States is often used to indicate the actual cover provided by the crop and the incorporation of the crop as a green manure. In the 1920s in the southeastern United States, hairy vetch and crimson clover have been grown over winter and plowed into the soil as green manure to benefit corn and cotton production (Pieters, 1927). In Alabama, the amount of hairy vetch seed sold in 1920 was about 4,536 kg, and increased to 272,155 kg by 1925 (Pieters, 1927). In the sandy soils of Virginia, spinach or kale that was grown in the winter, were followed by cowpeas or soybeans that were then plowed into the soil preceding the next crop of spinach or kale (Pieters, 1927). The development of cheap nitrogen fertilizer by the Haber-Bosch process transformed agricultural production. The use of cover crops still has value in modern times, however, much of the use and associated research is focused on agronomic crops and not specialty crops. From 2019-2020 the Sustainable Agriculture Research and Education (SARE) program conducted a voluntary survey of 1,172 farmers that actively utilize cover crops as an aspect of their cropping system and found that 94% of horticulture producers stated that their cover crop use was primarily motivated by effects on improved soil health and structure and 81% of horticultural crop growers were also motivated by potential weed suppression (SARE, 2020). Of the horticultural producers surveyed 34.8% reported a 5% or greater increase in net profits from the use of cover crops, 23.4% saw a net increase in profits from 2-4%, and only 3.8% saw reduction in net profits from the use of cover crops (SARE, 2020). There is a need for further research for specialty crop farmers to make informed decisions about cover crop use in different production systems, particularly with cucurbit crops which may benefit from improvements to soil health and sustainability through the use winter cover crops in the season before production.

Common Winter Cover Crops for Arkansas

Cover crops are chosen based on their potential to provide services to the soil or to the subsequent cash crop. Grass cover crops, such as cereal rye, are known for the ability to produce large amounts of biomass even at low seeding rates by expansion of the growth area through tillers, resulting in large amounts of biomass accumulation even at reduced seeding rates such as in a cover crop mix with a legume (Boyd et al., 2009). Small annual grains may also be utilized as a wind break between rows to protect new transplants from prevailing winds (Lamont, 2005).

Legume cover crops are typically utilized in a cropping system as a nitrogen input through their ability to convert atmospheric nitrogen gas (N_2) into stored plant nitrogen before ultimately breaking down into the forms ammonium (NH_4^+) and nitrate (NO_3^-) which can be taken up by subsequent crops (Clark, 2007). Legumes typically have a lower carbon to nitrogen ratio than grasses, so the legumes plant material breakdown more rapidly and released nutrients contained in the biomass more quickly (Clark, 2007).

Brassicas represent a third group of cover crops that are planted. Some of the species used include: turnips (*Brassica septiceps)*, mustard (*Brassica cretica)*, canola (*Brassica napus and Brassica rapa)* and forage radish (*Raphanus sativus)*. One benefit of a mustard cover crops is the biofumigation attribute of isothiocyanates, an allelochemical produced from the breakdown of glucosinolate content of plants, which can suppress insect pests such as nematodes and click beetle larva, such as the eyed click beetle (*Alaus oculatus*), and suppresses soil-borne diseases such as *Pythium* root rot and *Rhizoctonia solani* (Brown and Morra, 2005). Other brassicas, like turnips, also have a strong, deep penetrating taproot that provides deep soil mining for nutrients and potentially breaks up hardpans present in the soil (Williams and Weil, 2004).

Black-seeded Oats

Black-seeded oats (*Avena sativa* L.), also known as common oats or spring oats is a cool-season annual cereal and a member of the Poaceae family. Black-seeded oats are often grown as an affordable biomass producer and a nutrient catch crop; however, it can be winter killed in hardiness zone 6 and colder (Clark, 2007). Black oats have been shown to have a lower carbon to nitrogen ratio than other grasses, increasing the potential for nitrogen additions to be taken up by subsequent cash crops following termination (Bauer & Reeves, 1999). Black oats have allelopathic properties in the leaf tissue that may inhibit small weed seed germination in near proximity to the plant (Price et al., 2008). Seeding rates for black oats can be approximately 112 $kg \cdot ha^{-1}$ when broadcast or 56 to 78 $kg \cdot ha^{-1}$when drilled (USDA-ARS-NSDL, 2010). Black oats grown as a cover crop for cotton and soybean production were effectively roller crimped, reducing the weed pressure and reduced herbicide inputs (Ashford and Reeves, 2003).

Cereal Rye

Cereal Rye (*Secale cereale* L.), also known as common rye, rye, winter rye, grain rye, or cultivated rye, is often planted as a fall cover crop. The benefits of cereal rye as a cover crop include building soil structure, reducing compaction, limiting erosion, suppressing weeds, and scavenging nitrogen. Cereal rye can take up 28-56 $kg \cdot ha^{-1}$ of nitrogen that may otherwise be lost to leaching from fallow ground (Clark, 2007). Nitrate in the soil not taken up by a cash crop can be readily leached; growing a catch crop, such as cereal rye, is important to reach the deeper soil levels (below 1 m) that may have leached nitrate and bring it back into the cash crop system as a net input (Kristensen and Thorup-Kristensen, 2004). The nitrogen-scavenging capacity of cereal rye exceeds that of legume monocrops (Brennan et al., 2012), Cereal rye used as a monoculture or in part of a mixture with other cover crops has superior abilities to take up residual nitrogen from the soil compared to future cash crops or legume cover crops (Ranells and Wagger, 1997).

Winter Wheat

Winter wheat (*Triticum aestivum* L.) is a winter annual cereal grain that is planted for soil erosion control, suppression of weeds, nutrient scavenging, and adding organic matter to the soil (Clark, 2007). The fine root system of wheat can improve soil tilth in the upper horizons of the soil (Roberts et al., 2018).

Austrian Winter Pea

Austrian winter pea (*Pisum sativum* L. ssp. *arvense*) is a legume grown for its nitrogen-fixing ability and quick growth (Clark, 2007; Pavek, 2012). Nodulation occurs on the pea roots formed by the bacteria *Rhizobium leguminosarum.* The bacterium is essential for the conversion of atmospheric nitrogen (N_2) to ammonia (NH_3) (Clark, 2007). Austrian winter pea seeds needs to be inoculated with *Rhizobium leguminosarum* before planting to ensure nitrogen fixation. Typical seeding rates of Austrian winter pea as a cover crop are 56 to 90 $kg \cdot ha^{-1}$ when drilled or 101 to 112 $kg \cdot ha^{-1}$ when broadcast seeded (Clark, 2007).

Crimson Clover

In the Southeastern United States Crimson clover (*Trifolium incarnatum* L.) is often used as a stand-alone winter annual legume cover crop but can also be incorporated into a mix with vetches (*Vicia* spp.), other clovers, such as red clover (*Trifolium pratense)*, or with grasses, such as cereal rye (Clark, 2007; Young-Mathews, 2013). Crimson clover can potentially reseed and become a weed if improperly managed (Young-Mathews, 2013). When grown as a winter annual, crimson clover can effectively suppress weeds and fix up to 78 to 168 $kg \cdot ha^{-1}$ nitrogen, when terminated at bloom stage (Clark, 2007). Crimson clover has been shown to flush *pythium* and *rhizoctonia* due to the decaying plant material, which can infect cash crop plants (Clark, 2007).

Mustard

Mustards can be beneficial because it grows fast and produce high amounts of biomass. Mustards do not produce as much biomass as other cover crops such as cereal rye, but mustard can grow more rapidly and can overtake many other species (Brennan & Boyd, 2012; Clark, 2007). Typical seeding rate for mustard is 5.6 to 13.1 $kg \cdot ha^{-1}$ when drilled or 11.2 to 16.8 $kg \cdot ha^{-1}$ when broadcast applied (Clark, 2007). A benefit for mustards over other brassicas is the high content of chemical compounds, glucosinolates, in the plant that when released and broken down have been shown to reduce pest populations. While other brassicas, like turnips, are used for their deep rooting which can break up soil compaction, mustards are shallower rooted similar to small grains (Clark, 2007).

Cover Crop Mixes

Establishing a mix of different types of cover crops in a single planting can provide a broader set of benefits from planting the cover crop over a single species (Clark, 2007). A mix of cereal and legume cover crops can both scavenge excess nitrogen and fix nitrogen (Brennan et al., 2012). Interplanting cereal rye with a legume may also result in more biomass compared to a monoculture brassica forming a larger effect in terms of surface biomass production and soil organic matter, due to cereal rye's large biomass production ability (Brennan & Boyd, 2012). Cover crop mixes of grasses and brassicas may be dominated by the grass species due to the fast growth rate of the grass, which can out-compete the brassicas and reduce the diversity of the planting (Murrell et al., 2017). To optimize cover crop species diversity in a mix the legume or brassicas seeding should be increased 50% or more of the monoculture seeding rate, whereas the grass should be reduced to only 20% of its monoculture seeding rate (Murrell et al., 2017). When a mix of a legume and grass is used, a higher seeding rate of the legume relative to the grass, may be more effective to capture the benefits of the legume, because legumes have larger seed by mass which makes it more affected by the mix reduction ratio (Brennan & Boyd, 2012). In a cover crop mix, irrigating may increase the biomass of the legume to maximize its growth (Brennan & Boyd, 2012).

Cover Crop Establishment Timing

Cover crop establishment timing is important to maximize cover crop biomass. Biomass of the cover crop is closely related to weed control, with more cover crop biomass generally resulting in better weed control (Teasdale et al., 2007; Webster et al., 2013). When planting cover crops in the fall, longer days and warmer temperatures early in the fall are important for allowing crops to develop a strong root system before winter and increase biomass (Murrell et al., 2017). Legumes, red clover, for example, need more than one month of growth prior to the first winter freeze for establishment in the fall for quality growth in the spring. Legumes planted in late summer rather than late autumn, are more effective at fixing nitrogen (Murrell et al., 2017). A variety of cover crops, legumes, and grasses, planted in September in Arkansas, produced more biomass compared to those same cover crops when planted later in November (Roberts et al., 2018). Cover crops planted in Pennsylvania at different times throughout September and October saw significant differences in biomass accumulation in May with crimson clover most affected by lower biomass in late planting dates, winter wheat less affected by the planting dates, and cereal rye not affected (Duiker, 2014). Wheat establishment in September in Nebraska produced greater biomass than when it was planted in October (Blue et al., 1990).

Cover Crops Effects on Weed Control

High weed populations increase agricultural production costs and reduce profit margins, while also increasing difficulty of harvest, and reducing crop quality and yield (Brandenberger et al., 2005). With continuing efforts towards reducing instances of herbicide-resistant weeds, there is increasing interest in the use of integrated weed management (IWM) which is the practice of controlling weeds through various means of chemical and non-chemical methods, rather than relying exclusively on herbicides (Norsworthy et al., 2012). Cover crops can suppress weeds in several ways, including surface residue mulch, competition for resources, and allelopathy. The ability of cover crops to suppress weed emergence is directly related to the amount of biomass present, for small-seeded annual weeds, which are the most affected by cover crop residue coverage (Teasdale et al., 1998). A reduction in weed seeds in the soil bank reduces future weed populations. Using a roller crimper, creates a dense mat of cover crop biomass, which can suppress weed emergence and reduce weed density (Teasdale and Mohler, 2000). Cereal rye is a large biomass producer which can be used to physically suppress weeds, but also has chemical properties that can suppress weeds. These allelopathic properties occur due to the production of benzoxazinones chemicals including, DIBOA (2, 4-dihydroxy-1, 4 (2H)-benzoxazin-3-one) which can effectively inhibit small broadleaf seed germination in the soil but are generally less effective against dicots (La Hovary et al., 2016). The ability of both single species and mixes of winter cover crops, including rye, rye and legume mixes, and wheat have been shown to reduce goosegrass populations six weeks after planting sweet corn (*Zea mays* var. rugosa) (Burgos and Talbert, 1996). Excellent control of both goosegrass and Palmer amaranth was observed in a sweet corn crop when a cover crop was used in conjunction with herbicides (Burgos and Talbert, 1996). While cover crops can control some weeds others show less of a response, and may increase their populations in subsequent seasons following cover crop use; for example, yellow nutsedge populations in watermelon following cereal rye increased 61% over two years (Burgos and Talbert, 1996). The increased growth in population of the yellow nutsedge in these observations demonstrates how problematic weed control can be when planting watermelons in the same location year after year. Cereal rye alone may reduce summer weeds in watermelon production; however, pre- and post-emergent herbicides may be needed for hard to control weeds such as yellow and purple nutsedge (Monday et al., 2015).

Cover Crops and Soil Health

Soil quality has been defined by the Soil Science Society of America (SSSA) Ad Hoc Committee on Soil Quality as, “the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to enhance water and air quality, and support human health and habitation” (Karlen et al., 1997). Soil health may be defined more broadly as “the capacity of soil to function as a vital living system to sustain biological productivity, promote environmental quality, and maintain plant and animal health” (Doran and Zeiss, 2000). Doran and Zeiss (2000) lay out sustainability measures as means to improve soil and environmental health which include conservation of soil organic matter by reduction of tillage, increase plant diversity, and to have a greater amount of carbon inputs into the soil than what is removed through harvest. Improved soil health by minimization of soil erosion through the retention of soil surface cover, such as cover crops, an optimization of nitrogen and phosphorus inputs that are synchronized with plant needs, and a reduction of fossil fuels and petrochemicals with more focus on renewable resource alternatives are also important to adopt (Doran and Zeiss, 2000). Healthy soil is an ecosystem of biota that stores water, decomposes plant and animal residue, recycles and transforms nutrients, breaks down and transforms toxins, and promotes plant health (Doran and Zeiss, 2000).

Organic matter in the soil is correlated with the development and support of soil structure (Haynes et al., 1991). Long periods of time under vegetable production with intensive cultivation (tillage) leads to a new lower equilibrium of soil organic carbon (SOC), 15-20g C kg^{-1}, compared to long term pasture equilibrium of 55-60g C kg^{-1} (Haynes & Tregurtha, 1999). Growing cover crops may not increase the measurable soil organic matter, however, the input of cover crop material can increase the soil microbe activity (Haynes & Tregurtha, 1999). When long periods of conventional tillage methods are used, negative effects on the soil may occur, including lower microbial activity, loss of soil aggregates, loss of soil organic matter, lower plant available nutrients, and a lower water-holding capacity (Bai et al., 2009). Growing a cover crop can increase the amount of water infiltration in the soil (Rice et al., 2001). A study comparing treatments of flail mowed hairy vetch cover crop versus polyethylene mulch, significantly greater amounts of water runoff following rain were seen in the polyethylene mulch treatments (Rice et al., 2001). The increased water runoff from polyethylene also contained increased levels of pesticides used in tomato production compared to hairy vetch treatments because the water containing the pesticides has less time to infiltrate the soil and degrade the pesticides, which can then lead to environmental issues to surrounding areas (Rice et al., 2001).

Higher soil aerobic activity, which is important for mineralization of organic matter and formation of NO_3^-, has been observed in the top 7.5 cm of soil in agricultural systems where tillage is eliminated (no-till), compared to systems where conventional tillage is used, and this difference is attributed to higher soil water content in the pores of no-till systems (Doran, 1980). In deeper layers of soil, 7.5 to 15 cm depth, conventional tillage systems have significantly more fungi, aerobic bacteria, and autotrophic nitrifiers (Doran, 1980). In a no-till system, the quantity of facultative anaerobes and denitrifiers, at a depth of 15 cm, has been found to be greater than in conventional tillage systems and this shift in biological activity led to greater opportunities for denitrification and loss of nitrate (Doran, 1980). Other studies have demonstrated the negative effect of a no-till system, such as a restriction of root growth due to soil compaction not relieved compared to areas that received tillage (Branco et al., 2014).

Terminating Cover Crops

In both no-till and conventional till systems that use cover crops, there must be some means by which the cover crop is killed so that it does not compete with the subsequent cash crop and in order to maximize certain beneficial aspects of the cover crop such as nitrogen release from legume cover crop biomass. Termination is the act of killing the growing cover crop, typically by mechanical (mowing or roller crimping) or chemical methods (herbicide). Many cover crops, including crimson clover, are terminated most effectively by mechanical methods at the mid- to late-bloom stage (Ashford & Reeves, 2003). A roller crimper can be used for mechanical termination. A roller crimper is a heavy cylinder with raised tines, typically filled with water, that is pulled or pushed over the soil and the cover crop a by a tractor that results in rolling down the plants into a mat, and snapping the stems, thus killing the plants while leaving the soil and roots intact. Cover crop maturity can effect the effectiveness of roller crimping for termination. Ashford and Reeves, (2003) discuss how black oats are most effectively terminated close to maturity when they have a higher carbon to nitrogen ratio. For maturity of the black oats in the spring to be achieved, plant establishment in the fall must be early enough to allow sufficient plant growth prior to freezing temperatures in winter which stops growth. In some cases effective cover crop termination prior to maturity by roller crimper alone is not effective, and glyphosate at half rate (0.84 $kg \cdot ha^{-1}$ active ingredient), must be sprayed following the roller crimper for a cover crop to be terminated (Ashford & Reeves, 2003). A planting and termination date study in Pennsylvania concluded that cereal rye planted in August, was more easily terminated than cereal rye planted in October using a roller crimper at the same termination date in spring (Mirsky et al., 2009). Termination timing is also important, early season roller crimping resulted in less than 50% effective termination while late season termination, closer to crop maturity, resulted in nearly 100% rate of termination (Mirsky et al., 2009). Using the roller crimper for termination of cereal grass cover crops is at least 95% effective when done at soft dough stage (Ashford and Reeves, 2003).

Effects of Cover Crops in No-till Systems

No-till systems typically rely on growing cover crops for a physical weed barrier, which is laid down on the soil surface and the next cash crop is directly planted into the cover crop mat without the use of tillage for pre-paring the soil surface. Planting into a no-tillage system can have positive and negative effects on yield and fruit quality of the next crop depending on the situation. Conservation tillage, a reduction of tillage to minimal disturbance or no disturbance of soil, is beneficial for keeping the soil surface covered with plant material which decreases erosion potential and increases water infiltration potential (Dabney et al., 2001, Baughman et al., 2001, Cooper et al., 2020). Benefits of a roller crimper compared to mowing or tilling of cover crops are that it is more time efficient and it leaves plant residue on the soil surface longer to prevent weed growth (Creamer and Dabney, 2002). The cash crop should be transplanted into a rolled cover crop to ensure production rather than direct seeded since the cover crop residue may slow or reduce seed germination due to cooler soil temperatures and a physical barrier (Morse, 1995, Morse, 1999). Leaving the cover crop residue on the soil surface may lead to slower breakdown of the residue which reduces the release of nutrients for subsequent cash crop plant uptake (Ashford and Reeves, 2003).

Cover Crop Effects on Nitrogen Cycling

Nutrient cycling in the soil, namely nitrogen, is dictated by transformations taking place within soil pores by microorganisms whose activity are dependent upon the microenvironment (Agehara and Warncke, 2005). The microenvironment is affected by temperature, water content, gas exchange, and soil substrate, whereas nitrogen mineralization is dictated largely by two factors, temperature and water availability (Agehara and Warncke, 2005). When soil temperature is below 10ºC mineralization is slowed, with an increase in temperatures results in increased mineralization rates. Mineralization is also slowed in dry soil or excessively wet soil with a general increase around 90% water holding capacity (Agehara and Warncke, 2005). Through proper field management, a farmer may be able to utilize the microenvironment to maximize nutrient availability for a cash crop, for this reason nitrogen inputs from cover crops may go through different patterns of conversion to plant available nitrogen in the soil in no-till systems than in tilled systems (Power, 1994).

When cover crops are incorporated into the soil with tillage, decomposition may be rapid, forming nitrate shortly after incorporation (Power, 1994). Legume cover crops, like Austrian winter pea and red clover, break down quickly due to low C:N ratios, and quickly cycle nutrients in the plant tissue back to the soil (Power, 1994; USDA-NRCS, 2015). Cover crops with greater lignin and cellulose concentrations, such as wheat and cereal rye, have a higher C:N ratio and are slower to degrade making the nutrients held in the cover crop more slowly available for subsequent crops (Ashford and Reeves, 2003). The use of a cover crop mix of legume and grass can effectively decrease the C:N ratio for the plant residue and improves the potential for nutrient mineralization (Kuo and Jellum, 2002).

Timing of cover crop planting and termination effects nitrogen availability from the cover crop biomass and these factors can be used to predict the cover crops use as a nutrient source. Grass cover crops, cereal rye in particular, increase in C:N ratio as they mature, which decreases the rate of plant material breakdown and reduces the availability of nitrogen to the watermelon plants because the nitrogen is held in grass biomass (Ashford & Reeves, 2003; Greenwood et al., 1990). Biomass accumulation at peak termination time for crimson clover in North Carolina produced as much as 5500 kg·ha^{-1}, resulting in an estimated 120 kg·N ha^{-1} (Reberg-Horton et al., 2012). In a no-till system, the cover crop residue remains on the soil surface helping to hold soil moisture, resulting in slower microbial activity and slower release of nitrogen from the cover crops. This gradual break down of the cover crops biomass may release nitrogen in a pattern and timing that better match the subsequent cash-crop nitrogen uptake pattern. In cotton production, when nitrogen was not a limiting factor, yields in no-till treatments that include either wheat or hairy vetch were greater than plots in a tilled system (Boquet et al., 2004). Plots with hairy vetch, did not need supplemental nitrogen applications, besides nitrogen applications at planting, in either no-till or tilled systems (Boquet et al., 2004). Other examples include how a cereal rye cover crop released more nitrogen when it was treated with glyphosate or mowed prior to incorporation into the soil compared to rye that was incorporated whole (Snapp and Borden, 2005). Peak nitrogen mineralization of cereal rye cover crops following incorporation into the soil was measured at 20 days (Snapp and Borden, 2005). Oats and cereal rye roots saw peak soil inorganic N levels 21 days following incorporation (Malpassi et al., 2000). Adding red clover (*Trifolium pratense*) into the soil saw nitrogen mineralization occur mostly in the first 70 days which may coincide with the needs of crops decreasing the fertilizer requirements (Sanchez et al., 2001).

Sarrantonio and Scott (1988), conducted a study and found an initial flush of nitrogen was released after incorporation of hairy vetch to 22 cm followed by a diminished release after the peak which was not utilized by the corn. More nitrogen was taken up by the corn in a no-till cover crop system, possibly due to greater soil moisture retention (Sarrantonio and Scott, 1988). Once in the nitrate form, nitrogen may be leached from the soil, prior to uptake by the plant

(Power, 1994). Leaching may occur when a fallow field with new additions of green manure (cover crop) has rainfall in excess of field capacity, or if the cash crop is not mature enough to take up the freed nitrate. Leaching is often from excess fertilizer or mineral nitrogen released from the breakdown of legumes (Campbell et al., 1994). Leached nitrogen may accumulate in ground water or rivers ultimately ending in large bodies of water or the oceans causing environmental issues (Padilla et al., 2018).

Cover Crops and Vegetable Production

Previous research has demonstrated the value of adding cover crops into plasticulture and no-till vegetable production systems, including some work on watermelon production. No-till cover crops were grown in five locations in Virginia to determine nitrogen inputs by growing seedless watermelon compared to a fertilized control plot, resulted in higher yields in the vetch, vetch + cereal rye, and crimson clover + cereal rye compared to the crimson clover only and the lowest yield in the control (Rangappa et al., 2002). A flail mowed hairy vetch cover crop planted before tomato received half as much pre-plant nitrogen fertilizer produced tomatoes that reached maturity later than when grown in plastic mulch, however, tomatoes in the hairy vetch cover crop residue saw increased yield later in the season indicating an immeasurable benefit besides nitrogen by the cover crop (Teasdale and Abdul-Baki, 1997). Tomatoes grown in cover crop plots of crimson clover, hairy vetch, and cereal rye plus hairy vetch resulted in higher tomato leaf nitrogen content despite receiving half the chemical nitrogen fertilizer compared to non-cover crop treatment tomatoes grown in black polyethylene and bare soil treatments (Abdul-Baki et al., 1996). Cover crop plots of cereal rye, cereal rye plus winter pea, and monocrop winter peas grown prior to tomatoes all produced a greater yield compared to a weedy no-till check and higher seeding rates of cover crops suppressed weeds more effectively (Akemo et al., 2000). A study of cover crop mixes of cereal rye and winter pea compare seeding rates and showed at 1:1 seeding rate had greater yield of tomatoes than a 3:1 rate, indicating higher populations of winter peas in the mix positively effected yield (Akemo et al., 2000). Pumpkins direct seeded into no-till, flail mowed cover crops of winter wheat and cereal rye had equal yields compared to bare ground pumpkins, however, pumpkins in cover crop treatments produced larger pumpkins (Walters and Young, 2010).

Cover crop use can cause concern for farmers in regard to potential negative effects on pest and disease pressure and some pests populations may increase with cover crop use. Zucchini (*Cucurbita pepo*) planted directly into a rye roller crimped cover crop had increased transplant loss and reduced yield in part due to high predation by cutworms (Agrotis, Amathes, Peridroma, Prodenia spp.) in the cover crop plots (Leavitt et al., 2011). By contrast Colorado potato beetle (*Leptinotarsa decemlineata*) and tomato hornworm (*Manduca quinquemaculata*) were kept below economic threshold in tomato production that utilized cover crops and no correlation between pest population and cover crops were made (Belfry et al., 2017). Anthracnose, bacterial spot and speck were all low with no increased incidence seen by any cover crop treatment (Belfry et al., 2017). A cover crop of crimson clover tilled into the soil as a green manure prior to laying polyethylene plastic bed was shown to reduce the occurrence of Fusarium wilt in triploid watermelons compared to treatments of mustard, cereal rye, and no cover crop (Himmelstein et al., 2014). Cover crops of oats and rye saw no negative influence on yield or quality of tomato nor an increase in pest pressures when compared to a no cover crop treatment (Belfry et al., 2017).

The effects cover crops have on specialty crop production systems is complex and their potential to improve weed control and crop production in these systems warrants further study in watermelon production in Arkansas. Further research is needed to better understand how single species cover crops and cover crop mixes may effect watermelon production in both plasticulture and no-till production systems.

Objectives

1. Compare the use of winter cover crop mixes to their single species components and a bare ground preemergence herbicide control for effects on yield, fruit quality, watermelon nitrogen status and weeds in plasticulture strip-till watermelon production.
2. Compare the use of winter cover crop mixes to their single species components and a bare ground preemergence herbicide control for effects on yield, fruit quality, watermelon nitrogen status and weeds in no-till watermelon production.
3. Develop recommendations for growers to improve cover crop selection in plasticulture strip-till and no-till watermelon production in Arkansas.

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Chapter 2: Effects of Winter Cover Crops on Strip-tilled Plasticulture Watermelon Production in Hope, AR

Abstract

In Arkansas growers often plant cereal rye, (*Secale cereale* L.), or winter wheat, *(Triticum aestivum* L.), winter cover crops prior to planting watermelons in the spring. Winter cover crop mixes, that include both grasses and legumes, have the potential to provide a greater range of benefits including nitrogen (N) to subsequent cash crops. Our study compared single species cool-season grasses, black-seeded oats, (*Avena sativa* L.), cereal rye and winter wheat single species cool-season legume and broadleaf cover crops (Austrian winter pea *(Pisum sativum arvense*), crimson clover (*Trifolium incarnatum* L.) and mustard (*Sinapis alba*) and legume + grass mixes of these cover crop species to a winter fallow (Control) to determine effects on weed control, watermelon plant tissue N content, and fruit yields in plasticulture watermelon production. We evaluated 12 winter cover crop treatments planted in early fall of 2017 and 2018 at the Southwest Research and Extension Center in Hope, Arkansas. The cover crops were terminated and strip-tilled followed by plasticulture bed formation and transplanting of 'Jubilee' watermelons in early spring of 2018 and 2019. Cover crops were left standing in the row middles for wind protection of transplants and for weed suppression. Our results showed that all of the legume + grass cover crop mixes and black-seeded oats as a single species were consistent across years in winter biomass production, biomass N content and winter weed suppression, while the other single species treatments varied in biomass production. The mixed species cover crop treatments tended to follow the pattern of the single species grass treatments for biomass and weed control likely due to the seeding rates used, which allowed grasses to predominate in the mixes. The only exception was the three-way mix of black-seeded oats+

Austrian winter pea + mustard which had lower biomass in 2019, when mustard alone also had low biomass compared to 2018. Mixed cover crop treatments were similar to grass only cover crops in terms of effects on summer weed suppression 30 days after termination of the cover crop, and achieved similar weed control to a preemergence herbicide (Control). Cover crop treatments generally had no effect on watermelon petiole nitrate content, with the exception that black oats resulted in higher watermelon nitrate-N content at small fruit stage relative to watermelons grown following winter fallow (Control). Most cover crop treatments had similar fruit yield ($kg \cdot ha^{-1}$) and fruit number as the Control, except winter wheat and winter wheat + Austrian winter pea which had lower watermelon yield ($kg \cdot ha^{-1}$). Cereal rye and winter wheat had fewer marketable fruits per plant than the Control. Our results indicate that cover crop mixes have a place in plasticulture watermelon production in Arkansas for row middle weed control. Specifically, cereal rye + Austrian winter pea resulted in the numerically highest yields and fruit numbers per plant. We do not recommend planting winter wheat cover crop prior to plasticulture watermelon due to yield loss; instead, black-seeded oats can be used as grass-only cover crop in plasticulture.

Introduction

Watermelon is a minor crop in Arkansas with around 1,214 hectares of production statewide (Andersen and Spradley, 2003). Cultivars grown in the state include many seedless varieties for urban centers and large-seeded cultivars including ‘Crimson Sweet’ and ‘Jubilee II’ which are more popular in rural areas (Andersen, 2011). Plasticulture production, which involves forming a raised bed covered with black plastic mulch overlaying drip irrigation is a common method of production for watermelons in the Southeast. A typical raised plastic bed is 10 to 15 cm tall and 76 cm wide (Lamont, 1993). The plastic mulch has many benefits including early and consistent warming of the beds, moisture retention and management, and weed control (Lamont, 1993). Soltani et al., (1995) reported earlier and increased yields when watermelons are grown on black plastic mulch beds compared to bare ground.

While the plastic mulch suppresses some weeds in the row, weed pressure in watermelon production continues to be a challenge due to the lack of herbicides that are effective on broadleaf weeds in-season. Once watermelons have vined out, cultivation can no longer be done to control weeds. Research has shown how weeds growing in the row middles between plastic beds can negatively affect vegetable crop yield and quality (Monks and Schultheis, 1998; Price et al., 2018; and Terry et al., 1997). Many farmers rely on herbicides for weed control throughout the season; however, preemergence herbicides applied at bed formation break down by late season and few postemergence herbicides are available (Vollmer et al., 2020). In Arkansas 95% of fields are sprayed with herbicide for weed control followed by manual weeding in watermelon plasticulture production (Andersen and Spradley, 2003).

Sustainable practices in agriculture are increasingly valued by specialty crop growers. The use of winter cover crops is one method adopted by many watermelon growers in eastern Arkansas for soil conservation. Cover crops are grown in the off-season period and provide many benefits to the soil and subsequent cash crops. Cover crops are chosen based on their potential to provide benefits to the soil or to the subsequent cash crop (Clark, 2007)

Grass cover crops, such as cereal rye, are known for the ability to produce large amounts of biomass even at low seeding rates because of its high tillering capacity, which compensates for reduced plant population such as in a cover crop mix with a legume (Boyd et al., 2009). Small annual grains may also be utilized as a wind break between rows to protect new transplants from strong winds (Lamont, 2005).

Legume cover crops are typically utilized in a cropping system as a N input through their ability to convert atmospheric N gas (N_2) into stored plant N before ultimately breaking down into the forms ammonium (NH_4^+) and nitrate (NO_3^-) which can be taken up by subsequent cash crops (Clark, 2007). Legumes typically have a lower C to N ratio than grasses, so the legumes plant material breakdown more rapidly and released nutrients contained in the biomass more quickly (Clark, 2007).

Brassicas represent a third group of cover crops that are commonly planted. Some of the species used include: turnips (*Brassica septiceps)*, mustard (*Brassica cretica)*, canola (*Brassica napus and Brassica rapa)* and forage radish (*Raphanus sativus)*. Benefits of a mustard cover crops include biofumigation which is attributed to isothiocyanates, an allelochemical produced from the breakdown of glucosinolate content of plants (Brown and Morra, 2005). The isothiocyanates can suppress insect pests such as nematodes and click beetle larva, such as the eyed click beetle (*Alaus oculatus*) and also suppression of soil-borne diseases such as *Pythium* root rot and *Rhizoctonia solani* (Brown and Morra, 2005). Other brassicas, like turnips, also have a strong, deep penetrating taproot that provides deep soil mining for nutrients and potentially breaks up hardpans present in the soil (Williams and Weil, 2004).

Cover crops in row middles of plasticulture systems can reduce weed growth. Price et al., (2018) demonstrated that cereal rye cover crop can be integrated into the row middles of a plasticulture system in Georgia with some benefit to weed control. Price et al., (2018) concludes that further work is needed to fine tune conservation management practices including cover crops for plasticulture systems. Some eastern Arkansas watermelon farmers have adopted similar practices, typically growing winter wheat or cereal rye cover crops incorporated in the bed before plastic is laid but are killed with glyphosate and left standing in row middles for weed control and to serve as a windbreak to protect young transplants from sand blasting in windy weather due to their sandy soils. Price et al., (2018) found that planting a cereal rye cover crop with minimal tillage on a raised plastic bed resulted in equal watermelon yield as watermelon in raised plastic bed with conventional tillage. Spring-seeded cereal rye terminated with appropriate herbicides could reduce weeds in watermelon in the early season without any negative effects on watermelon yield (Vollmer et al., 2020).

There is limited research on mixes of grasses and a legume cover crop incorporated into plasticulture raised beds for watermelon production. Arkansas farmers that do utilize cover crops often rely only on grass cover crops, in particular winter wheat, despite that their sandy soils are N limited and could benefit from a mixture including a legume. Growing a mix of cover crop types (grass, legume, and brassica), can broaden the overall benefits of planting a cover crop. A mix of cereal and legume cover crops can both scavenge excess nitrogen and fix nitrogen (Brennan et al., 2012). Grass cover crops typically have high lignin and cellulose concentrations and a high C:N ratio that slows degradation and release of nutrients (Ashford and Reeves, 2003). Legume cover crops break down quickly due to lower C:N ratios, resulting in fast release of nutrients that benefits the cash crop (Power, 1994; USDA NRCS, 2015). A cover crop mix of legume and grass can lower the overall C:N ratio of the cover crop material and increase the nutrient mineralization rate for increased uptake by the cash crop (Kuo and Jellum, 2002).

Cover crops must be terminated to release nutrients back into the soil. Termination method is also important for the fast release of nutrients from the cover. Incorporation of cover crops into the soil can cause rapid decomposition and the release of nitrate (Power, 1994). In plasticulture watermelon production, the cover crop can be strip-tilled and incorporated into the beds where the plastic is laid, while the cover crop in the row middles are left standing to prolong weed suppression.

The effects cover crops may have on specialty crops is complex and warrants further research in watermelon production in Arkansas. Our project is focused on evaluating the use of legume and grass mixed cover crop treatments compared to single species cover crops and a winter fallow plus preemergence herbicide control for their effect on watermelon production.

Materials and Methods

Research was conducted on winter cover crop mixes integrated into strip-till plasticulture watermelon production at the University of Arkansas System Division of Agriculture Southwest Research and Extension Center (SWREC) located in Hope, Arkansas (AR) (33.7107°N, 93.5573°W) over two years from 2017-2019. The SWREC is in hardiness zone 8a on a Sacul fine sandy loam soil (Soil Survey staff, 2021).

The experimental design was a randomized complete block design of 12 treatments with five replications, resulting in 60 plots. Plots were 3.7 m by 9.1 m with 3.0 m alleys between plots in the same row. No additional alley was set between plots in adjacent rows. The 12 cover crop treatments (Table 1) consisted of three grasses and three broadleaves grown singly and in mixed species combinations. Acronyms for treatment only will be used henceforth. The grasses evaluated were: black-seeded oats (BO) (origin Arkansas, Southern Solutions, 21301 Hwy 17 Clarendon, AR, 72029) (112 $kg \cdot ha^{-1}$.), Cereal rye (CR), (origin not stated) (112 $kg \cdot ha^{-1}$.), Winter wheat (WW) (Arkansas, Southern Solutions, 21301 Hwy 17 Clarendon, AR, 72029) (101 $kg \cdot ha^{-1}$). The legumes were: Austrian winter pea (AWP) (Washington, Columbus Grain, 2051 Wilma Drive Clarkston, WA 99403) (56 $kg \cdot ha^{-1}$), and Crimson clover (CC) (Oregon grown, variety Dixie) (13 $kg \cdot ha^{-1}$). One broad leaf non-legume was evaluated: Mustard (MU) (Oregon grown) (5.60 $kg \cdot ha^{-1}$). The mixed species combinations included: BO+AWP (56 $kg \cdot ha^{-1}$, 39 $kg \cdot ha^{-1}$), CR+AWP (56 $kg \cdot ha^{-1}$, 39 $kg \cdot ha^{-1}$), WW+AWP (50 $kg \cdot ha^{-1}$, 39 $kg \cdot ha^{-1}$), BO+CC (56$kg \cdot ha^{-1}$, 9.0 $kg \cdot ha^{-1}$), BO+AWP+MU (39 $kg \cdot ha^{-1}$, 28 $kg \cdot ha^{-1}$, 3.4 $kg \cdot ha^{-1}$). The Control consisted of a winter fallow plot followed by application of preemergence herbicide of S-metolachlor (Dual II Magnum at 1.17$L \cdot ha^{-1}$) after transplant. Cover crop species were chosen based on species available to Arkansas growers and being well-adapted for the Southeastern U.S. (Roberts et al., 2018; Clark, 2007). Cover crop seed was sourced from Southern Soil Solutions Inc. (Clarendon, AR). Seeding rates for mixes were chosen based on recommendations for rate adjustments for grass and legume mixtures which equates to a 30% reduction in seeding rate for legumes and a 50% rate reduction for grasses compared to the respective seeding rates of each cover crop planted separately (Clark, 2007).

Cover Crop Establishment

Prior to planting the soil was tilled and a smooth seedbed was prepared. The AWP and CC treatments were inoculated (Graph-Ex SA™ ABM®, Van Wert, OH) prior to planting.

Inoculation for legume seeds is important to ensure a presence of the nitrogen-fixing bacterium Rhizobium, allowing the symbiotic process of atmospheric nitrogen fixation to occur. Cover crop planting dates were October 11, 2017 and September 12, 2018. The AWP seeds were broadcast-seeded by hand and incorporated to a depth of approximately 2.54 cm via rolling harrow. All other seeds where hand broadcasted across the remaining plots and pressed into the soil surface with a roller.

Cover Crop Biomass and Nutrient Sample

Immediately prior to cover crop termination in spring a single cover crop biomass sample per plot (0.75 m^2) was collected by cutting all plant material at ground level. Weeds were separated from each sample, identified, placed in a separate bag, dried, weighed. Samples were taken April 11, 2018 and April 5, 2019 when CR, CC, AWP, and MU were flowering and WW was at boot stage The BO were at stem elongation or "jointing" stage during biomass sampling in either year.

A separate plant tissue sample (0.09 m^2) was collected from each plot for analysis of nutrient content. Weeds were not separated from these samples; all plant tissues per plant tissues per plot were composited and analyzed as one sample. Tissue samples were dried at 55°C and ground to pass through a 1 mm sieve, then prepared by HNO_3 digestion and analyzed by Spectro ARCOS ICP, a total N and C analysis was done by combustion, Elementar VarioMAX Cube for analysis of macro and micronutrients. Plant nutrient content preparation and analyzed by the University of Arkansas Agriculture Diagnostic Laboratory, Fayetteville, AR.

Spring Field Preparation

Cover crop termination occurred on April 26, 2018, and April 10, 2019. Termination was achieved by mowing cover crops in a strip down the center of the plot and incorporating the material into the soil with a rotary tiller. The tilled strip was then prepared for laying drip tape and plastic mulch two weeks later. The remaining cover crop was left standing on the sides of the plot to act as wind break for the young watermelon plants and to control weeds in the row middles. Watermelon transplants (9 per plot), cultivar ‘Jubilee’, (Sustainable Seed Company, (Chico, CA) in 2018 and NeSeed™ (Hartford, CT) in 2019), were planted at 0.91 m spacing into the plastic mulch on April 30, 2018, and April 24, 2019. Dual II Magnum (S-metolachlor) (1.17 $L{\cdot}ha^{-1}$) was applied to Control plots post-transplant in row middles. No herbicide was applied in cover crop treatment plots.

Watermelon Crop Management

A preplant application of phosphorus was applied at 95 $kg{\cdot}ha^{-1}$ of P_2O_5 to the tilled plot middle due to indications from soil test (Mehlich 3) indicating medium P concentration (32ppm) analyzed by University of Arkansas Cooperative Extension Service Soil Testing and Research Laboratory Marianna, AR. No further N or P was applied pre-transplant. After transplanting a weekly fertigation schedule was adopted from the Southeastern Vegetable Crop Handbook which bases N and K rate on the growth stages of the watermelon crop (Kemble et al., 2021). Krista™ K soluble potassium nitrate fertilizer (Yara, Tampa, FL) was applied weekly via drip irrigation for a total of rate of 103.4 kg $N{\cdot}ha^{-1}$ and 290.26 kg $K{\cdot}ha^{-1}$ in 2018 and 90.8 kg $N{\cdot}ha^{-1}$ and 255.03 kg $K{\cdot}ha^{-1}$ in 2019. Additional water was supplied to the plants by drip irrigation as needed.

A reduced disease management program was adapted from recommendations in the Southeastern Vegetable Crop Handbook (Kemble et al., 2021). The fungicide Ridomil Gold® SL

(Syngenta®, Wilmington, DE) was applied through the drip irrigation a month post-transplant 1168 $ml \cdot ha^{-1}$. Foliar fungicides Bravo Weather Stik® (ADAMA, Raleigh, NC), three applications in 2018 and four applications in 2019, and Kocide® 3000 (Certis USA, Columbia, MD), three applications 2018 and two applications in 2019, were applied at labeled rates.

Summer Weed Biomass and Assessment

Summer weed biomass samples were collected per plot from a 0.75 m^2 area at 30 days and 60 days after cover crop termination. Weeds were identified to the genus level. The biomass was then dried and weighed to calculate total weed biomass ($kg \cdot ha^{-1}$).

Watermelon Petiole Nitrate Sampling

Petiole samples for nitrate analysis were collected at three physiological stages of watermelon development (early vine running, small fruit size, and fruit maturity) (Hochmuth G. 1994b). One petiole from the most recently matured leaf of the main vine was collected from each plant in each plot and bulked to constitute a composite sample (Hochmuth G. 1994a). The petioles were placed in a marked plastic bag and immediately put on ice. This process was done in the early morning.

All petioles collected from each plot, where placed in a hand-held garlic press to extract the petiole sap. The collected sap was then placed in a Horiba "Cardy" Model S-040 NO3-meter, (HORIBA Advanced Techno C., Ltd., Kyoto, Japan), and the petiole nitrate (ppm) was recorded. The petiole nitrate reading was converted to nitrate-N by multiplying the Cardy meter reading ppm by 0.2259 to account for only the N within the nitrate molecule (Hochmuth, 1994). The sap extraction and nitrate measurement was done within 15 hours from the time of sampling.

Watermelon Harvest

Watermelon fruit were harvested, sorted into marketable fruits and culls, and weighed. The cull rate (%) was derived from this data set. The incidence of fruit disorders was also noted. Two harvests timed a week apart took place in July of 2018 and 2019. At the time of harvest, watermelons were classified as marketable if they had an elongated shape (typical of the variety) without blemishes and weighed more than 5.0 kg; otherwise, the fruit was classified cull (USDA-AMS, 2006; Hassell et al., 2007). The weight of 5 kg is low for Jubilee watermelons. A typical marketable watermelon is 11.3-20.4 kg, but the overall individual fruit weights of watermelon in our trial were low due to plant stress from heavy rain in May of both years of this study and competition from weeds. All cull fruits were scored for occurrence of fruit rots including Anthracnose disease or other belly rot, gummy stem blight, and blossom end rot (BER).

Weather Data

Daily high and low temperatures were collected on-site from the beginning of cover crop planting September 2017 through final harvest July 2019 by the National Weather Service NOAA (National Oceanic and Atmospheric Administration) climatological data for Hope 3 NE, AR whose data are collected by staff at the SWREC. A meteorological grade rain gauge collected precipitation amounts (Table 2).

Statistical Analysis

The University of Arkansas Agricultural Statistics Laboratory conducted statistical analysis using SAS version 9.4. The N assessment data (nitrate-N) was assumed to have a gamma distribution and was analyzed based on a split-plot design with the whole plot being cover crop as main factor treatment arranged in a randomized complete block design. Assessment date was the split-plot factor. The yield data was analyzed as a randomized complete block design with cover crop as independent variable. Average marketable fruit weight, total cull weight, total marketable fruit weight, and marketable yield per plot were assumed to have a gamma distribution. Least squares means for significant effects were separated using a protected least significant difference (LSD) procedure. To further evaluate the effect of cover crop type on select response variables, a separate split-plot analysis was performed wherein the 12 treatments within the four cover crop groups (grass, legume, mustard, mixed and Control) were the whole plot factors and year was the split-plot factor. Cover crop biomass, winter weed biomass, marketable fruit ($kg \cdot ha^{-1}$), and number of fruit per plant were assumed to follow a gamma distribution. Cover crop group was not significant for most response variables; these results are presented in part where appropriate. For clarity, the cover crop group names will be capitalized when referred to as treatments as a part of the group analysis (Legumes, Grasses, Mixes, Mustard and Control) and will use lower case lettering when referring only to these general cover crop types. All analyses were conducted using the GLIMMIX procedure in SAS version 9.4.

Results and Discussion

Cover crop and winter weed biomass

Cover crop treatments include Austrian winter pea (AWP), crimson clover (CC), mustard (MU), black-seeded oats (BO), cereal rye (CR), winter wheat (WW), black-seeded oats + Austrian winter pea (BO+AWP), cereal rye + Austrian winter pea (CR+AWP), winter wheat + Austrian winter pea (WW+AWP), black-seeded oats + crimson clover (BO+CC), black-seeded oats + Austrian winter pea + mustard (BO+AWP+MU), and Control (Table 1). Cover crop species vary in biomass production and subsequent effects on weed growth from year to year (Table 3). In these tests the grass cover crops had higher biomass in some years while legume treatments had higher biomass in other years (Figure 1, 2). The mixture of grass and legume cover crops were consistent in biomass production in both years. In most cases the reduction in winter weed growth in mixed cover crop treatments was equal to that of the grass cover crop only treatments, indicating that cover crop mixes may be good substitutes for CR only or WW only cover crops before watermelons. The exception to this was the grass cover crop BO, which had consistently higher biomass production in both years than the other grass-only treatments and could be a substitute for pure-stand WW or CR cover crops.

In 2018 all cover crop treatments produced similar amounts of biomass, except for the two legume-only treatments AWP and CC (Figure 1). No individual grass treatment was statistically different from its corresponding cover crop mix treatment in 2018, which indicates equal amounts of biomass can be produced by a single grass cover crop alone vs. the same grass specie mixed with a legume. The MU treatment was statistically similar to BO, CR, CR+AWP, and BO+CC.

In 2019 cover crop biomass ($kg{\cdot}ha^{-1}$) for mixes and some grasses was lower than in 2018 for the treatments, MU (1606 $kg{\cdot}ha^{-1}$ (2018); 165 $kg{\cdot}ha^{-1}$ (2019)), CR (2519 $kg{\cdot}ha^{-1}$ (2018); 729 $kg{\cdot}ha^{-1}$ (2019)), WW (3079 $kg{\cdot}ha^{-1}$ (2018);1108 $kg{\cdot}ha^{-1}$ (2019)) and BO+AWP+MU (2603 $kg{\cdot}ha^{-1}$ (2018)); 1143 $kg{\cdot}ha^{-1}$ (2019)). In this year the treatments with the highest cover crop biomass included the legumes (AWP, 2843 $kg{\cdot}ha^{-1}$ and CC, 2036 $kg{\cdot}ha^{-1}$), treatments with black-seeded oats (BO, 1910 $kg{\cdot}ha^{-1}$, BO+AWP 1704 $kg{\cdot}ha^{-1}$, BO+CC, 1940 $kg{\cdot}ha^{-1}$) and the WW+AWP 2128 ($kg{\cdot}ha^{-1}$) treatment (Figure 1). However, BO, and BO+AWP were not statistically different from treatments with lower cover crop biomass including WW, CR+AWP, and BO+AWP+MU. The AWP 2842.53 $kg{\cdot}ha^{-1}$ had higher cover crop biomass than CR+AWP 1154 $kg{\cdot}ha^{-1}$, CR 729 $kg{\cdot}ha^{-1}$ and WW 1108 $kg{\cdot}ha^{-1}$. This, points to the high performance of the legume AWP relative to the grasses CR and WW which had poor crop growth in 2019. Reduced cover crop biomass relative to 2018 was observed for WW, MU and CR and all mixes that included MU and CR.

Low grass biomass in 2019 may be attributed to the saturated ground and standing water throughout the field. The MU treatment had the lowest cover crop biomass (165 $kg \cdot ha^{-1}$) in 2019 relative to all other treatments across both years. The second lowest biomass producing cover crop in 2019 was CR (729 $kg \cdot ha^{-1}$) which had higher biomass than MU, but had significantly lower biomass compared to all other cover crop treatments and mixes except WW (1108 $kg \cdot ha^{-1}$). This is an important finding as CR and WW are commonly planted in Arkansas prior to watermelons, but our research showed that BO produced a consistent amount of biomass compared to the other grass cover crops in the Southeastern part of the state across the two years of our study. Additionally, in 2019, the three-way mix treatment BO+AWP+MU had lower biomass (1143 $kg \cdot ha^{-1}$) than AWP but was similar to BO (1910 $kg \cdot ha^{-1}$) and BO+AWP (1704 $kg \cdot ha^{-1}$). The addition of mustard to BO+AWP resulted in somewhat lower biomass in 2019 when MU did poorly, although there was no significant difference between BO+AWP and BO+AWP+MU.

All grass treatments, mixed treatments, and the legume treatment CC (138 $kg \cdot ha^{-1}$) resulted in reduced weed growth relative to the Control (461 $kg \cdot ha^{-1}$) in 2018; however, AWP and MU treatments had similar weed biomass (279, 172 $kg \cdot ha^{-1}$) as the Control (Figure 1). All the grass and their relative mixes were similar in winter weed biomass in 2018 except WW (10 $kg \cdot ha^{-1}$) and WW+AWP (50 $kg \cdot ha^{-1}$), where the addition of AWP to WW resulted in reduced weed suppression relative to WW alone. Also, while the legume treatment CC had less weed growth than the Control, it had similar amount of weed biomass as AWP and MU but more winter weed biomass than all other treatments. The low plant architecture of CC seemed to suppress winter weeds better than the Control relative to the vining architecture of AWP, when the two had similar cover crop biomass in 2018.

In 2019, an increase in winter weed biomass relative to 2018 was seen in all grasses and cover crop mixes except WW+AWP, despite that weed biomass in the Control (winter fallow) was similar across both years. In 2019 all cover crops treatments resulted in less winter weed growth than a winter fallow (Control) and all treatments were similar in winter weed growth except for the MU treatment which had more weed biomass than the BO treatment. In our trial CR was able to reduce winter weed biomass equal to BO despite that CR produced much less biomass than BO. The equal reduction in winter weed biomass despite differences in cover crop biomass may be due to allelopathic properties in the CR that can limit weed growth or the growth pattern between the two crops (La Hovary et al., 2016).

Analysis of cover crop types by grouping the treatments, into: “Mustard”, “Mix”, “Legume”, “Grass”, and “Control” was undertaken to better understand the relationship between cover crop types and cover crop biomass and weed biomass. The effect of Group x year was significant for both cover crop biomass and winter weed biomass ($p<0.05$) (Figure 2). The group analysis confirmed that in 2018 the “Grass” cover crops had the highest average amount of biomass (2737 $kg \cdot ha^{-1}$) however, they were not statistically different from the “Mix” cover crop treatment (2375 $kg \cdot ha^{-1}$) which confirms that mixed species cover crops can produce similar biomass to grass only cover crops (Figure 2). Further, the “Mix” and “Mustard” had equal amounts statistically of cover crop biomass production in 2018 (2375, 1606 $kg \cdot ha^{-1}$) whereas the “Legume” group had the lowest average amount of cover crop biomass (754 $kg \cdot ha^{-1}$). In 2019 a cover crop group analysis showed that all “Legume” treatment had significantly higher biomass (2439 $kg \cdot ha^{-1}$) than “Grass” (1249 $kg \cdot ha^{-1}$) and “Mixes” (1614 $kg \cdot ha^{-1}$), and “Mustard” (165 $kg \cdot ha^{-1}$) treatments, and that “Mixes” were again not statistically different than “Grass” types demonstrating that the grass species in the evaluated cover crop mixes predominated and had more influence on biomass production in both years (Figure 2). “Mustard” had the lowest amount of biomass in 2019 and the lowest biomass between both years.

The cover crop group analysis comparison between the amounts of winter weed biomass in 2018 showed the highest numerical average for cover crop biomass of the “Grass” group had the lowest amount of winter weed biomass (10 $kg \cdot ha^{-1}$) (Figure 2). The “Mix” group had lower winter weed biomass (30 $kg \cdot ha^{-1}$) than the “Mustard” (172 $kg \cdot ha^{-1}$), “Legume” (209 $kg \cdot ha^{-1}$), and “Control” 461 $kg \cdot ha^{-1}$), which were all statistically equal to one another. The poor establishment and growth in “Legumes” and “Mustard” resulted in similar weed control to the fallow ground “Control” (Figure 2). Winter weed suppression by all cover crop groups in 2019 showed all cover crop types were statistically similar to one another and all had significantly lower winter weed biomass compared to the “Control”. The lack of difference between weed biomass in 2019 shows that high amounts of a legume cover crop can reduce winter weed biomass as effectively as high amounts of a grass cover crop. In both years, the Control had similar amounts of weed biomass, however 2019 numerically had a higher amount in (883 $kg \cdot ha^{-1}$) indicating slightly higher weed pressure overall in 2019 (Figure 2).

The differences in cover crop biomass between 2018 to 2019 are likely related in part to differences in cover crop planting date where cover crops in 2019 where established a month earlier (September) than the cover crops in 2018 (October). An earlier planting date may benefit legumes and research suggests that a later planting may not affect grasses as much as legumes. Murrell et al., (2017) found that legumes, such as red clover, have a greater amount of quality growth in spring when planted and established one month prior to the first freeze in the fall. Duiker, (2014) found that various cover crops planted in Pennsylvania at various times from September through October exhibited planting date effect on biomass accumulation in May with a greater effect on crimson clover by a late fall planting date, less of an effect on winter wheat, and cereal rye showing no effect. However, grasses can also be impacted by planting dates, where wheat established in September in Nebraska produced greater biomass than when it was planted in October (Blue et al., 1990). Differences in the field across two years can be seen in a shift of winter weed species composition. In 2018 the predominant species were from the genus *Oenothera*, *Festuca* and *Cardamine*. In 2019, *Juncus* species, commonly known as rushes, were predominant. Rushes are typically found in wet areas and near water sources; their abundance in the second year might be an indication of prolonged wet soil conditions. Weather may have also affected cover crop growth between the two seasons. The average low temperature in winter 2018 was 12.2 °C while 2019 was much cooler with an average low of 2.5 °C (Table 2). Average high in 2018 winter was 27.1 °C and in 2019 was 14.0 °C (Table 2). In 2019, the ground had more standing water and lower average temperatures than in 2018, which does not favor cover crop growth. Our research showed that AWP and CC were not affected by the wet ground and the temperatures still averaged above freezing so it was not winter killed. For grass cover crops, BO was not affected by weather in 2019 like CR and WW which saw a decline in biomass compared to 2018. Winter cover crops will have less growth and biomass development when temperatures are closer to or below freezing (Murrell et al., 2017).

The ability of winter cover crops to reduce weed growth compared to fallow ground has been well established (Clark, 2007; Hayden et al., 2012). High cover crop biomass is generally correlated with increased weed suppression. Teasdale et al., (1998), found the amount of cover crop biomass has a direct effect on the ability of the cover crop to suppress weed emergence, most notably on small-seeded annual weeds. Research by Boyd et al., (2009) demonstrated how grasses are generally thought to be high biomass producing cover crops, but our results for AWP and legumes in general, demonstrate that legumes can also suppress weeds when high biomass is produced, but when they have low cover crop biomass they can be as weedy as fallow ground. In our results cover crops treatments with low cover crop biomass had high weed biomass in 2018 (Figure 2), however in 2019 when legume cover crops had higher biomass than the grasses all cover crops types had similar weed biomass. We found that the biomass produced by mixed species cover crops consistently follows a similar trend to that of the grass, rather than the legume component of the cover crop mix. This meant that in years where the grass had relatively higher or lower biomass so did the mixes. The grasses and mixes suppressed weeds equally well and always had lower weed biomass than the Control even in years of poor grass biomass production. In years of high legume biomass production and low grass biomass, legumes can suppress weeds at an equal level. The tendency for the mixes to mimic the grasses in biomass production is likely due in part to the seeding rates used - where the grass was reduced to a 50% rate while the legume was reduced to a 60% rate. This rate reduction still allowed for the grasses to predominate in the stand.

By contrast, MU treatment had the lowest cover crop biomass in 2019 but suppressed weeds similarly to all other treatments in that year. It has been noted that mustard is a low biomass producing cover crop but it does grow more rapidly initially and can overtake many other species (Clark, 2007; Brennan & Boyd, 2012). Our observations of mustard as a cover crop in Arkansas are that it grows rapidly in the fall, but flowers in the early winter or easily winter kills and in some years little evidence of the cover crop remains by early spring. Early season weed suppression during fall may explain why the biomass for mustard cover crop was low in 2019 following a cold winter relative to 2018 but similar weed control was observed at both years. The inclusion of mustard in the three-way treatment (BO+AWP+MU) likely resulted in reduced weed control relative to BO or BO+AWP treatments.

Cover Crop C:N and Nitrogen Content

The impact of cover crop species on cover crop C:N ratio and N content ($kg{\cdot}ha^{-1}$) varied by year (Table 3). In 2018 all the cover crop mix treatments had similar or lower C:N content relative to their individual grass or legume components, which would indicate the N contained in the cover crop biomass would be equally available or more available to the next cash crop (Figure 3). In both years all the cover crop mix treatments and BO had statistically higher N content than the Control, except BO+AWP 22 $kg\ N{\cdot}ha^{-1}$, in 2018, whereas the 2018 legumes (AWP 9 $kg\ N{\cdot}ha^{-1}$ and CC 10 $kg\ N{\cdot}ha^{-1}$) compared to 2019 legumes (AWP 60 $kg\ N{\cdot}ha^{-1}$, CC 47 $kg\ N{\cdot}ha^{-1}$) and the remaining grass treatments in 2018 were higher (CR 58 $kg\ N{\cdot}ha^{-1}$, WW 37 $kg\ N{\cdot}ha^{-1}$) compared to lower 2019 (CR 17 $kg\ N{\cdot}ha^{-1}$, WW 29 $kg\ N{\cdot}ha^{-1}$) were sometimes no different or lower statistically than the Control (16 (2018), 16 (2019) $kg\ N{\cdot}ha^{-1}$) for N content (Figure 3). Legume N content was related to cover crop biomass production in each year, with low amounts of N ($kg\ N{\cdot}ha^{-1}$) that would be slowly available (C:N ratio above 25:1) in 2018 when low legume cover crop biomass occurred, and high amounts of N that would be more readily available (C:N ratio approximately 25:1) in 2019 when legumes had high cover crop biomass. A similar amount of N content was observed in the biomass of MU as was present in the weeds found in the Control in both years.

In 2018, all **c**over crop treatments had statistically higher cover crop biomass C:N ratio than the Control (17:1) except for WW+AWP (22:1) and BO+AWP+MU (16:1) (Figure 3). All mixes had similar C:N ratio relative to their individual grass and legume components, except AWP (48:1) had a higher C:N ratio than CR+AWP (31:1), BO+AWP (46:1), and

BO+AWP+MU (16:1). The phenological stage of the cover crops varied at the time of sampling in 2018 with MU being post bloom, AWP had minimal flowering, CR was at anthesis, WW at heading stage, and BO and CC showed very little maturity. These differences in maturity likely effected the cover crop C:N ratio as seen in other research in which grass cover crops have wider C:N ratios as they mature, which decreases the rate of plant material breakdown and reduces the availability of nitrogen to the watermelon plants because the nitrogen is held in grass biomass (Greenwood et al., 1990; Ashford & Reeves, 2003).

All cover crop treatments in 2019 had similar C:N ratios to the Control (Figure 3). Treatments consisting of single species were not different statistically from those same species in a mixed treatment. A similar N release rate from all the cover crop treatments would thus be expected. The cover crops varied in phenological stage from the previous year. The MU was flowering but also had very little growth. More development and maturity were seen in individual AWP in 2019 than in 2018, however, less flowering was seen in the grass +AWP treatments, particularly WW+AWP. More maturity was seen in the individual CC treatments for 2019 than in 2018, however, like AWP, BO+CC had reduced growth. The grass cover crops were similar stages of maturity between the two years, but WW was less mature with fewer plants headed out in 2019 than in 2018.

The cover crop treatments AWP and CC both had lower N content (kg $N \cdot ha^{-1}$) than the Control and the lowest overall N content of any treatments for 2018 (Figure 3). The amount of N content (kg $N \cdot ha^{-1}$) of all other treatments, except MU, was higher relative to the Control in that year. Numerically, BO+AWP+MU had the highest nitrogen content (kg $N \cdot ha^{-1}$) and it had higher N content than species grown individually or in a pair (AWP, MU, BO, or BO+AWP), all other mixes were similar to their individual components.

In 2019 the cover crop N content (kg N·ha^{-1}) was higher than the Control (16 kg N·ha^{-1}) in both legumes treatments, (AWP 60 kg N·ha^{-1}, CC 47 kg N·ha^{-1}), a grass treatment (BO 49 kg N·ha^{-1}) and all cover crop mix treatments (BO+AWP 38 kg N·ha^{-1}, CR+AWP 32 kg N·ha^{-1}, WW+AWP 37 kg N·ha^{-1}, BO+CC 37 kg N·ha^{-1}, BO+AWP+MU 34 kg N·ha^{-1}). Only CR (17 kg N·ha^{-1}) and WW (29 kg N·ha^{-1}) were similar in N content to the Control. The legume treatment AWP had numerically the highest N content (kg N·ha^{-1}) which corresponded to its high biomass in 2019, but other treatments, CC, BO, BO+AWP, WW+AWP, BO+CC, BO+AWP+MU, were similar. In 2019 MU numerically had the lowest N content (10 kg N·ha^{-1}) of all the treatments due to the lack of cover crop biomass and was similar to the Control.

No significant differences in cover crop N content (kg N·ha^{-1}) for individual mixed treatments was observed between years, except (BO+AWP+MU) had higher N content in 2018 (70 kg N·ha^{-1}) than 2019 (34 kg N·ha^{-1}). This indicates that mixes may be a more reliable N input and benefit from having both a legume and a grass to reduce fluctuations in N (kg N·ha^{-1}) inputs from year to year, relative to their individual species performance in Southwestern, AR. The grasses, BO and WW were also consistent in N content, whereas variability in N content was observed for CR likely related to variability in biomass production across years. Our data did not show variation amongst grasses for C:N ratios, however, other research has. Black oats have been shown by (Bauer & Reeves, 1999) to have a lower C:N than some other grasses which increases the speed of N release from the biomass following termination. In 2018, cover crop biomass was low for AWP and CC, and N is a percentage of total biomass, so low biomass also resulted to low N (kg N·ha^{-1}) content (Figure1, Figure 2). The lack of biomass accumulation by an individual species treatment can be compensated if grown as a mix. Other research has demonstrated variability in C:N amongst cover crops based on cover crop type, biomass quality, and timing of termination (Clark, 2007; Power, 1994). Cover crops with high C:N ratios accumulate relatively low amounts of N compared to C while cover crops with low C:N ratios accumulate relatively high N compared to C. Grasses, such as cereal rye, typically have high C:N ratios (>25:1). Legumes such as crimson clover typically have low C:N ratios (<20:1). Ashford et al., (2003) discusses that cover crops with greater amounts of lignin and cellulose, typically grasses, can reduce nutrient availability from the cover crop biomass due to slower break down of the biomass. Kuo and Jellum, (2002), discuss the potential benefit of a cover crop mix as a method to effectively decrease the C:N ratio of the biomass and improve the potential for nutrient mineralization. Our research found similar results with multiple instances in 2018 where mixes had lower C:N ratios compared to the individual components.

Timing of cover crop termination is important for release of nutrients. Roberts et al., (2020) discuss how Austrian winter pea in Arkansas terminated in mid-March can provide approximately 56 to 67 N $kg{\cdot}ha^{-1}$, but if terminated at first bloom in mid to late April in Arkansas, can provide more than 168 N $kg{\cdot}ha^{-1}$. Our study did not have different termination dates, however, legume maturity varied by year with more flowering occurring in 2019 possibly due to the early planting date in fall. The more mature legumes in 2019 had much higher aboveground N content in the cover crop biomass than in 2018.

Watermelon Petiole Nitrate-N

Cover crop treatments effect on watermelon petiole nitrate-N levels was found to be impacted by the time of sampling (Table 4) and was limited to the BO treatment increasing petiole nitrate-N levels relative to the Control treatment at small fruit stage. In addition, watermelon petiole nitrate-N levels were impacted by the time of sampling across the two years of the trial where petiole nitrate-N was lower in 2018 at “early vining” (1,873 ppm) and “mature fruit" (444 ppm) sampling stages than those stages respectively (2,751 ppm and 583 ppm) in 2019. Petiole nitrate levels were similar in 2018 (476 ppm) and 2019 (473 ppm) at small fruit stage. Differences between years for higher petiole nitrate-N levels in 2019 than in 2018 could be due to higher amounts of estimated N in cover crop plant biomass and an overall narrower C:N ratio in 2019 that resulted in higher early N uptake (Table 4, Figure 4).

At the first sampling stage, early vining, there were no differences between any cover crop treatment or the Control for watermelon petiole nitrate-N. The numerically highest petiole nitrate-N ppm was found in the BO (803 ppm) treatment at early vining stage. The range for sufficient petiole nitrate-N ppm for early vining (vines at 15 cm) is 1,200-1,500 ppm (Hochmuth, 1994a). Our trial had petiole nitrate-N levels below the sufficiency range recommended at the early running stage (Hochmuth, 1994a). The similar petiole nitrate-N levels in all treatments to the Control at this stage shows that cover crops did not supply additional N to the watermelon plants. One possible explanation is that watermelon growth was too early compared to N mineralization.

Petiole nitrate-N content decreased from the early vining stage to the small fruit stage. At the small fruit stage, BO (369 ppm) had statistically higher petiole nitrate-N than legume only treatments (AWP (75ppm), CC (71 ppm)), MU (133 ppm), WW (95 ppm), and the mixes, and WW+AWP (85 ppm), BO+CC (106 ppm). The BO treatment was the only treatment with a significantly higher (369 ppm) amount of nitrate-N ppm than the Control treatment (101 ppm) at small fruit stage. The range of sufficient petiole nitrate-N ppm for first fruit 5 cm is 1,000-1,200 (Hochmuth, 1994a). Our trial had every treatment below the sufficiency levels for petiole nitrate-N which indicates the fertilizer applied through drip irrigation was insufficient to overcome the N deficiency from the beginning of transplant.

At the mature fruit stage BO (398 ppm) and CR+AWP (357 ppm) had statistically higher petiole nitrate-N than legume only treatments AWP (75 ppm), CC (68 ppm) and mixes, WW+AWP (109 ppm) and BO+CC (73 ppm). No cover crop treatment had a statistically different level of petiole nitrate-N than the Control at harvest. The sufficiency range of petiole nitrate-N for fruit at harvest is 600-800 ppm (Hochmuth, 1994a). Two treatments had petiole nitrate-N levels above this range (BO, CR+AWP). The lower petiole nitrate-N in legume-only plots may be due to the fast decomposition of plant material and corresponding rapid release of N well in advance of the peak need for the crop. On the other hand, the timing of N mineralization from BO and CR+AWP aligned better with watermelon plant need in a strip-tilled system. A valid concern for farmers is aligning the watermelon plant needs and the cover crop N mineralization rate.

Cover crops had no effect on watermelon petiole nitrate-N in the very early season when the crop starting vining. Nitrogen mineralization from cover crops typically peaks around 20 days following incorporation into the soil and continues for up 70 days, declining with time after peak mineralization (Snapp and Borden, 2005; Malpassi et al., 2000; Sanchez et al., 2001). In our study approximately 50 days passed from cover crop termination to first nitrate petiole sampling date in both years. Thus, our first sampling date occurred after the estimated peak time-period for N release in the literature. Continued decomposition of grass cover crops like BO, and in some cases CR+AWP, may have released N until later in the season, affecting the petiole nitrate-N levels once watermelon fruit development started. More research is needed to better understand the nitrogen dynamics of BO and CR+AWP with watermelon in SW Arkansas, but BO and CR+AWP seem to supply some nitrogen to watermelons into mid and late season better than legume cover crops.

Summer weed biomass

Summer weed biomass during the watermelon-growing season, taken at two sampling dates, 30 and 60 days following cover crop termination, was found to be impacted by winter cover crop treatment but this effect varied by sampling date, in that several cover crop mixes (BO+AWP, WW+AWP and BO+CC) and grasses (BO, CR and WW) were able to suppress weed growth in the row middles of a plasticulture system to the same level as a preemergence herbicide (Control) at both sampling dates while others only suppressed weeds equal to the Control at the first sampling date. Further summer weed biomass varied by sampling date in each year. An equal amount of weeds biomass was present at the first sampling date in 2018 and 2019 (194 kg·ha^{-1}, 182 kg·ha^{-1} respectively), however, higher weed biomass was found at the second sampling date in 2018 (731 kg·ha^{-1}) than in 2019 (508 kg·ha^{-1}). Less weed biomass early on in 2019, may indicate less ideal growing conditions in the field. The amount of weed biomass did increase from the 30-day sample to 60-day sample as continued weed growth occurred throughout the season.

Summer weed biomass (kg·ha^{-1}) at 30-days after cover crop termination was statistically higher than the Control (184 kg·ha^{-1}) in the CC (329 kg·ha^{-1}) and MU (334 kg·ha^{-1}) treatments. All other treatments suppressed weeds in the row-middles to the same degree as a preemergence herbicide (Control) (Figure 5).

At 60-days after cover crop termination weed biomass (kg·ha^{-1}) had doubled and greater variability was seen between cover crop treatments for effect on weed suppression. The grasses (BO 544 kg·ha^{-1}, CR 562 kg·ha^{-1}, WW 468 kg·ha^{-1}) and mixes (BO+AWP 624 kg·ha^{-1}, WW+AWP 569 kg·ha^{-1}, BO+CC 714 kg·ha^{-1}) remained similar to the Control (384 kg·ha^{-1}) in weed biomass. All other treatments had statistically higher weed biomass than the Control however many were similar to grasses and these mixes. The treatment WW (468 kg·ha^{-1}) was the only treatment to have significantly less weed biomass than both legume treatments (AWP 961 kg·ha^{-1}, CC 912 kg·ha^{-1}) which had the highest weeds biomass. Individual grass species and the mixes made up of the same species were similar in weed biomass at both sampling dates except for BO+AWP had higher weed biomass than BO at the 30-day sampling period. While there are treatments that had equal amounts of weed biomass to Control at the first sampling date, a trend can be seen where the cover crop weed suppression is lost as the cover crop biomass breaks down more by the second sampling date.

In the supplemental analysis, the "Group" effect was significant (p= 0.0002) on summer weed biomass with "Mixes" (327 kg·ha^{-1}), "Grasses" (275 kg·ha^{-1}) and the "Control" (256 kg·ha^{-1}) being similar, whereas the "Legume" (482 kg·ha^{-1}) and "Mustard" (482 kg·ha^{-1}) had higher summer weed biomass. This further emphasizes that potential for grass and mixes species cover crops to control summer weeds in row-middles to a single preemergence herbicide application in strip-till watermelon production.

Our research has shown similar results to other studies, showing that grass cover crops reduce weeds more effectively, and for a longer period of time, than legumes. Teasdale and Abdul-Baki, (1998) found in a no-tillage system that flail mowed cover crop mixes dominated by cereal rye outperformed a legume only cover crop for weed biomass reduction. Creamer et al., (1997) found in a no-tillage system that cereal rye included in mixtures with legumes was more effective than mixtures with other grasses or no grass at all for long term weed control at 8 weeks following termination in the spring. Our project showed similar findings that cover crop mixes can be effective for weed control but in strip-tilled systems and equivalent to the standard practice of a preemergence herbicide. The weed control effect of cover crops is reduced the longer the period of time from cover crop termination, as the cover crop biomass in the row middles breaks down and allows weed growth as seen by the increase in weed biomass from the 30-day to the 60-day.

Watermelon Yield

While yield and fruit quality varied across the two years of the experiment, winter cover crops affected watermelon yields, and fruit number in a plasticulture system. Notably, when compared to the Control, WW and its mix WW+AWP resulted in lower yield ($kg \cdot ha^{-1}$), and CR and WW resulted in fewer marketable fruit per plant, whereas CR+AWP had yield numerically higher yield than the Control. This is an important finding as it indicates that some cover crop mixes are preferable for maintaining watermelon yield over the standard use of cereal rye and winter wheat as winter cover crops that precede watermelon in plasticulture systems. Cover crop interaction with year was not significant for any yield-related parameter.

Overall yield in our trial was low due to disease, rodent damage, row middle weed pressure, and fruit disorders including BER and sun scald in both years of our trial. However, we feel our results are still important because growers often deal with these unpredictable occurrences and as extreme weather trends become more common. Cover crop and year effects were both significant when analyzed separately; however, the higher effect of treatment across years was not significant indicating the same trend of cover crop effect on watermelon in both years.

All cover crop treatments were similar to the Control for marketable yields, except WW 4,838 $kg \cdot ha^{-1}$ and WW+AWP 9,212 $kg \cdot ha^{-1}$ which had lower marketable fruit weights. All individual cover crop treatments were similar to their corresponding mixed cover crop treatments demonstrating that mixed treatments affect marketable yield. The treatments WW and WW+AWP had the numerically lowest yields; however, WW was not different than AWP (8,820 kg·ha^{-1}), CC (10,836 kg·ha^{-1}), MU (9,234 kg·ha^{-1}), CR (11,000 kg·ha^{-1}), BO+AWP (9,753 kg·ha^{-1}), and BO+CC (9,513 kg·ha^{-1}) treatments. The number of fruit per plant by was similar for all cover crop treatments compared to the Control (0.46), except CR (0.44) and WW (0.22) which had fewer fruit per plant. The treatments of BO (0.48), BO+AWP (0.39), CR+AWP (0.55), and BO+AWP+MU (0.46) had more fruit per plant than CR and WW. The CR+AWP had the highest numerical number for fruit per plant indicating a potential benefit seen in the Mix.

The fruit cull rate (54-74%) did not differ statistically across cover crop treatments (Table 6). The incidence of BER (7-18%) and fruit rot (3-11%) also did not differ across treatments (Table 6). Reduced marketable yield and low marketable fruit numbers were observed in both years of the trial, with very poor and significantly lower yields observed in 2019. The reason for reduced yield in 2019 was an increase in weed pressure in transplant holes and row middles as well as an increase in plant diseases, which caused a reduction in the quality of growth for the watermelon plants throughout the field. In-row visual weed data was not collected, however, the weed presence in the field was noticeable in 2019. Weed growth was more prevalent in transplant holes in 2019 than in 2018, so competition for resources may have impacted the ability of watermelons to grow. Watermelon vines in 2019 appeared to have developed disease issues that reduced foliage and growth, indicating possible downy mildew infection. The increase in disease may be due to twice as much precipitation in 2019 compared to 2018 for the months of March, April, and June resulting in standing water alongside beds. Watermelon fruit considered a cull was at 80% in 2019 compared to 39% in 2018. The increase in culled fruit may be due to weakened plants due to increase weed pressure in transplant holes and diseased watermelon plants.

The year of 2018 had a significantly more marketable fruits per plant than the 2019 season. The higher number of watermelons in 2018 may be due to it being the first year of trial, and less disease was present in the field from a previous crop and weed pressure was not as high. Weeds in 2018 may gone to seed which would increase the weed pressure in 2019.

Year was also significant for cull rates, with the highest percent of cull occurring in 2019. The high number of culls in 2019 the lower marketable yield (kg·ha^{-1}) and lower number of marketable fruits per plant in 2019 than in 2018 demonstrates an issue outside of the cover crop treatments that affected watermelon development. Cull information also included the total watermelon affected by BER or fruit rot. The percent of total watermelon fruit diagnosed with BER or fruit rot were not affected by cover crop treatments. However, year did affect each symptom differently from one another. A greater percent of fruits was affected with BER in 2019 than in 2018, while a greater percentage of fruits was affected by fruit rot in 2018 than in 2019.

The data from both years demonstrate the overall benefit of choosing a cover crop like BO (12,118 kg·ha^{-1} marketable watermelon) or a mix such as CR+AWP (13,180 kg·ha^{-1} marketable watermelon) or BO+AWP+MU (12,374 kg·ha^{-1} marketable watermelon) over monoculture CR (11,000 kg·ha^{-1} marketable watermelon) or WW (4,838 kg·ha^{-1} marketable watermelon) often grown by Arkansas farmers. While grass only cover crops of CR and WW produced high amounts of cover crop biomass in one season, the next season was low. Crops such as BO and the mixed treatments were more consistent in biomass production. Our data suggests that WW may impede N uptake in the plant as seen by the low petiole nitrate-N levels in WW and WW+AWP at fruit development stages; however, legumes AWP and CC also had low levels compared to BO and CR+AWP. The low petiole nitrate-N across all treatments including the Control indicates that nitrogen fertilization may have been insufficient throughout the field as heavy rainfall and saturated soils may have caused leaching of nitrate.

The grass cover crops (BO, CR, WW) did provide numerically lower summer weed biomass ($kg \cdot ha^{-1}$) than other treatments and were similar to a single application of herbicide (Control); however, that benefit did not equate to higher marketable yield in CR (11,000 $kg \cdot ha^{-1}$) and WW (4,838 $kg \cdot ha^{-1}$) or fruit per plant. Burgos and Talbert (2000), found that allelochemicals extracted from cereal rye did inhibit shoot growth of various cucurbit seedlings in Petri dish bioassays. While this study demonstrated the potential for allelopathic chemicals to affect cucurbit plant growth and yield, a study with cucurbit transplants is needed to evaluate crop response in the field.

When looking at the number of marketable watermelons per plant, lower numbers than expected were seen in all treatments due to the high amount of culled fruit; however, treatments of BO (0.48), BO+AWP+MU (0.46), and CR+AWP (0.55) did have a higher number of marketable fruit per plant compared to WW (0.22), and WW+AWP (0.37). While CR did have an appreciable amount of yield, the plants produced a limited of number fruit (0.44) but was similar to the Control (0.46). The low marketable yield in treatments that contain winter wheat suggests there may be a negative effect of the cover crop on watermelon growth and yield that could not be determined through our data collection. Alternatively, BO and mixes BO+AWP+MU and CR+AWP may be beneficial to watermelon plants through continued release of nutrients from plant biomass. The biomass of BO and CR+AWP may break down and release nutrients at a rate that is similar matches the needs of the watermelon plant and results in increased yield. No literature was found to have used black-seeded oats in specialty crops, so further research would be beneficial.

Conclusions

Winter cover crops mixes are preferable over the grower standard of a single grass species like CR or WW for use in plasticulture watermelon production. Cover crop mixes on average were more consistent in biomass and cover crop N production and had similar amounts of N inputs as legumes and grass species. However, we did not always see a direct relationship between cover crop N content and watermelon plant tissue petiole nitrate-N content. A grower that does want to use a single species grass may consider BO since our results showed it supplied a higher amount of N for watermelon plant uptake than other cover crops. In addition, CR+AWP had consistently higher nitrate-N petiole readings than the Control. Both BO and CR+AWP were among the highest yielding cover crop treatments we evaluated. The three-way mixture of BO+AWP+MU was also high yielding, but the mixture was less reliable biomass producer in years when mustard had poor performance. While weeds were problematic throughout the field, cover crops of grasses and mixes were similar in weed Control to a preemergence herbicide early in the season. The BO maintained weed Control equal to the Control throughout the season, whereas CR+AWP had weed Control similar to the Control early in the season but slightly higher weed biomass later. Organic production may be difficult to utilize a roller-crimper due to the difficulty of cover crop termination in a no-till system. Cereal rye is the best choice for a cover crop that grows tall enough in Arkansas for potential termination by roller-crimper only. Based on the cover crop mixes and seeding rates evaluated we encourage Arkansas watermelon growers consider using BO+AWP or CR+AWP winter cover crops in strip-tilled plasticulture systems.

Tables and Figures

Table 1.Winter cover crop treatments and seeding rates planted at the University of Arkansas Southwest Research & Extension Center, Hope, AR in 2017 and 2018.

Treatment Name	Treatment Acronym	Scientific Name	Seeding Rate ($kg \cdot ha^{-1}$)
	Legumes and other broadleaves		
Austrian winter pea	AWP	*Pisum sativum* (L.) ssp. Arvense	56
Crimson clover	CC	*Trifolium incarnatum* L.	13.4
Mustard	MU	*Sinapis alba* L.	5.6
	Grasses		
Black-seeded oats	BO	*Avena sativa* (L.)	112
Cereal rye	CR	*Secale cereale* L.	112
Winter wheat	WW	*Triticum aestivum* L.	101
	Mixes: Grass, legumes and broadleaf		
Black-seeded oats + Austrian winter pea	BO+AWP		56, 39
Cereal rye + Austrian winter pea	CR+AWP		56, 39
Winter wheat + Austrian winter pea	WW+AWP		50, 39
Black-seeded oats + Crimson clover	BO+CC		56, 9.0
Black-seeded oats + Austrian winter pea + Mustard	BO+AWP+MU		39, 28, 3.4

Table 2. Monthly temperature and precipitation during winter cover crop and watermelon growing seasons for 2017, 2018, and 2019 growing seasons at the University of Arkansas Southwest Research & Extension Center, Hope, AR.

		Temperatures (°C)				
Year	Month	Average High *	Average Low	Minimum	Maximum	Precip (mm)
			2017-2018 Winter Cover Crop Season			
2017	September	30	17	11	36	8
	October	26	10	5	33	27
	November	20	7	-4	28	29
2018	December	13	1	-6	24	225
	January	9	-4	-16	20	71
	February	15	3	-4	26	336
	March	21	7	-2	28	168
	Average	**19**	**6**	**-2**	**27**	**123**
			2018 Watermelon Season			
	April	21	6	-2	28	126
	May	30	18	9	35	107
	June	33	21	14	36	44
	July	35	22	17	41	102
	Average	**30**	**17**	**10**	**35**	**95**
			2018-2019 Winter Cover Crop Season			
	September	29	20	13	35	180
	October	23	12	2	32	151
	November	14	2	-4	26	156
2019	December	12	3	-4	22	200
	January	12	0	-5	19	140
	February	14	4	-6	25	157
	March	17	4	-6	25	95
	Average	**17**	**6**	**-2**	**26**	**154**
			2019 Watermelon Season			
	April	22.5	9.3	-1.1	30	228
	May	27.8	16.6	10.0	32	324
	June	29.6	18.4	13.3	33	150
	July	30.3	20.7	15.0	34	125
	Average	**27.5**	**16.2**	**9.3**	**32**	**207**

*NOAA climatalogical data for Hope 3 NE, AR

Table 3. Winter cover crop and winter weed biomass, cover crop carbon to nitrogen ratio (C:N), and nitrogen content at the University of Arkansas Southwest Research & Extension Center, Hope, AR sampled in spring 2018 and 2019.

		Above ground biomass ($kg \cdot ha^{-1}$)			
Treatment		Cover crop [z]	Winter weed	Nitrogen	C:N
Cover crop [y]					
	AWP	1,775	277	35	37
	CC	1,418	165	28	32
	MU	886	235	15	29
	BO	2,261	63	40	28
	CR	1,624	73	37	28
	WW	2,093	111	33	31
	BO+AWP	2,053	157	30	35
	CR+AWP	1,531	115	34	27
	WW+AWP	2,420	101	43	27
	BO+CC	2,094	69	35	27
	BO+AWP+MU	1,873	142	52	20
	Control	*	647	16	20
	p-value	*<.0001*	*<.0001*	*<.0001*	*0.0004*
Year					
	2018	2,109	103	32	33
	2019	1,533	256	34	24
	p-value	*<.0001*	*<.0001*	*0.1836*	*<.0001*
Cover crop x Year					
	p-value	*<.0001*	*0.0041*	*<.0001*	*<.0001*

[z] Mean separation by least square means. Different letters for each response variable indicate significant differences ($p<0.05$).
[y] Cover crop treatments: Austrian winter pea (AWP), crimson clover, (CC), mustard (MU), black oats (BO), cereal rye (CR), winter wheat, (WW), various combinations of these and winter fallow Control.

Table 4. Petiole nitrate (nitrate^{-}N) of watermelon at three stages of crop development (early vine running, small fruit, and mature fruit) at the Southwest Research & Extension Center, Hope, AR for 2018 and 2019.

Treatment			Petiole Nitrate-N (ppm)[z]
Cover crop [y]			
	AWP		166
	CC		254
	MU		319
	BO		524
	CR		377
	WW		283
	BO+AWP		311
	CR+AWP		421
	WW+AWP		186
	BO+CC		243
	BO+AWP+MU		393
	Control		294
		p-value	*0.3424*
Year			
	2018		275
	2019		354
		p-value	*0.0025*
Crop Stage			
	Early vine running		593
	Small fruit		157
	Mature fruit		191
		p-value	*<.0001*
Cover crop x Year			
		p-value	*0.7664*
Cover crop x Crop stage			
		p-value	*0.0192*
Year x Crop stage			
		p-value	*0.0133*
Cover crop x Year x Crop stage			
		p-value	*0.3160*

[z] Mean separation by least square means. Different letters for each response variable indicate significant differences ($p<0.05$).

[y] Cover crop treatments: Austrian winter pea (AWP), crimson clover, (CC), mustard (MU), black-seeded oats (BO), cereal rye (CR), winter wheat, (WW), various combinations of these and winter fallow Control.

Table 5. Weed biomass between row middles in winter cover crop residue in plasticulture watermelon at two sampling dates at the University of Arkansas Southwest Research & Extension Center, Hope, AR, in 2018 and 2019.

Treatment			Above ground Biomass (kg·ha^{-1})[z]
Cover crop [y]			
	AWP		571
	CC		563
	MU		513
	BO		311
	CR		357
	WW		313
	BO+AWP		407
	CR+AWP		440
	WW+AWP		351
	BO+CC		388
	BO+AWP+MU		463
	Control		277
		p-value	*0.0056*
Year			
	2018		462
	2019		345
		p-value	*0.0021*
Cover crop x Year			
		p-value	*0.0955*
Sample date			
	30 days		198
	60 days		627
		p-value	*<.0001*
Cover crop x Sample date			
		p-value	*0.0263*
Year x Sample date			
		p-value	*0.0289*
Cover crop x Year x Sample date			
		p-value	*0.2241*

[z] Mean separation by least square means. Different letters for each response variable indicate significant differences (p<0.05).

[y] Cover crop treatments: Austrian winter pea (AWP), crimson clover, (CC), mustard (MU), black-seeded oats (BO), cereal rye (CR), winter wheat, (WW), various combinations of these and winter fallow Control.

Table 6. Mean marketable yield, number of marketable fruit per plant, cull fruit, incidence of blossom end rot (BER), and general fruit rots for watermelon grown in plasticulture following winter cover crops at the Southwest Research & Extension Center, Hope, AR in 2018 and 2019.

Treatment		Marketable yield (kg·ha^{-1})[z]		Marketable fruit per plant (#)		Cull (%)		BER (%)		Fruit rot (%)
Cover crop [y]										
	AWP	8,820	abcd	0.38	abcde	67%		13%		6%
	CC	10,836	bcd	0.42	cde	50%		11%		6%
	MU	9,234	bcd	0.39	cde	60%		7%		9%
	BO	12,118	ab	0.48	abc	56%		13%		6%
	CR	11,000	abcd	0.44	e	61%		13%		8%
	WW	4,838	d	0.22	e	72%		12%		10%
	BO+AWP	9,753	abcd	0.39	abc	59%		11%		9%
	CR+AWP	13,180	a	0.55	a	54%		13%		9%
	WW+AWP	9,212	cd	0.37	de	61%		18%		3%
	BO+CC	9,513	bcd	0.37	cde	57%		16%		11%
	BO+AWP+MU	12,374	a	0.46	ab	62%		12%		9%
	Control	12,913	ab	0.46	abcd	55%		13%		8%
	p-value	*0.0139*		*0.0016*		*0.2236*		*0.8914*		*0.9243*
Year										
	2018	26,848	a	0.67		39%	b	7%	b	12%
	2019	4,957	b	0.15		80%	a	19%	a	4%
	p-value	*<.0001*		*<.0001*		*<.0001*		*<.0001*		*<.0001*
Cover crop x Year										
	p-value	*0.1238*		*0.0520*		*0.2620*		*0.9105*		*0.8282*

[z] Mean separation by least square means. Different letters for each response variable indicate significant differences (p<0.05).
[y] Cover crop treatments: Austrian winter pea (AWP), crimson clover, (CC), mustard (MU), black-seeded oats (BO), cereal rye (CR), winter wheat, (WW), various combinations of these and winter fallow Control.

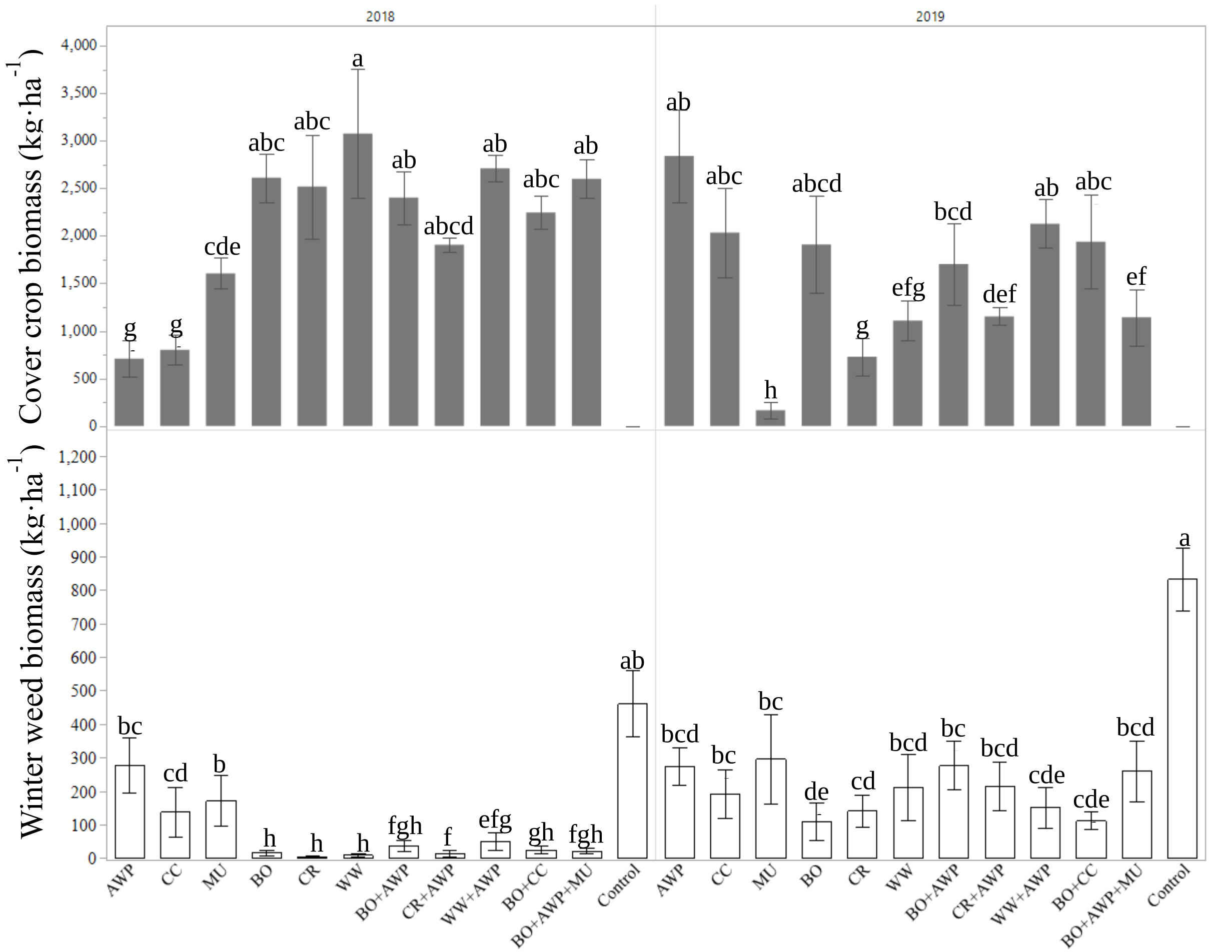

Figure 1. Winter cover crop and weed biomass for cover crop treatments by year at the University of Arkansas Southwest Research & Extension Center, Hope, AR sampled in spring 2018 and 2019. Cover crop treatments: Austrian winter pea (AWP), crimson clover, (CC), mustard (MU), black-seeded oats (BO), cereal rye (CR), winter wheat, (WW), various combinations of these and winter fallow Control. Means with different letters for each attribute are significantly different ($p < 0.05$).

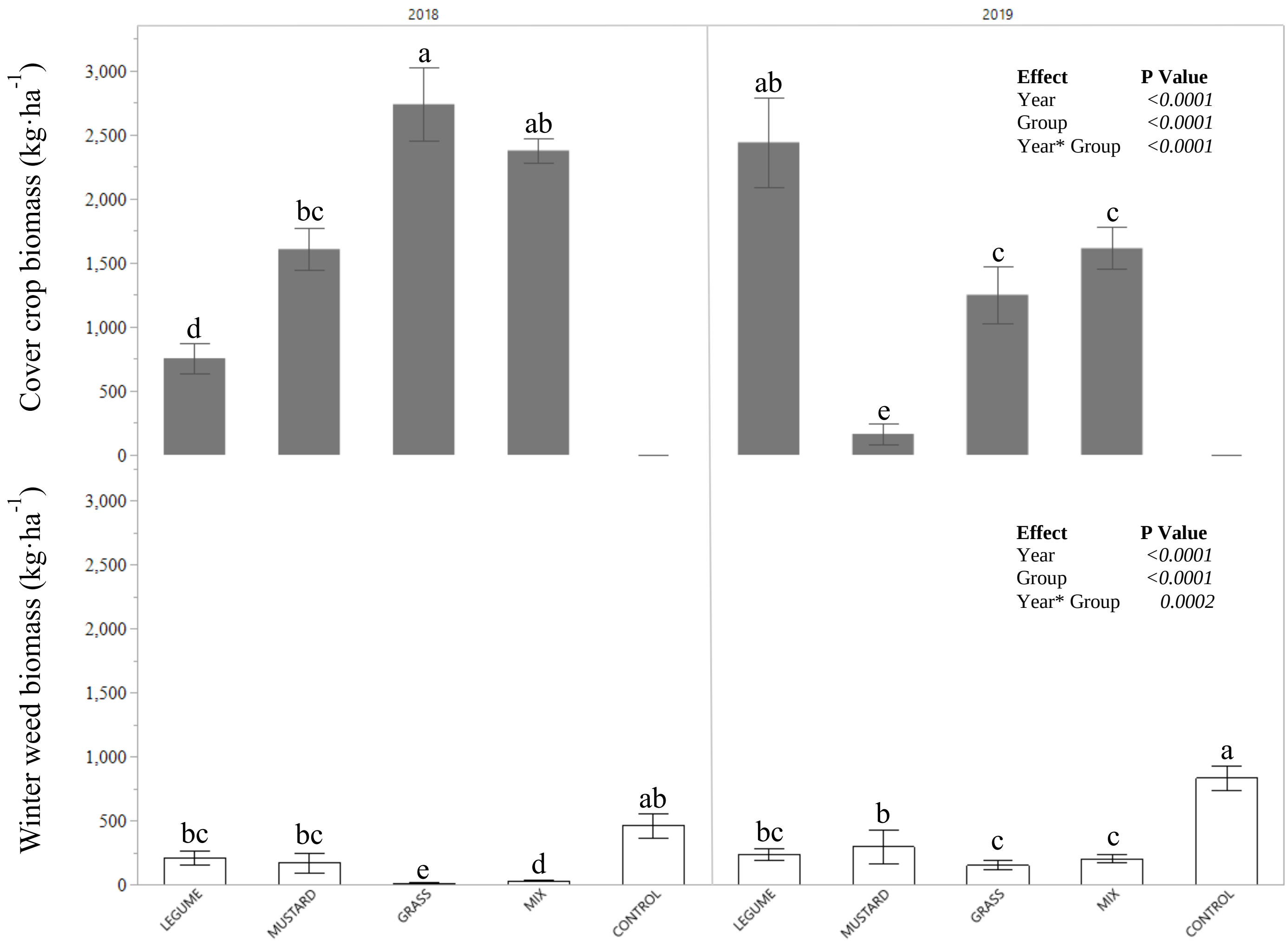

Figure 2. Cover crop and weed biomass for contrast groups by year at the University of Arkansas Southwest Research & Extension Center, Hope, AR sampled in spring 2018 and 2019. Cover crop treatments: Austrian winter pea (AWP), crimson clover, (CC), mustard (MU), black-seeded oats (BO), cereal rye (CR), winter wheat, (WW), various combinations of these and winter fallow Control. Means with different letters for each attribute are significantly different ($p < 0.05$).

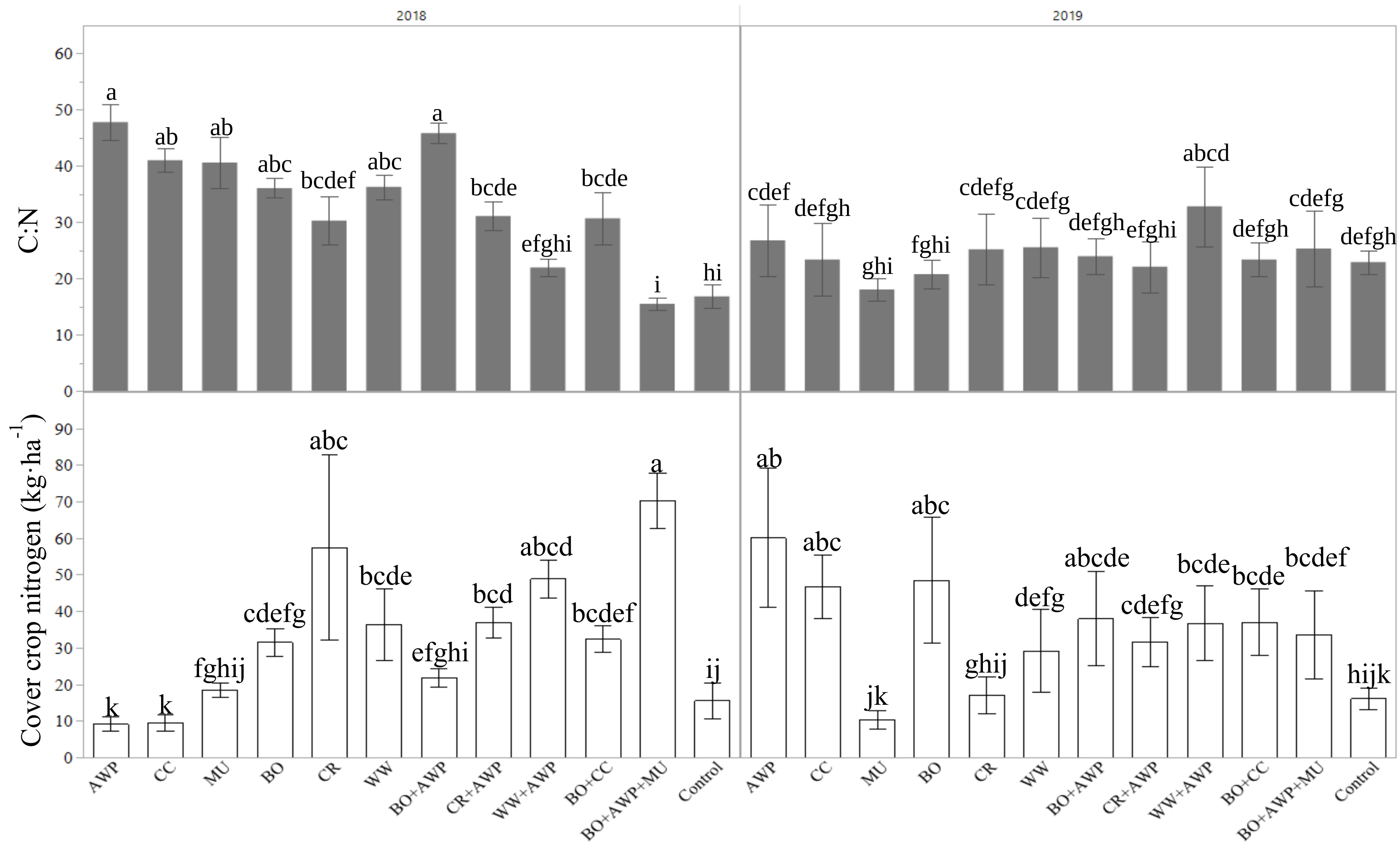

Figure 3. Winter cover crop and weeds carbon to nitrogen ratio (C:N), and cover crop nitrogen content at the Southwest Research & Extension Center, Hope, AR sampled in spring 2018 and 2019. Significant differences of means shown with letters found using protected least square means. Cover crop treatments: Austrian winter pea (AWP), crimson clover, (CC), mustard (MU), black-seeded oats (BO), cereal rye (CR), winter wheat, (WW), various combinations of these and winter fallow Control. Means with different letters for each attribute are significantly different at $p < 0.05$.

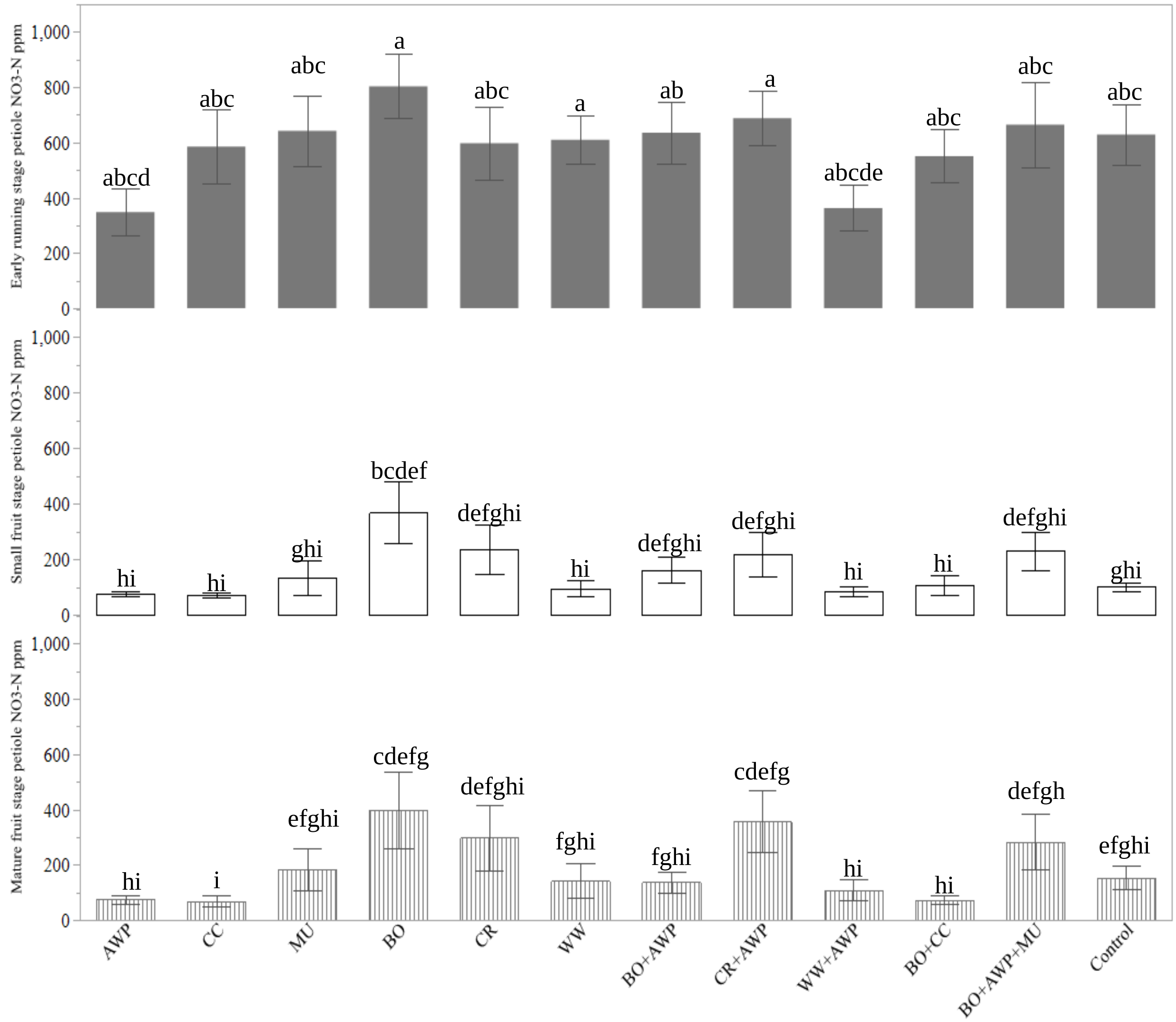

Figure 4. Mean petiole nitrate (nitrate-N) of watermelon plants by cover crop treatment at three stage of crop stage (early running, small fruit, and mature fruit) at the University of Arkansas Southwest Research & Extension Center, Hope, AR for 2018 and 2019. Cover crop treatments: Austrian winter pea (AWP), crimson clover, (CC), mustard (MU), black-seeded oats (BO), cereal rye (CR), winter wheat, (WW), various combinations of these and winter fallow Control. Means with different letters are significantly different at $p < 0.05$.

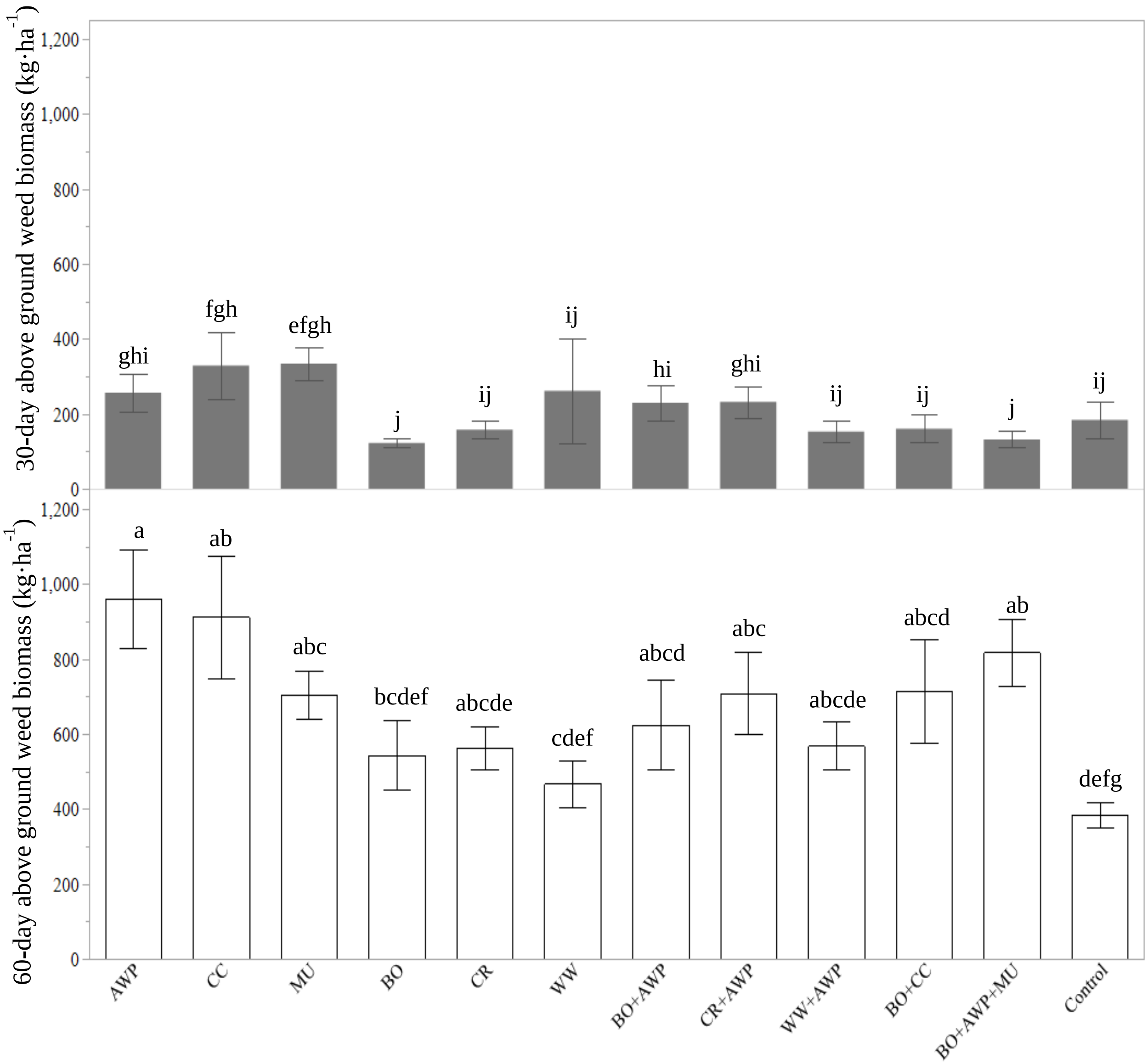

Figure 5. Mean summer weed biomass accumulation (kg·ha^{-1}) taken at 30 and 60-days following cover crop termination at the Southwest Research & Extension Center, Hope, AR sampled in 2018 and 2019. Cover crop treatments: Austrian winter pea (AWP), crimson clover, (CC), mustard (MU), black-seeded oats (BO), cereal rye (CR), winter wheat, (WW), various combinations of these and winter fallow Control. Means with different letters are significantly different ($p < 0.05$).

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Chapter 3: Winter Cover Crops and a No-till Watermelon Production System, Kibler, AR

Abstract

Bare-ground watermelon, *Citrullus lanatus* (Thunb.) Matsum. & Nakai, production that relies on herbicides for weed control is low cost but results in poor weed control late in the season as preemergence herbicides degrade and vines spread over the soil making it difficult to cultivate. Winter cover crops rolled-down to cover the soil surface prior to planting watermelon may provide increased weed control, and supply nutrients to the watermelon crop. We compared winter cover crop grasses (black-seeded oats (*Avena sativa* L.), cereal rye, (*Secale cereale* L.), and winter wheat (*Triticum aestivum* L.)), cool-season legumes and a broad leaf (Austrian winter pea (*Pisum sativum* arvense), crimson clover (*Trifolium incarnatum* L.), mustard (*Sinapis alba*) and legume + grass mixes of these individual species for effects on the production of watermelons transplanted into the rolled cover crop residue in a no-till system compared to a winter fallow preemergence herbicide control. Response variables included: cover crop biomass, weed biomass (winter and summer), watermelon petiole nitrate, and watermelon yield and fruit quality. Our analysis indicates winter cover crop biomass was higher and more consistent when planting mixes of legumes +grasses. Grasses and mixes suppressed winter weeds better than legumes; however, the legumes and mixes had higher nitrogen (N) content than the grasses which was later observed to sometimes result in higher watermelon petiole nitrate-N in the early season. Summer weed suppression at the 30-day sample date was often better following a winter cover crop grass or mix than following legumes and grasses and some mixes provided weed control similar to a preemergence herbicide control. Watermelon yields may have been more impacted by N inputs from cover crops than weed control provided by them, as higher watermelon yield ($kg \cdot ha^{-1}$) were observed when watermelons were planted into legumes and

cover crop mixes than in grass treatments. This is an important result as cover crops are generally used in no-till systems for weed control but our results show they can provide other benefits to no-till watermelon production. Due to the reduction in watermelon yield ($kg \cdot ha^{-1}$) in grasses, in particular winter wheat, compared to other cover crop types our recommendations for bare-ground or no-till watermelon systems is to plant a cover crop mix that includes a grass and legume such as cereal rye + Austrian winter pea or black-seeded oat + crimson clover.

Introduction

Watermelon production is a minor crop in Arkansas with around 1214 hectares of production statewide (Andersen and Spradley, 2003). Cultivars grown in the state include many seedless varieties for urban centers and large-seeded cultivars including ‘Crimson Sweet’ and ‘Jubilee II’ which are more popular in rural areas (Andersen, 2011). Plasticulture production, which involves forming a raised bed covered with black plastic mulch overlaying drip irrigation is a common method of production for watermelons in the Southeast; however, increasing concern about the disposal of plastic mulch raises concern for long-term sustainability of the practice. Removal of the plastic requires labor and cost an estimated $250 per hectare (Shogren and Hochmuth, 2004). Proper disposal of polyethylene mulch is an issue since recycling is difficult due to soil and debris on the plastic which landfills may not accept or for which they charge a tipping fee (Lamont, 2005). Alternatives to plasticulture watermelon production are bare-ground or no-till production utilizing cover crops.

In Arkansas, both bare-ground and plasticulture watermelon production systems are utilized, and for both weed control is almost totally reliant on herbicide followed by manual weeding (Andersen and Spradley, 2003). Weed control in watermelon production is a major limitation throughout the production season. Once watermelons have vined out, cultivation can no longer be done to control weeds. High weed populations increase agricultural production costs and reduce profit margins, while also increasing difficulty of harvest, and reducing crop quality and yield (Brandenberger et al., 2005). Many farmers are reliant on herbicides for weed control throughout the season; however, preemergence herbicides applied at transplant break down by late season and few postemergence herbicides are labelled for use in watermelons (Vollmer et al., 2020).

Sustainable practices in agriculture are increasingly valued by specialty crop growers. Cover crops are grown in the off-season period and provide many benefits to the soil and subsequent cash crops. Cover crops are selected based on their potential to provide benefits to the soil or to the subsequent cash crop (Clark, 2007). The use of winter cover crops is one method adopted by many watermelon growers in eastern Arkansas for soil conservation; however, the growers currently only use either winter wheat or cereal rye.

Different cover crop types have unique benefits. Grass cover crops, such as cereal rye, are known for the ability to produce large amounts of biomass even at low seeding rates because of its high tillering capacity, which compensates for reduced plant population such as in a grass + legume mix which can have the grass seeding rate reduced by 50% (Boyd et al., 2009). Small annual grains may also be utilized as a wind break between rows to protect new transplants from strong winds (Lamont, 2005).

Legume cover crops are typically utilized in a cropping system as a nitrogen input due to their ability to convert atmospheric nitrogen gas (N_2) into stored plant nitrogen before ultimately breaking down into the forms ammonium (NH_4^+) and nitrate (NO_3^-) which can be taken up by subsequent cash crops (Clark, 2007). Legumes typically have a lower carbon to nitrogen ratio than grasses, so the legumes plant material breakdown more rapidly and release nutrients contained in the biomass more quickly (Clark, 2007).

Brassicas represent a third group of cover crops that are commonly planted. Some of the species used include: turnips (*Brassica septiceps)*, mustard (*Brassica cretica)*, canola (*Brassica napus and Brassica rapa)* and forage radish (*Raphanus sativus)*. Benefits of a mustard cover crops include biofumigation which is attributed to isothiocyanates, an allelochemical produced from the breakdown of glucosinolate content of plants (Brown and Morra, 2005). The isothiocyanates can suppress insect pests such as nematodes and click beetle larva, such as the eyed click beetle (*Alaus oculatus*) and also suppression of soil-borne diseases such as *Pythium* root rot and *Rhizoctonia solani* (Brown and Morra, 2005). Other brassicas, like turnips, also have a strong, deep penetrating taproot that provides deep soil mining for nutrients and potentially breaks up hardpans present in the soil (Williams and Weil, 2004).

Growing a mix of cover crop types (grass, legume, and brassica) can broaden the overall benefits of planting a cover crop. A mix of cereal and legume cover crops can both scavenge excess nitrogen and fix nitrogen (Brennan et al., 2012). Grass cover crops typically have high lignin and cellulose concentrations and a high carbon to nitrogen ratio that slows degradation and release of nutrients (Ashford and Reeves, 2003). Legume cover crops break down quickly due to lower carbon to nitrogen ratios and thus quickly release their stored nutrients (Power, 1994; USDA NRCS, 2015). A cover crop mix of legume and grass can lower the carbon to nitrogen ratios of the cover crop material and reduce the nutrient mineralization rate for increased cash crop plant uptake (Kuo and Jellum, 2002).

An alternative to plastic mulch for weed control is a cover crop mat formed by a roller crimper. A roller crimper can be used to form a dense mat of cover crop biomass, which suppresses weed emergence and reduces weed density (Teasdale and Mohler, 2000). A roller crimper is beneficial over mowing or tilling in the cover crops because it is more time efficient and the plant residue remains on the soil surface longer to prevent weed growth (Creamer and Dabney, 2002). By leaving the cover crop residue on the soil surface, the nutrients are released from the biomass more gradually as the plant biomass breakdown is slowed, allowing a longer period for nutrient uptake by the cash crop (Ashford et al., 2003). The use of a roller crimper to form a cover crop mat has been shown to be useful for vegetable production. Forcella et al., (2015) found a roller crimped cereal rye cover crop reduced the amount of hand weeding time and had similar yields for watermelons compared to stale ground plots, but yield was not consistent over a two-year period. Ciaccia et al., (2016) found zucchini yield was higher when grown in a roller crimped barley cover crop compared to fallow ground or a barley green manure treatment. Other studies have evaluated the effect of cover crops on vegetable production but involving different cover crop termination methods. Teasdale and Abdul-Baki, (1998) found that tomatoes grown in flail mowed cover crop mixes of cereal rye and a legume tended to have higher tomato yield than monoculture cereal rye. Walters and Young, (2010) found pumpkins direct seeded into no-till, flail mowed cover crops of winter wheat and cereal rye had equal yields compared to bare ground pumpkins, however, pumpkins in cover crop treatments produced larger pumpkins.

Termination method also effects the release of nutrients from the cover crop to be available for plant uptake. When cover crops are incorporated into the soil through tillage rapid decomposition occurs and the release of nitrate from the biomass may not coincide with the cash crop nutrient uptake requirements (Power, 1994). When cover crops are part of a no-till system, the cover crop residue remains on the soil surface helping to hold soil moisture, resulting in lower microbial activity and slower release of N from the cover crops. The slowed break down of the cover crops biomass may release N in a pattern and timing that better matches the subsequent cash-crop nitrogen uptake pattern. In cotton production, when N was not a limiting factor, yields in no-till treatments that include either wheat or hairy vetch were greater than in a tilled system (Boquet et al., 2004).

The effects cover crops may have on no-till production is complex and warrants further research for watermelon production in Arkansas. In this study we aimed to evaluate the use of mixes of legume and grass cover crops for their effect on no-till watermelon production compared to single species cover crops and a winter fallow plus preemergence herbicide control.

Materials and Methods

An untilled (no-till) winter cover crop watermelon trial was conducted over three seasons from 2018-2020 at the University of Arkansas System Division of Agriculture Vegetable Research Center located in Kibler, AR (35.3791°N, 94.2333°W). The site is in USDA hardiness zone 7a on a Roxana silt loam (Soil Survey staff, 2021).

The experimental design was a randomized complete block design of 12 treatments with five replications, resulting in 60 plots. Plots were 3.7 m by 9.1 m with 3.0 m alleys between plots in the same row. No additional alley was set between plots in adjacent rows. The twelve cover crop treatments (Table 1) consisted of three grasses and three broadleaves grown singly and in mixed species combinations. Acronyms for treatment only will be used henceforth. The grasses evaluated were: black-seeded oats (BO) (origin Arkansas, Southern Solutions, 21301 Hwy 17 Clarendon, AR, 72029) (112 $kg \cdot ha^{-1}$.), Cereal rye (CR), (origin not stated) (112 $kg \cdot ha^{-1}$.), Winter wheat (WW), (Arkansas, Southern Solutions, 21301 Hwy 17 Clarendon, AR, 72029) (101 $kg \cdot ha^{-}$

^{1}). The legumes were: Austrian winter pea (AWP), (Washington, Columbus Grain, 2051 Wilma Drive Clarkston, WA 99403) (56 kg·ha^{-1}), and Crimson clover (CC), (Oregon grown, variety Dixie) (13.4 kg·ha^{-1}). One broad leaf non-legume was evaluated: Mustard (MU), (Oregon grown) (5.60 kg·ha^{-1}). The mixed species combinations included: Black-seeded oats + Austrian winter pea (BO+AWP), (56 kg·ha^{-1}, kg·ha^{-1}), Cereal rye + Austrian winter pea (CR+AWP), (56 kg·ha^{-1}, 39 kg·ha^{-1}), Winter wheat + Austrian winter pea (WW+AWP), (50 kg·ha^{-1}, 39 kg·ha^{-1}), Black-seeded oat + Crimson clover (BO+CC), (56 kg·ha^{-1}, 9.0 kg·ha^{-1}), Black-seeded oat + Austrian winter pea + Mustard (BO+AWP+MU), (39 kg·ha^{-1}, 28 kg·ha^{-1}, 3.4 kg·ha^{-1}). The Control consisted of a winter fallow followed by application of preemergence herbicide S-metolachlor (Dual II Magnum at 1.17L·ha^{-1}) after transplant. Cover crop species were chosen based on species available to Arkansas growers and being well-adapted for the southeastern U.S. (Roberts et al., 2018; Clark, 2007). Cover crop seed was sourced from Southern Soil Solutions Inc. (Clarendon, AR). Seeding rates for mixes were chosen based on recommendations for rate adjustments for grass and legume mixtures which equates to a 30% reduction in seeding rate for legumes and a 50% rate reduction for grasses (Clark, 2007).

Cover Crop Establishment

The ground was tilled and a smooth seedbed was prepared prior to seeding the cover crops in the fall of each year. Treatments that contain Austrian winter pea or crimson clover were inoculated using inoculum (Graph-Ex SA™ ABM®, Van Wert, OH), to ensure the presence of Rhizobia for potential atmospheric nitrogen fixation (Clark, 2007). Cover crop planting dates were October 6, 2017, September 11, 2018, and September 12, 2019. Austrian winter pea seeds were broadcast-seeded by hand and incorporated via cultivation with a tractor and rolling harrow (2017) and garden rake (2018 and 2019) to approximately 2.54 cm. All other seeds were then hand broadcasted on the soil surface following Austrian winter pea incorporation. Overhead irrigation was used for establishment of cover crops if needed in the early fall but was not used subsequently.

Cover Crop Biomass and Nutrient Sample

Cover crop biomass samples (0.75 m^2) were collected for each plot with all material cut at ground level prior to cover crop termination. Weeds were separated from each sample, identified, placed in a separate bag, dried, weighed. Samples were taken April 4, 2018, April 12, 2019, and March 30, 2020, when cereal rye was at anthesis and Austrian winter pea, mustard, and crimson clover were in flowering stage. Winter wheat and black oats were at stem elongation or "jointing stage" in all three years.

Cover crop nutrient samples (0.09 m^2) were also sampled from each plot. For nutrient samples weeds were not separated from cover crops and were analyzed collectively. All samples were dried at 55°C and ground to pass a 1 mm sieve, samples prepared by HNO3 digestion and analyzed by Spectro ARCOS ICP, a total nitrogen and carbon analysis was done by combustion, Elementar VarioMAX Cube for assessment. Plant nutrient content preparation and analyzed by the University of Arkansas Agriculture Diagnostic Laboratory, Fayetteville, AR.

Spring Field Preparation

Cover crop termination occurred in spring April 4, 2018, April 12, 2019, and March 30, 2020. A cover crop mat was formed using a 1.83 m wide Goliath Crimper Roller (RTP Outdoors) to break cover crops stems at the ground level. All cover crops plots were rolled in the same direction through the center of the plots. The edges of plots were not crimped and remained standing to act as wind breaks for watermelon plants. Applications of glyphosate (Cornerstone®

Plus by WinField® United, St. Paul, MN) were applied over entire field following label recommendations two times in 2018 and 2019, and three times in 2020 for complete kill of cover crops.

Watermelon Transplant

Watermelon plants, cultivars Jubilee, (Sustainable Seed Company, Chico, CA (2018)(NE Seed, Hartford, CT (2019 and 2020)), and Nenhems #790 Elongated Diploid Hybrid Seeded (2018 second planting only), were transplanted directly into the cover crop mat with minimal soil disturbance. Nine plants per plot spaced evenly at 0.91 m between plants in the center of plots next to drip irrigation tape were planted April 20, 2018 (died), May 9, 2018 (replant), April 23, 2019, and April 20, 2020. Dual II Magnum (S-metolachlor) ($1.17 L \cdot ha^{-1}$) was applied to Control plots post-transplant. Twelve drip irrigation lines, with output of 0.87 LPH and emitters every 30.5 cm, had water source from single lead pipe and covered five replications covering 61 m per line.

Fertility

The fertilizer schedule was adapted from the Southeastern Vegetable Crop Handbook which bases rate on growth stages of the watermelon plant (Kemble et al., 2018). No preplant fertilizer was applied. Fertilizer used was Krista™ K soluble potassium nitrate fertilizer (Yara, Tampa, FL) through drip irrigation on a weekly basis and amounted to 79.73 kg $N \cdot ha^{-1}$ (2018), 99.46 kg $N \cdot ha^{-1}$ (2019), and 104.05 kg $N \cdot ha^{-1}$ (2020). Additional water was supplied to the plants by drip irrigation as needed.

Disease and Pest Management

A reduced disease management program was adapted from recommendations in the Southeastern Vegetable Crop Handbook (Kemble et al., 2021). The fungicide Ridomil Gold® SL (Syngenta®, Wilmington, DE) was applied through the drip irrigation immediately post-transplant 2.34 $L \cdot ha^{-1}$ and a second application 1.17 $L \cdot ha^{-1}$ followed approximately 30 days later. Foliar fungicides, Bravo® C/M (Fermenta Plant Protection Company, Painesville, OH), Bravo Weather Stik® (ADAMA, Raleigh, NC), or Quadris® (Syngenta®, Greensboro, North Carolina) per labeled rates were applied multiple times during the season. Insecticide applications were only used if pest pressure exceeded economic thresholds. In 2019, high spotted cucumber beetle (*Acalymma vittatum*) and striped cucumber beetle (*Diabrotica undecimpunctata*), populations were treated with Sevin® XLR Plus (Tessenderlo Kerley Inc., Phoenix, AZ) was used at the label rate. In 2020, cutworms (*Agrotis* spp.), striped cucumber beetles (*Acalymma vittatum*), and spotted cucumber beetles (*Diabrotica undecimpunctata*), required Control and Capture 2EC (FMC® Corporation, Philadelphia, PA) was used two times.

Summer Weed Biomass and Assessment

Summer weed biomass samples (0.75 m^2) were collected at approximately 30-days and 60-days after cover crop termination. Weed species was identified, the biomass was then dried and weighed.

Watermelon Petiole Nitrate (Nitrate-N)

Watermelon petiole nitrate (nitrate-N) samples were collected at three times watermelon crop phenological stages (early vine running, small (5.08 cm) fruit size, and at fruit maturity) of the watermelon plants based on Hochmuth G. (1994b). One petiole from a most recently matured leaf, typically four to six leaves back from the end, was collected from each plant in each plot and bulked to constitute a composite sample (Hochmuth G., 1994a). Samples were collected early in the morning and placed on ice prior to sap extraction and analysis within 12-15 h from sample collection.

All petioles collected from each plot, where placed in a hand-held garlic press to extract the sap. The collected sap was then placed in a Horiba "Cardy" Model S-040 NO_3-N meter, (HORIBA Advanced Techno C., Ltd., Kyoto, Japan), and the parts per million nitrate was recorded. The petiole nitrate reading was converted to nitrate-N by multiplying the Cardy meter reading ppm by 0.2259 to account for only the N within the nitrate molecule (Hochmuth, 1994).

Watermelon Harvest

Two harvests took place in 2018 and 2020 one week apart once fruit had reached maturity. The 2019 season required an additional third harvest due to variation in maturity by treatment. At the time of harvest, watermelons were rated as marketable if they had an elongated shape (typical of the variety) without blemishes weighed more than 5.0 kg; otherwise the fruit was classified cull (USDA-AMS, 2021; Hassell et al., 2007). Size of marketable watermelons is subjective and may vary by location and grower (Hassell et al., 2007). One factor for determining a marketable watermelon is the permissible shape set by the USDA Standards for Grades of Watermelons (USDA-AMS, 2021). The weight of 5 kg per fruit is low for Jubilee watermelons, a typical marketable watermelon ranges from 11.3-20.4 kg, but the average weight of watermelons in our trial was lower and so we set a lower standard for what we considered marketable. Reasons for a culled watermelon included, anthracnose disease or other belly rot, gummy stem blight, bird/pest damage, inadequate pollination, under-ripe (weighing less than 5.0 kg), blossom end-rot sun scald causing severe yellowing spots or splitting.

Weather Data

Daily high and low temperatures were collected daily by a Hobo ® Pro Series data collection instrument on station premises from the beginning of cover crop planting in October 2017 through final harvest in July 2020 (Table 2). A meteorological grade rain gauge collected precipitation accumulation.

Statistical Analysis

The statistical design was analyzed as a split-plot in which the twelve cover crop treatments within the four-cover crop "Groups" (grass, legume, mustard, mixed, control) were the whole-plot factors and year was the split-plot factor when analyzing cover crop biomass, winter weed biomass, marketable fruit ($kg \cdot ha^{-1}$), cull rates and fruit rot data. The design for the nitrate petiole (ppm) and summer weed biomass data was analyzed as a split-split plot with sampling stage as the split-split plot factor. For clarity we will capitalize cover crop "Groups" proper name's when referring to them as treatments as a part of the group analysis (Legumes, Grasses, Mixes, Mustard and Control) and will use lower case lettering when referring only to these general cover crops types. Least squares means for significant effects were separated using a protected least significant difference (LSD) procedure. All analyses were conducted using the GLIMMIX procedure in SAS version 9.4. The University of Arkansas Agricultural Statistics Laboratory assisted with conducting all statistical analysis.

Results and Discussion

Cover crop treatments include Austrian winter pea (AWP), crimson clover (CC), mustard (MU), black-seeded oats (BO), cereal rye (CR), winter wheat (WW), black-seeded oats + Austrian winter pea (BO+AWP), cereal rye + Austrian winter pea (CR+AWP), winter wheat + Austrian winter pea (WW+AWP), black-seeded oats + crimson clover (BO+CC), black-seeded oats + Austrian winter pea + mustard (BO+AWP+MU), and Control (Table 1). Cover crop group was found to be statistically significant for its effect on multiple response variables however the effect often varied by year. The presence of this effect indicates that the type of cover crop (Grass, Legume, Mustard or Mix) is more important than the individual species chosen. In other cases, cover crop treatments were statistically significant for certain response variables, again with the effects varying by year. In these cases, specific cover crop species were the bigger driver of the effect rather than larger cover crop type (group). Weather and rainfall (Table 2), along with planting date were variable across years and also likely impacted our results and we will discuss these for each response variable in more detail.

Cover crop and winter weed biomass

Watermelon growers in Arkansas using no-till should consider planting cover crop mixes as mixes, of a grass and legume. Mixes were among the highest biomass producing cover crop treatments across all years of our trial (1738 (2018), 4099 (2019), 3246 (2020) $kg \cdot ha^{-1}$), though in some years Mixes were no different than Legume treatments (1253 (2018), 4610 (2019), 2625 (2020) $kg \cdot ha^{-1}$) (Table 3, Figure 1). However, Mixes always had higher biomass than Grass treatments (1362 (2018), 2660 (2019), 1832 (2020) $kg \cdot ha^{-1}$) at our trial location. Mustard was generally a low biomass producer except in 2019. In general planting a winter cover crop resulted in less winter weed biomass, though certain legume cover crop treatments were no different than the Control in some years (Figure 2). However, cover crop legume treatments had similar weed biomass as when incorporated as a mix. Cover crop treatments made up of mixes however were shown to consistently suppress winter weeds to a similar level as grass cover crop treatments and both had much lower weed biomass than the fallow Control in all years. Winter weed biomass was highest in 2018 when cover crop biomass was lowest.

In 2018 the group of cover crop treatments made up of “Mixes” had the highest cover crop biomass (1738 $kg \cdot ha^{-1}$) production (Table 3, Figure 1). Both the Legume (1253 $kg \cdot ha^{-1}$) and Grass (1362 $kg \cdot ha^{-1}$) groups were similar in cover crop biomass accumulation but lower than the Mixes in 2018, and Mustard (800 $kg \cdot ha^{-1}$) was the lowest of all the groups. The high cover crop biomass in the Mix group compared to Legume and Grass groups may be due to combining the two cover crop types, allowing higher biomass accumulation than if each type was grown independently. Despite a late cover crop planting date in mid-October which allowed for less time for cover crop establishment prior to freezing, the legumes and grasses had similar cover crop biomass which is surprising as grasses are not as affected by late planting as legumes (Blue et al., 1990; Duiker, 2014; Murrell et al., 2017; Roberts et al., 2018). This could be related to the slightly warmer November in 2017 (Table 2). However, overall, due the late planting date in 2017, cover crop biomass overall was lower than in later years that had earlier planting dates.

Cover crop biomass production in 2019 was the highest for all groups than in any other year. The increased biomass accumulation may be attributed to the earlier planting date in September in 2019 and the consistent precipitation in September, October and November of 2018 which allowed for good crop establishment (Table 2). The Legume (4610 $kg \cdot ha^{-1}$), Mixes (4099 $kg \cdot ha^{-1}$) and Mustard (3336 $kg \cdot ha^{-1}$) groups were both similar in cover crop biomass production in 2019. Mustard biomass was higher than expected in 2019, and this result may be due to its maturity level at termination. In 2019 Mustard had flowered and was setting seed at termination and it had produced a thick woody stem that grew vertically producing high biomass, however; it did not cover the soil surface. By contrast, the Grasses had the lowest biomass in 2019 (2660 kg·ha^{-1}), and it is unclear why this occurred.

In 2020, the Mix and Legume groups had similar cover crop biomass production (3246 and 2625 kg·ha^{-1} respectively) and both had statistically higher cover crop biomass than the Grass group (1832 kg·ha^{-1}). The higher Mix production shows the positive response between two different types of cover crops benefitting from one another. Mustard (89 kg·ha^{-1}) had low biomass accumulation due to poor establishment at planting. The Mustard did grow, quickly went to flower in early spring and did not continue to develop biomass. There was an early freeze in early November of 2019 (Table 2) that likely arrested cover crop establishment in the fall and mustard seemed to be more affected by the severe temperatures.

In 2018 there was variability among the treatments for the amount of winter weed biomass present at termination in late March. The Control had the highest weed biomass (674 kg·ha^{-1}) but was not different from the CC treatment (271 kg·ha^{-1}). The other legume treatment, AWP (119 kg·ha^{-1}), was similar to CC but had lower weed biomass than the Control and was no different than the mixes which contained Austrian winter pea including BO+AWP (78 kg·ha^{-1}), CR+AWP (36 kg·ha^{-1}), WW+AWP (55 kg·ha^{-1}), and BO+AWP+MU (66 kg·ha^{-1}). The MU treatment had winter weed biomass (209 kg·ha^{-1}) similar to the legumes and was higher than the mix of BO+AWP+MU. Among the single species grasses CR (9 kg·ha^{-1}) had the lowest winter weed biomass and was lower than the other two grass treatments BO (120 kg·ha^{-1}) and WW (129 kg·ha^{-1}). The treatment of CR had the lowest amount of winter weed biomass numerically for 2018; however, it was not significantly different from its mix containing cereal rye, CR+AWP.

The grasses had similar biomass to all the mixes; however, numerically BO and WW had a higher amount of winter weed biomass than each of the mixes. The numerically higher amounts of winter weed biomass in the BO, WW, and AWP demonstrate the benefit of planting multiple cover crop types into a mix for potentially more diverse ground cover that can better control winter weeds (Brennan and Boyd, 2012; Teasdale et al., 1998).

In 2019, the Control had the highest amount of winter weed biomass (688 $kg \cdot ha^{-1}$). The two legumes AWP (87 $kg \cdot ha^{-1}$), CC (28 $kg \cdot ha^{-1}$), and MU (55 $kg \cdot ha^{-1}$) had similar amounts of biomass to each other (Figure 2). The treatments of BO (12 $kg \cdot ha^{-1}$) and CR (5 $kg \cdot ha^{-1}$) had lower winter weed biomass than the legumes, but WW (56 $kg \cdot ha^{-1}$) had similar amounts to AWP and CC. The grasses BO and CR had similar amounts of winter weed biomass to their corresponding mixes and all the mixes had lower winter weed biomass than their corresponding legume treatment. The mix of WW+AWP (35 $kg \cdot ha^{-1}$) was equal to both individual treatments of WW and AWP. The lack of weed control in WW and WW+AWP shows that WW may have inconsistent growth each year. In general cover crop mixes resulted in the lowest winter weeds, in a year when cover crop biomass was high across all cover crop types.

The Control and MU had equal amounts of winter weed biomass (419 and 338 $kg \cdot ha^{-1}$ respectively) in 2020, possibly due to the lack of cover crop growth in the MU in that year. The other broadleaf treatments (AWP, 99 $kg \cdot ha^{-1}$ and CC, 63 $kg \cdot ha^{-1}$) had lower winter weed biomass than the Control, but AWP had similar weed suppression to MU. Some mixes that contain Austrian winter pea were equal to the individual AWP treatment including BO+AWP (47 $kg \cdot ha^{-1}$), CR+AWP (17 $kg \cdot ha^{-1}$), and BO+AWP+MU (26 $kg \cdot ha^{-1}$). The grasses: BO (8 $kg \cdot ha^{-1}$), CR (12 $kg \cdot ha^{-1}$), WW (20 $kg \cdot ha^{-1}$) were all similar to one another for weed biomass and equal to the corresponding mixes they were a part of, except BO+AWP which had a more winter weed biomass than BO individually. The other groups CR+AWP (17 kg·ha^{-1}), WW+AWP (16 kg·ha^{-1}), BO+CC (16 kg·ha^{-1}), and BO+AWP+MU (26 kg·ha^{-1}) were equal to the individual grass species. In generally cover crop mixes resulted in the lowest winter weed biomass.

The trend of lower winter weed biomass in the grass treatments and in the mixes demonstrates the effect that grasses can have on weed suppression as an individual species or in a mix (Clark, 2007). Grasses have been shown to have allelopathic properties to reduce weed pressure. Price et al., (2008) confirmed the allelopathic properties in black oats leaf tissue extracts showing that it may inhibit small weed seed germination in near proximity to the plant.

Cover crop carbon to nitrogen and nitrogen content of biomass

The cover crop Mix group was more similar to the Legume group for cover crop N content and C:N ratios Mixes in most years of our trial despite lower seeding rates for legume relative to grasses in the mixes (Table 3) (Figures 3,4). The Legume and Mix groups had higher N content than the Control and the Grass group, however the Grass group had higher cover crop N content than the Control. Cover crops Mixes fell in between Grass and Legume groups for their C:N ratio. This has implications for how the nitrogen in the cover crop mixes will be released and shows that the Mix group is blending the qualities of the two individual groups for effect on C:N ratio.

The cover crops groups of Mix (32 kg N·ha^{-1}) and Legume (33 kg N·ha^{-1}) had equal amounts of cover crop N content in 2018 (Figure 3). Groups of Grass (23 kg N·ha^{-1}) and Mustard (17 kg N·ha^{-1}) were equal in N content, and both had lower N than Legume and Mixes cover crop groups. Mustard and Control were had similar N content (kg·ha^{-1}), which reflects the low cover crop biomass in the Mustard treatment because Control (11 kg $N \cdot ha^{-1}$) is measured from winter weeds only.

In 2019 the Legume group had high cover crop biomass and this resulted in the group having the highest nitrogen content (154 kg $N \cdot ha^{-1}$) (Figure 3). The Mix treatment produced lower N content (108 kg $N \cdot ha^{-1}$) than the Legume in 2019, but was still higher than any other treatment. Mustard and Grass groups had similar amounts of N content (43 and 29 kg $N \cdot ha^{-1}$ respectively) but were lower than both the Legume and Mix groups. All cover crop treatment groups were higher in N content than the Control (11 kg $N \cdot ha^{-1}$).

In 2020, the Legume and Mix groups had the highest cover crop N content (77 and 67 kg $N \cdot ha^{-1}$ respectively) and were higher than the other groups (Figure 3). The Grass group had higher nitrogen content (18 $kg \cdot ha^{-1}$) than the Mustard (8 kg $N \cdot ha^{-1}$) and Control (10 kg $N \cdot ha^{-1}$), which were statistically similar.

The C:N ratios in 2018 did not vary much between groups (Figure 4). The Legume group (22:1) had a lower C:N ratio than the Grasses (30:1) and was lower than the 25:1 ratio needed for nitrogen to be an input from the biomass back into the system (Clark, 2007). The Legume group was not statistically different however from the Mustard (27:1), Mix (26:1), or Control (26:1) groups which demonstrates that the N in the biomass of other cover crop groups would be released at a similar rate, however the amount of N varied by group. All the cover crop groups were relatively similar to one another in 2018 for C:N and this may be due to the grasses in the cover crop treatments not being close to maturity at the time of termination (Greenwood et al., 1990; Ashford & Reeves, 2003). The C:N ratio data was not analyzed for the 2019 season.

The C:N ratios were more variable in 2020 than in 2018 (Figure 4). The Legume (16:1) and Control (18:1) groups had similar C:N ratios, but the Legume was lower than all other cover crop Groups (Mix (22:1), Mustard (24:1) and Grass (47:1)). The Mustard and Mix were both similar to the Control group and close to the 25:1 ratio of C:N ratio needed for nitrogen inputs back into the soil from the cover crop biomass. The Grass group had a high C:N ratio and was higher than any treatment in 2018 or 2020. The wider range in C:N ratio in 2020 may be attributed to differences in plant maturity level at the time of sampling in 2020. While the termination date was similar in 2018 and 2020, the planting date was one month earlier in 2020 than in 2018 allowing cover crops CR, AWP, and WW more maturity. An earlier fall planting date has been attributed to increased development in cover crops (Ashford & Reeves, 2003).

In all three years, the Legume and Mix cover crop groups had the highest N content (kg $N \cdot ha^{-1}$) compared to the Mustard, Grass, or Control (Figure 3). The results are expected since the legumes can fix N whereas mustard and grasses are reliant on what residual N is in the soil. The amount of N in the Mix group compared to the Grass is group is important because it demonstrates the value of adding a legume to offset the low N content in the grasses (Kuo and Jellum, 2002).

Petiole Nitrate

Cover crop treatments consisting of mixes and legumes tended to have higher petiole nitrate-N levels than the grasses and the Control at the early running stage when cover crop biomass production was high or moderate (2019 and 2020) (Table 4, Figure 5,6,7). The higher levels of petiole nitrate-N in the early running stage is likely due to the breakdown of the legumes releasing nitrogen into the system more rapidly than the grass cover crops which often had higher C:N ratios and lower cover crop N content. The later petiole sampling stages “Small fruit” and “Mature fruit” had fewer differences between treatments for watermelon petiole nitrate-N which may be due to cover crops no longer releasing nitrogen back into the system and the increase in weeds throughout the field taking away nitrogen from the watermelon plants.

In 2018 compared to the Control (152 ppm), all cover crop treatments had significantly lower petiole nitrate-N at early running stage except the AWP (125 ppm) and WW+AWP (81 ppm) treatments (Figure 5). The mixes of CR+AWP (68ppm) and WW+AWP (81 ppm) were similar to AWP in petiole nitrate-N, whereas all other treatments had lower petiole nitrate-N. The legume CC (42 ppm) had lower petiole nitrate-N than AWP (125 ppm) treatment demonstrating a lower nitrogen input from one legume treatment to another. The grasses (BO (60 ppm), CR (66 ppm), WW (43 ppm)) treatments all had similar petiole readings and were similar to their corresponding mixes except WW+AWP (81 ppm) which had a higher petiole nitrate-N reading than WW. The significantly lower petiole nitrate-N readings from mixes BO+AWP (43ppm) and BO+AWP+MU (37 ppm) compared to AWP demonstrate that that while Mixes and Legume groups had similar C:N ratios and cover crop nitrogen content in 2018, they may have slightly different nitrogen release patterns to a subsequent watermelon crop in a no-till system. The mix of BO+CC was similar to CC for petiole nitrate-N.

In 2018 the Control treatment (218 ppm) had the highest petiole nitrate-N content at the small fruit sampling stage (Figure 5). The AWP (94 ppm) treatment was similar to WW+AWP (47 ppm), but only AWP had higher petiole samples than all other cover crop treatments, grasses (BO (38 ppm), CR (41 ppm), WW (37 ppm)) and mixes (BO+AWP (32 ppm), CR+AWP (32ppm), BO+CC (35 ppm), BO+AWP+MU (39 ppm)). All treatments including AWP were lower than the Control, indicating that all cover crop treatments had a negative effect on nitrogen uptake at small fruit stage in 2018. The N availability may be reduced by higher cellulose content cover crops and parts, stems, breaking down requiring nitrogen for microbial activity or competition from weed pressure within the field may have competed for nutrients with the watermelon plants (Ashford et al., 2003).

The petiole nitrate-N sample for the mature fruit stage in 2018 was taken when some mature fruit was seen in the field, however, many plants never set fruit in 2018. The higher levels of nitrate-N in the mature fruit sample compared to the small fruit samples may be due to the vegetative state in the watermelon plants. The watermelon plants in MU (191 ppm) had the highest petiole nitrate-N at the mature fruit stage and similar petiole nitrate-N to the Control at previous sampling periods. All other treatments and Control (75ppm) had lower petiole nitrate-N readings than MU; however, they were still higher than previous readings for all treatments at the other two stages except Control (218 ppm) at small fruit stage and Control (152ppm), AWP (125 ppm), and WW+AWP (81 ppm) at early running stage. The increased levels of ppm nitrate-N at the mature fruit stage may be related to an accumulation of nitrogen in the plant from throughout the season and a lack of watermelon fruit development (Llanderal et al., 2018).

The two legume cover crop treatments AWP (560 ppm) and CC (700 ppm) had the numerically highest watermelon nitrate-N levels compared to all other treatments at early running stage in 2019 (Figure 6). The mixes CR+AWP (420 ppm), WW+AWP (349 ppm, BO+AWP+MU (452 ppm) were similar to AWP for nitrate-N. The mix of BO+CC (330 ppm) had lower petiole nitrate-N than CC (700 ppm) at the early running stage in 2019. The treatments consisting of single species grasses (BO, 80 ppm, CR, 91 ppm, WW, 77 ppm) were all similar and all had lower petiole nitrate-N than their corresponding mixes at this stage; and were, along with MU (89 ppm), similar to the Control (111 ppm). The higher readings from AP an CC and the mixed cover crop treatments than MU, grasses, and Control indicates the legumes individually or in the mix were contributing nitrogen back into the soil for watermelon plant uptake early in the season. The high petiole samples in the groups Legumes and Mixes corresponds to the high amount of nitrogen ($kg \cdot ha^{-1}$) in the cover crop biomass by both groups in 2019 and an assumed low C:N ratio (Figure 4).

In 2019 petiole nitrate-N samples at small fruit stage showed the AWP (128 ppm) and CC (125 ppm) were equal to the Control (97 ppm) (Figure 6). Some grasses and mixes, BO (221 ppm), CR (187 ppm), BO+AWP (238 ppm), CR+AWP (170 ppm), and BO+CC (185 ppm) had higher petiole nitrate levels than the Control, however, only BO+AWP had a higher level than any component of the mix, AWP. The higher petiole nitrate-N levels in the grasses and some mixes may be due to a delayed release of nitrogen by the grasses compared to a rapid release seen in legumes.

All treatments had similar petiole nitrate-N to the Control at the mature fruit stage in 2019 (Figure 6). The legumes AWP and CC were similar to each other and to their respective mixes. The highest nitrate-N reading numerically was WW (101 ppm) at the mature fruit stage in 2019. The lack of variability in nitrate-N between most treatments may indicate that most nitrogen inputs from the cover crops have been utilized by the plants or lost by that time in the growing season. However, CC (55 ppm), and BO+CC (54 ppm) had statistically lower petiole nitrate-N than WW which may point to differences in the treatments impact on watermelon nitrogen uptake at this time period in 2019.

The petiole nitrate-N samples at early running stage in 2020 saw a trend of legumes AWP (827 ppm) CC (660 ppm) and all mixes BO+AWP (768 ppm), CR+AWP (420 ppm), BO+CC (895 ppm), BO+AWP+MU (782 ppm), except WW+AWP (349 ppm) to have higher petiole nitrate-N than the MU (201 ppm), grasses BO (437 ppm), CR (357 ppm), WW (295 ppm), and the Control (357 ppm). The legume AWP individually was similar to corresponding mixed treatments containing Austrian winter pea, (BO+AWP, CR+AWP, WW+AWP, and BO+AWP+MU). The legume CC was similar to BO+CC. Grasses (BO, CR, WW) had lower petiole nitrate-N than their respected mixes except BO which was equal to BO+AWP and BO+AWP+MU. The grasses were all similar in petiole nitrate-N ppm. The numerically higher nitrate-N ppm for grasses in BO (437 ppm), CR (357 ppm), WW (295 ppm) and mixes with black-seeded oats may indicate an advantage from black-seeded oats for increasing nitrogen availability not seen in the other grasses. The grasses and MU were not statistically different from the Control, which indicates that a lack of nitrogen input from those cover crops treatments relative to others for no-till watermelon in 2020.

The small fruit sampling stage in 2020 had lower petiole nitrate-N ppm, than at the running stage. All treatments were similar to the Control (136 ppm) for petiole nitrate-N at small fruit stage, except for BO (67 ppm) and CR+AWP (72 ppm) which were both lower. The legume AWP (138 ppm) had higher petiole nitrate-N than CC (80 ppm); however, CC was similar to MU (88 ppm) mid-season in 2020. The grasses showed variability with lower petiole nitrate-N in BO and CR compared to WW. The treatment AWP (138 ppm) compared to respective mixes containing Austrian winter pea, BO+AWP (91 ppm), WW+AWP (167 ppm), and BO+AWP+MU (179 ppm) were all similar for petiole nitrate-N; however, CR+AWP (72 ppm) was lower. The individual treatment BO (67 ppm) was similar to the mixes BO+AWP (91 ppm) and BO+CC (90 ppm) for petiole nitrate-N. Treatment CR (84 ppm) was similar for petiole nitrate-N to the mix CR+AWP (72 ppm).

The petiole sampling at mature fruit stage indicated that numerically AWP (239 ppm), CC (173 ppm) and WW+AWP (152 ppm) had the highest among treatments and had a significantly higher petiole nitrate-N compared to the Control (80 ppm) in 2020 (Figure 7). Compared to the respective mixes AWP was higher than BO+AWP (104 ppm), CR+AWP (102 ppm) and BO+AWP+MU (107 ppm). Only WW+AWP (152 ppm) had similar petiole nitrate-N to AWP. The treatment CC (173 ppm) was similar to BO+CC (114 ppm) for watermelon petiole nitrate-N at this stage. The grasses were all similar to each other and similar to their respective mixes, except WW (83 ppm) was lower than WW+AWP (152 ppm) in nitrate-N. The higher nitrate-N levels in the legumes may indicate the continued release of nitrogen as the plant material broke down. The mixes may not have continued to release as much N back into the soil for plant uptake due to the high cellulose content within the grasses offsetting the potential release from the legumes despite the Mixes having a C:N ratio around 25:1 and a similar amount of cover crop biomass N as the Legumes in 2020. The WW+AWP continued to have a higher nitrate-N level possibly indicating a positive response by WW in the mix absorbing leaked nitrogen from AWP but exact reasons are unclear from this study.

The release of N from the cover crops back into the soil for watermelon plant uptake is related to the maturity of the cover crops at the time of termination, the weather, the C:N ratio, and the overall amount of N within the cover crop biomass (Agehara and Warncke, 2005; Ashford & Reeves, 2003; Greenwood et al., 1990; Power, 1994). From our research we saw the treatments that contained the legume AWP or CC had higher levels of petiole nitrate-N at the "early vining stage". The later stages "small fruit" and "mature fruit", were less affected by cover crop treatments. The higher nitrate-N in the watermelon petioles at the "early vining stage" indicates a flush of N is released from the AWP or CC and taken up by the watermelon plants early in the growing season. The warm wet weather promoted rapid decomposition of the legumes allowing N uptake by the plants. Early in the season, weeds were less prominent, therefore, less competitive with the watermelon plants for nutrients. We found that legume cover crops both in single species or mixes can provide early season N to the watermelon plants in a no-till system in Arkansas.

Summer Weed Biomass

Winter cover crop treatments impact to summer weed biomass ($kg \cdot ha^{-1}$) varied across sampling date and year; however, differences in treatment were most notable at the 30-day sampling date. In 2019 similar or lower weed suppression compared to the Control was seen in every cover crop treatment, and in 2020, only MU, WW, and WW+AWP did not have equal or lower weed biomass ($kg \cdot ha^{-1}$) than the Control at the 30-day sample. Weed suppression is a primary goal of integrating cover crops into no-till systems and cover crop mixes, except for WW+AWP, all others were shown to be reliable for summer weed suppression in no-till watermelon production across two years of our trial, when cover crops were planted early in the fall. Cover crop treatments consisting of a grass, BO, CR and WW had similar summer weed control to the Control in all years of the trial at the 60-day sampling date, but in 2020, higher weed pressure was seen earlier in grass cover crops prior to the application of an in-season herbicide, which was equal to the Control for long term weed biomass suppression across the three years.

Winter cover crop treatments impacted summer weed biomass ($kg \cdot ha^{-1}$) across sampling date and year; however, differences in treatment were most notable at the 30-day sampling date. In 2019 similar or lower weed suppression compared to the Control was seen in every treatment, and in 2020, only MU (86 $kg \cdot ha^{-1}$), WW (41 $kg \cdot ha^{-1}$), and WW+AWP (36 $kg \cdot ha^{-1}$) did not have equal or lower weed biomass than the Control (9 $kg \cdot ha^{-1}$) at the 30-day sample.

Less weed suppression was seen for MU although not significantly in all years, while the mix and legume groups had higher amounts of weed biomass ($kg \cdot ha^{-1}$) overall. There was higher summer weed biomass in 2018 than 2019 and 2020, possibly due to the lower cover crop biomass ($kg \cdot ha^{-1}$) in that year (Table 3, Table 5).

Very high summer weed pressure was present in the field in 2018 and the most common weeds found included grasses from goosegrass, (*Eleusine* spp.), barnyardgrass (*Echinochloa* spp.), crabgrass (*Digitaria* spp.), and nutsedge (*Cyperus* spp.). The summer weed biomass accumulation ($kg \cdot ha^{-1}$) in 2018 at the 30-day sample varied across the treatments with a trend of higher weed biomass in legumes and mixes compared to the grasses and the Control (151 $kg \cdot ha^{-1}$). The legumes and broadleaf, AWP (1091 $kg \cdot ha^{-1}$), CC (1058 $kg \cdot ha^{-1}$), and MU (703 $kg \cdot ha^{-1}$) individually were similar to each other and were also similar to their corresponding mixes (BO+AWP (909 $kg \cdot ha^{-1}$), CR+AWP (717 $kg \cdot ha^{-1}$), WW+AWP (775 $kg \cdot ha^{-1}$), BO+CC (603 $kg \cdot ha^{-1}$), and BO+AWP+MU (876 $kg \cdot ha^{-1}$)). The grasses BO (304 $kg \cdot ha^{-1}$), CR (192 $kg \cdot ha^{-1}$), WW (393 $kg \cdot ha^{-1}$) were similar to one another, and BO and CR were no different from the preemergent herbicide applied Control (151 $kg \cdot ha^{-1}$) at the 30-day sampling. Some mixes were similar to their corresponding individual components with BO similar to BO+CC, and WW similar to WW+AWP; however, the remaining mixes had higher weed biomass than their corresponding grass cover crop treatment. The treatments BO+AWP and BO+AWP+MU had higher weed biomass than BO and the mix of CR+AWP had higher weed biomass than CR treatment. In a year with poor cover crop establishment and low biomass many cover crop mixes did not achieve weed control equal to grass treatments or a preemergence herbicide in the early season.

At the 60-day sample time, higher weed biomass was observed across the field as weeds continued to mature but most cover crop treatments were similar to the Control (793 $kg \cdot ha^{-1}$) except AWP (2138 $kg \cdot ha^{-1}$) and BO+AWP (2412 $kg \cdot ha^{-1}$). The legumes AWP (2138 $kg \cdot ha^{-1}$) and CC (1264 $kg \cdot ha^{-1}$) were similar to every mix cover crop treatment. The grasses had a trend of numerically lower weed biomass compared to the other treatments at that sampling date in 2018; however, most were similar to their respective mixes, except BO (819 $kg \cdot ha^{-1}$) which was lower than BO+AWP (2412 $kg \cdot ha^{-1}$). The relatively high amount of weed biomass in AWP cover crop individually and in the mix of BO+AWP may be due to the carbon to nitrogen ratio, about 25:1, and the relatively low cover crop biomass produced in 2018 resulting in a rapid breakdown of biomass (Table 3). The result that at the 60-day sample many cover crop treatments had similar summer weed suppression to that of the herbicide Control, is related to a grass herbicide application made mid-way through the summer; however, the timing of application was not adequate for total weed control because the application was made once weeds had grown more than 15 cm.

The 2019 season had lower summer weed biomass ($kg \cdot ha^{-1}$) compared to 2018. The lower weed biomass may be due to the increase in cover crop biomass with every cover crop group having higher cover crop biomass in 2019 (388 $kg \cdot ha^{-1}$) than in 2018 (993 $kg \cdot ha^{-1}$). At the 30-day sample all treatments had lower weed biomass or similar weed biomass to the Control (267 $kg \cdot ha^{-1}$). The single species broadleaves, AWP (200 $kg \cdot ha^{-1}$), CC (266 $kg \cdot ha^{-1}$), and MU (355 $kg \cdot ha^{-1}$) were all equal to the Control in weed biomass ($kg \cdot ha^{-1}$) which corresponds to their high cover crop biomass in 2019 relative to other years. The BO (42 $kg \cdot ha^{-1}$) and CR (75 $kg \cdot ha^{-1}$) treatments had less weed biomass than the Control while WW (190 $kg \cdot ha^{-1}$) was no different from the Control. The amount of weed biomass present in cover crop mixes was variable across treatment, with CR+AWP (33 kg·ha^{-1}) and BO+CC (56 kg·ha^{-1}) having lower amounts of summer weed biomass relative to the other mixes and to the Control (267 kg·ha^{-1}) and BO+AWP (110 kg·ha^{-1}), WW+AWP (126 kg·ha^{-1}), and BO+AWP+MU (184 kg·ha^{-1}) having equal weed biomass to one another and the Control. The treatment AWP (200 kg·ha^{-1}) was equal to BO+AWP (110 kg·ha^{-1}), WW+AWP (126 kg·ha^{-1}) and BO+AWP+MU (184 kg·ha^{-1}), but higher than CR+AWP (33 kg·ha^{-1}). Individually, BO (42 kg·ha^{-1}) was lower than BO+AWP (110 kg·ha^{-1}) and BO+AWP+MU (184 kg·ha^{-1}); however, it was equal to BO+CC (56 kg·ha^{-1}). The cover crop treatment WW (355 kg·ha^{-1}) and mix WW+AWP (126 kg·ha^{-1}) had a higher amount of weed biomass than other treatments within the same groups which indicates WW may not be as adequate at weed suppression as other grasses like BO and CR in some years.

At the 60-day sample, all cover crop treatments were similar to the Control (353 kg·ha^{-1}) for weed biomass (kg·ha^{-1}). The equal weed suppression by treatments to the Control may in part be due the single application of a grass herbicide following the 30-day sample to all plots, but weeds in the field were not only grasses and included broadleaves and sedges that were not impacted by the herbicide. However, when comparing among cover crop treatments the grass CR (341 kg·ha^{-1}) had lower weed biomass relative to both the AWP (871 kg·ha^{-1}) and WW (902 kg·ha^{-1}) treatments, indicating the CR was able to suppress weeds to a greater level than these two other treatments through mid-season. The continued weed suppression by cover crop mats throughout the summer comparable to the Control indicates that with enough cover crop biomass even legumes that may break down more quickly than grasses can still effectively reduce weeds similar to a preemergence herbicide.

In 2020 very, low weed biomass was observed across all treatments early in the season compared the same sampling period in 2018 and 2019 (Figure 10). Note that Figure 10 had a scale change on the Y-axis to accommodate the reduced amount of biomass for the 30-day sample compared to the same figures for 2018 and 2019.

At the 30-day sampling, lower summer weed biomass in mixed cover crop treatments containing BO and CR and a single legume than in single species legumes (AWP,CC) and grasses (BO, CR, WW). The mixes BO+AWP (0.33 $kg \cdot ha^{-1}$), CR+AWP (1.49 $kg \cdot ha^{-1}$), BO+CC (3.09 $kg \cdot ha^{-1}$), and BO+AWP+MU (2.00 $kg \cdot ha^{-1}$) had similar weed suppression or higher weed suppression of their individual components with BO+AWP and CR+AWP having the lowest numerical weed biomass. The WW+AWP (36 $kg \cdot ha^{-1}$) had higher amounts of weed biomass than the other mixes and was similar to both WW (41 $kg \cdot ha^{-1}$) and AWP (43 $kg \cdot ha^{-1}$) individually.

By the 60-day sampling weed biomass was not considerably different from the 2019 sampling at the same period. High population of nutsedge (*Cyperus* spp.) which was not affected by the graminicide applied after the 30-day sampling was the reason for the rapid increase in the amount of summer weed biomass between the 30- and 60-day sampling dates. The Control (344 $kg \cdot ha^{-1}$), MU (786 $kg \cdot ha^{-1}$), the grasses BO (542 $kg \cdot ha^{-1}$), CR (571 $kg \cdot ha^{-1}$), WW (587 $kg \cdot ha^{-1}$) and mixes BO+AWP (541 $kg \cdot ha^{-1}$), CR+AWP (470 $kg \cdot ha^{-1}$), WW+AWP (850 $kg \cdot ha^{-1}$), BO+CC (477 $kg \cdot ha^{-1}$), and BO+AWP+MU (358 $kg \cdot ha^{-1}$) all had similar weed biomass ($kg \cdot ha^{-1}$), whereas AWP (820 $kg \cdot ha^{-1}$) and CC (1038 $kg \cdot ha^{-1}$) had higher weed biomass than the Control. Numerically WW+AWP (850 $kg \cdot ha^{-1}$) had the highest weed biomass among the Mixes and Grasses. The similar amounts of weed biomass in most mixed treatments and the Control indicates that cover crop mats and preemergence herbicides have similar capacity to suppress nutsedges into mid-season in no-till watermelon production. A field that has nutsedge must be treated properly to ensure the spread of nutsedge does not continue naturally or through cultivation, since in-season control by both chemical and cultural means is limited.

Watermelon Yield:

Yield data was only analyzed for 2019 and 2020 since watermelon fruit production was negligible in 2018.

The group analysis indicated that similar watermelon fruit yield ($kg \cdot ha^{-1}$) was seen in all cover crop types compared to the Control, but when comparing cover crop groups to each other that Mixes and Legumes resulted in higher watermelon yield compared to the Mustard, and Grass (Table 6). More specifically when looking at individual treatments, again watermelon yield was no different across all winter cover crop treatments compared to the Control (7,961 $kg \cdot ha^{-1}$) but CR+AWP (13,964 $kg \cdot ha^{-1}$) was the numerically highest yielding treatment and was higher than MU (3,144 $kg \cdot ha^{-1}$) BO (5,338 $kg \cdot ha^{-1}$), CR (5,400 $kg \cdot ha^{-1}$), and WW (3,213 $kg \cdot ha^{-1}$).

Further analyzation from 2019 indicates the timing of watermelon maturity varied by treatment (data not shown). Harvest was completed across three weeks due to earlier watermelon maturity seen in AWP and CC, with 66% of total fruit in AWP harvested at this point and 46% by CC. The MU, BO, and WW had zero fruit harvested at the first harvest stage. The second harvest date one week later saw at least one harvested fruit in every treatment. The majority of fruit was not harvested until the third harvest for MU (96%), WW (94%) CR (81%), BO+AWP (78%), BO (71%), BO+CC (69%), CR+AWP (66%), and WW (55%). The early fruit maturity seen in the AWP and CC treatments indicates the additional inputs of N seen in the petiole nitrate-N samples increased the rate of watermelon plant development and fruit maturity (Figures 4, 5).

No interaction of cover crop treatment or group was seen by year indicating a consistency amongst the cover crop treatments and groups for their effects on watermelon yield each season. The highest watermelon yields occurred following the two winter cover crop legumes, (AWP and CC), and winter cover crop Mixes, (BO+AWP, CR+AWP, BO+CC, and BO+AWP+MU) (Table 6). The single species grasses (BO, CR, WW) may adequately suppress weeds throughout the growing season; however, these cover crop treatments also suppressed watermelon fruit production. In particular WW and MU should be avoided as single species cover crops grown for no-till watermelon production in Arkansas.

Yield was lower in 2020 (1,849 $kg \cdot ha^{-1}$) compared to 2019 (14,803 $kg \cdot ha^{-1}$); and is probably related to the nutsedge infestation that occurred throughout the field in 2020. Nutsedge was present in 2018, and spread to a greater extent in 2019, and became ubiquitous across the field in 2020. The amount of nutsedge biomass does not appear noticeable in weed biomass samples due to its short plant structure. The same field was used for all three years of this trial and the spread of nutsedge, which was not controlled by cover crops or the herbicides used in the trial, points to the need for integrated weed management tactics, including crop rotation or another strategy to mitigate nutgrass which is a major issue in watermelon production across the Southeast.

The number of marketable fruits per plant and blossom end rot (BER), belly fruit rot, and other fruit rots was not impacted by the various cover crop types (groups) or individual cover crop treatments. There was a lower number of marketable fruits harvested in 2020 compared to 2019.

The percent of culled fruit was high in both years due to BER, belly fruit rot, and other issues throughout all three years. A higher percentage of culled fruit was seen in 2020 (83.4%), 2019 (44.4%); which corresponds to an increase in BER in 2020. The high rate of BER may have been due to improper drip irrigation application during fruit development. The heavy presence of nutsedge may have competed with the watermelons for water in the heat of summer during fruit development. The lower rate of fruit rot in 2019 (12%) is partly due to the higher number of watermelons reaching adequate size compared to 2020 (22%) which had many watermelons affected by BER and not reaching a mature state. The season of 2019 was also impacted by heavy rainfall creating flooding issues that may have increase fruit rot disease pressures. The high percentages of BER and Fruit rot, however, are not associated with cover crop treatments as they were also problematic in the Control indicating that field management could have been improved for an overall increase in yield.

Our research indicates that watermelon growers utilizing watermelon no-till production can rely on a mix of BO+CC or CR+AWP for consistency of weed control in the winter and early summer, N inputs for the plants, and watermelon yields similar to or numerically higher than a bare-ground herbicide production system. The winter cover crop grasses we tested (black-seeded oats, cereal rye and winter wheat) resulted in lower watermelon yield compared to the legumes and some of the mixes, so we recommend to avoid monoculture grass production in a no-till watermelon system. The WW+AWP should also be avoided, since its watermelon yield was numerically lower than the other mixed cover crop treatments we evaluated, but still numerically higher than individual grasses. Plant residue of cereal rye has been shown to affect cucurbits by reduced vine length in *Cucumis sativus* (cucumber) and reduced canopy height in *Cucurbita pepo* (summer squash) in field studies (Burgos and Talbert, 2000). The results of our findings are important because many Arkansas farmers growing cover crops are currently using only a grass species, often cereal rye or winter wheat.

Conclusion

The objectives of our research were to evaluate alternative winter cover crops for no-till watermelon production in Arkansas with the consideration that many farmers are currently growing watermelons on bare-ground or rely on the single species grass cover crops cereal rye or winter wheat and need integrated weed management strategies. Our results indicate that a mix of legume and grass can consistently produce higher amounts of winter cover crop biomass than grass only cover crops. The increased cover crop biomass results in consistent winter weed suppression over fallow ground. The cover crop biomass found in Legumes and Mixes also contained higher amounts of N ($kg \cdot ha^{-1}$) which we demonstrated was made available to the watermelon plants at the early running stage. Specifically, higher petiole nitrate-N was seen in 2019 and 2020 at the early running stage for the cover crop mix treatments of CR+AWP and BO+CC compared to all the grasses cover crop treatments and the Control demonstrating these cover crop mixes release N into a no-till system at a time that aligns with plant uptake. Weed suppression at the 30-day sampling dates was similar or lower in CR+AWP and BO+CC compared to the herbicide control in 2019 and 2020 when cover crops were planted in September and good cover crop biomass was achieved. The yield represented appeared to be most impacted by the amount of N put into the system from the cover crops. Higher yield was seen in the Mix and Legume groups than the Grass; however, the three groups were similar to the Control. The CR+AWP was higher in marketable yield ($kg \cdot ha^{-1}$) than any of the grasses and other mixes were numerically higher in marketable yield ($kg \cdot ha^{-1}$) than the grasses and the Control. For these reasons, we suggest the use of CR+AWP or BO+CC by Arkansas farmers seeking to use cover crops in a no-till system. We also suggest the avoidance of WW and WW+AWP in no-till watermelon production due to low fruit yield

Tables and Figures

Table 1. Winter cover crop treatments, and seeding rates planted at the University of Arkansas Vegetable Research Station Kibler, AR in 2017, 2018, and 2019.

	Treatment Acronym	Scientific Name	Seeding Rate (kg·ha^{-1})
		Legumes and other broadleaves	
Austrian winter pea	AWP	*Pisum sativum* (L.) ssp. Arvense	56
Crimson clover	CC	*Trifolium incarnatum* L.	13.4
Mustard	MU	*Sinapis alba* L.	5.6
		Grasses	
Black-seeded oats	BO	*Avena sativa* (L.)	112
Cereal rye	CR	*Secale cereale* L.	112
Winter wheat	WW	*Triticum aestivum* L.	101
		Mixes: Grass, legumes, and broadleaf	
Black-seeded oats + Austrian winter pea	BO+AWP		56, 39
Cereal rye + Austrian winter pea	CR+AWP		56, 39
Winter wheat + Austrian winter pea	WW+AWP		50, 39
Black-seeded oats + Crimson clover	BO+CC		56, 9.0
Black-seeded oats + Austrian winter pea + Mustard	BO+AWP+MU		39, 28, 3.4

Table 2. Monthly temperature and precipitation during winter cover crop and watermelon growing seasons for 2017- 2020 at the University of Arkansas Vegetable Research Station, Kibler, AR.

		Temperatures (°C)				
Year	Month	Average High *	Average Low	Minimum	Maximum	Precip (mm)
		2017-2018 Cover Crop Season				
2017	September	31	16	11*	36*	0
	October	24	10	-2*	33*	63
	November	19	5	-2*	31*	9
	December	11	0	-8*	24*	50
2018	January	9	-3	-14	22	45
	February	12	2	-6	25	148
	March	18	6	-2	27	80
	Average	18	5	-3	28	56
		2018 Watermelon Season				
	April	19	7	0	29	85
	May	31	18	13	34	85
	June	33	21	15	36	55
	July	34	22	18	42	47
	Average	29	17	12	36	68
		2018-2019 Cover Crop Season				
	September	29	19	13	36	73
	October	22	12	3	33	86
	November	13	2	-6	24	104
	December	11	2	-5	19	122
2019	January	8	-1	-6	22	89
	February	12	2	-7	23	133
	March	16	4	-9	24	68
	Average	16	6	-2	26	96
		2019 Watermelon Season				
	April	23	10	-1	31	112
	May	27	16	10	32	234
	June	31	20	14	35	167
	July	33*	22*	18	36	50
	Average	28	17	11	33	141
		2019-2020 Cover Crop Season				
	September	33*	22*	19	36	44
	October	22	10	1	33	199
	November	14	2	-7	22	89
	December	13	1	-6	22	22
2020	January	11	2	-4	20	129
	February	12	2	-5	22	58
	March	19	8	1	32	134
	Average	18	7	0	27	96
		2020 Watermelon Season				
	April	21	9	1	32	143
	May	25	14	6	31	178
	June	32	20	13	35	37
	July	33	23	20	36	73
	Average	28	17	10	33	108

Table 3. Winter cover crop biomass, biomass of winter weeds, cover crop nitrogen content, and cover crop carbon to nitrogen ratio (C:N) at the University of Arkansas Vegetable Research Station Kibler, AR, 2018, 2019, and 2020.

Treatment		Above ground biomass ($kg \cdot ha^{-1}$)			
		Cover crop [z]	Winter weed	Nitrogen	C:N
Group	Legume	2,830	111	88	19
	Mustard	1,408	201	23	25
	Grass	1,951	41	23	39
	Mix	3,028	30	69	24
	Control	.	594	11	22
	p-value	*<.0001*	*<.0001*	*<.0001*	*<.0001*
Cover crop (Group) [y]	AWP	2,945	102	100	18
	CC	2,714	121	76	20
	MU	1,408	201	23	25
	BO	1,666	47	17	40
	CR	2,392	9	33	36
	WW	1,796	69	20	40
	BO+AWP	2,972	42	74	21
	CR+AWP	3,636	18	68	27
	WW+AWP	2,595	35	57	28
	BO+CC	3,026	24	69	24
	BO+AWP+MU	2,910	31	75	21
	Control	.	594	11	22
	p-value	*0.0543*	*0.0135*	*0.0255*	*0.3273*
Year	2018	1,340	151	27	27
	2019	3,419	81	82	.
	2020	2,256	90	47	27
	p-value	*<.0001*	*<.0001*	*<.0001*	*0.2164*
Group x Year	*p-value*	*<.0001*	*0.0288*	*<.0001*	*<.0001*
Cover crop (Group) x Year	*p-value*	*0.2619*	*0.0153*	*0.4963*	*0.5504*

[z] Mean separation by least square means. Different letters for each response variable indicate significant differences ($P<0.05$).

[y] Cover crop treatments: Austrian winter pea (AWP), crimson clover, (CC), mustard (MU), black-seeded oats (BO), cereal rye (CR), winter wheat, (WW), various combinations of these and winter fallow Control.

Table 4. Watermelon petiole nitrate (nitrate-N) at three stage of crop development (early running, small fruit, and mature fruit) at the University of Arkansas Vegetable Research Station Kibler, AR, 2018, 2019, and 2020.

Treatment			Petiole Nitrate (NO_3-N) (ppm)[z]
Group	Legume		233
	Mustard		110
	Grass		120
	Mix		199
	Control		140
		p-value	*<.0001*
Cover crop (Group)[y]	AWP		248
	CC		218
	MU		104
	BO		127
	CR		117
	WW		117
	BO+AWP		191
	CR+AWP		209
	WW+AWP		183
	BO+CC		204
	BO+AWP+MU		206
	Control		140
		p-value	*0.0367*
Year	2018		70
	2019		173
	2020		273
		p-value	*<.0001*
Crop stage	Early running		1,399
	Small fruit		480
	Mature fruit		406
		p-value	*<.0001*
Group x Year		*p-value*	*<.0001*
Treatment x Year (Group)		*p-value*	*0.1543*
Group x Stage		*p-value*	*<.0001*
Treatment x Stage (Group)		*p-value*	*0.2548*
Year x Stage		*p-value*	*<.0001*
Group x Year x Stage		*p-value*	*<.0001*
Cover crop x Year x Stage (Group)		*p-value*	*0.0011*

[z] Mean separation by least square means. Different letters for each response variable indicate significant differences (P<0.05).

[y] Cover crop treatments: Austrian winter pea (AWP), crimson clover, (CC), mustard (MU), black-seeded oats (BO), cereal rye (CR), winter wheat, (WW), various combinations of these and winter fallow Control.

Table 5. Summer weed biomass at two sampling dates in watermelon grown in roller-crimped winter cover crop at the University of Arkansas Vegetable Research Station Kibler, AR, 2018, 2019, and 2020.

Treatment			Above ground Biomass ($kg \cdot ha^{-1}$)[z]
Group	Legume		782
	Mustard		563
	Grass		390
	Mix		634
	Control		319
		p-value	*0.0001*
Cover crop (Group) [y]	AWP[y]		861
	CC		368
	MU		734
	BO		633
	CR		577
	WW		703
	BO+AWP		319
	CR+AWP		322
	WW+AWP		492
	BO+CC		563
	BO+AWP+MU		480
	Control		731
		p-value	*0.0127*
Year	2018		993
	2019		388
	2020		315
		p-value	*<.0001*
Time	30 days		277
	60 days		854
		p-value	*<.0001*
Group x Year		*p-value*	*<.0001*
Treatment x Year (Group)		*p-value*	*0.1016*
Group x Time		*p-value*	*<.0001*
Treatment x Time (Group)		*p-value*	*0.0567*
Year x Time		*p-value*	*<.0001*
Group x Year x Time		*p-value*	*<.0001*
Treatment x Year x Time (Group)		*p-value*	*0.0307*

[z] Mean separation by least square means. Different letters for each response variable indicate significant differences (P<0.05).

[y] Cover crop treatments: Austrian winter pea (AWP), crimson clover, (CC), mustard (MU), black-seeded oats (BO), cereal rye (CR), winter wheat, (WW), various combinations of these and winter fallow Control.

Table 6. Mean marketable yield, number of marketable fruit per plant, cull fruit, incidence of blossom end rot (BER), and general fruit rots for watermelon grown in no-till cover crop at Vegetable Research Station Kibler, AR, in 2019 and 2020.

Treatment		Marketable yield (kg·ha^{-1})[z]		Marketable fruit (#)		Cull (%)		BER (%)		Fruit rot (%)	
Group	Legume	10,585	a	0.45		58.3%		31%		9%	
	Mustard	2,144	b	0.11		86.5%		33%		16%	
	Grass	4,651	b	0.20		71.7%		35%		20%	
	Mix	10,938	a	0.45		55.7%		29%		15%	
	Control	7,961	ab	0.37		63.8%		17%		9%	
	p-value	*0.0118*		*0.0977*		*0.3021*		*0.4797*		*0.5662*	
Cover crop (Group)	AWP[y]	10,401	abc	0.43		61.3%		33%		12%	
	CC	10,769	abc	0.48		54.9%		29%		7%	
	MU	2,144	d	0.11		86.5%		33%		16%	
	BO	5,338	bcd	0.22		74.4%		29%		30%	
	CR	5,400	bcd	0.22		66.7%		39%		23%	
	WW	3,213	cd	0.15		74.6%		40%		13%	
	BO+AWP	9,634	abcd	0.39		61.0%		44%		11%	
	CR+AWP	13,964	a	0.58		51.2%		23%		19%	
	WW+AWP	7,939	abcd	0.34		56.4%		26%		16%	
	BO+CC	12,956	ab	0.53		52.1%		29%		11%	
	BO+AWP+MU	10,194	abc	0.42		57.8%		23%		14%	
	Control	7,961	abcd	0.37		63.8%		17%		9%	
	p-value	*0.0333*		*0.0959*		*0.8278*		*0.8163*		*0.2418*	
Year	2019	14,803	a	0.61	a	44.4%	b	10%	b	12%	a
	2020	1,849	b	0.09	b	83.4%	a	43%	a	22%	b
	p-value	*<.0001*		*<.0001*		*<.0001*		*<.0001*		*0.0184*	
Group x Year	*p-value*	*0.1293*		*0.3270*		*0.3203*		*0.4690*		*0.1035*	
Cover crop x Year (Group)	*p-value*	*0.3415*		*0.3117*		*0.3239*		*0.6244*		*0.1986*	

[z] Mean separation by least square means. Different letters for each response variable indicate significant differences (P<0.05).
[y] Cover crop treatments: Austrian winter pea (AWP), crimson clover, (CC), mustard (MU), black-seeded oats (BO), cereal rye (CR), winter wheat, (WW), various combinations of these and winter fallow Control.

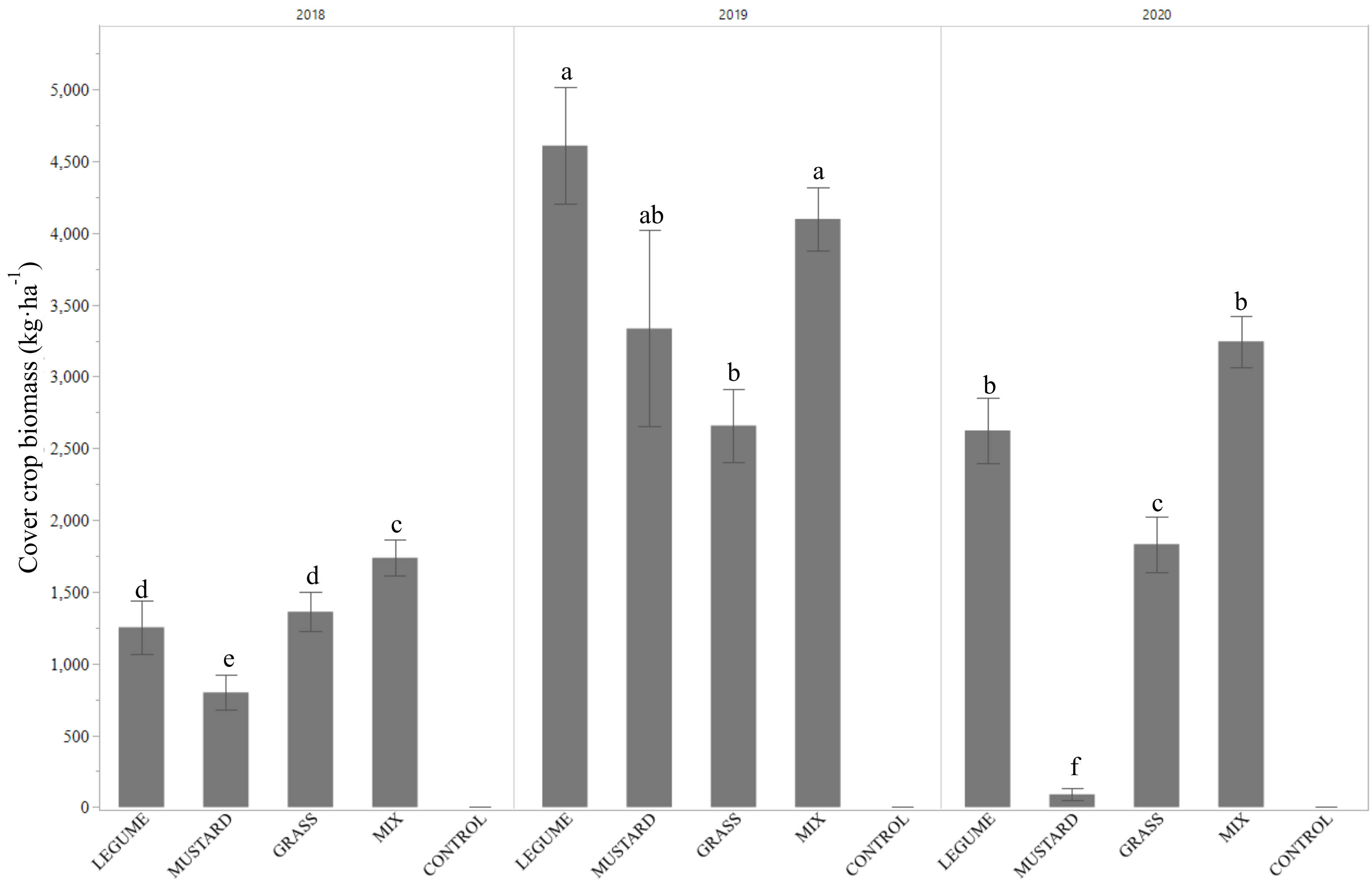

Figure 1. Winter cover crop biomass by cover crop groups in spring 2018, 2019, and 2020 at the University of Arkansas Vegetable Research Station, Kibler, AR. Means with different letters are significantly different ($p < 0.05$).

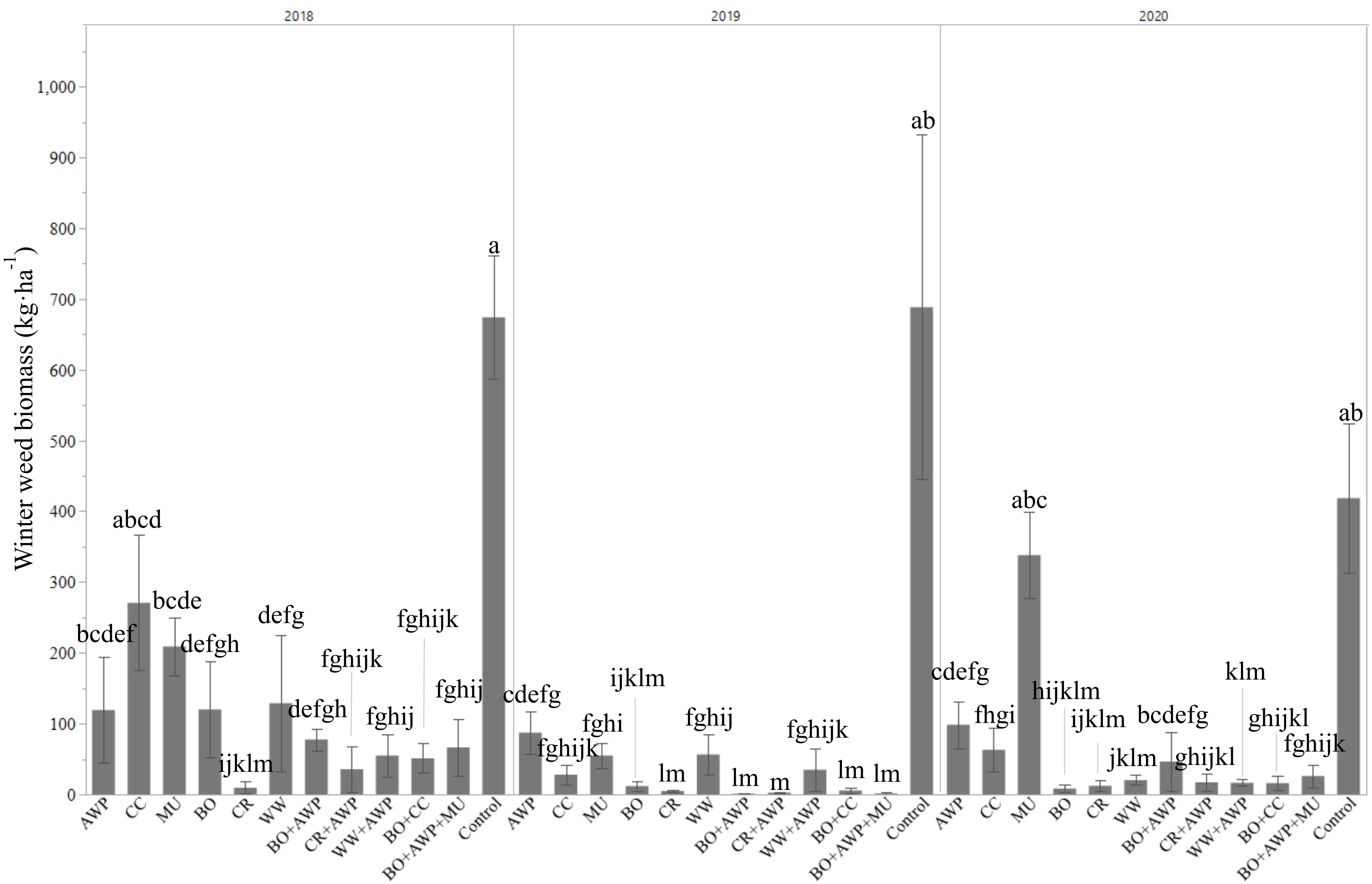

Figure 2. Winter weed biomass for winter cover crop treatments sampled in spring 2018, 2019, and 2020 at University of Arkansas Vegetable Research Station, Kibler, AR. Cover crop treatments: Austrian winter pea (AWP), crimson clover, (CC), mustard (MU), black-seeded oats (BO), cereal rye (CR), winter wheat, (WW), various combinations of these and winter fallow Control. Means with different letters for each attribute are significantly different ($p < 0.05$).

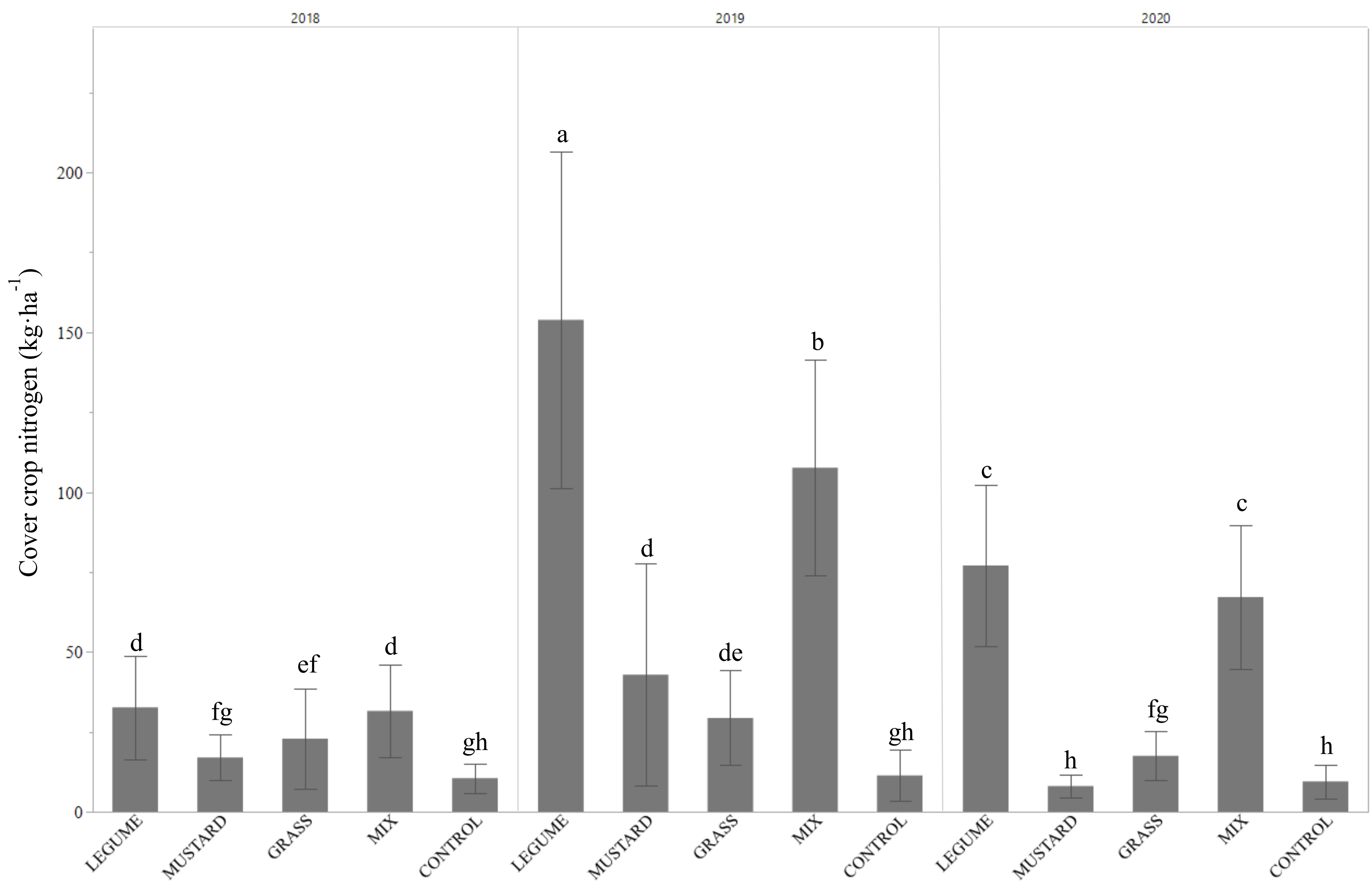

Figure 3. Winter cover crop and weeds nitrogen content by cover crop groups at the University of Arkansas Vegetable Research Station, Kibler, AR sampled in spring 2018, 2019, and 2020. Means with different letters for each attribute are significantly different ($p < 0.05$).

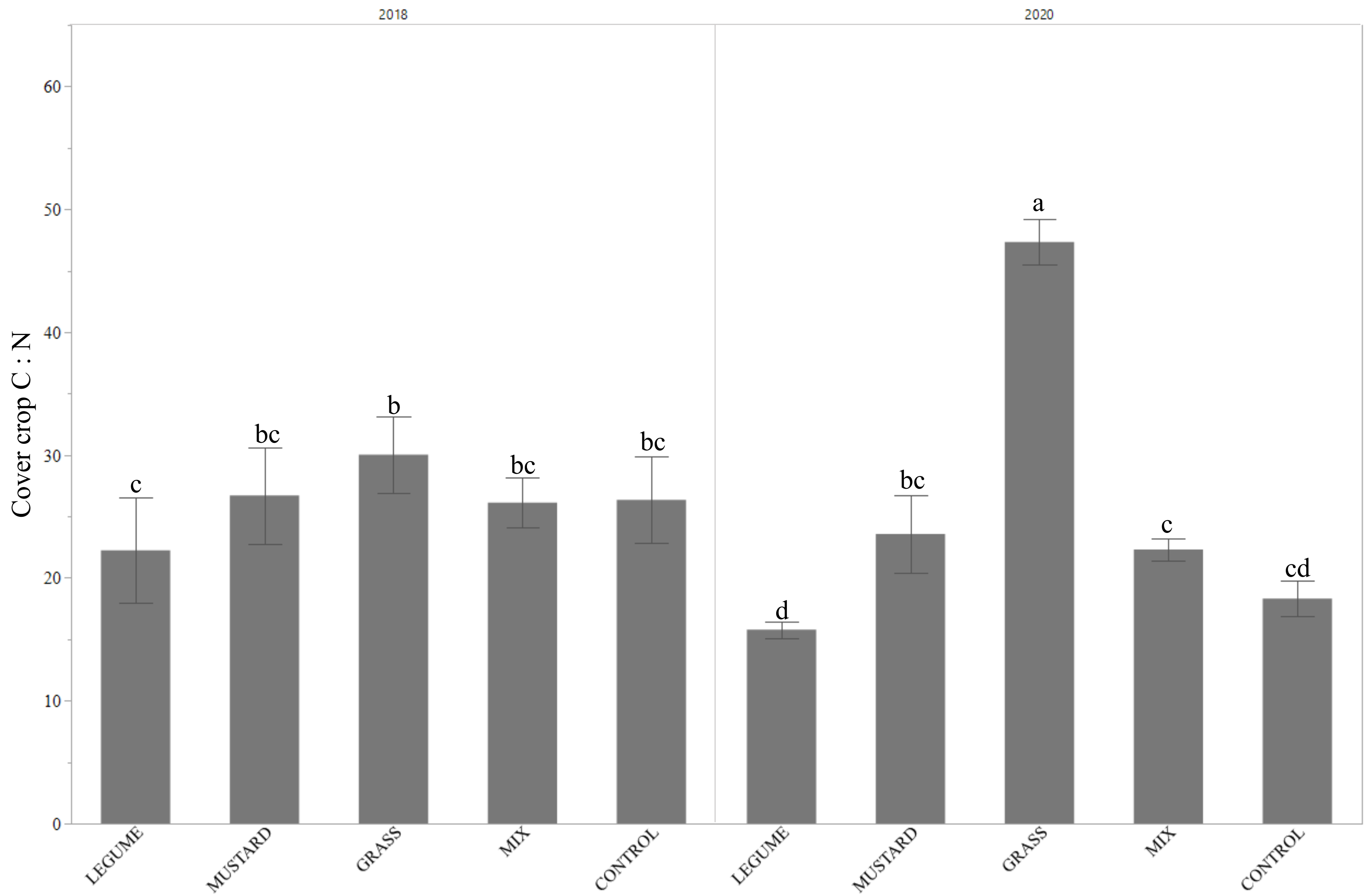

Figure 4.Winter cover crop carbon to nitrogen ratio (C:N) by cover crop group sampled in spring 2018 and 2020 at the University of Arkansas Vegetable Research Station, Kibler, AR. Means with different letters for each attribute are significantly different ($p < 0.05$).

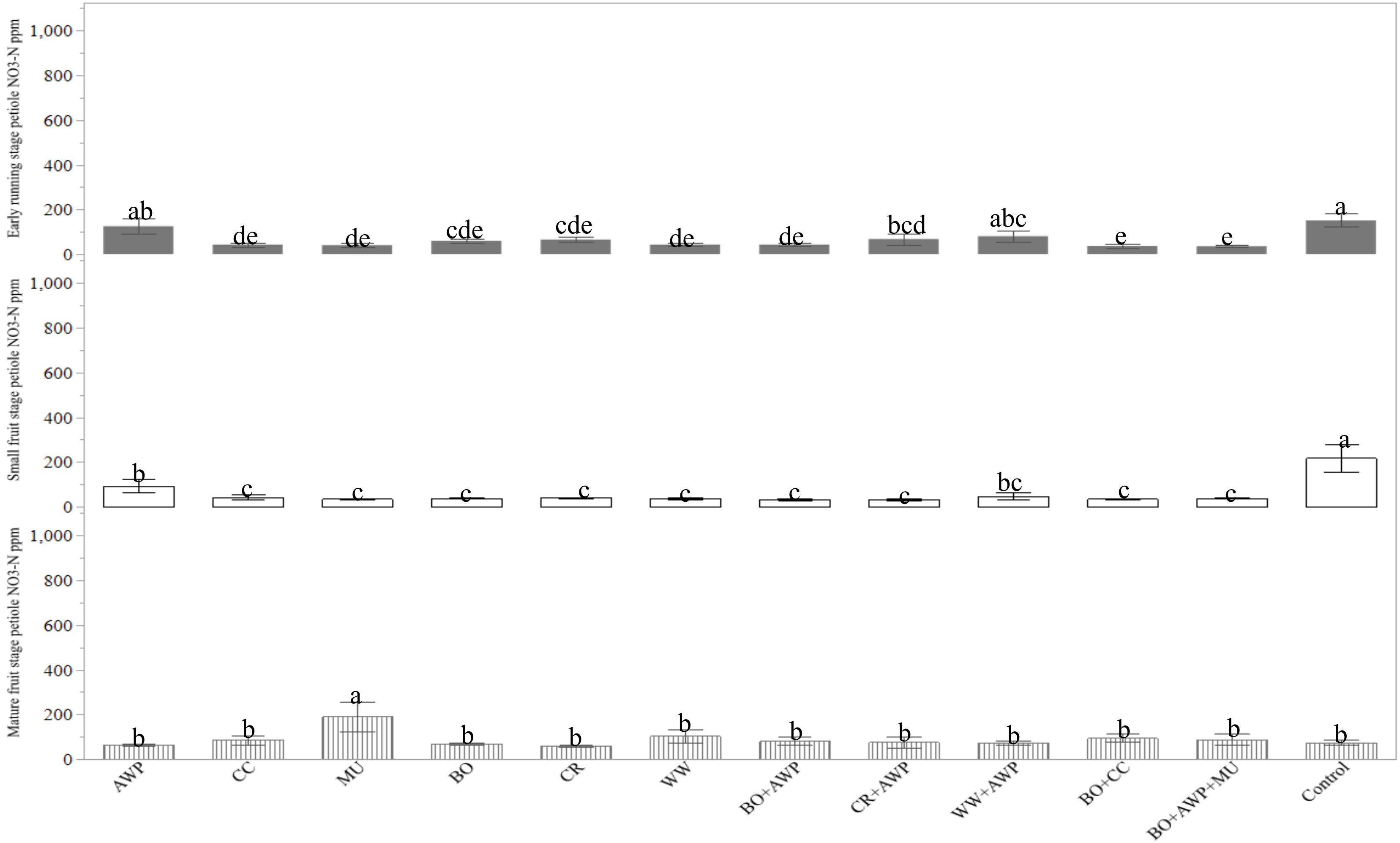

Figure 5. Mean petiole nitrate (nitrate-N) of watermelon plants by cover crop treatment at three stage of crop stage (early running, small fruit, and mature fruit) at the University of Arkansas Vegetable Research Station, Kibler, AR in 2018. Cover crop treatments: Austrian winter pea (AWP), crimson clover, (CC), mustard (MU), black-seeded oats (BO), cereal rye (CR), winter wheat, (WW), various combinations of these and winter fallow Control. Means with different letters are significantly different at $p < 0.05$.

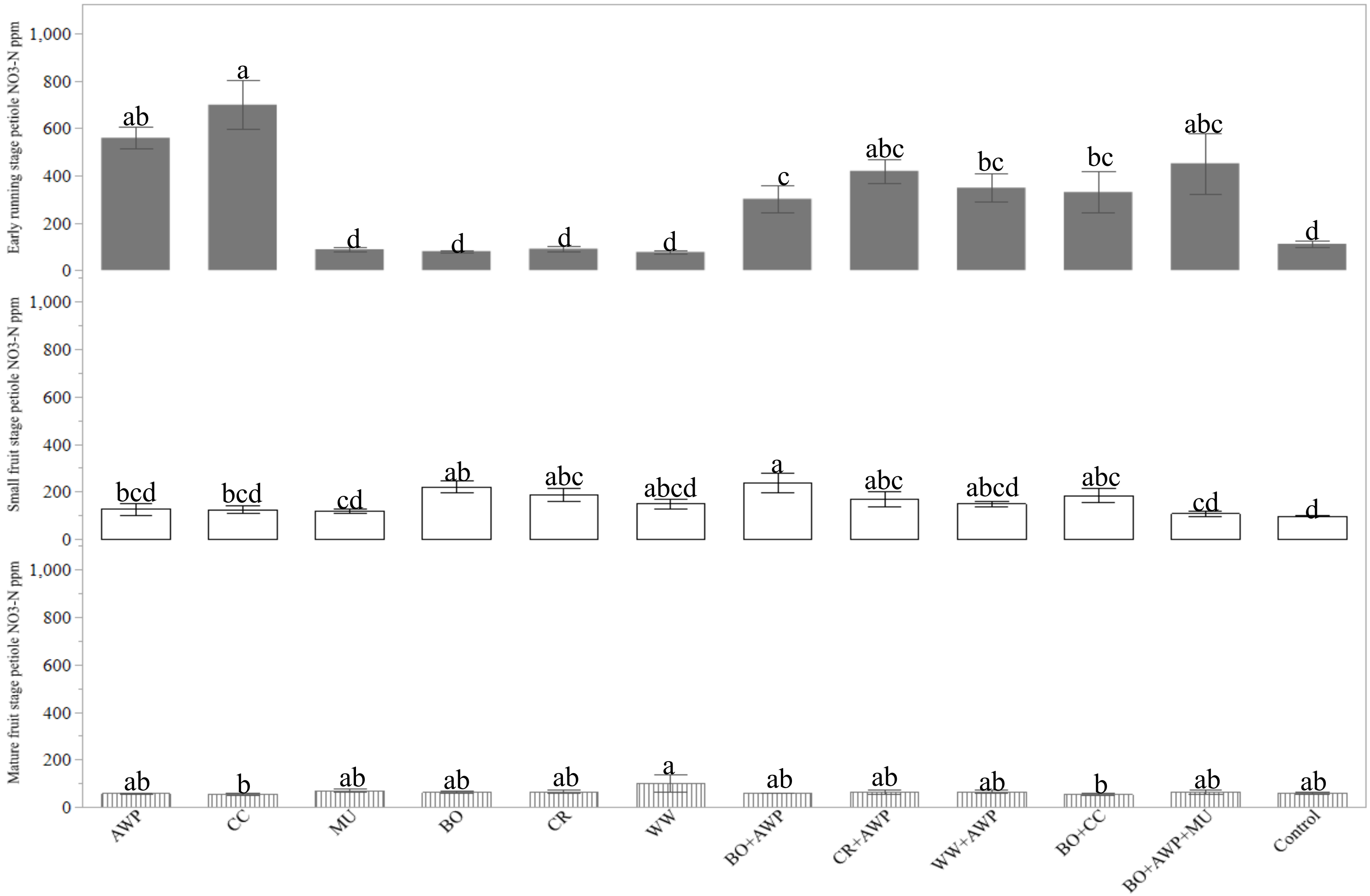

Figure 6. Mean petiole nitrate (nitrate-N) of watermelon plants by cover crop treatment at three stage of crop stage (early running, small fruit, and mature fruit) at the University of Arkansas Vegetable Research Station, Kibler, AR in 2019. Cover crop treatments: Austrian winter pea (AWP), crimson clover, (CC), mustard (MU), black-seeded oats (BO), cereal rye (CR), winter wheat, (WW), various combinations of these and winter fallow Control. Means with different letters are significantly different at $p < 0.05$.

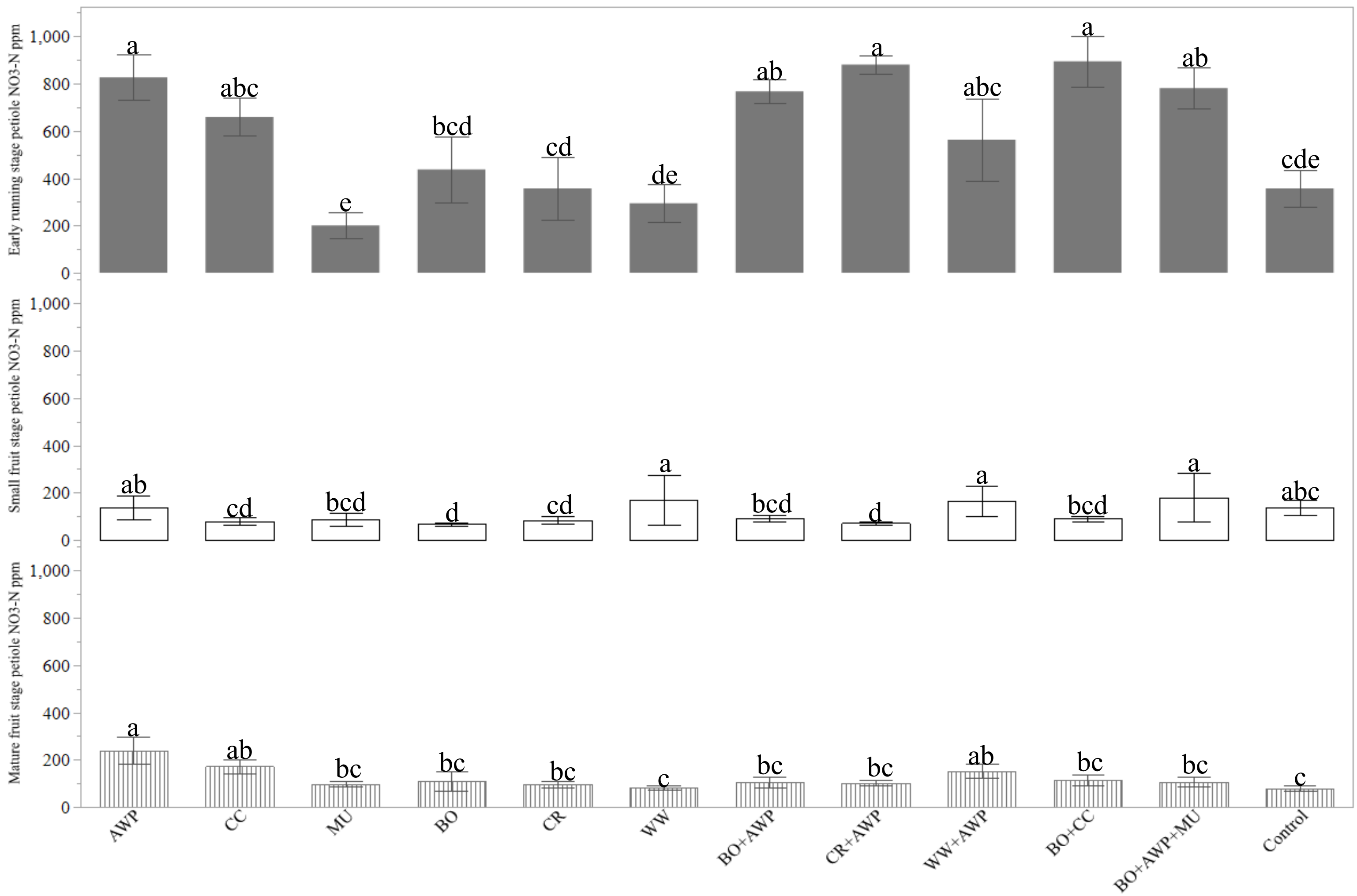

Figure 7. Mean petiole nitrate (nitrate-N) of watermelon plants by cover crop treatment at three stage of crop stage (early running, small fruit, and mature fruit) at the University of Arkansas Vegetable Research Station, Kibler, AR in 2020. Cover crop treatments: Austrian winter pea (AWP), crimson clover, (CC), mustard (MU), black-seeded oats (BO), cereal rye (CR), winter wheat, (WW), various combinations of these and winter fallow Control. Means with different letters are significantly different at $p < 0.05$.

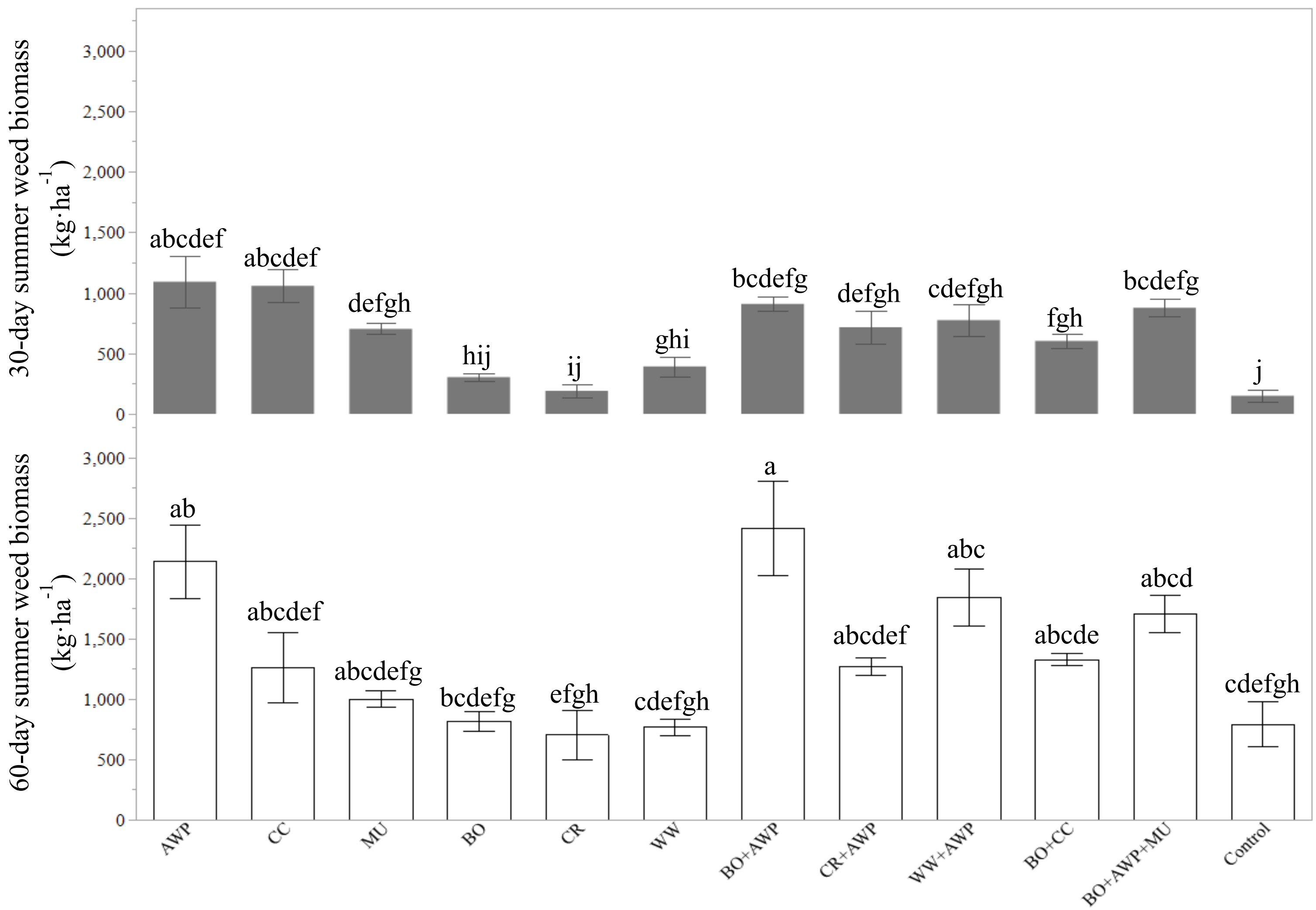

Figure 8. Mean summer weed biomass accumulation (kg·ha^{-1}) taken at 30 and 60 days following cover crop termination at the University of Arkansas Vegetable Research Station, Kibler, AR in 2018. Cover crop treatments: Austrian winter pea (AWP), crimson clover, (CC), mustard (MU), black-seeded oats (BO), cereal rye (CR), winter wheat, (WW), various combinations of these and winter fallow Control. Means with different letters are significantly different at $p < 0.05$.

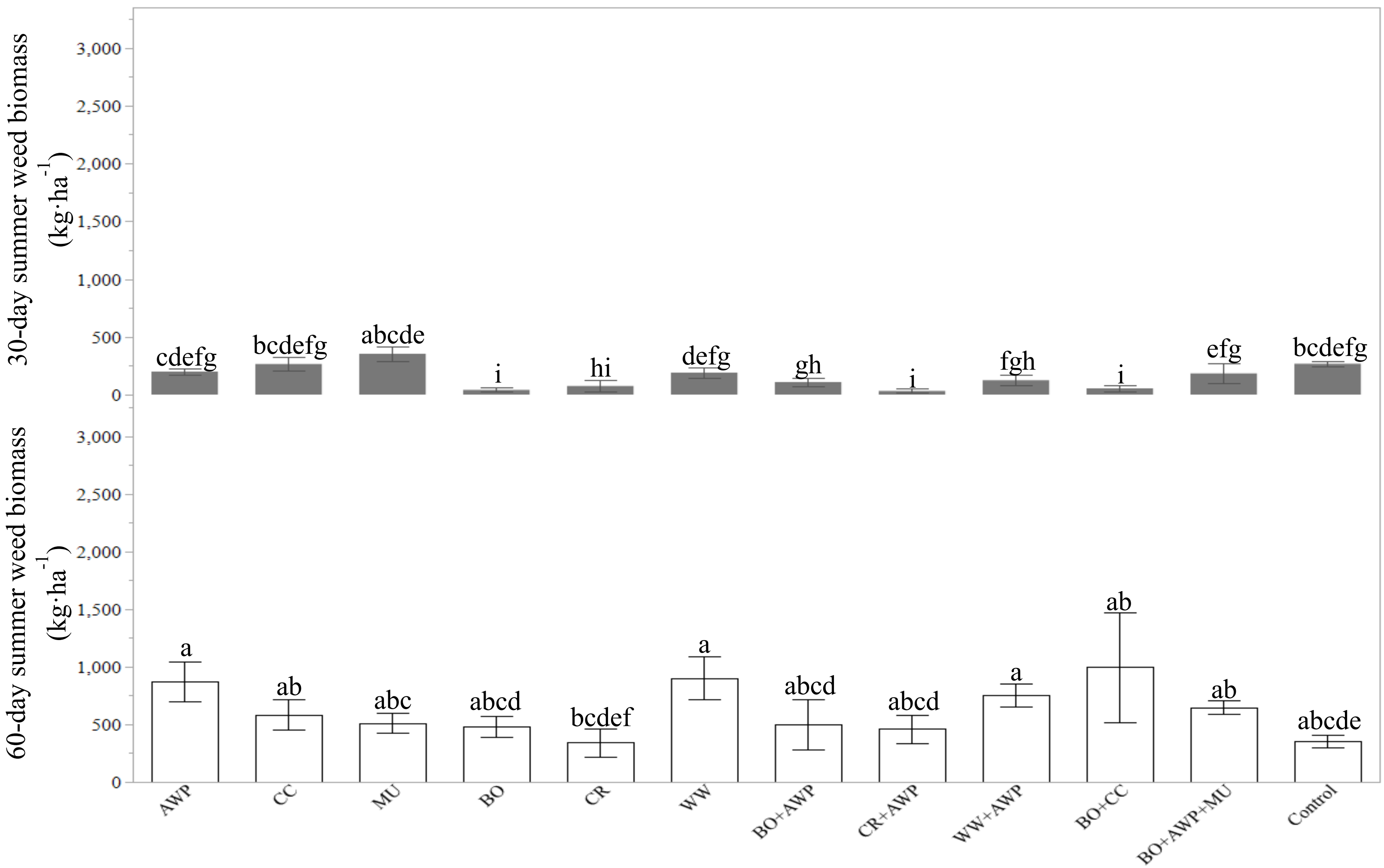

Figure 9. Mean summer weed biomass accumulation ($kg \cdot ha^{-1}$) taken at 30 and 60 days following cover crop termination at the University of Arkansas Vegetable Research Station, Kibler, AR in 2019. Cover crop treatments: Austrian winter pea (AWP), crimson clover, (CC), mustard (MU), black-seeded oats (BO), cereal rye (CR), winter wheat, (WW), various combinations of these and winter fallow Control. Means with different letters are significantly different at $p < 0.05$.

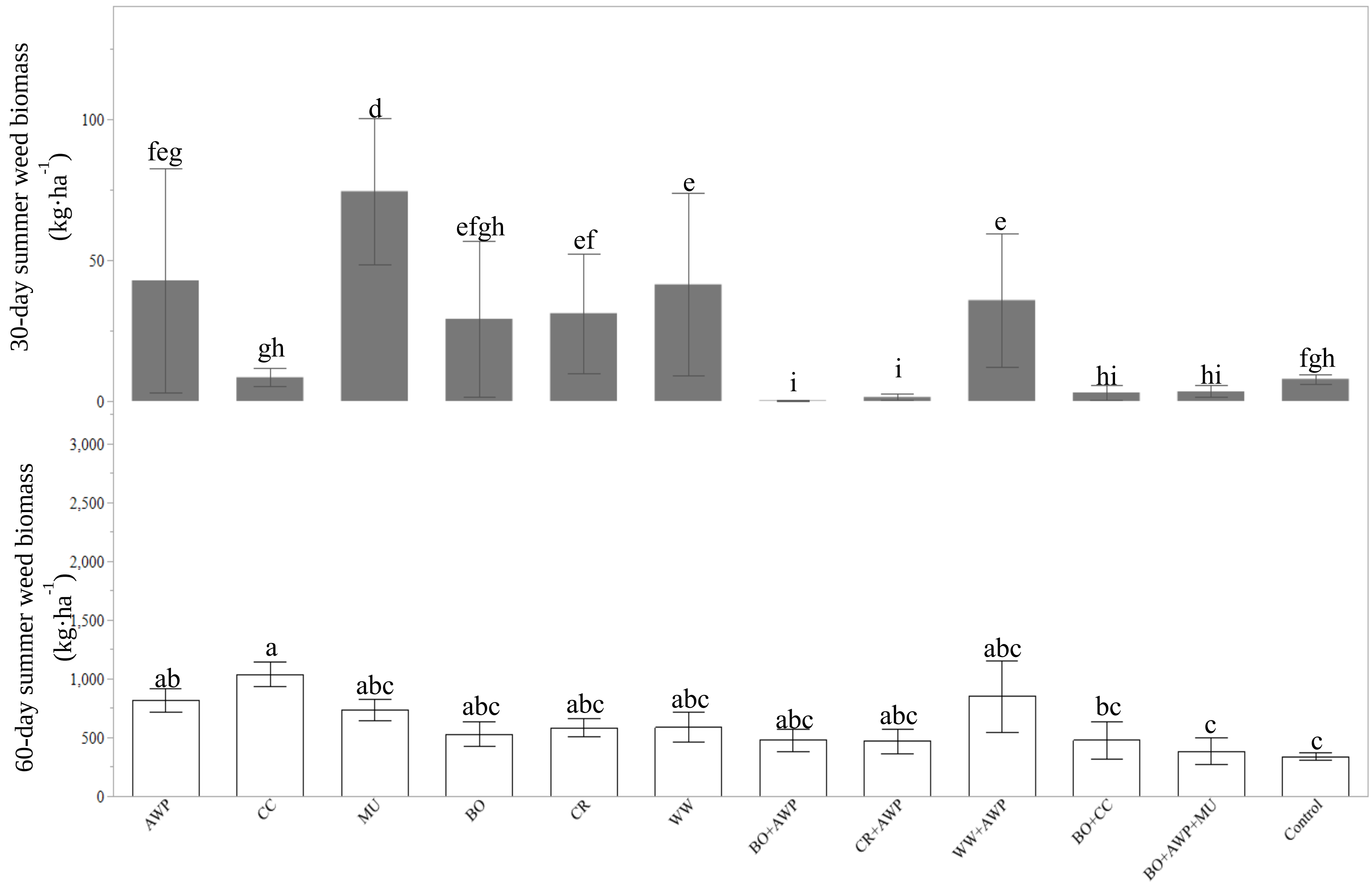

Figure 10. Mean summer weed biomass accumulation ($kg \cdot ha^{-1}$) taken at 30 and 60-days following cover crop termination at the University of Arkansas Vegetable Research Station, Kibler, AR in 2020. Significant differences of means shown with letters found using protected least square means. Cover crop treatments: Austrian winter pea (AWP), crimson clover, (CC), mustard (MU), black-seeded oats (BO), cereal rye (CR), winter wheat, (WW), various combinations of these and winter fallow Control. Means with different letters are significantly different at $p < 0.05$.

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Chapter 4: Conclusion

Our project focused on the benefits a cover crop mix, grass + legume, may have in a strip tilled "plasticulture" system and a no-till roller crimped system for Arkansas watermelon production. In the strip-till plasticulture production we found that cover crop mixes in Arkansas can be used for row middle weed suppression and that specifically cereal rye + Austrian winter pea resulted in the numerically highest yields and fruit numbers per plant, which is likely related to slightly elevated petiole nitrate-N in watermelons grown following cereal rye + Austrian winter pea.

In the no-till roller crimped system, we found that cover crops can provide weed control in the early part of the season as well as be a source of nitrogen for the watermelon plants when legumes are planted either individually or in a mix. Our results are important because a no-till system is generally focused on the weed suppression ability of the cover crop rather than the potential for nutrient inputs. The increase in nitrogen following legumes, again individually or part of the mix, resulted in higher watermelon yield compared to grass only treatments in a no-till system in Arkansas.

Our conclusion from both locations indicates that cereal rye + Austrian winter pea is suitable for the Arkansas watermelon grower in the both a strip-tilled plasticulture system and a no-till cover crop system. We also found that a winter wheat should also be avoided due to the reduction in watermelon yield seen in both systems.