EVALUATING COVER CROPS AND REDUCED TILLAGE'S EFFECT ON VEGETABLE YIELD AND WEED POPULATIONS IN ORGANIC AND CONVENTIONAL SYSTEMS

by

EMMA KATHERINE DAWSON

(Under the Direction of George Boyhan)

ABSTRACT

Cover crops and reduced tillage practices have been commonplace within agronomic crops for many years. The benefits of cover crops have been heavily researched and include improving soil health, increasing infiltration rates, reducing runoff and erosion. Despite these benefits, their adoption in vegetable production has been slower due to the perception that incorporating cover crops and reduced tillage causes yield reductions. Issues with weeds in these systems can also be a deterrent. Weed control in vegetables relies on an integrated approach, typically a combination of herbicides, tillage, and mulches. Weeds are a significant threat to vegetable yields, incorporating cover crops as a strategy for weed control may be effective at suppressing weeds within low-input agriculture. This research was conducted to determine the effect of cover crops combined with reduced-tillage on vegetable crop yield, weed abundance, and distribution and to evaluate variable fertilizers rates to overcome nitrogen sequestration by cover crops.

INDEX WORDS: Sustainable agriculture, organic weed control, vegetable crops, weed community dynamics, integrated weed management

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DEDICATION

To everyone who helped me along the way.

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CHAPTER 1

INTRODUCTION

Scientists have been studying the benefits of conservation tillage for years. Farmers popularized these practices after the Dust Bowl of the 1930s as a method of soil and water conservation (Claassen et al., 2018). The Conservation technology information center (CTIC) defines conservation tillage as any tillage system that leaves at least 30% of the soil surface covered by crop residue. Conservation tillage methods like no-till, strip tillage, and mulch tillage can reduce soil erosion and compaction, improve soil health, increase water holding capacity and soil organic matter (Busari et al., 2015; Grandy et al., 2006; Karlen et al., 1994). Other associated benefits include reducing fertilizer runoff, increasing infiltration, soil structure, and aggregate stability (Mulvaney et al., 2011; Riley et al., 2008). Cover crops and no-till systems offer further benefits, such as reducing resource use and decreasing the time spent preparing fields (Hoyt et al., 1994). There are some perceived drawbacks of no-till systems, including reduced nitrogen availability, equipment costs, and later planting dates due to lower spring soil temperatures (Bristow, 1988; Teasdale and Mohler, 1993; Zhang et al., 2009). Despite these challenges, no-till systems utilizing high biomass cover crops provide agroecosystems with countless benefits and could be a viable solution for weed control in organic vegetable production.

Conservation tillage is being implemented more frequently by farmers, and the number of acres under no-till has grown significantly in the past couple of decades. Practices such as ridge and strip tillage are more prevalent within agronomic crops like cotton (*Gossypium hirsutum*), field corn (*Zea mays*), and soybeans (*Glycine max*). A 2009 study done by the USDA estimated that for the eight major agronomic crops (barley (*Hordeum vulgare*), A 2009 study done by the USDA estimated that for the eight major agronomic crops (barley, corn, cotton, oats (*Avena sativa*), rice (*Oryza sativa*), sorghum (*Sorghum bicolor*), soybeans, and wheat (*Triticum aestivum*)), between 73.7 and 88.3 million acres were under a no-till management system (Horowitz et al., 2010). A second USDA study reported that there were 96.5 million no-till acres and 76.6 million acres using some conservation tillage method (Claassen et al., 2018). Along with the environmental benefits of a conservation tillage system, the same USDA study by Claassen et al. estimated that farmers who practice continuous conventional tillage use about six gallons of diesel fuel per acre each year. In contrast, continuous no-till needs less than two gallons per acre. This difference would lead to almost 282 million gallons of diesel fuel saved annually by farmers who practice continuous no-till.

In more recent years, conservation tillage systems have been studied for their potential to suppress weeds in agroecosystems. Cover crops can suppress weeds through physical interference (Teasdale and Mohler, 1993), buffered soil temperatures, increased habitat for weed seed predators (Haramoto and Gallandt, 2005), delayed release of plant-available nitrogen (Dyck and Liebman, 1995), and release of allelopathic chemicals (Wortman et al., 2013). The success of cover crops and their ability to suppress weeds depends on high biomass production. The greater the biomass and percent of the soil covered, the less light interception by weed seed occurs. The cover crop and the termination method used are critical in ensuring the cover crop's success and its ability to suppress weeds (Wortman et al., 2013). A common practice when planting cover crops is to use a mix of multiple species. These mixes typically include grain or grass species, which adds the necessary biomass, and a legume species, for nitrogen fixation.

Popular options include clover (*Trifolium spp*.), sunn hemp (*Crotalaria juncea*), and hairy vetch (*Vicia villosa*), common oat (*Avena sativa L*.), and Rye (*Secale cereale*). Research has been mixed on whether cover crop diversity or biomass is more important for weed suppression (MacLaren et al., 2019; Osipitan et al., 2018).

No-till Vegetable Production

The use of no-till production practices is commonplace in most agronomic row crops. Years of research have shown that cover crops and conservation tillage improve soil quality, add organic matter back into the soil, and suppress weeds. Large-scale vegetable farms have yet to adopt no-till as a common practice. When used in an agronomic system, crops are usually direct-seeded into the dried cover crop residue. One of the issues with no-till in vegetable production is that some small-seeded crops have difficulty emerging through the thick surface residue. Transplanting vegetables into the cover crop residue requires special equipment (MacLaren et al., 2019), such as roller crimpers and no-till transplanters. This may deter some farmers from switching to a no-till system. Another reason for the reluctance of growers to switch is the potential risk of inconsistent yields under a no-till system. Convincing farmers to make the switch relies on proving reduced tillage can lower the need for other inputs such as pesticides and herbicides (Phatak et al., 2002). In organic production, no-till must control weeds as well or better than traditional cultivation for their use to be justified.

A significant amount of research has been done investigating the effect of cover crops and no-till on agronomic crops such as soybean; however, less is known about the impact of these practices on horticultural crops. An increased interest in regenerative agricultural practices has led to more research evaluating reduced tillage within specialty crops. For example, broccoli grown in different cover crop mixtures showed higher yields in the rye and hairy vetch mixed cover than plants grown in hairy vetch alone (Mulvaney et al., 2011). This is likely due to the persistence of the residue throughout the season. Much of the research on no-till vegetable production has produced variable results (Delate, 2012; Herrero et al., 2001; Weil and Lounsbury, 2015). Some studies have reported finding decreased yields under a no-till system, and others have found no difference between conventional and no-till crop yields. For example, one study found that when using forage radish as a cover crop and under no-till management, spinach yields were one of the highest compared to other cover crops and tillage methods (Weil and Lounsbury, 2015). Research done on organic no-till pepper production reported that cover crops increased soil moisture in plots with cover crops (Díaz-Pérez et al., 2008). It was also determined that the moisture content is not affected by the type of cover crop used. Weed pressure in organic no-till plots was much higher than in conventionally tilled plots, consistent with many other no-till studies. Mechanical cultivation within conventional tillage helped to reduce the number of weeds. The study found that the no-till plots had a smaller mean fruit size and a lower percentage of marketable fruits than the conventionally grown plots (Díaz-Pérez et al., 2008). These results are most likely due to increased competition between crops and weeds.

While past research has been inconsistent, advances in equipment and a better understanding of ecological weed management can help increase these practices' success in horticulture crops. Without using herbicides and tillage as a weed control strategy, weed pressure not only increased but the weed composition of a field can be changed. In no-till systems, weed populations tend to shift from small-seeded annuals to grasses and perennial weeds (Ngouajio et al., 2003). These types of weeds can be even more problematic to deal with organically. In one study, results showed that plots with no cover had the most significant population of weeds. Plots with a summer cover of cowpea (*Vigna unguiculata*) mulched in the fall provided the best weed suppression (Ngouajio et al., 2003). Plots, where cowpeas were incorporated into the soil before transplanting the crop had the highest yield. Differences in yield could be due to the nitrogen fixed by the cowpea cover being released following termination and eventually being used by the crop. The second highest yield was from plots mulched with cowpea, followed by a summer fallow (Ngouajio et al., 2003). These results confirm that mulching within an organic system can provide additional benefits to crops and reduce weed pressure. Cover crops have been shown to provide some defense against weeds but not significant enough to be used alone without other control methods. When combined with additional practices, including crop rotation and long-term attempts to reduce the soil seed bank, together they can help control weeds in organic or low input cropping systems.

Cover Crops for Weed Suppression in Organic Systems

Due to increased interest in cover crops and no-till agriculture beginning in the 1980s, much research has been done on cover cropping's environment. The USDA has released a manual including possible cover crops that work well in the southeast. The Sustainable Agriculture Research and Education (SARE) center also created a book, '*Managing Cover Crops Profitably*,' which provides extensive information on different cover crops, their production practices, and how to integrate cover crops into your farm. The guide is both a resource to help farmers determine which cover crop is best suited for their needs and management guidelines. Cereal grains, legumes, and mustards are common cover crops in vegetable systems and have proven beneficial (Price and Norsworthy, 2013). Current research within cover crop systems focuses on determining which cover crops work best and in what combination to provide the best results for the desired outcome, whether weed suppression, organic enrichment, or adding nitrogen. Depending on the grower's goals, different cover crop species should be selected. A crop like oats, which produces a large amount of biomass, may be an option for a grower interested in reducing soil erosion and suppressing weeds (MacLaren et al., 2019). In contrast, a legume like Austrian winter pea (*Pisum sativum subsp. arvense*) or Sunn hemp (*Crotalaria juncea*) is a better choice for those looking to increase soil nitrogen and organic matter. Rye produces more biomass than hairy vetch, suppressing weeds throughout the growing season. Cover crops that produce high biomass are preferred for their ability to suppress weeds. Still, they have a high carbon to nitrogen ratio (C: N), which means they are more likely to tie up nitrogen that then is unavailable to the crop. Cover crops with a lower C: N ratio provides excess nitrogen in the soil following microbial decomposition

Weeds within an agricultural system can lead to significant crop losses. An analysis over seven years found that weeds caused an average 50% yield loss in corn, which equals a loss of 148 million tons of corn valued at over $26.7 billion annually (Soltani et al., 2016). Reduction in crop yield and quality is caused by competition for resources, increased harvest time and cost, and increased pests (Boydston and Williams, 2017; McErlich and Boydston, 2014). In organic production, weed control is the most problematic issue for growers (Bàrberi, 2002). The herbicides approved for organic production, such as acetic acids, corn gluten meal, and plant oils, tend to be less efficacious and only affect small, newly emerged weeds (McErlich and Boydston, 2014). These products generally offer no residual control either. Other organic weed management strategies like hand weeding can be time-consuming and are not feasible for largescale growers. Most growers traditionally rely on cultivation methods or the use of plastic mulches. Many of the current weed control strategies used in organic vegetable production are labor-intensive and can damage the soil (Zheng et al., 2018). Using cover crops for weed suppression aids in soil conservation and is less labor-intensive (Reberg-Horton et al., 2012). Weed management in organic systems depends on using an integrated weed management approach, which focuses on implementing a range of different control methods, unlike conventional agriculture, where weed control mainly relies on herbicides.

For cover crops to successfully suppress weeds in organic vegetable production, they need to be appropriately managed. The right cover crop mix for the region and time of year needs to be selected. Other factors such as the cover crops planting date, overwintering ability, potential biomass production, and anthesis date (Silva, 2014) determine whether a given crop is appropriate for organic no-till production. Mechanical equipment such as roller crimpers or flail mowers are the preferred method of cover crop termination in organic systems (Reberg-Horton et al., 2012). These methods require specific machinery and are popular within organics as they can often be successful at terminating cover crops without the use of herbicides. A roller-crimper consists of a hollow drum filled with water and blades attached to a tractor. As the farmer drives, the stems are cut down (Rodale Institute, 2021). The now terminated crop lays on the soil surface, forming a thick mulch. While a roller-crimper is a potential way to terminate the cover crop, it can be a limitation as some growers do not want to invest in large, expensive equipment. Mowing cover crops can lead to an uneven distribution of residue (Creamer and Dabney, 2002), leaving areas open for weeds to emerge. With both methods, the timing of termination is a crucial component. If termination is done before anthesis for cereal cover crops and early pod set for legume cover crops, regrowth issues may occur later (Silva, 2014). Each method of termination has its advantages and disadvantages, but both can be successful if appropriately implemented.

Organic Weed Control

Within organic systems, weeds are the biggest threat to crop yield (Fennimore and Doohan, 2008). Competition for resources, like water, light, and nutrients, makes it imperative that weeds be removed from crop systems. Traditionally this is done through secondary tillage and herbicides. The introduction of herbicides changed modern crop production. In most countries, much of agriculture relies on herbicides for weed control. Excessive use of conventional herbicides has led to a consistent increase in herbicide-resistant weeds since the 1960s (Baucom, 2019; Green and Owen, 2011; Heap, 2021; Peterson et al., 2018; Shaner, 2014). Unlike traditional methods, organic growers must use a wide range of tools to deal with weed pressure throughout the season (McErlich and Boydston, 2014). Weed management is critically important to both conventional and organic growers. By reducing weeds within a field, a grower can reduce production costs and improve crop quality. According to the U.S. Department of Agriculture, National Organic Program (USDA-NOP) pest, weed, and disease management practice standards (National Organic Program: USDA Organic Regulations, 2017), organic weed control options include mowing, mulching with either natural or plastic mulches, mechanical cultivation, hand weeding, livestock grazing, flame weeding, and specific natural or biological substances. As the demand for organic produce grows, growers are having difficulty meeting this demand due to challenges controlling weeds within organic production.

Hand weeding is a prevalent practice in organic agriculture. This method is time-consuming and can be very expensive. In California, costs associated with hand weeding and organic lettuce cultivation were estimated to be as high as $842/ha (Tourte et al., 2004). As labor and fuel costs rise, these costs are not likely to decrease. In some cases, hand weeding is still the best option in high-value crops or crops where botanical purity is required (McErlich and Boydston, 2014). Without effective organically certified herbicides, many organic growers must rely on hand weeding and mechanical cultivation to control weeds. However, hand weeding is not economically viable on a large scale, and mechanical cultivation can have damaging long-term effects on soil health. Herbicides approved for organic are formulated from naturally occurring compounds, like corn gluten meal, corn oils, and acetic acid (McErlich and Boydston, 2014). These products can also be expensive, so they are usually used on high-value crops or in limited situations. When using these organic herbicides, adequate spray coverage is necessary for maximum efficacy. Most of the available products need multiple applications, offer no residual control, often require adjuvants, and effectiveness dramatically depends on weather conditions (McErlich and Boydston, 2014). Without the reliance on synthetic herbicides for weed control, organic growers use various weed management strategies to manage weeds and reduce the soil's weed seed bank.

Weed control depends on the use of multiple integrated strategies working together. Organic growers utilize different practices such as hand weeding, crop rotation, competitive cultivars, cover crops, mulching, biological control, timing, and excellent sanitation practices. While these methods can help control weeds, they generally do not work on a large scale. Due to time and labor constraints, many of these practices would not be feasible outside small, organic farms.

Impact of Management Practices on Weed Communities

The abundance of weeds within an agroecosystem is the frequency the species occurs, and distribution is the measure of range. Understanding how weeds change in the landscape due to the selection pressures applied is essential to manage agricultural land properly. Management practices act as a selection pressure on weeds. Herbicide use, the timing of tillage, and integration of cover crops will cause changes among weed populations. These practices impact abundance, distribution, and diversity, which changes weed control decisions.

Research has shown that under long-term reduced tillage systems, perennial weeds and grasses are more dominant (Buhler, 1995; Kumar et al., 2020; Thomas et al., 2004). Reduced tillage systems and cover crops promote the biodiversity of weed species which may be related to cropland productivity (Nkoa et al., 2015; Roschewitz et al., 2005) and yield stability (Knapp and van der Heijden, 2018). Species susceptible to specific "filters" will eventually be removed from the system, leaving behind those that are more difficult to control. Cropland homogenization due to inorganic fertilizer use, monocultures, and selective herbicide use have selected for a few hard-to-control species with similar requirements as crops, making agroecosystems more susceptible to invasion by other aggressive weeds. The Broadbalk experiment, which began in 1843, provides long-term data on weed diversity within cropping systems. In 1867, 130 weed species were present; between 1991 and 2002, the number decreased to 50 species, with only 30 being identified yearly (Moss et al., 2004). An analysis done on 19 years of Broadbalk data by Storkey and Neve (Storkey and Neve, 2018) showed a strong negative relationship between yield and low species richness ($r^2 = 0.59$, $P < 0.001$). Plots wither higher species diversity had reduced yield losses. A newer interest within weed science is the ability to promote this species diversity without compromising crop yield. Cover crops are an essential component of ecological weed management that help achieve more sustainable weed management.

Fertilization type (organic vs. conventional), the application method (Rasmussen et al., 1996), and rate significantly affect weed density and community structure within agricultural lands. Proper fertilization improves a crop's competitiveness, but weeds are also responsive to soil nutrient levels (Blackshaw et al., 2004; Sweeney et al., 2008). Transitioning to an organic management system causes considerable changes in soil's chemical, physical, and biological properties. Organic practices promote soil health and increase the microorganism communities in the soil (Li and Kremer, 2000; Ngouajio and McGiffen, 2002). The transition to organic can also modify weed population dynamics. Changes in the soil can affect the weed seed bank, which ultimately determines weed flora distribution. Higher weed species diversity is associated with organic production (Koocheki et al., 2009), most likely due to the absence of herbicides. Removing pesticides and inorganic fertilizers and opting for organic amendments increases soil organic matter and increases soil pH. These changes make the soil more favorable for microbial activity. Beneficial microbes colonize weed seeds, and organic insecticides promote phytophagous insects that feed on weed seedlings (Ngouajio and McGiffen, 2002).

By knowing or predicting which weeds are more strongly related to cropping systems and management choices, growers can employ more precise weed management strategies to treat weeds of greater importance to that system. This, in turn, would reduce labor and herbicide use. Not only can cover crops act as a method of weed suppression within cropping systems, but they also provide additional ecological services that promote soil health, reduce inputs, and encourage biodiversity.

Multivariate and Nonparametric Statistics in Weed Science

Multivariate statistical analyses are techniques used to explore and understand trends in complex data sets. These methods analyze multiple variables together, hence the name "multivariate" (Kenkel et al., 2002). These tools are not new and have been used in population ecology for many years, but their adoption by agricultural researchers is more recent. The techniques are well-suited for community data, such as weed counts from experimental plots, as they consider the variables simultaneously rather than independently. Univariate approaches separately evaluate variables that may not detect the underlying community structure. Most studies in the field assess how different management strategies impact weed species. In a survey within an experimental unit, we expect there to be interactions. Independence and normality are critical assumptions of traditional parametric statistical tests, like analysis of variance. Data commonly taken in vegetation studies rarely meet these assumptions. When working with complex data structures, the goal is to reduce the data's complexity and identify similarities within and between groups (Nkoa et al., 2015).

There are a variety of suitable techniques depending on the researcher's goal. In multivariate analyses, the main objectives are descriptive modeling and predictive modeling based on hypothesis testing (Kenkel et al., 2002). Descriptive analyses attempt to find patterns and explain the data structure. Popular descriptive multivariate techniques include principal component analysis (PCA), principal coordinate analysis (PCoA), correspondence analysis (CA), discriminant analysis (DA), and nonmetric multidimensional scaling (NMDS). These exploratory analyses are recommended to be completed first since they may provide information that helps the user identify subsequent tests. Ordination methods like NMDS pick out patterns that are difficult to see at first glance. NMDS outputs a representation of the relationship between individuals (samples) and environmental descriptors (treatments) in low dimensional space. The resulting map corresponds as closely as possible to the actual distances. The coordinating distances in ordination and variable space maximize the rank order correlation of the distance values. In contrast to PCA and PCoA, NDMS is not an eigenanalysis. The axes are not associated with an eigenvalue. Meaning you cannot extract information from the axes to explain variable contributions (Palmer, 2004). The selected distance measure is used to calculate a dissimilarity matrix, and then the iterative algorithm searches for a stable solution that minimizes stress with robust patterns. NMDS is considered an indirect gradient analysis as it only uses the species from the sample matrix. Information about the environmental variables is used after for interpretation. Following a stable NMDS solution further statistical tests are needed to determine significant differences between treatments or groups.

Nonparametric tests such as a Kruskal-Wallis Analysis of variance (KW-ANOVA), Multi-response Permutation Procedure (MRPP), and indicator species analysis (ISA) are tests that can follow NDMS to determine statistical differences in predetermined groups. A KW-ANOVA is the nonparametric equivalent of an ANOVA. An H value indicates whether three or more groups are significantly different (Kruskal and Wallis, 1952). A KW-ANOVA is used on non-normally distributed data where the means cannot be compared; the test is based on ranks. The null hypothesis of the test is that groups are subsets from the same populations. Groups are combined and ranked to calculate the H statistic. H represents the variance between groups and follows a chi-squared distribution. If H exceeds the critical value, you can conclude that groups come from different populations (McKight and Najab, 2010). Following a significant result from the KW-ANOVA, further post-hoc analysis is required to determine which groups differ. A standard procedure is Dunn's test (Dunn, 1964). The test performs multiple pairwise comparisons. The null hypothesis in each comparison is that the probability of observing a random value in the first group that is larger than a random value in the second group is one-half (Dinno, 2015). Each comparison results in a *p*-value. If the value is significant, the null hypothesis is rejected, and we can confirm the two groups are different.

MRPP is another nonparametric approach to test the hypothesis that there is no difference between specified groups chosen a priori. MRPP is advantageous over other similar methods as it does not require data to meet distribution and normality assumptions. The test results in an *A* statistic or the chance corrected within-group agreement. When groups are the same, the $A = 1$ and the observed delta is 0. If heterogeneity within groups equals expectation, then $A = 0$. However, if there is less agreement within groups than expected, $A < 0$ (Mota et al., 2010), the *p*-value from MRPP is obtained through permutations, is the probability that the within-group distance the same as amongst-group distances. If the *p*-value is significant, the null hypothesis is rejected, the groups are not the same. Similar to an ANOVA or KW-ANOVA, MRPP provides information on whether groups are significantly different. It does not identify in which groups the differences occur. An MRPP should be followed by multiple pairwise comparisons and an indicator species analysis (ISA).

Dufrêne and Legendre (Dufrêne and Legendre, 1997) proposed the indicator species analysis as a method to identify indicator species and species assemblages that characterize sites. Developed as a simple alternative to Hill's (Hill, 1979) two-way indicator species analysis (TWINSPAN), ISA does not rely on a complex correspondence analysis (CA) ordination algorithm. ISA has mainly been used to detect species at sites based on different environmental conditions. Indicator species are defined as the most characteristic species of each group, found primarily in a single group and present in most of that group's sites (Dufrêne and Legendre, 1997). Species abundance and occurrence are used to produce an indicator value (IV) for each species relative to *a priori* groups of interest (McCune and Grace, 2002; Mota et al., 2010). The *IV* is the product of two values, A_{ij} (mean abundance of species *i* in the sites of group *j*) and B_{ij} (relative frequency of species *i* in the sites of group *j*). These values range from 0 to 1, with a species with an *IV* of 1, implying that it is a perfect group indicator. The highest *IV* for each species is the *IVmax*. The significance of this value for each species is calculated through Monte Carlo randomizations. The IV_{max} is recalculated for each randomization. The IV_{max} *p*-value is obtained from the proportion of times the IV_{max} from the randomizations equals or exceeds the IV_{max} from the nonrandomized, original data set (Severns and Sykes, 2020). A high *IV* and low *p*-value mean a species is a strong, statistically significant indicator of the associated group.

While the methods presented are not new, their use is less common outside of ecological studies. Multivariate and nonparametric analyses can be powerful tools to help researchers understand complex data. Understanding how agricultural management practices change weed abundance and distribution is important for deciding control strategies. The type of data collected within these studies can be challenging to analyze using more common statistical tests. Multivariate methods can be beneficial for those interested in exploring and modeling the structure, composition, and dynamic nature of weed communities (Kenkel et al., 2002).

Sweet corn production in the Southeast

Sweet corn is a genetic mutant that differs from traditional field corn, which causes the kernels to accumulate sugar instead of starch. Conventional breeding has been used to develop commercial hybrids. Breeders have used four mutants, *sh2, su1,* and *se* alone, and in combination with one another to produce "high sugar" varieties. These endosperm genes control the level of sugar in the corn. Thus, sweet corn varieties can be classified as standard, super sweet, sugary enhanced, and high sugar sweet corn (Lertrat and Pulam, 2007). Sweet corn is grown both for fresh consumption and for processing. Standard sweet corn is more commonly used for processing and canning, while the sweeter types are better for fresh consumption.

Thanks to different combinations of the endosperm genes, newer sweet corn varieties have higher sugar content, extended shelf lives, and better post-harvest quality. In recent years sweet corn production in Georgia has grown substantially. It now makes up 13.9% of vegetable production in the state, surpassing onions and watermelon (Wolfe and Stubbs, 2019). In 2017, the National Agriculture Statistics Service (NASS) reported that 30,000 acres of sweet corn were planted, almost a 7,000-acre increase since 2010 in Georgia. The farm gate value has also increased by $18 million from 2016 to 2018, and sweet corn now has an estimated $158,867,276 (USDA, NASS 2020).

Sweet corn is grown like traditional field corn. However, there is not much research on no-till or organic production of sweet corn. In 2005, 23.5% of corn was grown using no-till, and it was estimated to increase to 29.5% in 2009 (Horowitz et al., 2010). Many growers have switched to a no-till system in the Midwest and have had good results. Part of the success of no-till field corn relies on genetically modified varieties and intensive herbicide programs. The increase of sweet corn production in the state and the higher prices earned by sweet corn compared to field corn production could be a successful way for growers to increase profits. Organic growers could also benefit from no-till production if concerns surrounding weed control could be resolved. There are a small number of organic herbicides with limited effectiveness, so it is necessary to find new strategies for controlling weeds.

Brassica Production

Broccoli *(Brassica oleracea var. italica)* and cauliflower (*Brassica oleracea var. botrytis)* are two economically important crops within the Brassicaceae family. In 2019, 45162 hectares of broccoli and 18413 hectares of cauliflower were harvested. The estimated value of broccoli and cauliflower was $872.6 million and $465.8 million (USDA, NASS 2020), both of which have increased since 2018. Broccoli is native to the Mediterranean; it was widely cultivated in Italy and the Roman Empire, its introduction to the United States is recent. Broccoli and cauliflower are grown as cool-season crops, and the harvested head is made up of immature, tightly packed flower buds and forms between 85 to 90 days. Broccoli can be harvested multiple times during the season. Once the primary head is picked, secondary heads will start to form. Cauliflower can only be harvested once per season. Both of these brassicas are considered heavy feeders and have high nutrient requirements. Nitrogen recommendations range from 112 to 196 kg ha^{-1} and a preferred soil pH of 6 to 6.5 (Reiter et al., 2019). Part of the popularity of broccoli and cauliflower is due to their high nutritional content. Broccoli is high in vitamin C and contains vitamin A, vitamin B2, and calcium. Cauliflower contains fiber, vitamin K and is rich in antioxidants (Bhattacharjee and Singhal, 2018). A wide range of varieties and nutritional benefits have made these crops extremely popular in fresh markets and the processing industry.

There are five cultivar groups in broccoli – sprouting, purple, Chinese, and white flowering broccoli (Bhattacharjee and Singhal, 2018). Broccoli cultivars have greatly improved due to breeding efforts (Li et al., 2019). Recent improvements focused on increasing reproductive portions and decreasing vegetative structures, color, quality, and uniformity (Branca, 2008) were also improved. The development of disease and heat-tolerant varieties is essential in the southeastern U.S. The warm and wet climate of this region is the perfect environment for many plant diseases to thrive, and the mild winters allow some diseases to overwinter. Warm conditions lead to bolting and sun damage which reduces the quality and marketability of the crop. Because of these issues brassicas grown in Georgia are typically only grown in the cooler months as opposed to year-round.

There is less information about growing high-value crops like broccoli and cauliflower in a no-till system. The grower's efforts may not equal the return due to the possibility of reduced yields. Research evaluating vegetable crops under different sustainable growing practices is critical and much needed. As the amount of productive land continues to decrease and the demand for naturally grown produce increases, the use of cover crops and reduced tillage may mitigate the degradation of crop land while providing growers tools to implement within organic production. The research that has been done has again produced variable results (Aref et al., 1997; Infante and Morse, 1996; Schellenberg et al., 2009). In some cases, yields are equivalent to conventionally grown crops, but studies have also shown yield reduction. Continued research in this area will further develop management strategies to promote sustainable farming practices and stabilize yields.

Research Objectives

The objective of this research is to assess the practicality of using cover crops as a strategy in chemical and organic integrated weed management in sweet corn, to compare weed community characteristics among the different management practices, and to determine if sweet corn and brassica crops grown within a cover crop and reduced tillage system would result in a comparable yield to conventionally grown crops.

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CHAPTER 2

COVER CROPS WITH REDUCED TILLAGE CAN SUPPRESS WEEDS WITHOUT REDUCING SWEET CORN *(ZEA MAYS L.)* YIELD[1]

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Abstract

Along with the many known benefits of cover crops, they may be effective as an ecological weed management strategy in low-input agriculture. This research aimed to determine the effect of cover crops, combined with reduced-tillage and nitrogen inputs on sweet corn (*Zea Mays L.)* yield and weed communities. During the two-year study, the impact of cover crop on crop yield varied. Yield within the no-till conventional treatment plots was not significantly different from the conventional treatment (7672 kg·ha-1 and 8655 kg·ha-1, $p = 0.59$) in year one, but yields differed in year two. Weed density and plot area covered by weeds were not significantly different between conventional and no-till conventional treatments. Multivariate analyses showed associations between specific weed species and management practices. Weeds were the greatest in no-till organic treatments, and these treatments had significantly lower yields, suggesting additional weed control may be necessary for organic systems.

Introduction

Weeds competing for resources are the greatest threat to crop yield in vegetable systems (Bàrberi, 2002). Economic losses can be billions of dollars annually due to the cost of control, labor, and the reduced yields (Soltani et al., 2016). Herbicides are the most common method of weed control used in agriculture. However, the recent increase in consumer interest in organic growing practices has led to a shift away from herbicides as the primary strategy for weed control. Many growers use hand weeding within high-value horticultural crops, but this requires extensive labor and is expensive (Fennimore and Doohan, 2008; Kruidhof et al., 2008). Organic agriculture relies on frequent tillage to control weeds. Intensive tillage damages soil structure (Mulvaney et al., 2011; Riley et al., 2008), leads to increased erosion, reduced infiltration rates

(Busari et al., 2015; Karlen et al., 1994), and it releases carbon dioxide emissions from soil carbon stocks (Grandy et al., 2006), and can damage the crop. Controlling weeds in vegetable systems cannot be done using a single approach; success relies on integrated weed management (Kruidhof et al., 2008). Cover crops are a valuable component to be included in these integrated strategies.

Cover crops can suppress weeds through physical interference and competition for light (Teasdale and Mohler, 1993), buffered soil temperatures, increased habitat for weed seed predators (Haramoto and Gallandt, 2005), delayed release of plant-available nitrogen (Dyck and Liebman, 1995), and release of allelopathic chemicals (Creamer et al., 1996; Wortman et al., 2013). Higher biomass production is associated with increased weed suppression (Florence et al., 2019; Osipitan et al., 2018). Oat (*Avena Sativa L.*) is a popular cover crop choice due to its fast growth habit and ability to produce substantial biomass (Clark, 2008; MacLaren et al., 2019). Under the proper conditions, biomass production is reportedly between 2247 $kg \cdot ha^{-1}$ and 4483 $kg \cdot ha^{-1}$, in some cases as high as 8966 $kg \cdot ha^{-1}$ (Clark, 2008). Cover crop species, management decisions, and termination timing are all keys to the successful adoption of cover crops as a weed control strategy.

Weed species, abundance, and pressure within agroecosystems can be modified based on different management practices; these practices may select certain species over others. Community assembly theory (Diamond, 1975) can be applied to weeds within agricultural systems. Different abiotic and biotic factors can act as ecological filters that alter a community trajectory (Booth and Swanton, 2002) over time. Practices that impact weed community assembly include herbicide use, crop rotation, and tillage practices (Barroso et al., 2015; Smith, 2006). Insight on how applied practices alter communities can explain weed population shifts related to reduced tillage or organic herbicides. Knowledge of weed community changes can influence the control needed. Research has shown that long-term reduced tillage systems tend to select for perennial weeds (Ngouajio et al., 2003; Thomas et al., 2004), while organic systems have higher abundance and greater biodiversity of weeds compared to conventional systems (Pollnac et al., 2009).

Sweet corn is well known for being a heavy feeding crop, with some reports recommending nitrogen rates between 224-336 $kg \cdot ha^{-1}$ (Oktem et al., 2010; Sp, 2012). Cover crops like oat are also known to tie up nitrogen, making it unavailable to the cash crop that follows. This study included additional nitrogen treatments to evaluate whether sweet corn grown following a cover crop requires additional fertilizer to obtain similar yields as conventionally grown sweet corn. This study was designed to determine the effect of common oat (*Avena sativa L.*) cover crop with reduced tillage and variable nitrogen on organic and conventional sweet corn. The main objectives were to assess the practicality of using cover crops as a strategy in chemical and organic integrated weed management. To determine if sweet corn grown within a cover crop and reduced tillage system would result in a comparable yield to a conventionally grown crop and compare weed community characteristics among the different tillage methods.

Materials and Methods

Site description

The study was conducted in 2018-19 (Year 1) and 2019-20 (Year 2) at the University of Georgia Durham Horticulture Farm in Watkinsville, GA (lat 33°53'N, long 83°25'W). The experiment was arranged as a randomized complete block design with four replications. An oat cover crop was selected for its biomass potential. The cover crop seed was obtained from Athens Seed (Watkinsville, GA). It was fall planted and spring killed before the study in years one and two. Prior to cover crop termination in 2018, biomass was sampled using a 0.6 m x 0.6 m quadrat following the protocol described by Gaskin et al., 2015. The estimated cover crop biomass was 5568 $kg \cdot ha^{-1}$. The soil was a Cecil sandy loam (Fine, kaolinitic, thermicTypic Kanhapludults) with pH 6.1. Total precipitation during the experiment was 305 mm in year one and 228 mm in year two. The average temperature in 2019-20 was 22.2 °C, and 25.8 °C in 2020-21 (Figure 2.1).

Two different methods were used to prepare fields before planting, conventional tillage and no-till. In the no-till treatments, cover crop residue was left on the surface. Treatments included conventional tillage, no-till using conventional herbicides, and no-till using organic herbicides. Two additional treatments consisted of an organic no-till and a conventional no-till, both with 50% more nitrogen (Table 2.1). An increased nitrogen treatment was included to overcome the initial nutrient tie-up caused by the cover crop (Clark, 2008; Doran and Smith, 1991; Hartwig and Ammon, 2002). A check plot served as the control in each replication. It was prepared following conventional practices but received no herbicides or weed management. The cover crop in all treatments was terminated chemically and mechanically. Conventional plots were chisel plowed and tilled as usual. Before planting, conventional plots were treated with pre-emergent herbicides typical of a traditional field corn weed management plan. Organic treatments followed National Organic Program (NOP) guidelines (National Organic Program: USDA Organic Regulations, 2017). All fertilizer was applied by hand to reduce potential contamination between treatments. Herbicides were applied in the mornings under calm conditions to avoid any carryover between plots. 'Obsession' Sweet corn (*Zea mays L.*), a bicolor supersweet (sh2) variety, was obtained from Seedway, LLC (Hall, NY).

Year 1

Oat cover crop was direct seeded in the Fall of 2018 at a rate of 67 $kg \cdot ha^{-1}$. The cover crop was terminated two weeks before the planting date on 18 March 2019. Termination method for the conventional treatments included a burndown herbicide application of glyphosate (Mad Dog, Loveland Products, Inc., Loveland, CO) at a rate of 0.70 to 0.80 kg $ai \cdot ha^{-1}$ based on recommendations (Hill and Sprague, 2019; Legleiter et al., 2012). Following chemical termination, the cover crop was flail mowed using a Vrisimo MiniMax 72" flail mower (Valley Tool Manufacturing Company, Hughson, CA). Conventional plots were subsequently tilled (Kuhn Power Tiller 72", Kuhn North America, Inc., Columbia, TN) to prepare for planting. In the NT plots following chemical and mechanical termination, the residue was left on the soil surface. Cover crop in the organic plots was terminated using glacial acetic acid ($C_2H_4O_2$) diluted to 20% (Duda Energy LLC, Decatur, AL). Before planting, conventional plots received a pre-emergent herbicide application of Atrazine at a rate of 1.6 kg $ai \cdot ha^{-1}$ (Southern Ag, Rubonia, FL) and Dual II Magnum, at 1.1 kg $ai \cdot ha^{-1}$ (Syngenta International AG, Greensboro, NC) following recommendations for sweet corn production in the region (Culpepper, 2015). No other plots received additional pre-emergent weed control. Each treatment plot had a total area of 32.5 m^2 (7.62 m x 4.27 m) with a 3-meter buffer between plots. Two sprinklers (Orbit Irrigation Products LLC, Bountiful, UT) were placed within each replication. Irrigation was applied with the aim of 25-38 mm per week throughout the experiment's duration, depending on rainfall.

The crop was direct-seeded on 11 April 2019 using a 1991 John Deere (Moline, IL) model 7300 'Max-Emerge' planter with a Dawn (Dawn Equipment Company, Sycamore, IL) no-till coulter followed by a Keeton seed firmer and Dawn spiked closing wheels. Sweet corn was seeded at 0.28 meter in-row spacing on 0.91-meter center to center. In 2019, corn was planted in two passes creating eight total rows within each plot.

The two fertilizer rates were 224 kg·ha^{-1} and 336 kg·ha^{-1}. Half of the fertilizer was surface applied at planting 112 and 168 kg·ha^{-1}, for the low and high rates, respectively. For the conventional treatments, 10N– 4.4P–8.3K fertilizer (Athens Seed Company, Watkinsville, GA) was used. The organic plots received Harmony Ag Organic Fertilizer (5N-1.75P-2.5K, 7 Springs Farm, Check, VA). The remaining nitrogen was side-dressed six weeks after planting, 22 May 2019. The nitrogen source was dependent on the treatments, conventional plots received calcium nitrate (15N-0-0, Yara North America, Tampa, FL), and feather meal (13N-0-0, Mason City By-Products, Inc., Mason City, IA) was applied to the organic plots. Corn was harvested at maturity indicated by brown silks on 21 June 2019. Ears were harvested from the four inner rows to avoid edge effects. Measurements of crop yield were taken at harvest.

Year 2

The experimental methods were repeated for the second year with a few changes. Due to the land available at the Durham Horticulture Farm, the exact experiment location differed from year one. Plots had a total area of 33.4 m² (1.8 m x 18.3 m) with a 3-meter buffer between them. The crop was planted in one pass instead of two like the previous year, resulting in plots with four rows of sweet corn. The experiment was slightly delayed due to COVID-19 restrictions.

The oat cover crop was planted in the Fall of 2019 and terminated on 27 May 2020, two weeks before planting. Termination methods followed those from 2019, including chemical and mechanical termination. Before planting, conventional treatments received a pre-emergent herbicide application of Atrazine (1.6 kg ai/ha) and Dual II Magnum (1.1 kg ai/ha). Half of the fertilizer was applied as a pre-plant on 1 June 2020. The crop was direct seeded on 2 June 2020 using the no-till vacuum seeder. The remaining nitrogen was side dressed by hand six weeks after planting on 14 July 2020. Overhead irrigation was applied at the rate of 25-38 mm, dependent on rainfall. Sweet corn was harvested at maturity on 12 August 2020, ten weeks after planting. Crop yield measurements were taken at harvest.

Components of Crop Yield

Yield and yield components were evaluated to determine the impact of the treatments on crop yield. The total weight and number of all harvested ears from each plot were documented, the yield was then extrapolated to $kg \cdot ha^{-1}$. The length, width, and tip fill of five randomly sampled ears from each plot were recorded. Tip or kernel fill is used as a measurement of quality. Poor tip fill is caused by various issues, including insects, environmental stress, or poor pollination (Nielsen, 2003). Tip fill was recorded on a scale of one to five, with one being poor and five being excellent. Tip fill was rated by one person in both years to avoid bias. Within each treatment plot, the heights of five representative plants were measured at harvest.

Population Complex

Weeds were sampled using a 0.3 m x 0.3 m quadrat (0.09 m^2 — quadrat was randomly tossed inside each plot six times following an 'X' pattern to ensure a representative sample. The number of weeds and species within the quadrat was recorded. Weed density per m^2 was calculated from the total weeds per plot, based on the formula modified from Booth et al. 2010 (Nkoa et al., 2015). In both years, weed counts were taken at 5 and 9 weeks after planting. Percent coverage of the plots was determined by visual estimation of the percentage of ground covered by weeds.

Statistical Analysis

This study was designed to evaluate the effect of cover crop and no-till production practices on yield and weed populations. Statistical analyses were done using R 3.6.3 (R Core Team 2020). Analysis of variance (ANOVA) was used to analyze yield data. Preplanned comparisons were chosen *a priori* to focus on comparisons of scientific interest between specific treatments. We were interested in comparing the conventional plots with the no-till conventional plots, as one of the disadvantages of no-till agriculture can be yield reduction. Other contrasts included comparing treatments with added nitrogen to those without and conventional compared to organic treatment. Significance was set at $\alpha \leq 0.05$ level. The yield was significantly different between 2019 and 2020. Magnitude differences resulted in *treatment* $\times$ *year* interactions, so data from year one and year two were analyzed separately.

The weed data from 2019-20 was recorded as presence-absence data of species within the sampling quadrat and the total number of weeds. Data from 2019-20 included total overall weed count and totals by individual species. The number of weeds per sample was counted and summed for each treatment plot. Count data were log-transformed to fit normality assumptions. A log transformation is appropriate in this case as the data set did not include zeros. Weeds within each plot were compared using ANOVA. Significance ($\alpha \leq 0.05$) was determined with Tukey's honestly significant difference (HSD) for all treatment effects. Percent coverage scores were transformed using an arcsin (angular) transformation (Freeman and Tukey, 1950). Percentage data often have a binomial distribution; the angular transformation makes the distribution normal for the appropriate analysis. Transformed data were analyzed using ANOVA followed by Tukey's (HSD) at $\alpha < 0.05$ level. Weed count data from 2020 was further analyzed using multiple multivariate statistical analyses, including non-metric multidimensional scaling

(NMDS), Kruskal Wallis ANOVA, multiple response permutation procedure (Zimmerman et al., 1985), and an indicator species analysis. Research has indicated that management practices lead to weed population shifts, modifying species abundance and pressure over time (Barroso et al., 2015; Buhler et al., 1994; Tuesca et al., 2001). These statistical analyses were used to identify the differences in species abundance and distribution based on the treatment.

NMDS (McCune and Grace, 2002) provides a visual representation of the relationship between data points in multidimensional space. The output provides a map of *n* individuals in the ordination space. The NMDS provides a stress value which is a product of a normalized loss function. The value indicates how well the algorithm has arranged the points in the ordination space while preserving the distances represented in the original matrix (Dexter et al., 2018). Proposed guidelines for interpretation of NMDS recommend that stress < 0.05 gives an accurate representation with no chance of misinterpretation, stress < 0.1 corresponds to a stable solution with little risk of incorrect conclusions, stress < 0.2 is usable, but higher values may provide misleading results, stress of > 0.2 is generally uninterpretable (Clarke, 1993). Before running the analysis, 2020-21 weed data were separated by date, then transformed using a ($\log_{10} x + 1$) transformation. The number of random restarts supplied to the function was 100, with three dimensions (k), using Gower's distance (Gower, 1971).

A Kruskal -Wallis ANOVA was employed to determine statistically significant differences between weed species within the different treatment plots. This analysis is a rank-based, non-parametric test and appropriate when data do not meet the normality assumptions required for an ANOVA. A non-parametric test was necessary in this case due to the number of zeros present in the data set. Dunn's test, a non-parametric post hoc test comparing treatment groups, followed the Kruskal Wallis ANOVA to identify the significant treatment differences.

Multi-response Permutation Procedure (MRPP) is another non-parametric approach that provides a test of significance between groups of sampling units using a dissimilarity matrix. MRPP provides information on differences between specified groups; in this case, groups were the treatments. MRPP does not indicate which species are causing the differences.

To evaluate the differences among species within the treatment plots, the MRPP was followed by post hoc pairwise comparisons and an indicator species analysis (ISA) (Dufrêne and Legendre, 1997)). ISA uses the species abundance and frequency to produce a maximum indicator value for each species to determine indicators of site groups. In this analysis, the groups were the treatments. The indicator index value (*IV*) measures the association between a species and the site group and then looks for the group corresponding to the highest association value. A permutation test determines the statistical significance of this relationship at the $P < 0.05$ level. The NMDS and MRPP were both performed using the R "vegan" package (Oksanen et al., 2020). R package, "indicspecies," was used to complete the ISA (Caceres and Legendre, 2009).

Results and Discussion

Weed Pressure

Data were separated by year and sampling date for the analysis. Weed species present within treatment plots differed between the years. Thirty weed species were identified in 2018-19. Of the species present, eighteen were annual broadleaves; eight were perennial broadleaves, three were annual grasses, and one was a perennial grass. In 2019-20, eighteen species were identified during the study: eight annual broadleaves, three perennial broadleaves, five annual grass species, and one perennial grass (Table 2.2).

Differences were discovered among weed density and percent coverage between the treatments in 2019 and 2020 (Table 2.3). In year one, at five weeks after planting the check, NT

Org and NT Org + N had the highest weed density, between 0.85 to 0.96 weeds per square meter. These three treatments were not significantly different from each other but differed from the Conv, NT Conv, and NT Conv + N plots. The latter three treatments had significantly fewer weeds. At nine weeks, the NT Conv and NT Conv + N treatments had mean densities of $0.22/m^2$ and $0.27/m^2$, both less than the Conv treatment's mean density. Five weeks after planting, both the NT Org and NT Org + N treatments had the highest weed pressure, which was not significantly different from the check. The NT Conv, NT Conv + N, and Conv treatments had significantly fewer weeds than the organic treatments. These trends persisted nine weeks after planting. By nine weeks, the percent of the NT Org and NT Org + N plots covered by weeds was between 88 and 91%, neither treatment differed significantly from the check. The area covered by weeds in the NT Conv, NT Conv + N, and Conv was between 14 and 19%, with the no-till plots having a slightly lower percent coverage. Percent coverage and mean density were both the lowest in the NT Conv and NT Conv + N treatment plots.

In year two, the NT Org and NT Org + N treatments again had the highest weed density, besides the check, but density was slightly less than in year one, with $0.67/m^2$ and $0.47/m^2$, respectively (Table 2.3). At five weeks after planting, NT Org and NT Org + N treatments were not significantly different from the NT Conv treatment. The weed density increased to 0.91 and 0.94 weeds per square meter by week nine. Weed density in the NT Conv plots was significantly lower than the NT Org plots but greater than the Conv treatment. The NT Org and NT Org + N treatments seemed to provide better weed control initially in year two. Five weeks after planting, the percent of the treatment plot covered by weeds was between 56 and 68%. While weeds covered less area than in 2019, they still had significantly more weed pressure than the NT Conv, NT Conv + N, and Conv treatments. By the nine-week sampling date, the plot area covered was almost 100%. The NT Conv, NT Conv + N, and Conv treatments had very low weed pressure at five weeks, 1, 0, and 2%, respectively. At nine weeks, the area covered increased to 10, 2, and 16%. The NT Conv and NT Conv + N were not significantly different from one another at nine weeks; however, the Conv treatment was significantly different from all the treatments based on Tukey's HSD.

None of the plots received any additional weed control throughout the season in either year, so these results are promising. The cover crop in the NT Conv and NT Conv + N treatment performed season-long weed suppression as well as the conventional pre-emergent herbicides and tillage used in the Conv treatment. Based on the results from both years of the experiment, using cover crops with no additional weed control practices may not be applicable in an organic system. However, using cover crops and reduced tillage as part of an integrated weed management plan could lower herbicide use by reducing the amount of post-emergent herbicide applications throughout the season while providing weed suppression and along with the additional benefits offered by reduced tillage.

Weed Communities

The null hypothesis of the NMDS ordination is that the weed community data is unstructured, and there are no differences between the treatment groups. The NMDS provides a stress value which is a product of a normalized loss function. A stable solution was reached after 25 and 50 runs for the two sampling dates. The stress values for weeks five and nine were 0.129 and 0.101, respectively. At five weeks after planting, the distribution of weeds within the check and both NT Org treatments are clustered together on the right side of the graph (Figure 2.2). Weeds in the Conv and NT Conv treatments are crowded together at the top left, with the other treatments being dispersed through the ordination space. Shepard's graph (Figure 2.3) indicates a strong relationship between the NMDS ordination distance and the original observed distance (Non-metric $R^2 = 0.98$, Linear $R^2 = 0.94$) at five weeks. Nine weeks after planting, the distribution of weeds within the treatment groups becomes more defined in the ordination space (Figure 2.4). The Check and NT Org are again primarily distributed through the bottom right quadrant. NT Conv and NT Org + N are distributed on the left side in the upper and lower quadrants of the graph. The Conv is near the center and has the fewest points. The NT Conv + N treatment is in the upper right quadrant and is more isolated from the other groups. The shepherd's plot at nine weeks (Figure 2.5) again shows a strong relationship between the NMDS ordination distance and the original observed distance (Non-metric $R^2 = 0.99$, Linear $R^2 = 0.95$). The NMDS plots show that the patterns of weed distribution differ within the treatments. NMDS scores associated with the different species are reported in Table 2.4. Scores represent the species contribution to the axes. These analyses were performed after one season under no-till. In a long-term reduced tillage system, more defined patterns would be expected to emerge. The subsequent analyses confirm the initial findings by the NDMS that species frequency and distribution were influenced by the treatments.

At five weeks, the Kruskal-Wallis ANOVA found carpetweed (*Mollugo verticillate),* crabgrass (*Digitaria sanguinalis*, buckwheat (*Polygonum convolvulus*), and goosegrass (*Eleusine indica)* were different between the treatments. By the nine-week sampling, carpetweed, crabgrass, and goosegrass were still different among treatments (Table 2.5), along with two additional species, pigweed (*Amaranthus spp.)* and oat (*Avena sativa L.).* Oat was used as the cover crop in the experiment but was classified as a weed if plants persisted following termination. Dunn's test revealed in which treatments species differed (Table 2.6).

Carpetweed was significantly different between the check and all other treatments at both sampling dates. Carpetweed was significantly different in the check compared to all other treatments at both sampling dates. Crabgrass, buckwheat, and goosegrass were significantly different in the check at five weeks. At nine weeks, oat and crabgrass were significantly different in the check. Crabgrass abundance was different in the NT Conv, Conv, and NT Org compared to NT Org + N and NT Conv + N. Goosegrass was more significant in the check than all other treatments except NT Conv + N. The results of the Dunn's test only indicates if abundance was greater in one treatment compared to another, but it does not identify species abundance. Following these initial tests, further analysis was done using MRPP and ISA to examine the weed community makeup further.

The MRPP (Table 2.7) confirmed the previous analyses that there were significant differences in the weed populations of the treatment groups at both five and nine weeks (p = 0.001). The A-value is the chance corrected within-group agreement **(A = 1 – (observed δ/expected δ))** at both sampling dates A was greater than 0. This indicates that the populations within the groups are more similar than between groups. MRPP only identifies if groups are different, not which groups differed. The pairwise comparisons following the MRPP (Table 2.8) identified groups with significantly different weed populations. The abundance of weeds in the Check treatments differed significantly from all other treatments at both dates. Weeds in the Conv and NT Conv plots were only different from the NT Org at five weeks and both NT Org and NT Org + N at nine weeks. These results correspond to the initial ANOVA performed on the weed density and coverage data. The NT Conv and NT Conv + N were not significantly different from the Conv plots. This again confirms that when cover crops are used as part of a conventional system, they can provide similar weed control.

The ISA identified four significant species at week five, carpetweed, crabgrass, buckwheat, and goosegrass (Table 2.9). These results are consistent with the Kruskal Wallis ANOVA results, which found the same species significant. Carpetweed was strongly (stat value = 0.838, p = 0.001) associated with the check. Buckwheat was significantly associated with the check but was not as strong of an indicator. The two components reported by the ISA provide further information about species composition. Component A is the probability that a sampled site belongs to the target site group, given the species was found. Component B is the sample estimate of the probability of finding the species in sites belonging to the site group (Dufrêne and Legendre, 1997). For carpetweed, A = 0.8017, meaning it occurs in most sites belonging to the check, but (B = 0.875) the species was not present at every plot within this treatment. The species related to the no-till treatments are of greater interest within the scope of this study.

Goosegrass was associated with the check, and NT Org (stat value= 0.373, p = 0.013) and crabgrass was strongly associated with the check, NT Org, and NT Org + N (stat value = 0.751, p = 0.001). The same four species were significant at nine weeks after planting, along with pigweed (*Amaranthus spp.*) and oat (*Avena sativa L.)*. Goosegrass and pigweed were associated with the check and NT Org + N treatments. Crabgrass was strongly and significantly associated with the check, NT Org, and NT Org + N treatments (stat value = 0.933, p = 0.001). Oat was the only species related to the NT Conv and NT Conv + N treatments (stat value = 0.486, p = 0.012). This is likely due to incomplete termination of the cover crop in the NT Conv plots before planting. Of these significant species, three are annual broadleaves, and two are annual grasses, with one perennial grass. The annual broadleaf species were only related to the check and the two NT Org treatments. In contrast, the only species strongly associated with the NT Conv treatments was an annual grass species. Grass species related to the no-till treatments are generally wind-dispersed, which can contribute to their establishment in the absence of tillage. Increased grass emergence can also be due to seedling emergence as many types of grass are able to germinate and establish on a firm soil surface covered with residue that maintains soil moisture (Tuesca et al., 2001). These results show that different cropping systems do have significant impacts on weed assemblages, and species shifts can occur in only one season.

The data from this study suggest that cover crops and no-till, when used in combination with conventional practices, can provide comparable weed control to conventionally grown sweet corn without significant yield losses. When used with organic herbicides, Cover crops and no-till did not offer the same level of weed suppression throughout the season. For use within organic production, these practices may be applicable if a grower provides additional weed control. However, weed control that does not include mechanical methods (soil disturbance) is time-consuming and may only be appropriate on a small scale. The increased nitrogen applied also did not increase yields consistently.

The multivariate analyses identified species that were significantly associated with NT Org and NT Conv treatments. Understanding the weed communities present in agricultural systems is directly related to management decisions. The results support previous findings (Barroso et al., 2015; Kruidhof et al., 2008; Smith, 2006; Thomas et al., 2004) that different management decisions apply selection pressure to weeds and alter the community's structure over time. Manipulating other practices such as tillage type and timing, fertilizer, and herbicide application will further impact how weed communities assemble. Knowing how these practices may impact weed populations allows for more finely tuned weed management choices to target problematic species.

Crop yield

Specific measurements of crop performance and yield were significantly affected by the treatments (Table 2.10). Plant height was affected in the first year. Plants from the Check, NT Org, and NT Org + N treatments were shorter than the Conv, NT Conv, and NT Conv + N treatments. Plants shorter in height can be shaded out by surrounding plants, reducing their exposure to photosynthetically active radiation (PAR). Photosynthetic CO_2 exchange rates decline with shading (Ephrath et al., 1993), reducing yield potential. Ear length was significantly affected by treatments in year one but not in year two. In year two, the measured ear length within each treatment was consistent with the average variety length of 203 mm. Tip fill was measured but not included in the analysis because ~ 90% or more of harvested corn had some level of tip damage due to corn earworms (*Helicoverpa zea*).

In 2019, the NT Conv and Conv treatments had the highest yield, 7672 $kg \cdot ha^{-1}$ and 8655 $kg \cdot ha^{-1}$, respectively (Table 2.10). Yields from these two treatments were not different from one another. The additional nitrogen did not significantly affect the NT Org and NT Org + N. However, the NT Conv + N's yield was significantly lower than the NT Conv. Past studies have found that weed species are as responsive to higher N levels as the crop. The results here follow previous findings that increased fertilizer may benefit weeds at the crop's expense (Blackshaw et al., 2003; Blackshaw et al., 2004; Di Tomaso, 1995), leading to reduced yield.

The total yield of the treatments varied between the first and second years of study. In 2019-20, the Conv and NT Conv again had higher yields than the other treatments. This variation could be due to the delayed planting date in 2020. Later planting dates have been shown to have decreased weed pressure compared to earlier planting dates in both sweet corn and soybean production (Buhler and Jeffery, 1996; Williams, 2009). Lower weed pressure means less competition for resources, thus increasing the crop's nitrogen, leading to the increased yield.

Individual ear weight was determined by dividing the total weight from the treatment plot by the total number of ears harvested. The weight of individual ears was significantly different between treatments in both years. These results followed a similar pattern as the overall yield. In 2019 ears from NT Org, NT Conv + N, and NT Org + N had the lowest individual ear weight but were significantly higher than the check. Ears from the NT Conv treatment weighed significantly more than those from the NT Conv + N treatment. This result corresponds to the difference between the two treatments in the overall yield as well.

A key difference in both yield and ear weight between years one and two of the study was the check treatment. In year one, the check had the lowest overall yield and individual ear weight, and it was lower than all the treatments. In year two, the check was not significantly lower than any other treatment in yield or ear weight. These differences could be due to the later planting date in year two and weather variations; year two had greater rainfall during the experiment. In year one, the NT Conv yield was not significantly different from the Conv yield. The variation in the yield of the no-till treatments is consistent with past studies that have also reported unreliable crop yields under reduced tillage (Delate, 2012; Díaz-Pérez et al., 2008; Herrero et al., 2001; Weil and Lounsbury, 2015). Inconsistent yields can be a deterrent for growers to convert to a reduced tillage system, but the results suggest that reduced tillage can produce comparable yields to those of tilled systems

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Table 2.1. Description of six different treatments from 2019 and 2020 with abbreviations

Treatment	Abbreviation	Description of Treatment
Check (1)	-	Plots were plowed and tilled but received no herbicide treatments. Same fertilizer rates as conventional, no-till conventional, and no-till organic treatments
No-till conventional (2)	NT Conv	Cover crop terminated with Glyphosate. Residue was mowed and left on the soil surface. Plots were not tilled. Received conventional fertilizer at the regular rate.
Conventional (3)	Conv	Plots were plowed and tilled. Prepared following typical field corn production practices. Received conventional fertilizer at the regular rate.
No-till organic (4)	NT Org	Cover crop sprayed with acetic acid and mowed for termination. Residue left on the soil surface. Plots received organic sources of fertilizer at the regular rate.
No-till conventional + N (5)	NT Conv + N	Cover crop terminated with Glyphosate. Residue was mowed and left on the soil surface. Plots were not tilled. Received 50% more conventional fertilizer.
No-till organic + N (6)	NT Org + N	Cover crop sprayed with acetic acid and mowed for termination. Residue left on the soil surface. Plots received organic sources of fertilizer at the 50% more than the regular rate.

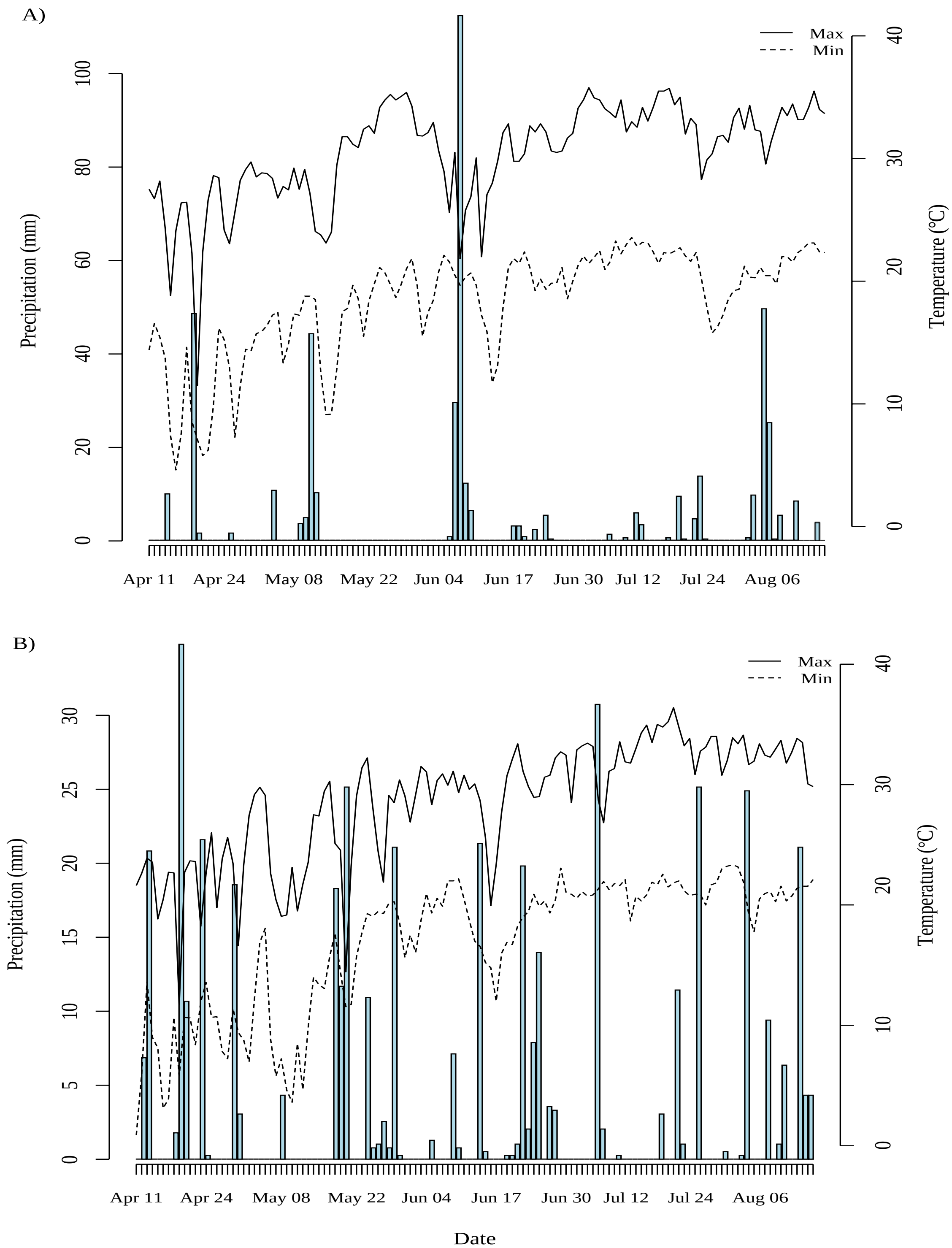

Figure 2.1. Daily high/low temperatures (°C) and precipitation (mm) during the study from A) 2018-19, and B) 2019-20; collected from the Watkinsville-Horticulture weather station – Oconee county, Georgia.

Table 2.2. Weed species present during each year, EPPO code, Type of weed; AG = annual grass, AB= annual broadleaf, PG= perennial grass, PB= perennial broadleaf

Species	Common name	EPPO code	Type	Year
Digitaria sanguinalis	Crabgrass	DIGSA	AG	2019
Mollugo verticillata	Carpetweed	MOLVE	AB	2019
Cyperus spp.	Nutsedge	1CYPG	PG	2019
Eleusine indica	Goosegrass	ELEIN	AG	2019
Amaranthus spp.	Pigweed	1AMAG	AB	2019
Portulaca oleracea	Common Purslane	POROL	AB	2019
Oenothera laciniata	Cut leaf evening primrose	OEOLA	AB	2019
Citrullus lanatus	Watermelon	CITLA	AB	2019
Oxalis stricta	Oxalis	OXAST	PB	2019
Avena Sativa	Black seeded oat	AVESA	AG	2019
Chenopodium album	Lambs quarter	CHEAL	AB	2019
Lepidium virginicum	Virginia pepperweed	LEPVI	AB	2019
Rumex crispus	Curly Dock	RUMCR	PB	2019
Solanum carolinense	Horse nettle	SOLCA	PB	2019
Ipomoea purperea	Morningglory	PHBPU	AB	2019
Acalypha ostryifolia	Hophornbeam copperleaf	ACCOS	AB	2019
Erodium cicutarium	Storksbill	EROCI	AB	2019
Modiola caroliniana	Bristly mallow	MODCA	AB	2019
Plantago lanceolata	Buckhorn Plantain	PLALA	PB	2019
Lamium amplexicaule	Henbit	LAMAM	AB	2019
Ampelopsis arborea	Peppervine	AMCAR	PB	2019
Commelina communis	Asiatic dayflower	COMCO	AB	2019
Physalis angulata	Cut leaf ground cherry	PHYAN	AB	2019
Conyza canadensis	Horseweed	1CNDG	AB	2019

Taraxacum officinale	Dandelion	TAROF	PB	2019
Eupatorium capillifolium	Dog fennel	EUPCP	PB	2019
Solanum lycopersicum	Tomato	LYPES	AB	2019
Dichondra carolinensis	Carolina ponysfoot	DIORC	AB	2019
Trifolium pratense	Red clover	TRFPR	PB	2019
Pseudognaphalium obtusifolium	Rabbit Tobacco	GNAOB	AB	2019
Avena sativa	Black seeded oat	AVESA	AG	2020
Mollugo verticillata	Carpetweed	MOLVE	AB	2020
Digitaria sanguinalis	Crabgrass	DIGSA	AG	2020
Amaranthus	Pigweed	1AMAG	AB	2020
Oenothera laciniata	Cut leaf evening primrose	OEOLA	AB	2020
Cyperus esculentus	Nutsedge	CYPES	PG	2020
Ipomoea purpurea	Morningglory	PHBPU	PB	2020
Polygonum convolvulus	Wild buckwheat	POLCO	AB	2020
Plantago lanceolata	Buckhorn plantain	PLALA	PB	2020
Eclipta prostrata	Eclipta	ECLAL	AB	2020
Eleusine indica	Goosegrass	ELEIN	AG	2020
Oxalis stricta	Oxalis	OXAST	PB	2020
Citrullus lanatus	Watermelon	CITLA	AB	2020
Panicum clandestinum	Deertongue	PANCL	AG	2020
Euphorbia maculata	Spotted spurge	EPHMA	AB	2020
Cyperus odoratus	Flatsedge	CYPFE	PG	2020
Poa annua L.	Annual bluegrass	POAAN	AG	2020
Gnaphalium spicatum	Cudweed	GNAPU	AB	2020

Table 2.3. Percent coverage and weed density of treatment plots at 5 and 9 weeks after planting. *Significance of treatment effects (P > F; NS = not significant at 0.05 level). Means in the same treatment group (rows) not sharing a letter are significantly different at the 0.05 level based on adjusted P using Tukey's honestly significant difference.

	Percent Coverage		Mean Density (m^2)	
Treatment	5 weeks	9 weeks	5 weeks	9 weeks
		2019		
Check	0.75bc	0.81b	0.89b	0.86b
NT. Conv	0.18a	0.14a	0.20a	0.22a
Conventional	0.15a	0.19a	0.16a	0.28a
NT. Org	0.83c	0.91b	0.96b	0.85b
NT. Org + N	0.80c	0.88b	0.85b	1.06b
NT. Conv + N	0.23ab	0.16a	0.26a	0.27a
Significance	0.0005	<0.0001	<0.0001	0.0002
		2020		
Check	0.74b	1.0b	1.02c	1.15b
NT. Conv	0.01a	0.1a	0.19ab	0.28a
Conventional	0.0a	0.02c	0.05a	0.06c
NT. Org	0.68b	0.99b	0.67bc	0.91b
NT. Org + N	0.56b	0.99b	0.47bc	0.94b
NT. Conv + N	0.02a	0.16a	0.18a	0.28a
Significance	<0.0001	<0.0001	<0.0001	<0.0001

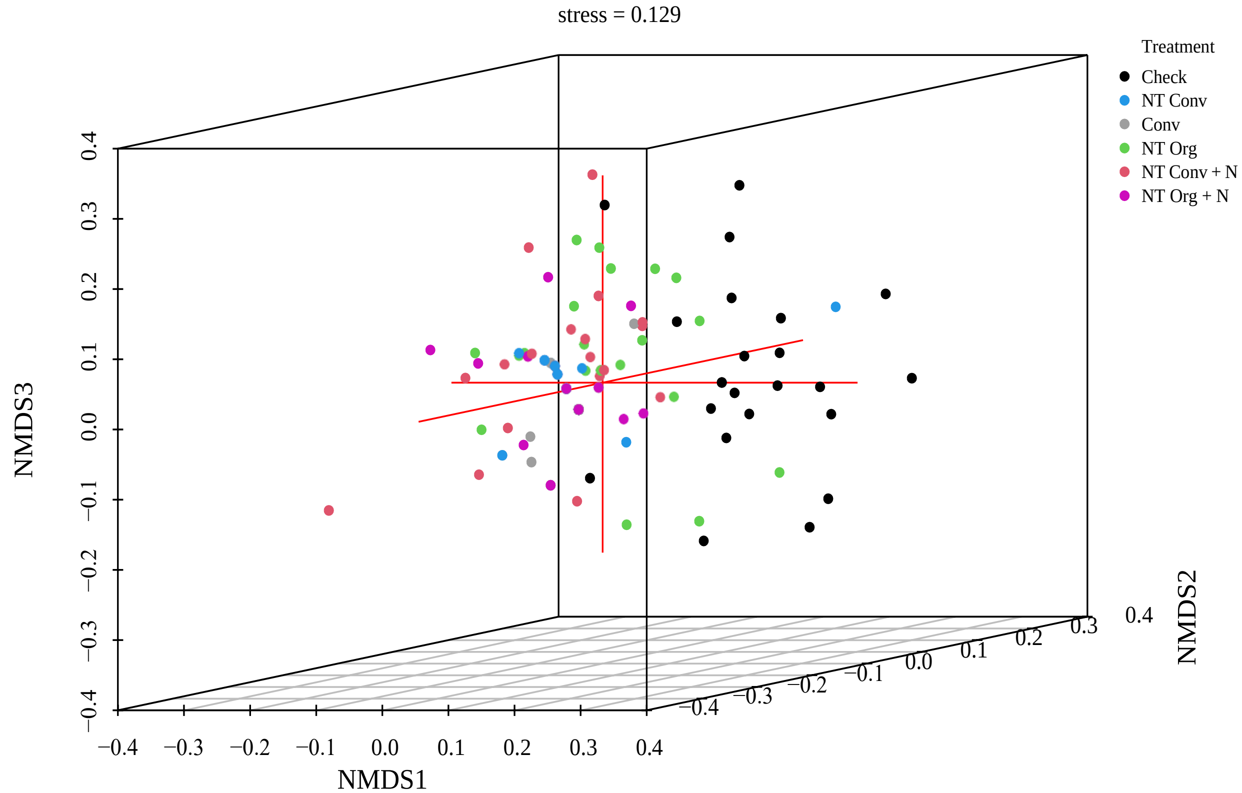

Figure 2.2. Plots of 3D Nonmetric Dimensional Scaling (NMDS) solution of weed flora at five weeks after planting the crop. See Tables 1 and 3 for abbreviations. The distribution of weeds within the treatments are significantly different, based on the analysis of similarity (ANOSIM, R = 0.163, p = 0.004).

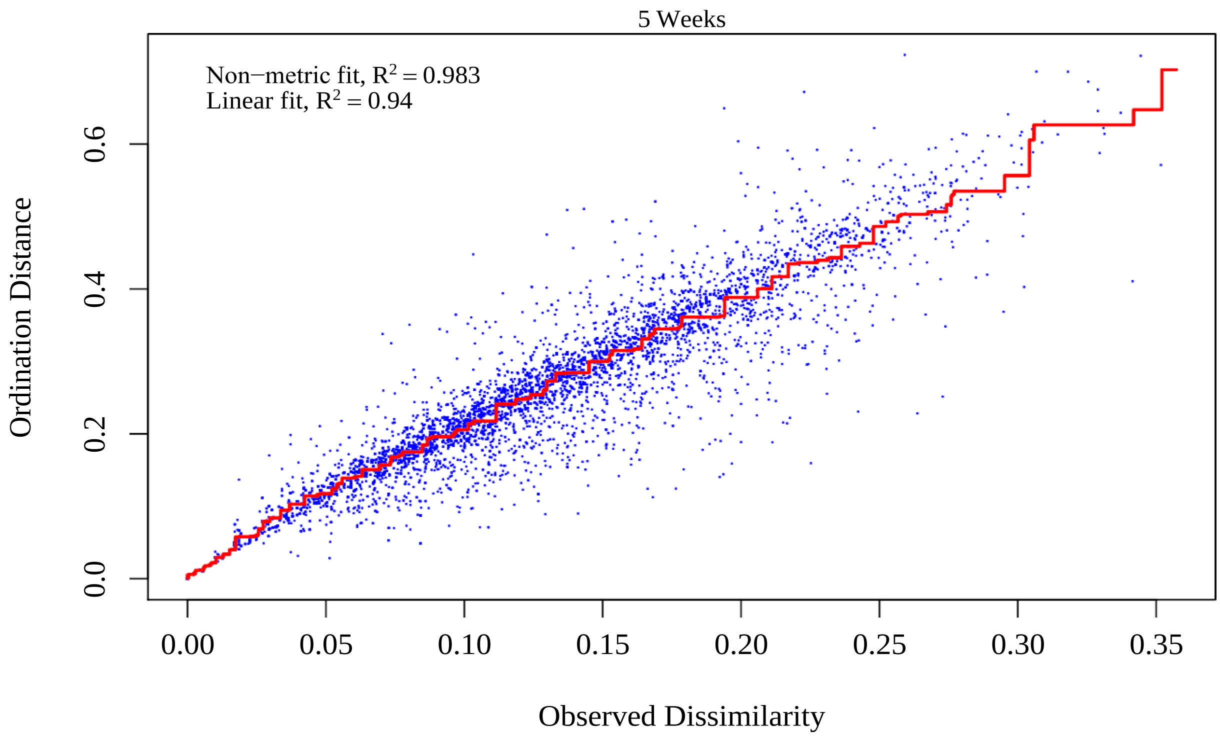

Figure 2.3. Shepard's plot for week 5 NMDS results. R^2 values indicate a strong relationship between NMDS ordination distance of weed species and the original observed distance of weeds in the field.

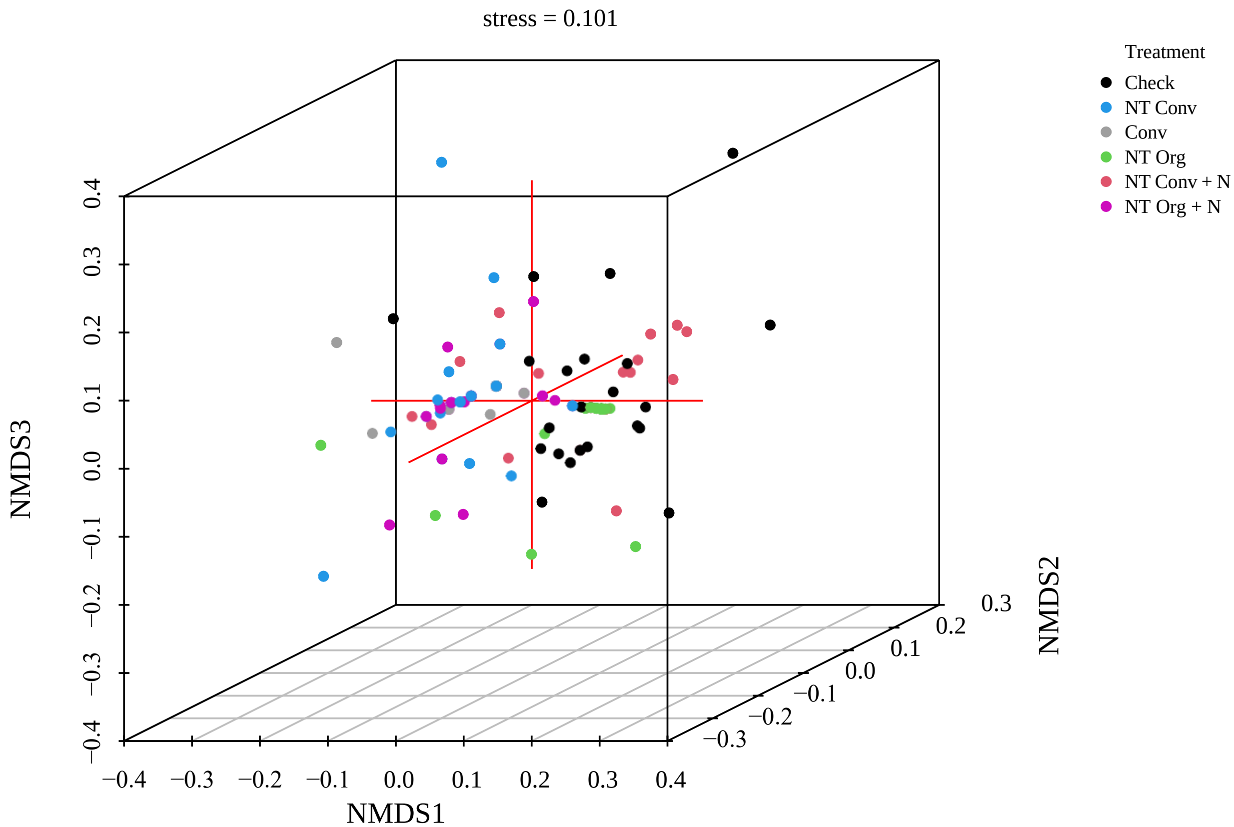

Figure 2.4. Plots of 3D Nonmetric Dimensional Scaling (NMDS) solution of weed flora at nine weeks after planting the crop. See Tables 1 and 3 for abbreviations. The distribution of weeds within the treatments are significantly different, based on the analysis of similarity (ANOSIM, R = 0.269, p = 0.004).

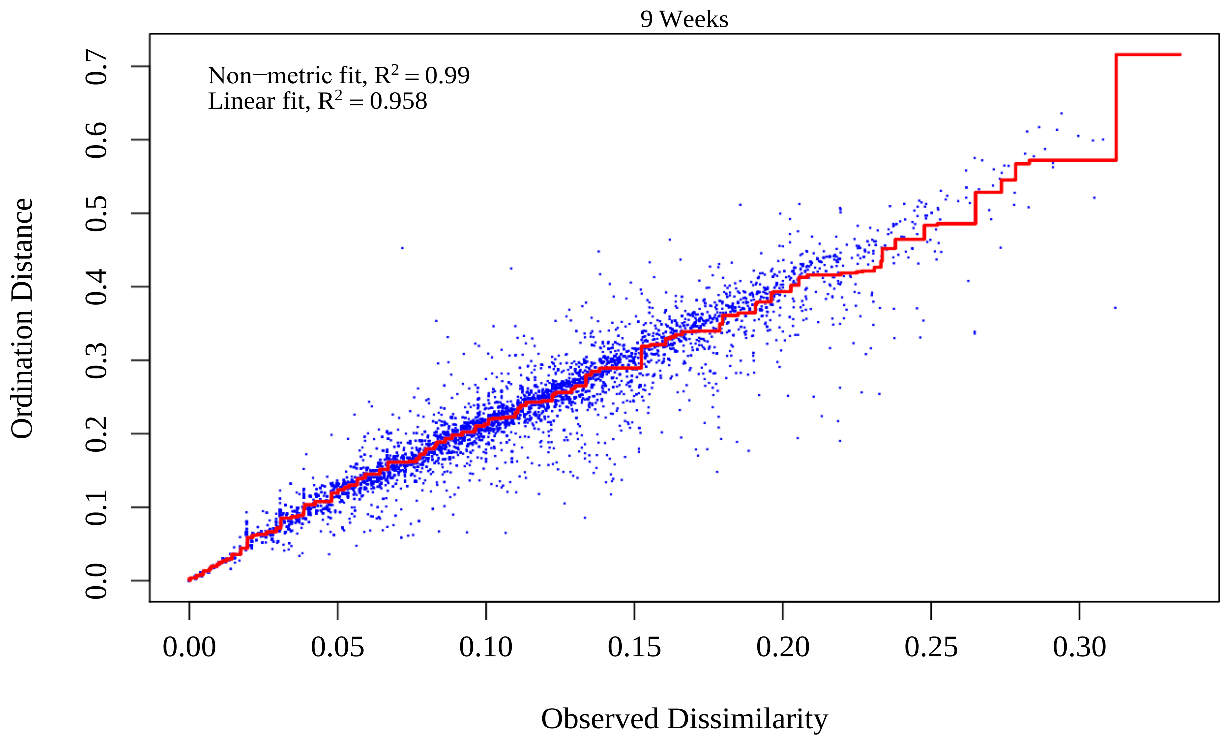

Figure 2.5. Shepard's plot for week 9 NMDS results. R^2 values indicate a strong relationship between NMDS ordination distance of weed species and the original observed distance of weeds in the field.

Table 2.4. NMDS species scores. See Table 2.3 for abbreviations.

	5 weeks		
Species	NMDS1	NMDS2	NMDS3
AVESA	-0.16037	-0.0662	-0.09888
MOLVE	0.179957	-0.16663	0.085263
DIGSA	0.146512	0.097718	-0.10656
AMAG	0.06747	-0.09178	0.067357
OEOLA	-0.11146	0.220454	0.021327
CYPES	0.097958	0.246422	0.084638
PHBPU	-0.00916	-0.01819	0.4388
POLCO	0.183793	-0.10109	0.09773
PLALA	0.09357	0.547949	0.080667
ECLAL	-0.20939	-0.0064	-0.07372
ELEIN	0.126337	-0.14119	-0.1028
OXAST	-0.07042	0.222628	-0.17164
CITLA	0.09093	-0.05979	-0.18066
PANCL	0.0352	-0.47537	0.459159
POAAN	0.51243	0.039401	0.049553
	9 weeks		
Species	NMDS1	NMDS2	NMDS3
AVESA	-0.23206	0.0526	-0.05149
MOLVE	0.011853	-0.21817	0.013488
DIGSA	0.111681	0.033598	-0.02079

AMAG	0.08376	-0.04128	0.105829
OEOLA	0.151399	-0.04842	-0.22691
CYPES	-0.08161	0.004628	-0.24293
PHBPU	0.019072	-0.02126	-0.00457
POLCO	0.213358	0.399468	0.447919
ECLAL	0.08662	0.289666	0.063607
ELEIN	0.113177	-0.0667	0.169758
OXAST	-0.25992	-0.38928	-0.2799
CITLA	0.213358	0.399468	0.447919
EPHMA	-0.328	0.014006	0.333156
CYPFE	-0.29098	0.157571	0.495578
GNAPU	-0.08889	-0.13275	0.051362

Table 2.5. Kruskal-Wallis test results for differences in species present between treatment groups at 5- and 9-week sampling. X^2 = the rank sum statistic used to compute the p-value. Significance of treatment effects (0.05 level).

	Sample			
	5 Weeks		*9 Weeks*	
Species	X^2	*p*-value	X^2	*p*-Value
AVESA	5.19	0.39	16.8	0.005
MOLVE	79.2	<0.001	22.9	0.003
DIGSA	51.9	<0.001	93.5	<0.001
AMAG	10.9	0.05	13.9	0.02
OEOLA	8.25	0.14	3.04	0.69
CYPES	3.46	0.63	6.96	0.22
PHBPU	5.65	0.34	8.93	0.11
POLCO	15.5	0.008	5.0	0.42
PLALA	4.07	0.54	-	-
ECLAL	4.07	0.54	4.03	0.55
ELEIN	17.5	0.004	33.7	<0.001
OXAST	11.3	0.05	5	0.42
CITLA	4.24	0.52	5	0.42
PANCL	5.04	0.41	-	-
EPHMA	-	-	4.03	0.55
CYPFE	-	-	5	0.42
POAAN	5.04	0.41	-	-
GNAPU	-	-	4.03	0.55

Table 2.6. Dunn Test results, post-hoc comparisons for differing significant species at 0.05 between treatments. (Treatments, 1 = Check, 2 = NT Conv, 3 = Conventional, 4 = NT Org, 5 = NT Org + N, 6 = NT Conv + N). See Table 2.1 and 2.3 for abbreviations.

5 Weeks			*9 Weeks*		
Species	Comparison	*p*-Value	Species	Comparison	*p*-Value
MOLVE	1 v 2	<0.001	AVESA	1 v 6	0.038
MOLVE	1 v 3	<0.001	MOLVE	1 v 2	0.024
MOLVE	1 v 4	<0.001	MOLVE	1 v 3	0.003
MOLVE	1 v 5	<0.001	MOLVE	1 v 4	0.001
MOLVE	1 v 6	<0.001	MOLVE	1 v 5	0.002
DIGSA	1 v 2	<0.001	MOLVE	1 v 6	0.003
DIGSA	1 v 3	<0.001	DIGSA	1 v 2	<0.001
DIGSA	1 v 6	<0.001	DIGSA	1 v 3	<0.001
DIGSA	2 v 4	0.0005	DIGSA	1 v 6	<0.001
DIGSA	2 v 5	0.032	DIGSA	2 v 4	<0.001
DIGSA	3 v 4	<0.001	DIGSA	2 v 5	<0.001
DIGSA	3 v 5	0.012	DIGSA	3 v 4	<0.001
DIGSA	4 v 6	<0.001	DIGSA	3 v 5	<0.001
DIGSA	5 v 6	0.024	DIGSA	4 v 6	<0.001
POLCO	1 v 2	0.022	DIGSA	5 v 6	<0.001
POLCO	1 v 3	0.022	ELEIN	1 v 2	0.009
POLCO	1 v 6	0.021	ELEIN	1 v 3	<0.001
ELEIN	1 v 3	0.015	ELEIN	1 v 4	<0.001
			ELEIN	1 v 6	0.003
			ELEIN	3 v 5	0.011
			ELEIN	4 v 5	0.011

Table 2.7. Summary statistics for MRPP. Results are comparing across all treatments. A = chance-corrected within-group agreement. Significance at 0.05 level.

		MRPP		
Sample	*A*	Expected δ	Observed δ	*p*-Value
5 weeks	0.142	0.098	0.084	0.001
9 weeks	0.233	0.073	0.057	0.001

Table 2.8. Pairwise comparisons between treatments with corrections for multiple testing. Finding differences in weed species and abundance within treatment groups. Significance at 0.05 level.

	5 Weeks				
Treatment	Check	NT. Conv	Conv	NT. Org	NT. Org + N
NT. Conv	0.003	-	-	-	-
Conv	0.003	0.305	-	-	-
NT. Org	0.003	0.045	0.032	-	-
NT. Org + N	0.003	0.726	0.724	0.367	-
NT. Conv + N	0.003	0.758	0.345	0.052	0.758
	9 Weeks				
	Check	NT. Conv	Conv	NT. Org	NT. Org + N
NT. Conv	0.0017	-	-	-	-
Conv	0.0017	1	-	-	-
NT. Org	0.009	0.0017	0.0017	-	-
NT. Org + N	0.0505	0.0017	0.0017	0.3113	-
NT. Conv + N	0.0017	1	1	0.0017	0.0017

Table 2.9. Weed species significantly associated with specific treatment groups as determined by ISA (indicator species analysis). Significance of treatment effects at 0.05 level

Species	Association	A^z	B^y	stat-value	*p*-Value
			5 Weeks		
MOLVE	Check	0.802	0.875	0.838	0.001
POLCO	Check	0.667	0.208	0.373	0.013
ELEIN	Check, NT Org	0.712	0.313	0.472	0.009
DIGSA	Check, NT Org, NT Org + N	0.9015	0.625	0.751	0.001
			9 Weeks		
MOLVE	Check	0.528	0.625	0.575	0.003
ELEIN	Check, NT Org + N	0.892	0.417	0.610	0.001
AMAG	Check, NT Org + N	0.941	0.167	0.396	0.012
AVESA	NT Conv, NT Conv + N	0.667	0.345	0.486	0.012
DIGSA	Check, NT Org, NT Org + N	0.935	0.931	0.933	0.001

[z] *A = specificity* - sample estimate of the probability that the surveyed site belongs to the target site group given the fact that the species has been found.

[y] *B = sensitivity* - sample estimate of the probability of finding the species in sites belonging to the site group

Table 2.10. Total yield, individual ear weight and plant height compared across treatments. Probabilities from preplanned comparisons of interest, Significance of treatment effects (P > F; NS = not significant at 0.05 level)

	Total yield ($kg \cdot ha^{-1}$)		Ear weight (g)		Ear Length (cm)		Plant height (cm)	
Treatment	*2019*	*2020*	*2019*	*2020*	*2019*	*2020*	*2019*	*2020*
Check	1,396	4,843	126.46	315.43	15.63	20.25	41.83	63.75
NT. Conv	7,672	4,179	254.37	298.63	19.97	20.51	59.75	67.20
Conventional	8,655	6,667	229.36	332.85	19.98	20.26	61.67	65.50
NT. Org	1,825	2,374	153.31	291.49	16.64	19.16	44.17	63.25
NT. Org + N	3,251	3,475	153.29	328.05	17.03	19.98	46.5	66.90
NT. Conv + N	3,568	4,893	134.88	305.84	19.26	19.27	51.16	67.90
Probabilities								
Overall	0.002	0.000	0.013	0.05	0.004	NS	0.002	NS
Check vs Other	0.020	0.363	0.059	0.714	0.004		0.009	
Conv vs NT Conv	0.592	0.003	0.514	0.025	1.0		0.692	
NT Org vs NT Org + N	0.439	0.147	0.999	0.018	0.736		0.631	
NT Conv vs NT Conv + N	0.035	0.339	0.005	0.614	0.546		0.089	
NT Conv + N vs NT Org + N	0.862	0.067	0.630	0.132	0.071		0.341	

CHAPTER 3

RESPONSE OF BROCCOLI *(BRASSICA OLERACEA VAR ITALICA) AND* CAULIFLOWER (*BRASSICA OLERACEA VAR. BOTRYTIS)* TO VARIABLE FERTILIZER RATES UNDER NO-TILL PRODUCTION[2]

[2] Dawson, E.K., G.E. Boyhan, R. McNeill. To be submitted to *HortTechnology*

Abstract

Cover crop residue ties up nitrogen in agricultural land due to immobilization. This process results in lower initial nutrient availability for the crop following cover crop termination. Growers attempt to overcome this nitrogen deficit by applying higher rates of fertilizer. Increased use of fertilizer leads to nutrient runoff and leaching, which have detrimental environmental effects. Legume cover crops fix nitrogen and break down quicker, releasing nutrients to crops sooner. Leguminous species within a cover crop mixture could reduce the need for increased fertilizer applications in no-till systems. This study's goal was to evaluate two brassica crop responses to variable fertilizer rates under no-till. Yields from the nitrogen treatments in both crops (112, 168, 224, 280, and- 336 $kg·ha^{-1}$) were not affected by nitrogen treatments. These results indicate that increased nitrogen did not improve yields under no-till, suggesting that growers do not need to increase nitrogen rates in these systems.

Introduction

A widespread critique of conservation agriculture, specifically no-till production, is an initial yield reduction due to the cover crop immobilizing nitrogen (Clark, 2008; Hartwig and Ammon, 2002), making it unavailable to the subsequent crop. Numerous studies have investigated this claim with variable results. In some cases, yield is not affected and may even be increased compared to conventional practices (Nunes et al., 2018; Testani et al., 2020; Weil and Lounsbury, 2015). In contrast, many other studies have reported reduced yields in these no-till systems (Leavitt et al., 2011; Nielsen et al., 2016). Despite the countless benefits of reduced tillage such as increased soil organic matter, reduced soil erosion and runoff, soil health improvements, and weed suppression being proven by extensive research (Acharya et al., 2019; Mulvaney et al., 2011; Phatak et al., 2002; Triplett and Dick, 2008), yield impacts are the most crucial factor within the horticulture industry.

Not all growers are willing to sacrifice yield and profits for the long-term environmental benefits. Due to its affordability and yield improvements, nitrogen use and application rates have increased within agriculture. Due to the perceived yield loss caused by cover crops, there may be a desire to increase nitrogen levels to overcome this. Nutrient use efficiency is the ability of crops to take up nitrogen and other nutrients from the soil and effectively produce quality yields (Benincasa et al., 2011; Good et al., 2004). Increasing research focus has been placed on optimizing yield under low input systems to reduce nitrogen use and limit its environmental impact (Hirel et al., 2011). Growing leguminous cover crops may improve nitrogen availability to the crop, overcoming these potential adverse effects on yield while using lower inputs.

Sunn hemp (*Crotalaria juncea*) is a tropical legume that is popular as a summer cover crop due to its ability to produce biomass above 4000 $kg \cdot ha^{-1}$ and fix nitrogen, above 100 $kg \cdot ha^{-1}$ in as little as twelve weeks (Clark, 2008; Schomberg et al., 2007). Sunn hemp, therefore, is an excellent warm-season cover crop. Because it does not produce seed in temperate regions, seed can be expensive and challenging to grow in the United States, discouraging its use. However, the additional nitrogen and reduced labor costs make it an attractive cover crop for growers looking to fill field space following a summer harvest before planting a fall cash crop. Sunn hemp provides other ecosystem benefits, including weed suppression, pollinator resources, and the ability to suppress nematodes (Meagher et al., 2017).

Pearl millet (*Pennisetum glaucum L.*) is a plant that is well suited as a cover crop within agroecosystems but is underutilized compared to other popular cover crops like oat and rye. Multiple millet species have been adopted for cover crop use, including Japanese (*Echinochloa esculenta*), proso (*Panicum miliaceum)*, browntop (*Urochloa ramosa)*, and foxtail (*Setaria italica)*. These plants have previously been grown in forage or wildlife settings and for seed production. Due to the range of plants included in the "millet" group, there is the opportunity for use as a cover crop in vegetable systems. They have a fast growth habit and mature in 60 to 80 days. Pearl millet, in particular, is well suited to the Southeast.

Pearl millet grows in hot, humid climates and is drought tolerant. In comparison, other species such as proso millet are more suited to the plains' dry conditions (Myers, 2018). Millet's can produce significant biomass that is suitable for mechanical termination. While not a legume like Sunn hemp, the C: N ratio is around 50, not as high as other cover crops, which means less nitrogen is tied up in its breakdown. Millet offers additional benefits, like the ability to break up compacted soils and suppress nematodes (Clark, 2008; Sheahan, 2014; Wang and Noite, 2010). Research on which cover crops work best in specific systems, regions, and varying crops is still ongoing. There is always a need for further studies to identify the best combination of management strategies for improving cover crops in reduced tillage vegetable systems.

Brassica crops, including broccoli and cauliflower, are essential horticultural crops (Rakow, 2004). Total production of cauliflower in 2019 totaled 10.1 million cwt, a six percent increase from 2018, and broccoli production in 2019 totaled 17.4 million cwt (USDA, NASS 2019). Members of this family are descendants of the wild cabbage and have been selectively bred for certain desirable traits. These cool-season crops are typically grown through the fall and winter in the Southeast, as the warm spring and summer temperatures often lead to bolting and poor crop quality. They are considered heavy feeders and have a relatively high nutrient requirement. Nitrogen recommendations range from 112 to 196 kg ha^{-1} and a preferred soil pH of 6.0 to 6.5 (Reiter et al., 2019). Proper nutrient management is essential for the successful cultivation of crops, minimizing fertilizer runoff, and lessening environmental damage due to excess fertilization. Legume cover crops may reduce inorganic fertilizer applications by fixing nitrogen in the soil that becomes available to the following cash crop, in some cases up to 112 kg ha^{-1} (Sullivan and Andrews, 2012). Other cover crop species can sequester nitrogen that is later released following mineralization. Cover crops can reduce nutrient runoff and erosion, improving overall nutrient management (Abdalla et al., 2019).

As previously stated, whether cover crops improve or hinder crop yields is still debated. Within high-value horticultural crops, the adoption of no-till practices has been slow because of this. This study aimed to determine whether broccoli and cauliflower can be grown successfully under no-till practices while evaluating the effect of five different nitrogen levels on yield.

Materials and Methods

The experiment was conducted in 2018-19 (Year 1) and 2019-20 (Year 2) at the University of Georgia Durham Horticulture Farm in Watkinsville, GA (lat 33°53'N, long 83°25'W). The experiment was arranged as a randomized complete block design with four replications. A high and low fertilizer treatment was applied to broccoli and cauliflower for four treatments. The soil was a Cecil sandy loam (Fine, kaolinitic, thermicTypic Kanhapludults). Sunn hemp cover crop was planted in year one, and pearl millet was used in year 2. The cover crop was chemically terminated in both years, followed by mechanical termination using a roller-crimper attachment.

Year 1

Sunn hemp cover crop was direct-seeded 26 May 2019 at a rate of 22 kg·ha^{-1}. The cover crop was chemically terminated on 18 Aug 2019 using burndown chemicals, glyphosate (Mad Dog, Loveland Products, Inc., Loveland, CO) and Gramoxone SL 2.0 (Syngenta, International AG, Greensboro, NC). Recommended rates (Cornelius and Bradley, 2017) for chemical termination were used, 0.80 kg ai·ha^{-1} and 1.12 kg ai·ha^{-1}, respectively. Following chemical termination, cover crop residue was crimped using a roller-crimper attachment on 28 Aug 2019.

'Emerald Crown' broccoli and 'Snow Queen' cauliflower seeds were obtained from Johnny's selected seeds (Winslow, ME). Seeds were sown in fifty cell flats using Sungro professional mix (Sun Gro Horticulture, Agawam, MA) on 6 July 2019. Additional plants were started on 8 July 2019. Transplants were maintained in the greenhouse until planting at about four true leaves, 29 August 2019. A no-till Mechanical Transplanter 5000WD (Mechanical Transplanter Co., Holland, MI) was used to plant seedlings. The equipment had difficulty cutting through the cover crop residue, not thoroughly planting transplants, so planting was completed by hand where needed. Drip irrigation was set up using 1.5 cm drip tape with 30.5 cm emitter spacing (Toro, Bloomington, MN). Irrigation was applied at 25-38 mm per week depending on rainfall (Figure 3.1). There were fifteen plants within each experimental unit, spaced 48 cm apart. Plots were 1.8 m wide and 9.0 m long, with a total plot area of 55.0 m^2. Plots had a 3.0 m buffer between them. The lower nitrogen treatment was 196 kg·ha$^{-1,}$ and the increased nitrogen treatment was 50% higher, 294 kg·ha^{-1}. Half of the fertilizer 10N– 4.4P–8.3K (Athens Seed Company, Watkinsville, GA) was applied at planting, and the remainder was side dressed five weeks after planting, 22 Sept 2019. GardenTech Sevin Insect Killer (TechPac, L.L.C., Atlanta, GA) was applied on 30 Aug 2019 and subsequently throughout the season for insect control (6, 23 Sept 2019, 9 Oct 2019).

Plants were harvested as they matured, beginning 29 Oct 2019 until 13 Dec 2019. Broccoli plants produced multiple heads during the season, and cauliflower plants were harvested once. Yield measurements were taken at harvest.

Year 2

The experiment followed the same methods as in year one, with some minor changes. Due to COVID-19 restrictions at the University of Georgia, the sunn hemp cover crop could not be planted in time. The cover crop used in year two was millet. Millet is a warm-season annual grass that is well suited to the southeastern United States. It can produce significant biomass and reaches maturity in eight to ten weeks. The cover crop was direct seeded in July 2020 at 22-28 $kg \cdot ha^{-1}$. Plots were prepared one week before planting on 21 Sept 2020. The cover crop was terminated following the same methods as in year one.

We added additional treatments in the second year to better investigate the crop's response to variable nitrogen rates under a no-till system. There were five nitrogen rates, 112, 168, 224, 280, and 336 $kg \cdot ha^{-1}$. The five treatments were applied to both broccoli and cauliflower, ten treatments total. The experiment was laid out in a randomized complete block design with four replications. Half of each fertilizer treatment was applied at planting, and the remainder was applied five weeks later, on 2 Nov 2020. Inorganic 10N– 4.4P–8.3K fertilizer (Athens Seed Company, Watkinsville, GA) was used.

Broccoli and Cauliflower seeds were started in the greenhouse on 12 Aug 2020, and additional plants were started on 19 Aug 2020. Seedlings were maintained in the greenhouse until they were transplanted into the field on 28 Sept 2020. In year two, plants were transplanted by hand due to the equipment difficulty in year one. Plot dimensions and field spacing were as in year one. Drip irrigation was applied at 25-38 mm weekly, dependent on rainfall (Figure 3.1). At planting, Imidacloprid (BioAdvanced Fruit, Citrus and Vegetable Insect Control, S.B.M. Life Science Corp, Cary, NC) was applied through chemigation for insect control. Systemic insecticide eliminated the need for season-long Sevin applications as it controlled insects during the entire growing season. There were initial issues with Fusarium wilt (*Fusarium oxysporum*) and Alternaria leaf spot (*Alternaria brassicicola*). On 16 Oct 2020, Switch 62.5WG (Syngenta, International AG, Greensboro, NC) was applied to plants using a Smith 4-gallon turf and agricultural series no leak backpack sprayer (Smith Performance Sprayers, New York Mills, NY) at 27 $oz \cdot ha^{-1}$ based on the labeled rate. Infected plants were replaced, and stand counts were taken throughout the experiment.

Plants were harvested as they matured, starting on 23 Nov 2020 and ending 11 Dec 2020. Broccoli plants continue to produce heads throughout the season, allowing for multiple harvests. Cauliflower was harvested once.

Components of Crop Yield

The measurements taken were used to evaluated crop growth. Yield ($kg \cdot ha^{-1}$), the average weight of heads (g), the number of heads, and the diameter of the head (cm) were determined. Stand counts were taken in years one and two. Differences in stand count between treatment plots were only an issue in year two. Yield data was extrapolated to reflect yield per hectares.

Statistical Analysis

Due to added treatments in year two, results were analyzed separately. In year one, yield data from the high and low fertilizer treatments were analyzed independently by crop using Student's T-Test (t-test). Due to varying numbers of plants in each plot in year two, differences between treatment groups were analyzed using an Analysis of Covariance (ANCOVA), stand count being the covariate. The ANCOVA's significant results were followed up with a Tukey's honestly significant difference (HSD) post hoc comparison. All analyses were completed using R 3.6.3 (R Core Team 2020)

Results and Discussion

Interestingly in both years, the increased nitrogen rates did not significantly improve crop yield. These results indicate that increased fertilizer rates may not be necessary in a no-till system. In year one, the two fertilizer rates' differences may have been too small to see significant effects (Table 3.1). However, in year two, we expected to see differences in the yield components with the additional nitrogen treatments. While not included in this study, crop nutrient content and soil nitrogen levels could further explain the applied nitrogen's fate. Previous research has found that increased nitrogen levels lead to nitrogen losses due to leaching as the amount applied exceeded the crop's demand (Agostini et al., 2010; Tei et al., 2020).

The results from year two followed the same trend from year one (Table 3.2). For broccoli, the increased nitrogen treatments did not significantly improve any of the measured yield indices. The covariate stand count was significant, but treatments were still not significant when controlling for its effect with the ANCOVA. One point of interest for the broccoli yield was that the yield's increased slightly from 112, 168, and 224 $kg \cdot ha^{-1}$ and then began to decline past that point. These results once again suggest that there is a threshold for fertilization that is optimal, and increasing nitrogen past that point will not improve yield and may be detrimental to the crop. Similarly, the increased nitrogen rates did not significantly increase the cauliflower yield. The ANCOVA did find the number of heads per treatment was significantly different. The number of heads harvested from 336, 280, and 168 $kg \cdot ha^{-1}$ did not differ significantly. The number of heads from 112 and 224 $kg \cdot ha^{-1}$ was only significantly different from the highest nitrogen rate. As with broccoli, the covariate was significant but did not affect the significance of the treatments.

This study's results seem to agree with the idea that yields can peak and then diminish with additional fertilizer (Boyhan et al., 2007). This trend may be more evident with added treatment rates. An important finding from this study is that yields were not significantly increased with higher nitrogen levels under a no-till system. The yields harvested from the experiment in years one and two were lower than average yields. United States Department of Agriculture, National Agricultural Statistics Service's Vegetables 2019 Summary reported yields between 16924-17709 $kg \cdot ha^{-1}$, and 22192-24770 $kg \cdot ha^{-1}$ for broccoli and cauliflower, respectively. Plants in this study were planted 48.0 cm apart. In many commercial operations, plants are much closer, around 15 to 22 cm, explaining some yield differences. The overall yield may have been lower in this study, but the individual head size was comparable to the average crown size harvested in commercial production (Le Strange et al., 2010) and those reported by Renaud et al., 2014. While results indicated that increasing fertilization within no-till brassicas does not improve yields, a no-till system yielded lower than conventional systems. The lower overall yields under a no-till system are not unexpected. However, with continued experimentation and vegetable trials, the goal is to determine the best practices that conserve the environment and maintain stable yields.

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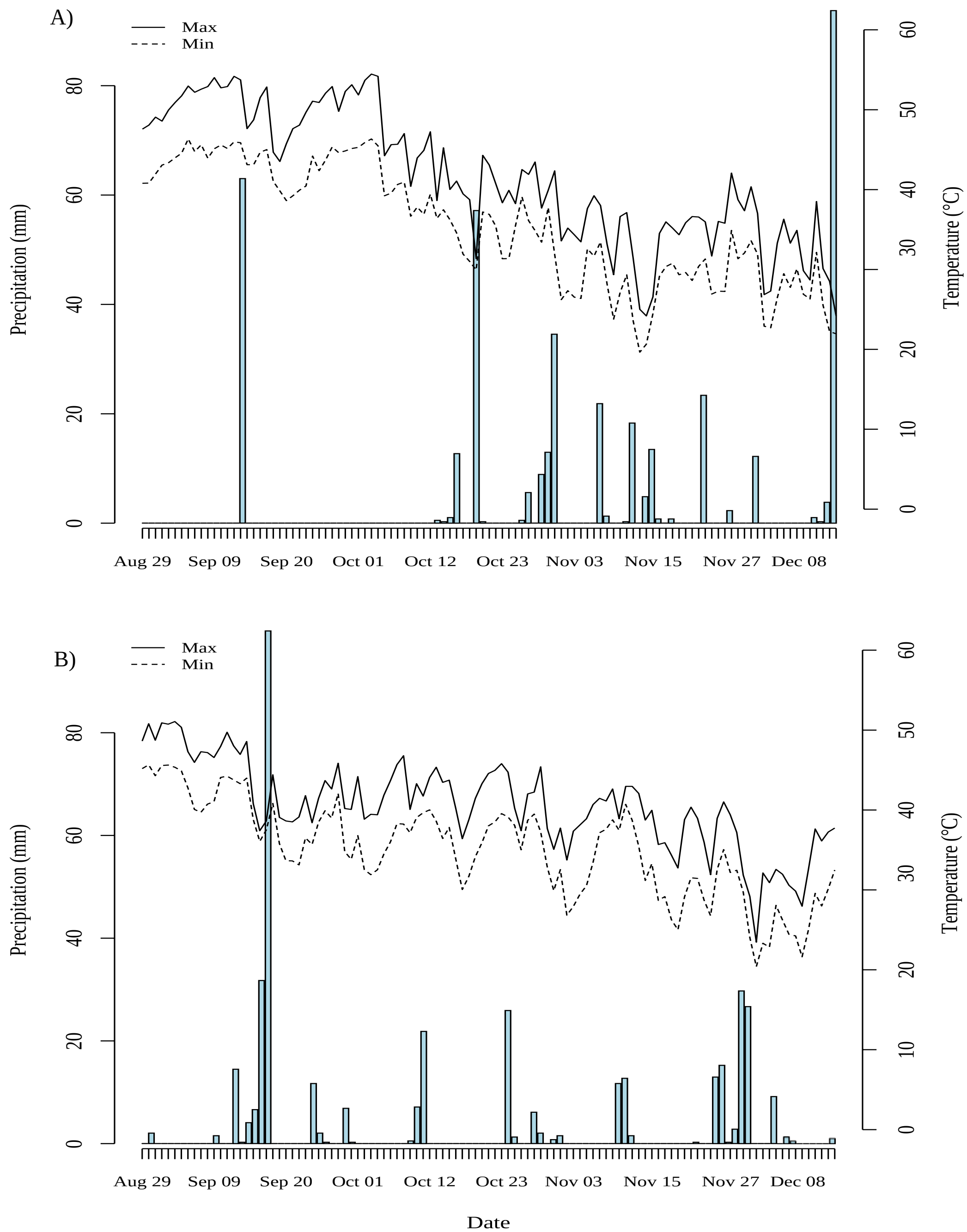

Figure 3.1. Daily high/low temperatures (°C) and precipitation (mm) during the study from (A) 2019, and (B) 2020; collected from the Watkinsville-Horticulture weather station – Oconee county, Georgia.

Table 3.1. Summary statistics for Broccoli and Cauliflower yield indices from 2019. Means in the same treatment group (rows) not sharing a letter are significantly different at the 0.05 level based on adjusted P using Tukey's honestly significant difference. (P > F; NS = not significant at 0.05 level).

Treatment ($kg \cdot ha^{-1}$)	Yield ($kg \cdot ha^{-1}$)	Number	Avg. head weight (g)	Diameter (cm)
		Broccoli		
196	5057	12707	395	14.5
294	4994	14202	344	14.5
Significance	NS	NS	NS	NS
		Cauliflower		
196	6861	5382	1285	14.1
294	8774	5681	1541	14.4
Significance	NS	NS	NS	NS

Table 3.2. Summary statistics for Broccoli and Cauliflower yield indices from 2020. Means in the same treatment group (rows) not sharing a letter are significantly different at the 0.05 level based on adjusted P using Tukey's honestly significant difference. (P > F; NS = not significant at 0.05 level).

Treatment ($kg \cdot ha^{-1}$)	Yield ($kg \cdot ha^{-1}$)	Number	Avg. head weight (g)	Diameter (cm)
		Broccoli		
112	2663	7923	735	12.6
168	2701	7774	754	12.7
224	2920	8222	781	12.6
280	2458	7176	744	11.9
336	2756	7325	812	12.6
Significance	NS	NS	NS	NS
Covariate	< 0.0001	< 0.0001	-	-
		Cauliflower		
112	4599	6129b	1619	14.4
168	4264	5232ab	1787	14.1
224	4397	5531b	1757	13.9
280	4570	5381ab	1868	14.4
336	3079	3737a	1707	13.9
Significance	NS	0.02	NS	NS
Covariate	< 0.0001	0.0001	-	-

CHAPTER 4

Conclusions

Sustainable and regenerative agriculture practices are continuing to gain interest among growers and consumers. Organic produce sales surpassed $55 billion in 2019 (McNeil, 2019), and the demand from consumers is not likely to decline any time soon. While the need is great, implementation of organic and sustainable practices can be slow. Lack of information, equipment, herbicide options, and labor requirements have prevented the widespread adoption (Reganold and Wachter, 2016) of these practices within horticultural crops. Continued research on conservation tillage and cover crops is necessary to improve these practices and encourage their use.

The objective of this research was to address challenges in vegetable production related to weeds and yield loss. The no-till sweet corn yields varied between experiment years, consistent with previous research (Pittelkow et al., 2015). The results show that no-till systems can produce yields comparable to conventional methods but not always reliably. In the brassica study, increasing fertilizer rates did not significantly improve yields compared to the lower rates. These results were interesting as it suggests that no till systems may not require additional nitrogen like previously thought. The yields from the study were still lower than conventional brassica yields, but the idea that additional fertilization may not be necessary within reduced tillage is something that should be further investigated. Another topic of further interest would be determining the best strategies to implement these practices in order to stabilize yields.

Weeds can decrease vegetable yields by an estimated 34 to 95% (Mennan et al., 2020; Oerke, 2006). Using cover crops alone or in combination with reduced-tillage practices offers another strategy for weed control in both conventional and organic agriculture. Incorporating these practices can reduce tillage and herbicide use when appropriately employed (Friedrich, 2005). This study suggests that no-till when used with cover crops terminated using conventional herbicides, weeds control is similar to conventionally tilled plots. The organically terminated plots did not offer the same level of season-long weed suppression. Cover crops terminated by roller-crimper may offer improved weed control in these cases compared to mowing.

Management practices lead to weed population shifts (Barroso et al., 2015; Smith, 2006), understanding weed communities within agricultural lands is critical in managing them. Tillage practices, herbicide type, and even fertilization can alter weed flora composition. Research has shown that weeds present under long-term reduced tillage are different from those present under conventional tillage (Tuesca et al., 2001). Analysis of weeds within this study's treatments revealed certain weed species significantly associated with no-tillage practices over conventional tillage. Cover crops and reduced tillage altered weed species abundance and composition. Knowledge of the species expected within and among fields can be used to make more informed decisions and prioritize resource conservation by incorporating cover crops as an ecological weed management tool. There is still room for further research to determine the best cover crop choices, planting, fertilizer rates and termination guidelines for diverse cropping systems that maximize cover biomass and subsequent weed suppression, without sacrificing yield.

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