2024

Integrating Early Season Clover Cover Crops as a Living Mulch in Broccoli and Transitional Organic Winter Squash Production in Eastern South Dakota

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INTEGRATING EARLY SEASON CLOVER COVER CROPS AS A LIVING MULCH IN BROCCOLI AND TRANSITIONAL ORGANIC WINTER SQUASH PRODUCTION IN EASTERN SOUTH DAKOTA

By

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A thesis submitted in partial fulfillment of the requirements for the

Master of Science

Major in Plant Science

South Dakota State University

2024

THESIS ACCEPTANCE PAGE

Alexis Barnes

This thesis is approved as a creditable and independent investigation by a candidate for the master's degree and is acceptable for meeting the thesis requirements for this degree. Acceptance of this does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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This Thesis is Dedicated to

South Dakota Specialty Crop Farmers and SDSU Extension Master Gardeners

ACKNOWLEDGEMENTS

This research was made possible by funding from the Specialty Crop Block Grant administered by the South Dakota Department of Agriculture and Natural Resources. Additionally, I would like to thank the SDSU Department of Agronomy, Horticulture and Plant Science for allocating land for this project and continued support. I would also like to thank Lang Lab Undergraduate Research Assistants, Graduate Research Assistants and the Southeast Research Farm faculty and technical staff for their help with this project and working through long, hot fieldwork days to make this project successful. Many thanks to Cedar Creek Gardens for collaboration with this project and the SDSU Extension Master Gardeners for volunteering their time and resources for research needs through very difficult labor shortages.

Special thanks to Thandiwe Nleya and Anne Fennell for their continued support with coursework and educating me about fruit production and the USDA Certified Organic Standards. John McMaine for joining my committee and providing support with water and soil health needs. Shout out to my friends and family for being there when I needed it the most!

Lastly, but certainly not least, I am so grateful for my advisors Kristine Lang and Rhoda Burrows. Thank you for the opportunity to join this lab team and work on an awesome project. I will forever remember the kindness and support I received in this program. I was able to grow as a student and a person and have learned so much from both of you. I am so excited to take what I have learned from you and move onto my next chapter at University of Illinois Extension.

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LIST OF ABBREVIATIONS

NTF: No-till with fabric

NT: No-till no fabric

TF: Tilled with fabric

T: Tilled no fabric

KC: White x Kura clover

RC: Red clover

WC: White clover

BG: Bare ground

ABSTRACT

INTEGRATING EARLY SEASON CLOVER COVER CROPS AS A LIVING MULCH IN BROCCOLI AND TRANSITIONAL ORGANIC WINTER SQUASH PRODUCTION IN EASTERN SOUTH DAKOTA

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Managing weeds, improving soil health, and reducing the use of plastic mulch continue to be priorities for South Dakota vegetable farmers. Farmers have expressed an interest in integrating cover crops into their farm systems. Clover cover crops used as a living mulch within and along cash crop rows may aid in weed suppression, nitrogen fixation, and prevent soil erosion. However, prior research has shown challenges of incorporating living mulch due to yield decreases. Research conducted in 2022 and 2023 in eastern South Dakota investigated the effects of four clover and four in-row soil management treatments on broccoli and organic winter squash production for small-scale vegetable farms in the Northern Great Plains. Whole plots (4) of Red clover, White clover, White x Kura clover and a bare ground control were direct-seeded in April of each year; management treatments were no-till + fabric, tilled + fabric, no-till and tilled. We hypothesized that the bare ground treatment and tilled clover treatments would produce the highest broccoli and squash yield, while clover and no-till treatments would suppress the most weeds. Winter squash was transplanted into the field in June for both seasons and was harvested in September 2022 and August 2023. Broccoli was transplanted into the field in July 2022 and June 2023 and was harvested several times in August and September for both seasons. Clover and weed count, height, and biomass were measured throughout the season. Weed height and biomass decreased throughout the season in broccoli production but increased for squash due to poor cover crop establishment in the spring for both years. South Dakota has experienced a drought for several years as well as summer heat waves that affect crop establishment. Broccoli and squash grown in the no-till plots were dramatically reduced due to competition with clover and weeds. Results from this trial highlight potential challenges and opportunities for managing clover cover crops as a living mulch during the first year of establishment for organic winter squash and fall broccoli production.

CHAPTER 1: INTRODUCTION TO COVER CROPS AND LIVING MULCH

Vegetable farmers commonly integrate plastic mulch into their systems due to the benefits of suppressing weeds and protecting the soil against erosion (Rylander et al. 2020; Tarrant et al. 2020). This increases the use of tillage and single-use plastic which can slowly leach chemicals into the soil, add to the environmental waste stream and must be removed yearly to adhere to the organic certification standards (Beriot et al. 2023; Shan et al. 2022). Farmers are seeking alternatives to single use plastic and have expressed an interest in cover crops and living mulches as well as no-till practices as soil health and nutrient management remains a concern (Chahal et al. 2021; Scavo et al. 2020). However, previous research has shown that using in row or intercropped living mulches can compete with cash crops and produce lower cash crop yields compared to conventional methods (Gruszecki et al. 2015; Pfeiffer et al. 2016; Vollmer et al. 2010).

Tillage

Tillage has been incorporated in farming practices for thousands of years and is still heavily relied on by farmers to this day, especially organic certified operations (Tillman et al. 2015). Tillage is beneficial for breaking up soil and distributing the O horizon within the A horizon (Kornillowicz-Kowalska et al. 2022). It is also helpful for early season weed management and provides loose soil for crops to be directly planted in (Chen et al. 2017). Organic farms struggle with weed management due to the low availability of non-synthetic herbicides available on the market, which results in high labor costs and increased presence of weeds (Abouziena et al. 2008; Chen et al. 2017). Tillage is a heavily incorporated practice on organic vegetable farms, primarily to mitigate weeds. However, tillage can have negative impacts on soil such as decreased organic matter and soil microbial communities, increased soil erosion, disruption of weed populations and decreased water retention (Cahal et al. 2021; Sharma et al. 2018). Tillage is a major cause of soil degradation in agricultural systems, leading to compaction, erosion, loss of organic carbon, and disruption of soil ecosystem processes (Pieper et al. 2015). Encouraging producers to reduce tillage and incorporate other methods can increase soil productivity and decrease soil erosion.

Tillage reduction can be a great way for farmers to plant in loose soil while encouraging soil conservation practices. Tillage reduction only requires the top 30% of the soil surface to be tilled which leaves soil residues below (Gruber and Claupein 2009). Conservation tillage increases carbon and organic matter in surface soils (to 15-cm depth) as well as active microbial biomass and aggregate stability, and alters availability of extractable nutrients (Gruber and Claupein 2009; Pieper et al. 2015). Soil organic matter and mycorrhizal fungi are very important components in soil health that are required by a large amount of vegetable crops (Pieper et al. 2015; Tarrant et al. 2020). Decaying plant matter and a sturdy soil cover can help to improve soil communities and provide nutrients that biodegrade into the soil (Nakamoto and Tsukamoto 2006; Scavo et al. 2020). Perpetual soil cover from decaying vegetation or living cover crops can decrease environmental damage from tillage impacts or even reverse them (Lounsbury et al. 2022). A non-tillage method for terminating cover crops in organic systems is rolling them flat or installing opaque tarping to smother plant matter back into the soil (Jokela and Nair 2016; Lounsbury et al. 2022).

No-till Production

No-till farming has been practiced around the world for thousands of years by many different cultures. No-till practices are very common within the regenerative movement and promote healthier soil structures, decreased soil erosion and increased soil biological activity (Newton et al. 2020; Schreefel et al. 2020; Vollmer et al. 2010). Risks of disease can be a concern in no-till operations since soil is not being worked and pathogens can live on the surface (Vollmer et al. 2010). Rising concerns with no-till vegetable production are the mitigation of weeds. Weeds can be a limiting factor in vegetable production which decreases crop quality and flavor but also can significantly reduce the yield of a cash crop, which makes the integration of no-till very difficult on organic vegetable farms (Chen et al. 2017; Law et al. 2006).

Plastic and Polyethylene Mulch

Polyethylene mulch and black landscape fabric have become essential additions for suppressing weeds on organic vegetable farms. Polyethylene mulch can provide shading from sunlight, high temperatures and decrease the germination stage for weed seedlings in planting rows (Rylander et al. 2020; Tarrant et al. 2020). Key benefits of plastic mulch include temperature moderation, increased moisture retention, reduced nutrient leaching, effective weed suppression in the crop row, and reduced soil splash that can lower incidence of some soil-borne diseases (Gao et al. 2019; Tarrant et al. 2020; Warren et al. 2015). These benefits can contribute to a better crop stand and overall increased crop yield in polyethylene mulch production (Pfeiffer et al. 2016). When organic producers use polyethylene mulch, the options for weed control for in-row planting beds include non-synthetic herbicides, which are expensive and not as effective as flaming or tillage (Chase et al. 2008). Plastic mulch limits weeds from sunlight which causes mulches to smother weeds and decrease crop competition (Rylander et al. 2020; Tarrant et al. 2020). Plastic mulch requires hand weeding in cash crop planting rows between the cash crops to reduce competition and the weed seed bank (Puka-Beals and Gramig 2021).

Plastic mulch can contribute to the environmental waste stream and become a nuisance for organic growers requiring the removal of mulch every growing season to maintain organic certification (Beriot et al. 2023; Shan et al. 2022). Non-biodegradable polyethylene plastic is the most widely used surface-applied mulch material and biodegradable alternatives are needed (Puka-Beals and Gramig 2020). Few biodegradable mulches are available on the market and are required to break down 90% of the product into the soil and most products have not been tested for authenticity (Zhang et al. 2019). The costs of controlling weeds and purchasing fertilizers to maintain soil fertility are significant and the outcomes of adopting living mulches and biodegradable surface-applied mulches are not well known (Puka-Beals and Gramig 2021). There is a need for a better understanding of living mulches and their impact on nitrogen fixation, however, plastic alone has encouraged organic vegetable farmers to take an interest in living mulches and slowly incorporate them onto their farming operations (Tarrant et al. 2020; Warren et al. 2015).

Cover Crops

Cover crops are commonly used in agronomic production with an increased curiosity by vegetable operations. Cover crops can be beneficial for soil erosion, distributing nutrients to the soil and nitrogen fixation (Alexander et al. 2019; Burgio et al. 2014; Nakamoto and Tsukamoto 2006). A common practice on farms is to use cover crops as green manures. The cover crop is planted prior to the growing season to allow a thick winter ground cover and it is winter-terminated, or is tilled into the soil prior to cash crop planting to incorporate nitrogen into the soil (Perkus et al. 2022). Cover crop selection is important because crop families, soil textures and management practices will impact the outcome of the soil on an organic farm (Alexander et al. 2019; Warren et al. 2015). Cover crops can be used as a living mulch, typically grasses, legumes and some cereals are chosen for different outcomes (Jokela and Nair 2016). Grass and legume cover crops provide producers with different soil health benefits and ground cover needs. Grass mulch is better suited for weed suppression due to its fast-growing properties and decomposes slowly (Vollmer et al. 2010). Legumes fix atmospheric N which allows N mineralized N to become available to cash crops after establishment (Alexander et al. 2019; Stein et al. 2022). Cereals can be a great early season addition which will cause less competition for late season broccoli planting (Jokela and Nair 2016)

Living Mulch and Weed Management

Living mulches are cover crops that can be annual, biennial or perennial that are simultaneously planted with a cash crop (Hinds et al. 2016). Living mulches provide multiple benefits such as weed suppression, decreased soil erosion, provide a thick ground cover for winter, water retention and pest control (Alexander et al. 2019; Burgio et al. 2014; Stein et al. 2022). Previous studies have utilized living mulches as a living pathway or intercropped into walkway rows as a living mulch and strip tilled into in row management treatments where vegetables are planted (Bruce et al. 2022; Puka-Beals and Gramig 2021; Tarrant et al. 2022). Common cover crops used as living mulches are foxtail millet, clovers, hairy vetch, cow pea, buckwheat, cereal rye and many others are useful in companion planting with vegetables (see cash crop section for competition data) (Bruce et al. 2022; Pfeiffer et al. 2016; Puka-Beals and Gramig 2021; Vollmer et al. 2010). Cover crops planted as a living mulch can also aid in providing host plants for beneficial insects which can decrease pest populations (Burgio et al. 2014; Hinds et al. 2016).

Weed management is a critical challenge facing organic farmers and is consistently cited as a priority for further research (Bruce et al. 2022; Florence et al. 2019). The availability of natural and synthetic herbicides in vegetable production has been limited for years and creates an emphasis for consistent weed control (Ogles et al. 2015). Small-scale vegetable producers trend towards organic practices due to the difficulty in applying synthetic herbicides in small amounts (Ogles et al. 2015). Cultural control of weeds at the germination stage in addition to reduced tillage can decrease weed populations and germination stages (Gruber and Claupein 2009; Rylander et al. 2020). The first plants that canopy and occupy an area have a better chance of surviving and competing for nutrients compared to others nearby (Strader et al. 2017).

Many factors can impact weed seed emergence and the weed seed bank, but soil disturbance can greatly impact weed germination. A large proportion of the weed seed bank remains on or close to the soil surface after crop planting in zero till systems (Chauhan and Johnson 2009; Rylander et al. 2020). Organic farmers mostly prefer plough-based conventional tillage rather than non-inversion conservation tillage (Gruber and Claupein, 2009). Another tillage challenge is the elimination of perennial legumes, often grass–clover, as an essential component of the crop rotation in organic farming (Bruce et al. 2022; Gruber and Claupein 2009). Tillage can cut and distribute rhizomatous root systems such as Canada thistle and cause severe weed infestations in vegetable systems (Gruber and Claupein 2009). Tillage alters soil particles and disrupts soil microbial communities that are critical in organic production (Chahal et al. 2021; Wang et al. 2015). Tillage can reduce crop residues and decrease the infiltration of raindrops which become more easily dislodged and splashed away (O'Rourke and Petersen 2016).

Living mulches planted between vegetable rows may decrease weed infestations, soil erosion, fertilizer and pesticide requirements, and soil compaction while enhancing organic matter, water in-filtration, and moisture or nutrient retention (Chase and Mbuya 2008; O'Rourke and Petersen 2016; Wang et al. 2015). There are multiple ways living mulches can suppress weeds and that includes roller crimping. Roller crimping is a no-till technique heavily used in cereal rye living mulches that can provide a ground cover while not disturbing the soil (Jokela and Nair 2016; Tarrant et al. 2020). If sufficient cover crop biomass is produced, the rolled cover crop mulch can provide season-long annual weed suppression for a cash crop planted through the mulch using no-till methods (Jokela and Nair 2016).

Cash Crop Yield

When cover crops are intercropped with vegetables as living mulches, they have the potential to suppress weed growth and they may compete with cash crops (Chase et al. 2008; Pieper et al. 2015; Tittarelli et al. 2018). Competition often is identified as the important mechanism of interference in most living mulch systems. Plants can interfere with or reduce yields of neighboring crops through allelopathy or competition for light, nutrients, water and space. Attempts to reduce competition in these systems have focused on mechanical or chemical suppression of mulch growth, screening for less competitive mulches, and variation of mulch planting dates (Jokela and Nair 2016; Tarrant et al, 2020).

Reductions in crop yields resulting from living mulches have been reported for multiple different cash crops including broccoli, zucchini, squash, onions, bell pepper, etc., (Hinds et al. 2016; Pfieffer et al. 2016; Vollmer et al. 2010; Warren et al. 2015). Organic growers have increased concerns about living mulches and their ability to decrease cash crop yields significantly which magnifies the need for more research. "Living mulches provide effective weed control primarily by outcompeting weeds; however, this can also result in the mulch competing with the cash crop, necessitating management strategies to reduce competition between living mulches and cash crops," (Pfeiffer at al. 2016). "Cover crops may be a smart alternative to living mulches, but does not provide the same soil quality as living mulches and generally require tillage, a practice some growers are abandoning. Strategies such as root pruning of the cover crops, staggered planting of the cover crop and cash crop, or use of living mulches in established perennial crops may assist in the reduction of competition during key growth periods and increase the success of a living mulch system," (Pfeiffer et al. 2016).

Cover crop and cash crop selection can play a role in the success of living mulches. Some crops may have a positive relationship compared to other crops due to different crop families and root structures, while crops like broccoli and peppers can have a negative relationship with living mulches due to the competition which results in a lower annual yield (Pfeiffer et al. 2016). Eggplant has been shown to produce a negative relationship between living mulches and yield growth, producing large amounts of marketable fruit in the bare ground treatments compared to crimson clover plots (Hooks et al. 2013). It was also shown by (Hinds et al. 2016) that zucchini squash yield was greater in the bare ground plots and significantly lower in the sun hemp living mulch plots. Additionally, the zucchini squash plants were larger in the bare ground control plots compared to the living mulch treatments proving negative competition. However, some studies have shown that cover crops as a living mulch have little to no impact on cash crop yield. Root crops such as onions may do well in a mixed grass and legume living mulch. According to (Vollmer et al. 2010), onion yield was not affected in a grass-legume cover crop mix compared to clover mix. It was speculated that legumes provided N concentrations while the grass suppressed more weeds. Early season spring cabbage in living mulch in Wisconsin, which did not experience extreme yield reducing effects compared to broccoli, which is interesting considering they are in the same crop family, are cultivated the same and extend the same root structures (Bruce et al. 2022). Lastly, a study performed in Italy showed no significant difference between roller crimped cereal rye living mulches and bare ground control treatments on yield, fruit quality and plant length for muskmelons (Tittarelli et al. 2018). These results demonstrate that soil structures, location and cash crops can have an impact on the competitiveness of the living mulches selected. Cash crops and the end goal of the field should be considered when selecting living mulches or cover crop integration.

Research in South Dakota

Our research compared first year establishment of clover cover crops as a living mulch in various management treatments as a sustainable alternative to polyethylene mulches. Soil management treatments, tilled and no-till, were implemented with and without landscape fabric in the vegetable planting rows as an alternative to plastic mulch since it can be reused for multiple growing seasons. Previous studies have shown broadcasted living mulches into wet Midwest systems (Bruce et al. 2022; Pfeiffer et al. 2016) however, our research drilled a clover and oat nurse crop to achieve better seed to soil contact in low moisture conditions in the Great Plains.

The objectives of this research were to 1) analyze the effects of various clover living mulch and their effects on weed suppression and marketable broccoli and organic winter squash yields. 2) Analyze the effects of various soil management treatments and their effects on weed suppression and marketable broccoli and organic winter squash yields.

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CHAPTER 2: INTEGRATING EARLY SEASON CLOVER COVER CROPS AS A LIVING MULCH IN TRANSITIONAL ORGANIC WINTER SQUASH PRODUCTION

INTRODUCTION

Clover cover crops

Midwest specialty crop producers have expressed an interest in replacing black plastic mulch with a natural alternative in their farm systems. Clovers are a perennial legume that is typically cultivated as a cover crop, living mulch or a green manure that can benefit producers prior or during the growing season (Alexander et al. 2019). Clovers can provide nitrogen fixation, weed suppression, decrease soil erosion, improve nutrient cycling, and improve soil structure (Alexander et al. 2019; Warren et al. 2015). Clovers are a perennial that require mowing and hand weeding events throughout the season that may add to farmers labor costs (Granatstein and Mullinix 2008; Puka-Beals and Gramig 2021). Efforts to integrate clovers have been shown to reduce cash crop yields (Jokela and Nair 2016; Perkus et al. 2022; Pfeiffer et al. 2016) which can negatively impact farm income.

Red clover *(Trifolium pratense)* is a biennial cover crop with a tap root (Pfeiffer et al. 2016). White clover *(Trifolium repens)* is a perennial cover crop with a stoloniferous structure (Sparks et al. 2015). White x Kura clover *(Trifolium repens x ambiguum)* is newer to the market with similar characteristics to Kura clover and has a rhizomatous root structure which makes it different from White clover (WC) (Ginakes et al. 2020;

Lane et al. 2019). WC is a common cover crop that vegetable farmers integrate into the systems in South Dakota. White clover is commonly integrated for weed suppression and nitrogen fixation for small vegetable systems across the United States (Alexander et al. 2019; Sparks et al. 2015). Kura clover is common for landscapers and landscape restoration due to its root structure and flowering potential (Ginakes et al. 2020). Kura clover and white clover are low growing and are easy to mow on vegetable systems, but they may become time intensive in high rainfall areas during the first year of establishment (Alexander et al. 2019; McCurdy et al. 2013). Red clover (RC) has a strong flowering potential which can attract pollinators to the field and may be beneficial for flowering crops like cucurbits or brambles (Tillman et al. 2015).

Living mulch

A living mulch is a cover crop that is simultaneously planted during the growing season that is never terminated (Burgio et al. 2014). Living mulches are commonly planted in the walkways and cash crop rows are strip tilled (Burgio et al. 2014; Hinds et al. 2016). Living mulches are becoming increasingly popular due to the need for improved soil health and ground covers along cash crop rows on vegetable farms (Depalo et al. 2017; Thériault et al. 2009). Living mulches may aid in weed suppression, decreased soil erosion, nitrogen fixation and water infiltration, which are all concerns expressed by Midwest vegetable producers (Stein et al. 2022; Thériault et al. 2009). Living mulches may offer benefits to pollinators as well as provide beneficial insects with a host plant to catch common cash crop pests (Tillman et al. 2015; Bruce et al. 2022).

Squash

Winter squash is a common cash crop grown on small farms during the summer season (Strader et al. 2017; Strang et al. 2015). Squash has become increasingly difficult to grow in the Midwest due to squash vine borer, squash bugs and cucumber beetles which can transmit diseases like bacterial wilt (Splawski et al. 2015; Tillman et al. 2015). Living mulches may aid in temperature regulation for sun scalding of squash compared to black plastic mulch or landscape fabric applications (Puka-Beals and Gramig 2021). Squash plants are sensitive to no-till systems. Prior research found a decrease in zucchini yields in ryegrass living mulch systems (Bruce at al. 2022). In Strader et al. (2017) squash yields were suppressed in red and white clover living mulch plots. Certain yellow squash cultivars have been bred to withstand certain diseases which can decimate squash crops during wet seasons (Coolong 2017).

The objectives of this research were to observe and analyze the effects of early season clover living mulches and various soil management treatments on weed suppression and winter squash cash crop performance. This research site was comparing the first year of establishment of clover cover crops as a living mulch in various tilled and no-tillage treatments as a sustainable alternative to single-use polyethylene mulches.

MATERIALS AND METHODS

Site Description

Field research was conducted from April to October in 2022 and 2023 at the South Dakota State University (SDSU) Southeast Research Farm in Beresford, South Dakota. The experimental treatments were located within the same field boundaries but were seeded in different plots side-by-side each year to investigate first year living mulch establishment as an alternative to black plastic mulch and their impacts on weed management, winter squash plant health and harvest performance. The soil structure at the experiment site is an Egan silty clay loam. The experiment site had experienced drought conditions for several years during and before this research trial. The area used for this experiment was in transition to USDA certified organic production and was previously managed as an agronomic research site growing a diverse forage mix.

Experimental Design

Whole plot (between row) management strategies investigated were 'Domino' White Clover (*Trifolium repens*), 'Dynamite' Red clover (*T. pratense*), 'Aberlasting' White x Kura Clover (*T. repens x ambiguum*) and a bare ground control treatment. 'Jerry' oats (*Avena sativa*) were applied within clover treatments to shade out early season weeds and improve clover establishment. In-row soil management treatments within clover whole plots include no-till no fabric, no-till fabric, tilled no fabric, and tilled with fabric. This study was a split plot randomized complete block design with four replicated blocks. Vegetable cultivars selected were 'Jester' delicata squash (*Cucurbita maxima*) as a cash crop and acorn squash 'Honey Bear' (*C. pepo var. turbinate*) as a guard row crop (Johnny's Selected Seeds, Winslow, ME). Winter squash was chosen for its semi-vining capability and represents a long season crop that is commonly grown by Midwest vegetable farmers.

Field Management

Key dates for field operation and data collection are outlined in Table A.1. Clover and oat treatments were seeded in a new area each year. Total field size was 122 m x 37 m' and clover whole plot dimensions were 9 m x 12 m. RC was seeded at 4.4 Kg/Ha, WC was seeded at 2.7 Kg/Ha and KC was seeded at 4.3 Kg/Ha. Oats were seeded with clovers at 13.6 Kg/Ha to outcompete and shade out early season weeds. Clover and oats were seeded on April 5, 2022 and April 17, 2023 using a 4.5 m no-till drill pulled by a John Deere tractor. Clover was hand broadcasted at triple the initial drilled rate on June 22, 2023 due to poor establishment early in the season which caused heavy competition with weeds.

On June 8 & 9, 2022 and June 5 & 6, 2023 field preparation events such as mowing, tillage, irrigation and landscape fabric installation occurred prior to squash planting (Table A.1.). Clover treatments were mowed with a zero-turn riding mower at a 20 cm height. Treatments that required tillage (tilled and tilled with fabric treatments) received two 0.91 m-wide tillage passes across 9 m management rows with a BCS 739 walk behind tiller (BCS, Oregon City, Oregon). Single drip tape irrigation lines with a 20.32 cm emitter spacing (The Toro Company, Bloomington, MN) were installed down each management row after tillage events. Drip tape was installed under fabric treatments for better water to root contact. Black woven landscape fabric was installed for no-till fabric and tilled fabric treatments with 15 cm steel landscape staples applied every 2.54 cm with a rubber mallet.

Winter squash cash crop ('Jester') and guard row plants ('Honeybear') were sown in 50 cell trays in a greenhouse on May 14, 2022 and May 8, 2023. On June 7, 2023, a pre-plant fertilizer, Sustane 8-2-4 (Sustane Natural Fertilizer Inc., Cannon Falls, MN) was applied at 33 g per planting hole at the time of squash planting. Pre-plant fertilizer was not applied in 2022. Delicata squash and acorn squash guard row plants were transplanted into the in-row soil management treatments with a trowel by hand. Cash crop management strips were nine meters long and consisted of nine ‘Jester’ squash transplants per row with a eight cm row spacing. Guard rows were 37 m long and consisted of 39 ‘Honeybear’ acorn squash plants per row for an eight cm row spacing.

Fertigation was applied several times over the course of the season in 2022 and 2023 (Table A.1.). Fertilizer was applied through drip irrigation with a Dosatron fertilizer injector (Ingersoll Rand, Davidson, NC) at 500 ppm using Nature’s Source Organic Plant Food 3-1-1 (Nature’s Source, Sherman, TX) for 1.5 hours per week.

Squash vine borer impacted 75% of squash plants in 2022 and 60% in 2023. In 2022, two of the four research blocks squash stems were vertically opened and vine borers were pulled out of each stem using small tweezers. A dirt and water mixture was applied to the cut stems to create a “cast” around the stem to heal the opening (Schuch et al. 2022). On August 10 and 12, 2022, Pyganic (Valent BioSciences, Libertyville, IL) was applied with a backpack sprayer to control spotted cucumber beetles and adult squash bugs. On blank August 2, 2023, DiPel DF (Valent BioSciences, Libertyville, IL) was applied with a backpack sprayer at the base of the squash stems to control vine borers. Entrust SC Spinosad (Corteva, Indianapolis, IN) was applied in June 2023 with a tractor sprayer due to high populations of grasshoppers.

Data Collection

A summary of data collected and associated dates is found in Table A.1. *Oat, Cover crop, weed height and biomass*. Data collection for clover establishment and weed competition was taken three times in 2022 and five times in 2023 randomly over the course of the season (Table A.1.). A 25x25 cm^2 quadrat was randomly tossed three times within the whole clover plot alleyways (between crop rows) and two times in each in-row soil management treatment (planting rows) to analyze the competition between weeds, oats and clovers. The tallest weed, oat and clover in each quadrat was measured from the base of the soil to the tallest leaf. Oats, clovers and weeds inside the quadrat were cut at the base of the stem and stored in a paper sample bag prior to biomass drying. Samples were then dried for approximately three days at 60 degrees Celsius in 2022 and five days at 43 degrees Celsius in 2023 in a gas conventional dryer. Dried samples were weighed to the nearest 0.1 grams with a small food scale to determine dried biomass weight. After data collection was taken, oats, clover and weeds were mowed in the whole plot walkways and hand cultivated in the bare ground treatments. Mowing and hand cultivation events occurred in 2022 and 2023 (Table A.1.). Mowing height was set at 10.16 cm from the ground with two passes along each row for height consistency with a BCS 739 walk behind flail mower. Bare ground treatments received two 36”-wide tillage passes per whole plot (between row) with a BCS 739 walk-behind tiller. No-till with fabric, no-till no fabric and tilled with fabric treatments were weeded by hand per 9 m management strip. Oats were hand weeded at the first weeding event for 2022 and 2023 due to competition with the clover and cash crop treatments (Table A.1.). Tilled no fabric treatments were hand cultivated with a stirrup hoe per nine meter management strip.

Squash petiole nutrient analysis. Squash petioles were sampled due to yellowing and wilting of the leaves noticed in July in 2022 and 2023. Petioles were collected on August 9, 2022 and August 18, 2023 (table A.1.). Five squash petioles were collected on the 9th node on each squash plant per 9 m management strips and placed in a brown paper sample bag prior to shipment. Squash petiole samples were sent to Ward Laboratories Inc., (Kearney, NE) the same day as collection to be analyzed for nitrogen, phosphorus and potassium levels.

Plant Height, Vine Length and SPAD Measurements. Vine Length was collected several times in 2022 and once in 2023 (Table A.1.). Vine length was measured across the two outermost leaves from the middle five plants of each 9 m management strip. Plant height was collected on September 24, 2022 and August 28, 2023 (Table A.1.). Plant height was measured from the soil at the base of the plant to the tip of the highest leaf.

SPAD measurements were collected in July, 2022 with a SPAD meter (Konica Minolta Sensing America Inc., Ramsey, NJ). SPAD measurements were collected on the middle five squash plants in each 9 m management strip on the most recently matured leaf five times. SPAD readings are an indirect measurement of chlorophyll content and are correlated with nitrogen content in several plants (Jokela and Nair 2016).

Squash dried plant biomass. In September 2022 and 2023, cash crop biomass was collected at the end of the season (Table A.1.). Two ‘Jester’ squash plants were trimmed at the base of the stem from each nine meter management strip and were placed into large brown sampling bags. Samples were dried at 60 degrees Celsius in 2022 for one week and 43 degrees Celsius in 2023 for 1.5 weeks in a conventional gas dryer due to necessary repairs on the dryer system. Dried cash crop biomass was weighed to the nearest 0.5 g to determine dried weight.

Harvest. A single harvest event took place on September 16, 2022 and August 28, 2023 (Table A.1.). Every squash fruit from the middle six plants in each 9 m management strip was harvested and graded into USDA quality standards (USDA AMS Standards). Size standards of squash were determined based on previous winter squash research (Hinds et al. 2016). Categories for this research included marketable (U.S. 1) free of imperfections and a diameter of 10 cm and above; non-marketable consisted of undersized fruit or fruit damaged by insect or rodent pests. Squash was graded visually, counted, and weighed at the time of harvest and was later composted or donated based on the condition of the fruit.

Statistical analysis

All data was analyzed in SAS (version 9.4). Harvest, SPAD, plant height, vine length, squash petiole analysis and squash dried plant biomass were analyzed using analysis of variance (ANOVA) for all response variables using the PROC GLIMMIX procedure with year, clover and management as fixed factors and clover as a split plot error term. All data were separated by year, and mean separations for treatment effects were based on Fisher's protected least significant differences at $p \leq 0.05$. If interactions were not present, data were analyzed based on main effects of clover and soil management treatments. When interactions between clover and soil management existed, data were analyzed and presented as differences among soil management treatments within each clover treatment.

Clover whole plot and in-row plant height and biomass were analyzed using repeated measures mixed model ANOVA using the Mixed procedure in SAS (version 9.4). Date, clover and management were fixed factors and block was treated as a random factor. All corresponding means separations were based on Fishers protected least significant differences at $p \leq 0.05$.

RESULTS

Clover whole plot height and biomass

White x Kura clover (KC) resulted in the least amount of biomass potential compared to the other clover treatments in 2022 (Table A.5.). KC height was similar to white clover (WC) height throughout the season and showed no differences among all clover height in September 2022 (Table A.4). By the end of the season, KC clover produced the least amount of biomass compared to the other clover treatments (Table A.5.). Red clover (RC) showed the greatest height potential until September when all clover performed the same (Table A.4.). RC biomass outcompeted WC in the beginning of the season for plant biomass but showed no differences in July or September (Table A.5.).

Weed biomass accumulated the most in bare ground (BG) treatments in the beginning of the season and decreased significantly throughout the 2022 season (Table A.5.). All clover treatments decreased by July and then increased significantly by September (Table A.5.). By the end of the season, KC treatments produced the greatest amount of weed biomass at 569 Kg/Ha, which was relative to the other treatments (Table A.5.).

Clover struggled to establish in the 2023 season (Table A.4.). Clover height showed no differences for June 5, while biomass showed no differences in June, July 6, and September (Table A.4.). WC plots had the most weeds in the beginning of the season compared to the other treatments (Table A.5.). RC produced the tallest height on July 6 compared to the other treatments but showed no differences between treatments for other dates (Table A.4.).

Weed biomass was high throughout the season due to poor clover establishment in 2023 (Table A.5.). Weed biomass was the greatest in BG treatments and decreased throughout the season compared to the clover treatments (Table A.5.). Weed biomass performed the same throughout the season within clover treatments, except for RC on July 28 which showed greater weed biomass compared to BG, WC and KC treatments (Table A.5.).

<u>Cash Crop Performance</u>

SPAD. Clover treatments effected squash plants ($p = 0.01$) for SPAD readings taken in 2022 (Table A.6.). Squash in the BG plots resulted in the highest outcome out of all treatments with 54.6 units compared to the clover treatments (Table A.6.). KC, RC and WC remained consistent in July for SPAD readings with a range of 34-37 units. Soil management treatments had no effect ($p = 0.5$) on SPAD readings taken in July 2022 (Table A.6.).

Squash Nutrient Petiole Analysis. Clover whole plots had an effect ($p = 0.01$) for on squash plants for % N analysis in the 2022 season (Table A.7.). Squash plants in the BG plots resulted in the highest amount of % N per plant (Table A.7.). Clover treatments were the same for % N per squash plant but were lower in the BG plots (Table A.7.). Soil management treatments had an effect ($p = 0.02$) on % N for squash plants in 2022 (Table A.7.) % N for squash plants in the T treatments were like NTF and NT treatment but was different from TF treatments. Squash plants in the NTF treatments were similar to T and NT treatments but were different compared to NT treatments (Table A.7.).

% N nitrogen for squash plants in the 2023 season differed ($p = 0.01$) among clover treatments (Table A.7.). % N for squash plants in the WC treatments were lower than BG plots, but higher than RC and KC plots by a few decimals (Table A.7.). Squash plants showed higher % N in comparison to the clover treatments (Table A.7.). Soil management treatments had no effect ($p = 0.1$) for % N analysis in 2023 (Table A.7.).

Squash Plant Height. There was an interaction among clover and soil management treatments ($p = 0.01$) for plant height collected in September 2022 (Fig. A.1.). Management treatments within clover whole plots showed no differences (Fig. A.1.). Squash plants in the WC, KC and RC plots resulted in the same height for NTF, TF and T treatments (Fig. A.1.). Squash plant height NT treatments were lower than the other management treatments in KC, RC and WC clover plots (Fig. A.1.).

Plant height was affected by whole plot clover treatments ($p = 0.01$) at the 2023 collection date (Table A.6.). Squash plants in the BG plots grew the tallest average plant height per plant compared to the clover treatments (Table A.6.). Squash plants in RC, WC and KC plots were 59% smaller than BG plots (Table A.6.). Management subplots affected squash plant height ($P = 0.01$) in 2023 (Table A.6.). Squash plants in the NT treatments were 59% smaller compared to the squash in the other soil management treatments (Table A.6.). Squash in the T treatments resulted in the highest average plant height at 80 cm compared to the other treatments (Table A.6.). TF and NTF treatments were similar and showed minimal differences (Table A.6.).

Squash Vine Length. Squash vine length differed (p = 0.01) throughout the 2022 field season (Table A.6.). During the July 29, 2022, event, vine length was considerably longer in BG plots compared to the clover treatments (Table A.6.). RC, KC and WC treatments resulted in no differences between treatments (Table A.6.). Squash plants in the RC treatments were an average of 128 cm below BG plot for vine length (Table A.6.). Management treatments also showed differences (p = 0.01) for July 2022 (Table A.6.). Squash plant height in the T treatments were similar to NTF and TF treatments, but NTF, TF and NT treatments were different (Table A.6.). Squash plants had shorter vines in the NT treatments compared to the other treatments (Table A.6.).

Clover treatments had an effect on squash vine length (p = 0.01) in September 2022 (Table A.6.) Squash plants in the BG plots resulted in the longest vine length compared to RC, WC, and KC treatments (Table A.6.). Squash vine length was 69% shorter in the clover treatments than BG plots, which is a dramatic difference for plant growth (Table A.6.). Soil management treatments followed similar trends for the September 2022 event (Table A.6.). Squash plant heigh in the NT treatment was lower than the T, TF and NTF treatments (Table A.6.).

Clover whole plots effected (p = 0.01) squash vine length collected in August, 2023 (Table A.6). Squash plants in the BG plots had the longest squash vines compared to the clover treatments (Table A.6.). Squash vines were 53% shorter in RC, KC and WC plots compared to BG squash plants (Table A.6.). Squash plants in the T treatments were similar to TF and NTF treatments for vine length in 2023 (Table A.6.). Squash plants resulted in a shorter vine length in the NT treatments by the end of the season compared to the other soil management treatments (Table A.6.).

Squash Dried Plant Biomass. Squash plants grown in the clover whole plots resulted in differences ($p = 0.01$) in 2022 (Table A.6.). BG plots resulted in the largest squash plants at 0.4 kg compared to the clover treatments (Table A.6.). There were no differences between squash biomass in the KC, RC and WC treatments at 0.1 kg, which is 75% lighter than BG squash (Table A.6.). Soil management treatments had an effect ($p = 0.05$) on squash biomass in 2022 (Table A.6.). Squash plants in the NT treatments resulted in the smallest plants compared to the other treatments, however, squash plants in the NTF, TF and T treatments showed no differences between each other but outperformed NT plots (Table A.6.).

Squash plants in the clover whole plots resulted in differences ($p = 0.01$) between clover treatments for squash biomass in 2023 (Table A.6.). BG squash plants weighed the most at one kilogram on average, which is 63% higher than squash grown in the clover plots (Table A.6.). The lightest squash plants weighed an average 0.2 Kg, which were collected from the RC, KC and WC plots (Table A.6.). Soil management treatments had an effect ($p = 0.05$) on squash biomass in 2023 (Table A.6.). Squash plants in the T, TF and NTF treatments performed the same and resulted in an average squash weight of 0.4 kg. Squash plants weighed an average of 0.3 Kg in the NT treatments, which is 25% lower than the other management treatments (Table A.6.).

Squash Harvest

Marketable fruit count. Marketable fruit count was affected by clover treatments (p = 0.01) in 2022 (Table A.8.). Squash plants in the BG plots resulted in the most marketable fruit with seven squash per plant compared to the clover treatments (Table A.8.). Squash plants in the RC, WC and KC treatments each had one fruit harvested per plant (Table A.8.). Soil management also influenced marketable fruit count (p = 0.01) in 2022 (Table A.8.) Squash plants in the NT plots produced two marketable fruits per plant, which is 33% fewer fruit compared to squash in the T, TF and NTF treatments (Table A.8.). Three marketable fruits were harvested from squash plants in T, TF and NTF treatments (Table A.8.).

There was an interaction of soil management treatments within clover whole plots (p = 0.01) for marketable fruit count in 2023 (Fig. A.2.). Fruit harvested from the TF and NTF treatments in the BG plots resulted in five fruit per plant, which was more fruit compared to T and NT treatments. Fruit harvested from the TF and NT treatments in the KC plots were similar, while NTF and T treatments were also similar (Fig. A.2.) Less than one fruit on average was harvested from the NT treatments in KC plots (Fig. A.2.) Fruit harvested from the NT plots was 20% less than TF, T and NTF treatments within RC plots (Fig. A.2). Fruit harvested in the TF, T and NTF treatments within WC plots was 77% more than squash harvested from NT treatments (Fig. A.2.).

Marketable Fruit Weight. Marketable fruit weight in the clover treatments resulted in differences (p = 0.01) in 2022 (Table A.8.). Fruit harvested from the BG plots resulted in an average of six kilograms squash per plant compared to the clover treatments (Table A.8.). Average fruit weight was 74% less than BG plots harvested from WC, KC and RC plots (Table A.8.). Soil management treatments had no effect on marketable fruit weight (p = 0.4) in 2022 (Table A.8.).

Clover whole plots effected (p = 0.01) average marketable fruit weight harvested in 2023 (Table A.8.). Squash plants in the BG plots produced an average fruit weight of three kilograms per plant compared to the clover treatments (Table A.8.). Fruit harvested from RC, WC and KC plots produced the same outcome for fruit weight in 2023 (Table A.8.). Soil management treatments effected (p = 0.01) average fruit weight per plant at the 2023 harvest event (Table A.8.). Squash harvested from TF treatments resulted in an average weight of two kilograms per plant, which is higher than squash harvested from NT and T treatments (Table A.8.). Average fruit weight NTF shared similar weights to TF, T and NT treatments (Table A.8.).

Non-marketable fruit count. Clover treatments had no effect on non-marketable fruit count (p = 0.7) in 2022 (Table A.8.). Soil management treatments had no effect on non-marketable fruit count (p = 0.7) in 2022 (Table A.8.).

Differences were shown among clover whole plots (p = 0.01) for non-marketable fruit count harvested in 2023 (Table A.8.). Fruit harvested from BG plots resulted in the highest amount of fruit harvested at three fruit per plant compared to the clover treatments (Table A.8.). 82% less fruit was harvested per plant in RC, KC and WC plots compared to BG (Table A.8.). Soil management treatments had no effect (p = 0.5) on non-marketable fruit harvested per plant in 2023 (Table A.8.).

Non-marketable fruit weight. Clover whole plots (p = 0.6) and management treatments (p = 0.6) had no effect on non-marketable fruit weight in 2022 (Table A.8.).

Differences were shown among clover whole plots (p = 0.01) for non-marketable fruit weight harvested in 2023 (Table A.8.) Squash plants in BG plots resulted in the highest average weight of one kilogram per plant, which is 90% higher than the clover treatments (Table A.8.). RC, KC and WC treatments showed no differences for fruit weight and resulted in an average non-marketable weight of 0.1 kg per plant (Table A.8.). Soil management treatments had no effect (p = 0.7) on non-marketable fruit weight harvested in 2023 (Table A.8.).

DISCUSSION

The objective of this research was to analyze the differences among clover treatments with different soil management treatments within planting rows. Another objective was to understand management treatments and clover whole plot effects on cash crop growth and yield response throughout the season. Research has shown living mulch to reduce cash cash crop yields even in high rainfall areas (Bruce et al. 2016; Hinds et al. 2016; Pfeiffer et al. 2016).

Weather effects and living mulch. Rainfall impacted clover establishment for both years of the living mulch trial. April 2022 received heavy rainfall, which was optimal for cover crop planting which means clovers were able to have a strong start. Moisture in April 2023 was lower than in 2022 and created issues with establishing 2023 clover plots, which seems common in midwestern studies (Bruce et al. 2022; Pfieffer et al. 2016). The 2022 season did not receive much rainfall throughout the season which caused the clover trial to suffer as the season went on. Precipitation varied throughout the season for 2023. Rainfall occurred throughout June and July which caused weeds to quickly emerge and the clovers to suffer further establishment. By the end of both seasons, weeds were the remaining greenery in the plot and clovers were difficult to be seen due high weed populations.

Limited moisture occurred in 2022 and 2023 for living mulch establishment, which occurred at different times of the season. In 2022, the month of April had high wind speeds and increased moisture conditions which posed concerns for clover establishment. Wind isn’t uncommon across the United States, high wind speeds were noticed in Washington (Zhang et al. 2019) which impacted living mulch establishment in strawberries. Living mulch could establish well early into the season until rainfall began to decrease in June and July which affected further clover establishment after mowing events. The mowing event that occurred in June 2022 was set to low at 5.1 cm, which cut clover and weeds too short and allowed for weeds to take over the plots due to decreased rainfall in June and July. Similar to North Dakota, (Puka-Beals and Gramig 2021) an emergency mowing event occurred in August 2022 due to the underestimated over-growth of weeds, which could also prove for poor establishment of clovers by the end of the season.

Clover establishment in 2023 had the opposite weather pattern 2022 received for early Spring. Snowfall and snow melting occurred until early April which caused the fields to be inaccessible until this point. Cover crops were not planted until April 17, 2023 (Table A.1.) and showed challenges with establishing due to limited rainfall in late April and the month of May (Table A.2.). This caused weeds to deplete the water table and vigorously compete with oats and clover that did not have much of a chance to survive. By the time overhead irrigation was applied, it was too late, and the weeds had already overtaken the area. This caused the weeds to act as a living mulch for year two of the project, which means no-till no fabric treatments did not exhibit as heavy of competition between clover, oats, and weeds with squash plants. Squash plants did have more of a chance to establish and canopy over weed treatments in 2023 compared to 2022 given the living mulch challenges, but yield decreases were still noticed in 2023. Similarly in Wisconsin, living mulch establishment suffered which showed yield decreases and squash canopy acting as a weed barrier (Strader et al. 2017).

In 2022, aisle mowing occurred with a push mower (Puka-Beals and Gramig 2021; Vollmer et al. 2010), which was too low for the clover treatments caused them to die off due to low soil moisture. In 2023, mowing events occurred with both a zero-turn sit down mower and a 91.4 cm-wide BCS flail mower (BCS, Oregon City, OR.) (Pieper et al. 2015). In 2023, mowing height was set to four inches to create less clover die off due to limiting moisture which was shown in 2022. Due to these mowing differences, labor times were not analyzed because the data would not be representative for both years and would show very large differences.

Types of weeds identified in research plots were the same in 2022 and 2023. Weeds noticed were typically broadleaves which include: kochia, common lambsquarters, velvet leaf, redroot pigweed, hedge bindweed and field plantain. As stated above, research plots were not able to establish well in 2022 and 2023, so weeds were spread across fields and found within many different clover and management treatments. Grasses were not as common, which may be a benefit because they can be timely to hand weed (Pfieffer et al. 2016). However, grasses that were noticed were bristly foxtail, crab grass and giant foxtail. Grasses were typically noticed around the header pipe of the irrigation, which may signify the presence of soil moisture impacting weed emergence (Perkus et al. 2022).

BG squash plants were the tallest, likely due to no competition between squash, oats, weeds and clovers. SPAD measurements were also highest in the BG treatments which could be speculated that the winter squash had 91.4 cm roots that drew nitrogen from down under. Plant biomass was noticeably bigger in 2023 and could be partly due to increased fertility practices (Warren et al. 2015). Fertigation frequency was increased in 2023 after observing signs of nitrogen deficiency in 2022. Fertigation events occurred every seven to ten days in 2023, which was more than 2022 which only had three fertigation events. Soil organic matter from 2022 soil tests were mitigated from 2023 fertilizer applications to give the squash a fair chance and to decrease leaf yellowing potential throughout the season as seen in 2022.

Similar to plant height, vines were longer on average in 2023 than in 2022. Increased fertigation in 2023 could have caused plants to uptake more nitrogen and produce faster growing stems (Warren et al. 2015). Squash vine length could have been contributed to clover die back due to the overshading of the clovers in both seasons (Strader et al. 2017). Fields became difficult to mow due to squash canopy, but squash vines visibly outcompeted weeds next to the fabric due to less light available to weeds.

In 2022, squash vine borer impacted 75% of harvestable squash plants, which caused plants to yellow and wilt in July. In 2023, 60% of squash plants were impacted by squash vine borer which caused the same plant effects as seen in 2022. In August 2022, squash plants were given a rescue plan of removing squash vine borers through a cut in the main squash stem and a cast was created with mud (Schuch et al. 2022). Squash plants survived and yielded squash fruit, but unsure if the rescue event positively impacted fruit growth. In 2023, proactive measures were taken for pest scouting to prevent vine borer concerns earlier in the season. DiPel DF was applied around squash stems in August 2023 for vine borer pressures. Vine borer pressure decreased compared to 2022, however plants began to yellow which created a need for squash petiole sampling to examine nutrient levels. Studied in Iowa, mesh row covers may prevent vine borers from entering squash stems (Nelson and Gleason 2019). Squash petiole samples were collected for both seasons due to the same concern of yellowing of squash leaves. Results showed differences for % N of squash plants in clovers and management treatments in 2022, but no differences for soil management treatments and few differences in clover treatments in 2023. The result of the % N squash petiole analysis shows there was a nutrient deficiency across the field, not one specific treatment which was suggested in (Hinds et al. 2016).

Plant biomass followed the same trends in 2022 and 2023. BG squash plants were the smallest compared to the clover treatments, which could mean there was less competition for the squash plants overall (Jokela and Nair 2016). The same trends were noticed in NT, which had the smallest squash plants which could signify more competition with clovers and weeds (Jokela and Nair 2016).

In 2022, marketable fruit count was higher overall than 2023, which could be due to the later harvest date in 2022. Fruit harvested from the BG plants were heavier than those harvested in clover plots. This was noted in Wisconsin, where squash fruit weighed less than bare ground squash (Strader et al. 2017). More fruit was harvested in the BG plots compared to the clover treatments which shows that clovers create a negative relationship with cash crop harvest performance. Less fruit was harvested from the NT treatments compared to TF, T and NTF treatments. This could mean that weeds and clover can steal nutrients, space, and light from cash crops (Hooks et al. 2013). In August 2022, weeds began to overtake clover and soil management plots and required a mowing event to knock down weeds. This caused the clovers to die off in July and weeds to take over which impacted cash crop yields and clover establishment.

In 2023 squash plants were drooping and wilting by August and harvest needed to take place to mitigate problems with fruit and further vine borer concerns (Nelson and Gleason 2019). Squash plants in 2023 produced less marketable squash compared to 2022 most likely due to earlier harvest and plant health concerns. Squash plants in BG plots produced more squash in 2023 mimicking 2022 which shows that clovers and weeds provide aggressive competition in the clover whole plots (Bruce et al. 2022; Pfieffer et al. 2016). The amount of fruit harvested was lower in the NT treatments, which was surprising due to poor clover establishment in 2023 which caused less competition with squash plants.

CONCLUSION

Establishment of early season clovers as a living mulch has shown negative effects on cash crop yield and plant health data. Even with wider-rows of tillage and landscape fabric, squash was still sensitive to yield declines. Weed suppression seemed promising in year one until drought conditions affected clover establishment and midseason growth. Low rainfall affected clover growth in the beginning and throughout the 2023 season which was not a major concern in other studies (Pfieffer et al. 2016; Tarrant et al. 2020)

Farmers who are considering integrating living mulches into their can see positive benefits such as improved soil health (Theriault et al. 2009) and may act as a beneficial green manure. Farmers should also consider the benefits of weed suppression (Puka-Beals and Gramig 2021; Rylander et al. 2020) from living mulches as well as the possibility of welcoming pollinators to the area (Splawski et al. 2014).

This research confirms that early season clover cover crops as a living mulch negatively influenced weed suppression and winter squash establishment in dry Great Plains conditions with little precipitation. Future research should consider increased early season supplemental irrigation to encourage clover growth and provide weed suppression. Future studies should consider nitrogen credit from the clovers throughout the season to measure competition between living mulch and squash. Tillage and landscape fabric applications still show little protection against yield loss which specialty crop farmers should consider if they are interested in incorporating living mulches into their systems.

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APPENDIX A

Table A.1 Dates of Key Field Operations and Data Collection Events Collected at the Southeast Research Farm, Beresford, SD.

Activity	2022	2023
Seeded Oats and Cover Crops	Apr. 5	Apr. 17
Seeded Squash Transplants in Greenhouse	14-May	8-May
Clover and Weed Counts	27-May	19-May
Mowed CC, Tilled, Pinned Fabric	8-Jun; 9-Jun.	5-7-Jun
Jester' and 'Honeybear' Squash Transplanted in Field	10-Jun.	7-Jun
Fertigation Events	10-Jun; 29-Jul; 18-Aug.	13-Jul; 20-Jul; 28-Jul; 3-Aug; 11-Aug; 15-Aug; 23-Aug
Collected Whole plot Clover Biomass	21-Jun; 6-Jul; 23-Sep.	5-Jun; 20-Jun; 5-Jul; 28-Jul; 1-Sep
Collected In-row Subplot Clover Biomass	21-Jun; 6-Jul; 23-Sep.	20-Jun; 5-Jul; 1-Sep.
Mowed CC / Weeded Subplots	27-May; 22-Jun; 7-Jul; 22-Aug.	5-Jun; 20-Jun; 5-Jul; 28-Jul.
Collected Vine length and SPAD Measurements	27-Jul.	N/A
Squash Vine Borer Extraction	10-Aug; 12-Aug.	N/A
Entrust Application for Grasshoppers	N/A	26-Jun
DiPel DF Application for Squash Vine Borer	N/A	2-Aug
Pyganic Application for Spotted Cucumber Beetles and Squash Bugs	25-Jul; 3-Aug.	2-Aug
Collected Squash Petioles for Nutrient Analysis	9-Aug	18-Aug
Stand Counts	16-Sep	25-Aug
Harvest	16-Sep	25-Aug
Collected Final Plant Height, Vine Length, and Squash Plant Biomass	24-Sep.	28-Aug

Table A.2. Mean monthly total precipitation and monthly average minimum and maximum temperature for the 2022 and 2023 research seasons at the Southeast Research Farm, Beresford, SD.

Year	Month	Minimum Air Temperature (°C)	Maximum Air Temperature (°C)	Average Air Temperature (°C)	Total Precipitation (cm)
2022	*April*	14.1	0.0	6.8	2.3
	May	21.9	9.5	15.6	5.7
	June	29.1	15.3	22.5	3.2
	July	30.8	17.5	24.1	3.3
	August	29.3	15.8	22.4	3.4
	September	27.3	11.1	18.9	3.3
2023	*April*	15.5	1.9	8.7	1.9
	May	25.4	11.1	18.3	3.0
	June	29.3	16.3	22.8	6.0
	July	28.1	15.3	21.7	10.2
	August	29.3	16.2	22.5	6.4
	September	27.3	12.9	19.8	5.3

Table A.3. Total average precipitation and average maximum and minimum daily air temperature collected from 1993-2023 in Beresford, SD.

Month	Minimum Air Temperature (°C)	Maximum Air Temperature (°C)	Average Air Temperature (°C)	Total Precipitation (cm)
April	1.6	15.4	8.5	6.4
May	8.6	22.1	15.3	9.1
June	14.5	27.6	21.1	10.4
July	16.8	30.0	23.4	7.9
August	15.3	28.8	22.1	8.1
September	9.7	24.3	17.0	7.1

Table A.4. Clover and weed whole plot (pathway) height accumulation collected from alleyways between planting 'Jester' delicata squash rows throughout 2022 and 2023 research seasons at the Southeast Research Farm, Beresford, SD.[z]

2022

	Weed Height (cm)			Clover Height (cm)		
Date	**June 6**	**July 6**	**Sept. 23**	**June 6**	**July 6**	**Sept. 23**
BG[y]	26 Aa[x]	28 Aa	0 b	0 C	0 C	0
KC	14 B	12 B	10 a	9 Ba	6 Bb	16
RC	13 B	14 B	11 a	15 Aa	10 Ab	16
WC	23 AB	13 B	8 a	9 Bab	6 Bb	15

2023

	Weed Height (cm)					Clover Height (cm)				
Date	**June 5**	**June 20**	**July 6**	**July 28**	**Sept. 1**	**June 5**	**June 20**	**July 6**	**July 28**	**Sept. 1**
BG	26 a	3 Bc	5 c	12 Bb	0 Bc	0	0 C	0 b	0 b	0 b
KC	28 a	21 Ab	11 c	25 Aab	22 Ab	6	4 a	0 b	3 a	2 a
RC	28 a	16 Ab	10 c	25 Aab	26 Aa	4	4 a	4 a	8 a	7 a
WC	30 a	21 Ab	10 c	28 Aa	28 Aa	4	5 a	0 b	4 a	4 a

[z]Uppercase letters represent differences among treatments within a single date column. Lowercase letters represent differences among dates within rows for single treatment type.

[y]BG: bare ground, KC: White x Kura Clover, RC: Red Clover, WC: White Clover.

[x]Values within the same column and treatment followed by the same letter are not statistically different according to Fisher's protected least significant difference ($P \leq 0.05$). Data are presented as management (M) within clover (C) treatments due to multiple response variables with M x C interactions.

Table A.5. Clover and weed whole plot (pathway) biomass accumulation collected from alleyways between planting 'Jester' delicata squash rows throughout 2022 and 2023 research seasons at the Southeast Research Farm, Beresford, SD.[z]

2022

	Weed Biomass (Kg/h)			Clover Biomass (Kg/h)		
Date	**June 6**	**July 6**	**Sept. 23**	**June 6**	**July 6**	**Sept. 23**
BG[y]	563 Aa[x]	494 Aa	100 B	0 C	0	0 B
KC	194 Bb	118 Bb	569 Aa	52 AB	43	24 B
RC	176 B	190 B	364 AB	73 Ab	57 b	166 Aa
WC	217 B	241 B	391 A	36 BCb	20 b	124 Aa

2023

	Weed Biomass (Kg/h)					Clover Biomass (Kg/h)				
Date	**June 5**	**June 20**	**July 6**	**July 28**	**Sept. 1**	**June 5**	**June 20**	**July 6**	**July 28**	**Sept. 1**
BG	34 Bbc	1140 Aa	37 Bb	283 Bbc	0 Bc	0	0	0	0	0
KC	716 Ba	710 Ba	390 Ab	591 ABa	600 Aa	7	5	1	6	2
RC	716 Bab	854 Ba	525 Ab	735 Aa	598 Ab	4	3	10	26	30
WC	779 Aa	847 Ba	509 Ab	718 ABa	586 Aa	11	4	1	17	27

[z]Uppercase letters represent differences among treatments within a single date column. Lowercase letters represent differences among dates within rows for single treatment type.

[y]BG: bare ground, KC: White x Kura Clover, RC: Red Clover, WC: White Clover.

[z]Values within the same column and treatment followed by the same letter are not statistically different according to Fisher's protected least significant difference ($P \leq 0.05$). Data are presented as management (M) within clover (C) treatments due to multiple response variables with M x C interactions.

Table A.5 Mean Cash crop performance data for 'Jester' Delicata squash plant grown in 2022 and 2023 at the Southeast Research Farm, Beresford, SD. Data includes, SPAD, plant height, vine length and dried squash plant biomass.

	2022				**2023**		
	July 29		**Sep. 23**		**Aug. 28**		
Treatment	**Vine Length (cm)**	**SPAD**	**Vine Length (cm)**	**Plant Dry Weight (Kg)**	**Plant Height (cm)**	**Vine Length (cm)**	**Plant Dry Weight (Kg)**
Clover (C)[z]							
BG	213.6 a	54.6 a	424.0 a	0.4 a	109.9 a	446.0 a	1.0 a
RC	84.6 b	34.6 b	98.0 b	0.1 b	48.9 b	131.6 b	0.2 b
WC	87.3 b	37.2 b	96.3 b	0.1 b	58.6 b	135.1 b	0.2 b
KC	90.8 b	36.4 b	100.6 b	0.1 b	49.7 b	131.1 b	0.2 b
p-value[x]	*0.01*	*0.01*	*0.01*	*0.01*	*0.01*	0.01	0.01
Management (M)[w]							
T	134.3 ab	41.0	197.4 a	0.2 a	80.3 a	223.1 b	0.4 a
NT	69.4 c	43.0	125.1 b	0.1 b	44.5 c	146.4 c	0.3 b
TF	145.4 a	38.6	205.5 a	0.2 a	77.4 ab	250.1 a	0.4 a
NTF	127.2 b	39.8	190.9 a	0.2 a	64.7 b	214.3 ab	0.4 a
p-value	*0.01*	*0.8*	*0.01*	*0.05*	*0.01*	0.01	0.05
C x M							
p-value	*0.2*	*0.5*	*0.6*	*0.9*	*0.5*	*0.5*	*0.7*

[z]Clover treatments were: bare ground (BG), red clover (RC), white clover, (WC), and white x kura clover (KC)

[y]Values within the same column and treatment followed by the same letter are not statistically different according to Fisher's protected least significant difference ($P \leq 0.05$).

[x]*p-values* based on *F* test.

[w]Management treatments were tillage (T), no-till (NT), tillage + fabric (TF), and no-till + fabric (NTF)

Table A.7. Average SPAD readings collected on July 29, 2022 and Average % N, P and K collected on August 9, 2022 and August 18, 2023 per 'Jester' Delicata squash plant grown in 2022 and 2023 at the Southeast Research Farm, Beresford, SD.

	2022				2023		
Treatment	**SPAD**	**% N**	**% P**	**% K**	**% N**	**% P**	**% K**
Clover (C)[z]							
BG	54.6 a[y]	4.6 a	0.5	2.8	3.2 a	0.4 b	2.2
RC	34.6 b	3.0 b	0.5	2.7	2.3 c	0.7 a	2.2
WC	37.2 b	2.7 b	0.5	2.5	2.5 b	0.7 a	2.4
KC	36.4 b	3.1 b	0.5	2.6	2.1 c	0.7 a	2.3
p-value[x]	*0.01*	*0.01*	*0.8*	*0.3*	*0.01*	*0.01*	*0.1*
Management (M)[w]							
T	41.0	3.5 ab	0.5 b	2.6 b	2.5	0.5 c	2.3
NT	43.0	3.6 a	0.6 a	3.1 a	2.7	0.7 a	2.3
TF	38.6	3.1 c	0.5 b	2.3 c	2.4	0.6 bc	2.1
NTF	39.8	3.2 bc	0.5 ab	2.4 bc	2.6	0.6 ab	2.3
p-value	*0.8*	*0.02*	*0.01*	*0.01*	*0.1*	*0.02*	*0.2*
C x M							
p-value	*0.5*	*0.5*	*0.8*	*0.06*	*0.1*	*0.1*	*0.1*

[z]Clover treatments were: bare ground (BG), red clover (RC), white clover, (WC), and white x kura clover (KC)

[y]Values within the same column and treatment followed by the same letter are not statistically different according to Fisher's protected least significant difference ($P \leq 0.05$).

[x]*p-values* based on *F* test.

[w]Management treatments were tillage (T), no-till (NT), tillage + fabric (TF), and no-till + fabric (NTF)

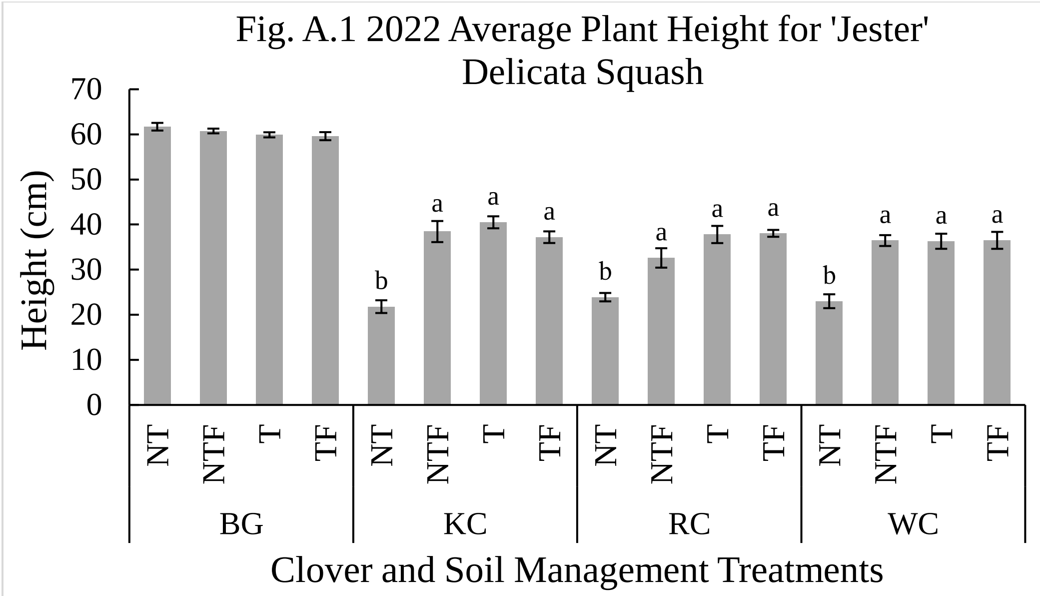

Fig. A.1. Average squash plant height collected on September 23, 2022 for ‘Jester’ delicata squash grown in Beresford, SD. Means with common letters within response variables (clover or soil management) are not difference according to Fisher’s unrestricted least significant difference procedure (a = 0.05) CxM interaction: p = 0.01. BG: p = 0.8, KC: p = 0.01, RC: p = 0.01, WC: p = 0.01.

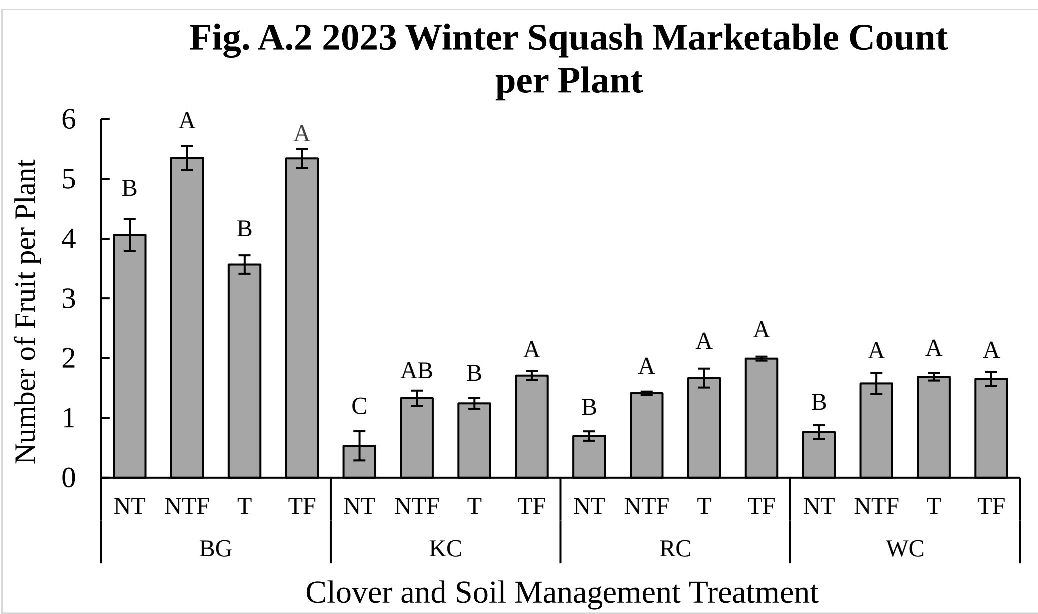

Fig. A.2. Average marketable fruit per plant collected on August 25, 2023 for ‘Jester’ delicata squash grown in Beresford, SD. Means with common letters within response variables (clover or soil management) are not difference according to Fisher’s unrestricted least significant difference procedure (a = 0.05) CxM interaction: p = 0.01. BG: p = 0.01, KC: p = 0.01, RC: p = 0.01, WC: p = 0.01.

Table A.8. Average fruit per plant from 'Jester' Delicata squash grown in 2022 at the Southeast Research Farm, Beresford, SD. Data includes marketable and non-marketable fruit count and weight.

	2022				2023		
	Marketable		**Non-marketable**		**Marketable**	**Non-marketable**	
Treatment	**Fruit Count**	**Fruit Weight (Kg)**	**Fruit Count**	**Fruit Weight (Kg)**	**Fruit Weight (Kg)**	**Fruit Count**	**Fruit Weight (Kg)**
Clover (C)[z]							
BG	7.0 a[y]	6.0 a	0.3	0.04	3.0 a	3.0 a	1.0 a
RC	1.0 b	0.5 b	0.5	0.09	0.7 b	0.4 b	0.1 b
WC	1.0 b	0.5 b	0.4	0.07	0.7 b	0.5 b	0.1 b
KC	1.0 b	0.7 b	0.4	0.08	0.6 b	0.4 b	0.1 b
p-value[x]	*0.01*	*0.01*	*0.7*	*0.6*	*0.01*	*0.01*	*0.01*
Management (M)[w]							
T	3.0 a	3.5	0.3	0.06	1.2 b	1.0	0.3
NT	2.0 b	1.1	0.5	0.08	0.8 b	1.0	0.4
TF	3.0 a	1.8	0.3	0.05	1.0 a	1.0	0.3
NTF	3.0 a	1.9	0.5	0.09	1.0 ab	1.0	0.3
p-value	*0.01*	*0.2*	*0.4*	*0.6*	*0.01*	*0.5*	*0.7*
C x M							
p-value	*0.7*	*0.4*	*0.5*	*0.5*	*0.1*	*0.3*	*0.2*

[z]Clover treatments were: bare ground (BG), red clover (RC), white clover, (WC), and white x kura clover (KC)

[y]Values within the same column and treatment followed by the same letter are not statistically different according to Fisher's protected least significant difference ($P \leq 0.05$).

[x]*p-values* based on *F* test.

[w]Management treatments were tillage (T), no-till (NT), tillage + fabric (TF), and no-till + fabric (NTF)

CHAPTER 3: INTEGRATING EARLY SEASON CLOVER COVER CROPS AS A LIVING MULCH TO IMPROVE SUSTAINABILITY IN BROCCOLI PRODUCTION

INTRODUCTION

Clover cover crops

Midwest specialty crop producers have expressed an interest in replacing black plastic mulch with a natural alternative in their farm system. Clovers are a perennial legume that is typically planted as a cover crop, living mulch or a green manure that can benefit producers prior or during the growing season (Alexander et al. 2019). Legumes can provide nitrogen fixation, weed suppression, decrease soil erosion, improve nutrient cycling, and improve soil structure (Alexander et al. 2019; Warren et al. 2015). Clovers are a perennial that require mowing and hand weeding events throughout the season that may add to farmers labor costs (Granatstein and Mullinix 2008; Puka-Beals and Gramig 2021). Efforts to integrate clovers have been shown to reduce cash crop yields (Jokela and Nair 2016; Perkus et al. 2022; Pfeiffer et al. 2016) which can negatively impact farm income.

Red clover *(Trifolium pratense)* is a biennial cover crop with a tap root (Pfeiffer et al. 2016). White clover *(Trifolium repens)* is a perennial cover crop with a stoloniferous structure (Sparks et al. 2015). White x Kura clover *(Trifolium repens x ambiguum)* is newer to the market with similar characteristics to Kura clover and has a rhizomatous root structure which makes it different from White clover (Ginakes et al. 2020; Lane et al. 2019). White clover is a common cover crop that vegetable farmers integrate into the systems in South Dakota. White clover is commonly integrated for weed suppression and nitrogen fixation for small vegetable systems across the United States (Alexander et al. 2019; Sparks et al. 2015). Kura clover is common for landscapers and landscape restoration due to its root structure and flowering potential (Ginakes et al. 2020). Kura clover and white clover are low growing and are easy to mow on vegetable systems, but they may become time intensive in high rainfall areas during the first year of establishment (Alexander et al. 2019; McCurdy 2013). Red clover has a strong flowering potential which can attract pollinators to the field and may be beneficial for flowering crops like cucurbits or brambles (Tillman et al. 2015).

Living mulch

A living mulch is a cover crop that is simultaneously planted during the growing season that is never terminated (Burgio et al. 2014). Living mulches are commonly planted in the walkways and cash crop rows are strip tilled (Burgio et al 2014; Hinds et al. 2016). Living pathways are becoming increasingly popular due to the need for improved soil health and ground covers along cash crop rows on vegetable farms (Depalo et al. 2017; Thériault et al. 2009). Living mulches may aid in weed suppression, decreased soil erosion, nitrogen fixation and water infiltration, which are all concerns expressed by Midwest vegetable producers (Stein et al. 2022; Thériault et al. 2009). Living mulches may offer benefits to pollinators as well as provide beneficial insects with a host plant to catch common cash crop pests (Tillman et al. 2015; Bruce et al. 2022).

Broccoli

Broccoli is a common cash crop grown on small farms during the spring or fall season (Hoidal et al. 2021; Muramoto et al. 2011). Broccoli has become increasingly difficult to grow in the Midwest due to increasing summer temperatures that causes broccoli to flower and bolt (Hoidal et al. 2021; Jokela and Nair 2016). Living mulches may aid in temperature regulation for cool sensitive crops compared to black plastic mulch or landscape fabric applications (Puka-Beals and Gramig 2021). Broccoli plants are sensitive to no-till systems and saw a decrease in cash crop yields in no-till cereal rye applications (Jokela and Nair 2016). In Pfeiffer et al. (2016) broccoli yields were suppressed 100% by red clover living mulch plots. Broccoli cultivar Sequoia, saw a 6-17% marketable yield reduction in Minnesota due to increased hot and dry summer temperatures in 2021 (Hoidal et al. 2021). Imperial broccoli cultivars planted on July 1 in Minnesota produced an 83-99% marketable yield in Minnesota in 2021, which was higher than multiple common broccoli cultivars (Hoidal et al. 2021). Researchers in South Carolina and New York are breeding broccoli crops to become more heat resistant (Farnham et al. 2011). Their study showed common western broccoli heads did not head in cooler climates (Farnham et al. 2011). Broccoli is a difficult crop to manage across the U.S. due to increasing temperatures and climate variability that genetic breeding may become necessary in the future (Farnham et al. 2021; Stansell et al. 2017).

The objectives of this research were to observe and analyze the effects of early season clover living mulch and various soil management treatments on weed suppression and broccoli cash crop performance. This research was comparing the first year of establishment of clover cover crops as a living mulch in various tilled and no-tillage treatments as a sustainable alternative to single-use polyethylene mulches.

MATERIALS AND METHODS

Site Description

Field research was conducted from April to October in 2022 and 2023 at the South Dakota State University (SDSU) Specialty Crop Research Field in Brookings, South Dakota. The experimental treatments were located within the same field boundaries but were seeded in different plots side-by-side each year to investigate first year living mulch establishment as an alternative to black plastic mulch and their impacts on weed management, broccoli plant health and harvest performance. The soil structure at the experiment site was a Barnes clay loam. The experiment site had experienced drought conditions for several years during and before this research trial. The area used for this experiment was managed using organic practices but was not certified organic. Experimental field location was previously managed for agronomy pathology studies.

Experimental Design

Whole plot (between row) management strategies investigated 'Domino' White Clover (WC) (*Trifolium repens*), 'Dynamite' Red clover (RC) (*T. pratense*), 'Aberlasting' White x Kura Clover (KC) (*T. repens x ambiguum*) and a bare ground control treatment (BG). Jerry oats (*Avena sativa*) were planted as an oat nurse crop within clover treatments to shade out early season weeds and improve clover establishment. In-row soil management treatments within clover whole plots include no-till no with fabric (NT), no-till with fabric (NTF), tilled no fabric (T), and tilled with fabric (TF). This study was a split plot randomized complete block design with four replicated blocks. Vegetable cultivars selected were 'Imperial' broccoli (*Brassica oleracea*) as a cash crop and cut flower varieties as a guard row crop. Broccoli was chosen for its cool season potential and ability to be planted in Spring or Summer and represents a crop that is commonly grown by South Dakota vegetable farmers.

Field Management

Key dates for field activities and data collection are outlined in Table B.1. Clover and oat treatments were seeded in a new area of the research field each year. RC was seeded at 4.4 Kg/Ha, WC was seeded at 2.7 Kg/Ha and KC was seeded at 4.3 Kg/Ha. Oats were seeded with clovers at 13.6 Kg/Ha to outcompete and shade out early season weeds. Clover and oats were seeded on April 26, 2022 and April 27, 2023 using a 1.5 m no-till drill pulled by a John Deere tractor. Total field size was 122 m x 37 m' and clover whole plot dimensions were 9 m x 12 m.

On July 15, 2022 and June 27, 2023 field preparation events such as mowing, tillage, irrigation and landscape fabric installation occurred prior to squash planting (Table A.1). Clover treatments were mowed with a zero-turn sit down mower at a 20 cm height. Treatments that required tillage (T and TF) received two 91 cm-wide tillage passes across 3.6 m management rows with a BCS 749 walk behind tiller (BCS, Oregon City, Oregon). Single drip tape irrigation lines with 20.32 cm emitter spacing (The Toro Company, Bloomington, MN) were installed down each management row after tillage events. Black woven landscape fabric was installed for no-till fabric and tilled fabric treatments with 15 cm steel landscape staples applied every 2.54 cm with a rubber black mallet.

‘Imperial’ Broccoli seeds (Johnny’s Selected Seeds, Winslow, ME) were sown in 50 cell trays in a greenhouse on June 7, 2022 and June 2, 2023 (Table B.1). Broccoli plants were transplanted into the in-row soil management treatments by hand using a trowel. Cash crop management strips were 3.6 m long and consisted of 20 ‘Imperial’ broccoli transplants per double row with a 30.48 cm row spacing. Two-meter-wide nylon mesh row covers (ProtekNet) over galvanized steel hoops, weighed down with sandbags, were installed to protect from deer and pest damage on the broccoli heads and leaves (Table B.1) (Nelson and Gleason 2019). Grasshopper pressure was persistent throughout the season but decreased as temperatures cooled down in the fall.

Fertigation was applied several times over the course of the season in 2022 and 2023 (Table B.1). Fertilizer was applied through drip irrigation with a Dosatron fertilizer injector (Ingersoll Rand, Davidson, NC) at 500 ppm using Nature’s Source Organic Plant Food 10-4-3 (Nature’s Source, Sherman, TX).

Data Collection

A summary of data collected and associated dates is found in Table B.1. *Oat, Cover crop, weed height and biomass*. Data collection for clover establishment and weed competition was taken five times in 2022 and 2023 randomly every 10-14 days over the course of the season (Table B.1). A 25x25 cm^2 quadrat was randomly tossed three times within the whole clover plot alleyways (between crop rows) and two times in each in-row soil management treatment (planting rows) to analyze the competition between weeds, oats and clovers. The tallest weed, oat and clover in each quadrat was measured from the base of the soil to the tallest leaf. Oats, clovers and weeds inside the quadrat were cut at the base of the stem and stored in a paper sample bag prior to biomass drying. Samples were then dried for approximately three days at 60 degrees Celsius in 2022 and five days at 43 degrees Celsius in 2023 in a gas conventional dryer. Dried samples were weighed to the nearest 0.1 grams with a small food scale to determine dried biomass weight. After data collection was taken, oats, clover and weeds were mowed in the whole plot walkways and hand cultivated in the bare ground treatments. Mowing and hand cultivation events occurred in 2022 and 2023 after clover and weed biomass was collected (Table B.1). Mowing height was set at 10.2 cm from the ground with two passes along each row for height consistency with a BCS 749 walk behind flail mower (BCS, Oregon City, OR). Bare ground treatments received two 91.4 cm-wide tillage passes per whole plot (between row) with a BCS 749 walk-behind tiller (BCS, Oregon City, OR). No-till with fabric, no-till no fabric and tilled with fabric treatments were weeded by hand per 3.6 m management strip. Oats were hand weeded in the broccoli rows at the first weeding event for 2022 and 2023 due to competition with the clover and cash crop treatments (Table B.1). Tilled no fabric treatments were hand cultivated with a stirrup hoe per 3.6 m management strip.

Hand weeding and mowing Labor analysis. Mowing and hand weeding events occurred three times in 2022 and 2023 after biomass collection events (table B.1). Two people were timed for hand weeding at each event while one person was timed for mowing events. Each mowing and hand weeding event were timed in minutes to evaluate labor.

Plant Height, Canopy width and SPAD Measurements. Canopy width was collected once in 2022 and twice in 2023 (Table B.1). Canopy width was collected across the two outermost leaf tips from the middle eight plants of each 3.6 m management strip. Plant height was collected once in 2022 and twice in 2023 (Table B.1). Plant height was measured from the soil at the base of the plant to the tip of the highest leaf.

SPAD measurements were collected once in 2022 and twice in 2023 with a SPAD meter (Konica Minolta Sensing America Inc., Ramsey, NJ). SPAD measurements were collected on the middle eight squash plants in each 3.6 m management strip on the most recently matured leaf five times. SPAD readings are an in-direct measurement of chlorophyll content and can aid with fertilizer calculations (Jokela and Nair 2016).

Broccoli dried plant biomass. In October 2022 and 2023 (table B.1), broccoli cash crop biomass was collected at the end of the season. Four ‘Imperial’ broccoli plants were trimmed at the base of the stem after all available broccoli heads were harvested from each 3.6 m management strip and was stored in large brown sampling bags. Samples were dried at 60 degrees Celsius in 2022 for one week and 43 degrees Celsius in 2023 for 1.5 weeks in a conventional gas dryer due to necessary repairs on the dryer system. Dried cash crop biomass was weighed to the nearest 0.5 g with a large food scale to determine dried cash crop weight.

Harvest. Two harvest events took place in 2022 and four events took place in 2023 (Table B.1). Only mature broccoli heads were harvested, weighed, and graded into distinct categories based on the USDA size and quality standards. Standards were modified during the season to measure broccoli head width instead of stem diameter, which is a difference from the USDA standards (USDA AMS). All broccoli heads were harvested on the final harvest date regardless of size. Marketable categories included U.S.

1 (free of imperfections and a head diameter between 10.1-15.2 cm) and U.S. 2 (free of imperfections and a head diameter of 7.6 cm). The head diameter for broccoli was in addition to the stem length requirements from the USDA (USDA AMS Standards). Non-marketable categories included any heads below 3 inches in diameter as well as puffiness, bolting and hollow stem.

Statistical analysis

All data was analyzed in SAS (version 9.4). Harvest, SPAD, plant height, Canopy width, hand weeding and mowing labor data and dried broccoli plant biomass were analyzed using analysis of variance (ANOVA) for all response variables using the PROC GLIMMIX procedure with year, clover and management as fixed factors and clover as a split plot error term. All data were separated by year, and mean separations for treatment effects were based on Fisher's protected least significant differences at $p \leq 0.05$. If interactions were not present, data were analyzed based on main effects of clover and soil management treatments. When interactions between clover and soil management existed, data were analyzed and presented as differences among soil management treatments within each clover treatment.

Clover whole plot and in-row plant height and biomass were analyzed using repeated measures mixed model ANOVA using the Mixed procedure in SAS (version 9.4). Date, clover and management were fixed factors and block was treated as a random factor. All corresponding means separations were based on Fishers protected least significant differences at $p \leq 0.05$.

RESULTS

Living Mulch Performance in 2022

Clover Whole Plot Biomass. Clover height and biomass increased during the 2022 season while weed height and biomass decreased (Table B.4. & B.5.). KC height stayed relatively consistent throughout the season with a peak height of 15 cm on August 9 (Table B.4.). KC clover plant biomass also increased throughout the season with the largest amount of dried biomass on October 5 at 1184 kg/h (Table B.5.). Weed height varied throughout the season in KC treatments with the tallest height on August 1 at 34 cm (Table B.4.). Weed biomass decreased throughout the season in KC plots with the smallest amount of dried weed biomass on October 5 at 8 kg/h (Table B.5.).

RC height fluctuated throughout the season with a peak height of 35 cm on September 9, 2022 (Table B.4.). RC clover plant biomass increased throughout the season to produce an average of 868 kg/h by the end of the season on October 5, 2022 (Table B.5.). Weed biomass in RC plots was the lowest in October with an average biomass of 13 kg/h and the highest amount of weed biomass was collected on September 9 at 279 kg/h (Table B.5.).

WC height fluctuated throughout the season with a peak height of 23 cm on September 9, 2022 (Table B.4.). WC plant biomass increased throughout the season for an end of season average of 1411 kg/h, which is higher than RC and KC treatments (Table B.5.). Weed biomass decreased throughout the season with the lowest amount of weed biomass recorded at the end of the season for an average of 45 kg/h (Table B.5.). The highest amount of weed biomass in WC plots was recorded on August 1 for an average weight of 208 kg/h (Table B.5.). The tallest weed height was 39 cm in September and the smallest height was 12 cm in October 2022 (Table B.4.).

Bare ground (BG) weed height and biomass increased and then decreased by the end of the season in 2022 (Table B.4. & B.5.). Peak weed height in BG plots was 22 cm in September. Peak weed biomass collected in BG plots was 212 kg/h in September, the same date the tallest weed height was found (Table B.5.).

Living Mulch Performance in 2023

KC biomass increased by the end of the season with a peak dried clover biomass weight of 386 kg/h (Table B.5.). Clover height fluctuated throughout the season between mowing events with the tallest height recorded for 13 cm in October (Table B.4.). Weed height increased by the middle of the season and decreased by the end of the season after mowing events (Table B.4.). Peak weed height in KC plots was 21 cm which was collected in August and September (Table B.4.). The shortest weed height was collected early in the season in June at 4 cm (Table B.4.). Weed biomass decreased to 20 kg/h by the end of the season, and resulted in a peak weed biomass in September at 375 kg/h (Table B.5.).

RC biomass increased the most by October compared to the other clover treatments at 616 kg/h (Table B.5.). RC height was the tallest in October at 28 cm which was taller than the other treatments (Table B.4.). Weed height in RC plots fluctuated throughout the season with a peak height of 19 cm which was collected in September and October (Table B.4.). The largest amount of weed biomass was collected in September at

433 kg/h (Table B.5.). The lowest amount of weed biomass collected in June was an average of 67 kg/h (Table B.5.).

WC height increased throughout the season with the tallest height collected in October at 15 cm (Table B.4). The largest amount of clover biomass was collected in October at 412 kg/h (Table B.5.). Weed biomass in WC plots was the highest in September at 524 kg/h and the lowest in June at 68 kg/h (Table B.5.). Weed height fluctuated throughout the season with the tallest height at 26 cm collected on September 7 (Table B.4.).

BG weed height and biomass decreased by the end of the season in October 2023 (Table B.5). Peak weed height in BG plots was 12 cm in September, while the peak amount of weed biomass collected was 557 kg/h collected in August (Table B.5.). The lowest amount of weed biomass was collected at the end of the season in October and produced an average of 20 kg/h (Table B.5.).

<u>Labor Analysis</u>

Timed Labor events for Mowing. Clover whole plots resulted in differences (p = 0001) for mowing events in July 2022 (Fig B.1.). RC plots took the longest to mow at 5.4 minutes compared to KC and WC plots. KC and WC resulted in similar outcomes with 4.7 and 4.4 minutes per plot (Fig. B.1.).

Clover whole plots also resulted in differences (p = 0.01) for mowing events in August 2022 (Fig B.2). RC plots took the longest to mow at an average of 7 minutes compared to KC and WC. KC plots took longer than WC plots at 5.7 minutes and WC plots took 4.8 minutes to mow (Fig. B.2.).

Clover whole plots resulted in differences (p = 0.01) at the end of the season in September 2022 (Fig. B.3). KC and RC plots took similar amounts of time to mow with 5.5 minutes and 6.1 minutes on average per plot (Fig. B.3.). WC plots took the least amount of time to mow compared to KC and RC plots at 4.6 minutes on average (Fig. B.3.).

Timed mowing events in July 2023 resulted in differences (p = 0.01) among clover whole plots (Fig. B.4.). KC and RC plots took almost the same amount of time to mow at 5.6 minutes and 5.5 minutes on average compared to WC plots (Fig. B.4.). WC plots took an average of 4.4 minutes to mow per plot (Fig. B.4.)

Clover whole plots resulted in differences (p = 0.01) for mowing events in August 2023 (Fig. B.5). Like July 2023, it took similar amounts of time to mow KC and RC with 5.9 minutes and 6.1 minutes on average to mow a plot (Fig. B.5.). WC plots took an average of 4.8 minutes of mowing time per plot compared to KC and RC (Fig. B.5).

Time mowing events in September 2023 resulted in differences (p = 0.01) among clover whole plot treatments (Fig. B.6). By the end of the season, KC and RC took the same amount of mowing time per plot at an average of 6 minutes (Fig. B.6.). WC plots took less time compared to KC and RC plots at 5.3 minutes of mowing time on average per plot (Fig. B.6.).

Timed labor events for hand weeding 2022. There was an interaction between management and clover fixed effects (p = 0.04) on hand weeding events in July 2022 (Fig. B.7.) NT treatments in the BG plots took the longest to weed at 22.7 minutes on average compared to the clover treatments (Fig. B.7.). T, TF and NTF treatments took similar amounts of time to weed at 2.8, 1.2 and 2 minutes on average per plot for hand weeding (Fig. B.7.). NT treatments in the KC treatments took an average of 22 minutes to hand weed compared to the other treatments (Fig. B.7.). TF and NTF took the same amount of time to hand weed compared to T and NT treatments, while T treatments took more time compared to TF and NTF. NTF, TF and T treatments took similar amounts of time to hand weed plots in the RC treatments compared to NT treatments (Fig. B.7.). NT plots took an average of 18 minutes to hand weed per plot compared to the other treatments. NT and T treatments took more time to hand weed compared to TF treatments in the WC plots (Fig. B.7.). Hand weeding times in NTF treatments took similar amounts of time compared to TF and T treatments (Fig. B.7.).

There were differences among soil management treatments ($p = 0.04$) for hand weeding events in August 2022 (Fig. B.9.). NT treatments took the longest to hand weed at an average of 5.3 minutes per plot compared to the other treatments (Fig. B.9.). TF treatments took less time to hand weed compared to T and NT treatments (Fig. B.9.). NTF plots took similar amounts of time to hand weed compared to T and TF treatments at an average of 1.7 minutes per plot (Fig. B.9.). Clover whole plots resulted in no differences ($p = 0.3$) for hand weeding events in August 2022 (Fig. B.8).

There were no differences among clover treatments for time needed to weed in September 2022 (Fig. B.10.). Soil Management treatments resulted in differences ($p = 0.09$) between treatments for hand weeding events in September 2022 (Fig. B.11.). TF treatments took the least amount of time to hand weed at an average of 0.6 minutes per plot compared to the other treatments (Fig. B.11.). NTF and T treatments took similar amounts of time to hand weed compared to TF and NT treatments (Fig. B.11.).

Timed labor events for hand weeding 2023. There was an interaction between management and clover fixed effects (p = 0.04) on hand weeding events in July 2023 (Fig. B.12.). NT treatments in the BG plots took the longest to weed at 22.4 minutes on average compared to the clover treatments (Fig. B.12.). T, TF and NTF treatments resulted in similar outcomes at 4.53, 1 and 3.8 minutes on average per treatment for hand weeding (Fig. B.12.). NT plots in the KC treatments took an average of 18.2 minutes to hand weed compared to the other treatments (Fig. B.12.). TF and NTF took the same amount of time to hand weed compared to T and NT treatments, while T treatments took more time compared to TF (Fig. B.12.). NT treatments took the longest to hand weed in RC plots compared to the other treatments. TF treatments took the least amount of time to hand weed for an average of 0.9 minutes per plot (Fig. B.12.). T treatments took longer to weed compared to NTF and TF treatments, while NTF treatments took longer to weed compared to TF treatments at an average of 2.3 minutes per treatment (Fig. B.12.).

Clover whole plots resulted in no differences (p = 0.5) between treatments for hand weeding in August 2023 (Fig. B.13.). Hand weeding events in August 2023 resulted in differences for soil managements treatments (p = 0.01) (Fig. B.14). T and NTF treatments resulted in similar outcomes for hand weeding events at 2.2 minutes and 2.1 minutes on average per plot (Fig. B.14). TF treatments took the least amount of time to hand weed compared to the other clover treatments (Fig. B.14). NT treatments took the longest amount of time to hand weed compared to the other treatments at an average of 5.6 minutes per plot (Fig. B.14.).

There were differences among soil management treatments (p = 0.08) for hand weeding events in September 2023 (Fig. B.16). TF treatments took the least amount of time to hand weed compared to T and NT treatments for an average of 0.4 minutes per plot (Fig. B.16). T and NTF treatments took similar amounts of time to weed compared to NT plots (Fig. B.16.). NT plots took the longest amount of time to hand weed for an average of 2.8 minutes per plot compared to the other treatments (Fig. B.16.). Clover whole plots resulted in no differences ($p = 0.5$) between treatments for hand weeding in August 2023 (Fig. B.15.).

Cash Crop Performance

Broccoli Midseason Plant Height. There was an interaction between clover and soil management treatments ($p = 0.01$) for midseason broccoli plant height in 2023 (Fig. B.17.). NT treatments in KC plots resulted in the smallest broccoli height compared to the other soil management treatments (Fig. B.17.). Broccoli plants in the NTF and T treatments were taller than broccoli plants in the NT plots in KC treatments (Fig. B.17.). TF and T treatments were also similar and greater than NT treatments (Fig. B.17.). Clover and soil management treatments had no effect on BG and RC plots (Fig. B.17.).

Broccoli midseason canopy width. There was an interaction between soil management and clover whole plots ($p = 0.01$) for midseason broccoli canopy width in 2023 (Fig. B.17). Broccoli width was longer in TF and NTF treatments compared to NT plots within all clover treatments (Fig. B.17). T and NT plots were similar, while T plots were also like NTF treatments (Fig. B.17).

Broccoli Midseason SPAD Readings. Clover cultivars and soil management treatments had no interaction ($p = 0.3$) on broccoli chlorophyll content during midseason

2023 (Fig. B.18.). Additionally, clover whole plots did not affect SPAD readings (p = 0.4) as well as soil management treatments (p = 0.6).

Broccoli End of Season plant height. Broccoli plant height in both clover whole plots and soil management treatments resulted in no differences (P = 0.8) between treatments at the end of the season in October 2022 (Fig. B.23.).

Broccoli plant height varied among clover treatments (p = 0.05) in 2023 at the end of the season (Fig. B.19.). Broccoli plants in the BG plots were the tallest at 58 cm compared to the clover treatments (Fig. B.19). Broccoli plant height in the RC, KC and WC treatments performed the same at 49 cm (Fig. B.19). There were no interactions between clovers and soil management treatments (p = 0.1) for broccoli plant height in 2023 at the end of the season (Fig. B.20.).

Broccoli End of Season canopy width. Broccoli canopy width in clover whole plots and soil management treatments resulted in no interaction (p = 0.6) between treatments at the end of the season in 2022 (Fig. B.23.).

Broccoli canopy width in the clover whole plots resulted in differences (p = 0.01) between treatments at the end of the season in 2023 (Fig. B.19.). Broccoli plants in the BG plots produced the widest plants at 60 cm compared to the clover treatments (Fig. B. 19.). RC, KC and WC treatments performed the same at 41 cm compared to BG treatments.

Broccoli canopy width in the soil management treatments resulted in an interaction (p = 0.01) between treatments at the end of the season in 2023 (Fig. B.20.).

Broccoli End of Season SPAD Readings. There was an interaction between clover and soil management treatments (p = 0.02) for SPAD readings at the end of 2022 (Fig. B.22.). Soil management within KC treatments resulted in differences (p = 0.01) compared to RC, WC and BG plots (Fig. B.22.). Broccoli plants in the T treatments in KC plots resulted in the highest SPAD reading compared to NT and TF treatments (Fig. B.22.). NTF treatments were similar to NT and T treatments within KC plots but resulted in higher readings compared to TF plots (Fig. B.22.) Broccoli plants in the NTF and T treatments for KC plots performed similarly to one another. BG, RC and WC were not statistically different between treatments (Fig. B.22.).

There was no interaction between clover whole plots and soil management treatments (p = 0.2) for end of season 2023 broccoli SPAD readings (Fig. B.21).

Broccoli Whole Plant Dried Biomass. Clover whole plots resulted in differences (p = 0.01) between treatments for dried broccoli biomass in 2022 (Table B.6.). BG treatments resulted in the heaviest dried broccoli plants at 163 g compared to the clover treatments (Table B.6.). KC, RC and WC showed no differences between clover treatments (Table B.6.).

Soil management treatments had no effect on (p = 0.6) broccoli plant dried biomass in October 2022 (Table B.6.).

Clover whole plots had an effect (p = 0.01) on broccoli dried plant biomass in October 2023 (Table B.6). Broccoli plants in the BG treatments were the heaviest at 152 g compared to the clover treatments (Table B.6.). Dried broccoli plants in the KC, RC and WC treatments performed the same (Table B.6.).

Soil management plots had an effect on (p = 0.01) dried broccoli plant biomass in October 2023 (Table B.6.). Dried broccoli biomass was the lightest in NT treatments at 57 g compared to the other treatments (Table B.6.). Dried broccoli plants in the TF plots weighed 108 g which was like NTF plots at 105 g (Table B.6.). Dried broccoli plants in the T treatments were lower than NTF and TF but were heavier than NT treatments at 85 g (Table B.6.).

Broccoli Harvest. Clover whole plots effected (p = 0.01) marketable broccoli head count in 2022 (Table B.7.). The greatest amount of marketable broccoli heads was harvested from the BG plots compared to the clover treatments (Table B.7.). Additionally, broccoli heads harvested from WC and KC treatments had five marketable heads per plot compared to RC (Table B.7.). Soil management treatments resulted in no differences (p = 0.2) for marketable broccoli head count in 2022 (Table B.7.).

Clover whole plots had an effect (p = 0.01) on marketable head weight in 2022 (Table B.7.). Broccoli plants in the BG plots resulted in the highest average broccoli head weight at three kg per 20 plants compared to the clover treatments (Table B.7.). KC, RC and WC broccoli plants showed similar broccoli head weights within one another compared to BG (Table B.7.). Soil management treatments (p = 0.5) had no effect on marketable broccoli head weight in 2022 (Table B.7.).

Marketable broccoli head count resulted in differences (p = 0.01) from the clover whole plots for non-marketable broccoli head count in 2022 (Table B.7.). Broccoli plants in RC, KC and WC treatments resulted in an average of seven heads per 20 plants (Table

B.7.). Soil management treatments had no effect (p = 0.8) on non-marketable broccoli head count in 2022 (Table B.7.).

Marketable head weight was affected by clover whole plot treatments (p = 0.01) in 2022 (Table B.7.). Broccoli plants in BG plots resulted in the heaviest broccoli head weight at seven kg per 20 plants compared to the clover treatments (Table B.7.). KC, RC and WC broccoli plants resulted in the same average head weight of 0.1 kg per 20 plants (Table B.7.). Non-marketable broccoli head weight was not affected (p = 0.8) by soil management treatments in 2022 (Table B.7.).

There was an interaction (p = 0.01) among soil management treatments within clover whole plots for marketable broccoli head count in 2023 (Fig. B.24). Broccoli plants in NT treatments in the BG plots resulted in the highest number of marketable heads at eight heads per 20 plants compared to NTF, T and TF treatments within BG (Fig. B.24.). Broccoli plants in the NTF and TF treatments in the KC plots resulted in the most amount of marketable broccoli heads compared to T and NT treatments within KC Fig. B.24.). T treatments in the KC plots produced 3.4 marketable broccoli heads per 20 plants (Fig. B.24.). Broccoli plants in NTF and TF treatments in the RC plots resulted in similar outcomes for marketable broccoli heads compared to NT treatments (Fig. B.24.). Broccoli plants in the NT and T treatments within RC were similar for marketable broccoli head count at zero and two heads (Fig. B.24.). T treatments were also similar to TF and NTF treatments in RC plots (Fig. B.24.). Broccoli yielded worse in the NT plots for KC, RC and WC plots compared to BG treatments (Fig. B.24.). More marketable broccoli heads were harvested from TF and NTF treatments within WC compared to T treatments which only harvested one marketable head (Fig. B.24.).

There was an interaction (p = 0.02) among soil management treatments within clover whole plots for non-marketable head count in 2023 (Fig. B.24.). Broccoli plants in TF, NTF and T treatments within BG resulted in the highest presence of non-marketable heads (Fig. B.24.). Broccoli plants in NT plots in the BG treatments resulted in an average of 10 non-marketable heads per 20 plants (Fig. B.24.). Zero broccoli heads were harvested from NT treatments in RC, KC and WC plots (Fig. B.24.). Three non-marketable broccoli heads were harvested from T treatments within KC plots (Fig. B.24.). 10 non-marketable broccoli heads were harvested from TF treatments within RC plots compared to NTF, T and NT treatments (Fig. B.24.). Broccoli heads in T and NTF treatments resulted in 3.8 and 3.5 non-marketable broccoli heads per 20 plants which was more than NT plots (Fig. B.24.). 12 non-marketable broccoli heads were harvested from TF treatments within WC plots, which was considerably higher compared to T and NTF (Fig. B.24.). Broccoli plants in T and NTF treatments resulted in similar outcomes with three and four non-marketable heads per 20 plants (Fig. B.24.).

There was an interaction (p = 0.05) among soil managements treatments within clover whole plots for marketable broccoli head weight in 2023 (Fig. B.25.). Broccoli heads in TF, T and NTF treatments in the BG plots resulted the same compared to NT treatments within BG (Fig. B.25.). Broccoli heads in the NT plots resulted in an average head weight of one kg which is less compared to the other treatments in the BG plot (Fig. B.25.). Broccoli heads harvested from TF and NTF treatments within KC plots weighed 0.6 kg and 0.5 kg which is more than NT plots (Fig. B.25.). Harvested broccoli head weights were similar among T and NTF treatments within KC plots (Fig. B.25.). Broccoli heads in the TF treatments within RC plots resulted in an average weight of 0.9 kg which was larger than NT plots (Fig. B.25.). Broccoli plants in T and NTF treatments resulted in similar outcomes with an average harvested head weight of 0.25 kg and 0.27 kg within RC plots (Fig. B.25.). Broccoli heads in the TF and NTF plots were heavier than those in the NT and NTF treatments within WC plots (Fig. B.25.).

Broccoli plants in the soil management treatments resulted in no interactions ($p = 0.06$) between treatments for marketable broccoli head weight in 2023 (Fig. B.25).

DISCUSSION

Weather and Living Mulch Performance

Weather impacts on clover establishment. Rainfall impacted clover establishments for both seasons of the living mulch trial, which was not noticed in other studies (Bruce et al. 2022; Pfieffer et al. 2016; Tarrant et al. 2020). April 2022 had adequate soil moisture and was great for clover cover crop planting which means clovers and oats were able to have a strong start. Moisture in April 2023 was lower than 2022 and created concerns with establishing 2023 clover plots. Sprinklers were required in May and June 2023 due to limited moisture and emerging weeds in the trial plots. The 2022 season received more moisture than 2023 and produced a better clover stand early in the season compared to 2023. Moisture varied throughout the season for 2023. Rainfall occurred throughout June and July which caused weeds to grow quickly and the clovers to suffer further establishment. By the end of both seasons, clovers were the remaining foliage in the plot and weeds were difficult to see due to decreasing temperatures and high clover populations.

In 2022, the month of April had high wind speeds and increased moisture conditions which posed concerns for clover establishment. 2023 clover establishment had the opposite weather pattern 2022 received for early Spring. Snowfall and snow melting occurred until early April which caused the fields to be inaccessible until this point. Cover crops were not planted until April 17, 2023, and showed challenges with establishing due to limited rainfall in late April and the month of May. This caused weeds to deplete soil moisture and vigorously compete with oats and clover that didn't have much of a chance to survive.

Clover biomass. Living mulch was able to establish well early in the season until rainfall started to decrease in June and July which effected weed growth after mowing events. Mowing events were initially set to 10.1 cm, but clovers and weeds were still growing aggressively and later decreased to 5.1 cm without clover dying back. In 2022, clover plots were weeded every seven to ten days (Puka-Beals and Gramig 2021), which created less competition with weeds for clovers overtime, but that wasn't the case in 2023. Clover biomass was collected, and plots were weeded every 10-14 days due to labor constraints in 2023, which caused high weed populations throughout the season and increased competition for broccoli plants. BG plots were hand cultivated in 2022 due to plot sizes being too small at 14 cm. This was adjusted to 15.24 cm in 2023 to fit the BCS 749 tiller attachment. This change effected weed growth in 2023, which saw a decrease of weeds present in BG whole plots by the end of the season which was most likely due to the intense tillage of the BCS (Bruce et al. 2022; Hinds et al. 2016).

In 2022, WC plots produced the largest amount of clover biomass by the end of the season compared to the other clovers, which is not surprising considering other studies saw similar effects (Lin et al 2011; Perkus et al. 2022). WC plots also had less weeds compared to the other plots, which makes this a very promising cover crop for weed suppression (Abouziena et al. 2008; Perkus et al. 2022). RC plots underperformed compared to WC and KC plots for weed suppression which is disappointing for growers and researchers interested in incorporating this cover crop into their system. Higher weed populations can increase competition as well as distribute weed seeds into those systems and cause added labor costs in the future (Pfieffer et al. 2016; Vollmer et al. 2010). KC plots weren't far behind WC plots as far as clover biomass establishment, but also showed a high population of weeds throughout the season which can be a concern for vegetable growers.

In 2023, the opposite establishment occurred for the clover plots. RC plots produced the highest amount of biomass and lowest amount of weed biomass which was very surprising due to its less competitive nature (Pfeiffer et al 2016). White clover only produced 412 kg/h in 2023, which was incredibly low compared to 2022. KC clover also underperformed in 2023 with a peak biomass of 386 kg/h by the end of the season. The underperformance can most likely be due to labor constraints which caused plots to be weeded and mowed less often in 2023 compared to 2022. Field location in 2023 also had more compacted soil compared to 2022, which could be due to vehicle access and decreased rainfall. Plots in 2023 also had a higher presence of perennial weeds like Canada thistle, perennial sow thistle and dandelions which made weeding events very difficult and further disrupted the weeds populations.

Weeds collected were noticeably different between plots. Weeds in the BG plots included purslane, redroot pigweed, ladysthumb, common lambquarters and venice mallow. Weeds in the northern most living mulch plots consisted of many broadleaves such as Canada thistle, western salsify, perennial sowthistle, bull thistle, dandelions and waterhemp. This was different in the Southernmost living mulch plots that primarily contained grass weeds such as yellow and green foxtail, wooly cup grass, crabgrass, giant foxtail and barnyard grass. Weeds such as green and yellow foxtail were noticeably present in the RC plots compared to KC and WC which could mean that grasses are more competitive than broadleaves and RC may not be as competitive against grasses compared to WC and KC (Kahl et al. 2019; Puka-Beals and Gramig 2021).

Timed labor events for hand weeding and mowing. Hand weeding events decreased in labor time throughout both seasons in 2022 and 2023, which was also noticed in Wisconsin (Pfieffer et al. 2016). Hand weeding took more time in the beginning of the season after broccoli was planted in BG plots due to grass weeds such as green and yellow foxtail, crab grass and wooly cup grass. As the season went on, BG plots were easier to manage once weed populations declined. In July, WC plots took the longest to weed compared to KC and RC plots which could be due to its competitive roots structure in the beginning of the season (Tarrant et al. 2020). WC plots took noticeably long to weed due to a high population of weeds that needs to be extracted to decrease competition with the clovers and decrease labor costs. After July in both seasons, clover treatments were no longer significant and performed the same for time needed to weed plots.

NT treatments took the longest to hand weed compared to T, NTF and TF treatments due to high weed populations and the competitive nature of drought tolerant weeds. After July, NT treatments took less time to weed once weed populations were contained and clovers were able to further grow. TF treatments took the shortest amount of time to hand weed due to the fabric suppressing weed populations. NTF treatments were right behind TF treatments for time needed to hand weed. NTF treatments allow for the soil to receive soil health benefits from the clover while suppressing weeds and decreasing labor costs overtime. T treatments were difficult to hand cultivate in 2023 due to sporadic rain events which made the stirrup hoe difficult to use in T treatments. Very few studies show the impact of labor time needed to weed and mow living mulch plots, which highlights the values of the results in this study (Pfieffer et al. 2016).

Mowing events took longer as the season progressed in 2022 and 2023. Red clover took the longest to mow early in the season due to their woody like structure which would get caught in the push mower (Puka-beals and Gramig 2021). As the season went on, KC and RC plots were relative in the amount of time it took to mow which was surprising for KC due to its low growing structure (Sparks et al. 2015). WC plots took the least amount of time to mow in August and September due to its low growing potential. Farmers and researchers should consider labor costs and the time needed to weed and mow clover living mulch strips. WC treatments showed the greatest amount of weed suppression as well as the least amount of time to mow, which, may be beneficial for farmers searching for a low cost input into their systems.

<u>Cash Crop Performance</u>

Broccoli Plant Height and canopy width. BG broccoli plants were the tallest and widest compared to the clover treatments by no surprise due to decreased competition between oats, weeds, and clovers. It was surprising that RC plots performed the same as

KC and WC plots for broccoli plant height considering red clover is very competitive for light and space due to its tall structure (Hooks et al. 2013). Plant height was taller in conventional tilled cereal rye rows than it was in no-till and strip tilled rows in Iowa (Jokela and Nair 2016). Similar to the Iowa study, broccoli plants grown in the BG plots were taller than those in the NT living mulch plots.

Broccoli plants in 2023 were noticeably larger than broccoli plants in 2022. Broccoli plants were planted three weeks earlier in 2023 compared to 2022 which increases the amount of time for broccoli plants to grow. Changes to fertigation schedules in 2023 may have impacted broccoli growth compared to 2022 (Warren et al. 2015).

Broccoli SPAD Readings. SPAD readings did produce an interaction in 2022 but did not in 2023. SPAD did not differ much between systems, except for KC plots. SPAD readings were not significant in 2023 which could be due to early establishment of clovers and more time is needed for clovers to deposit nitrogen to the soil (Alexander et al. 2019).

Broccoli Whole Plant Dried Biomass. Dried broccoli plant biomass differed in weight in 2023 than it did in 2022. This could partly be due to the longer season in 2023 compared to 2022 and the changes in the fertigation schedule in 2023. It was also noticed in Iowa, that conventional tilled rows, stripped tilled and no-till broccoli grow in in roller crimped cereal rye had no effect on dried plant biomass (Jokela and Nair 2016).

In 2022, dried broccoli plant biomass was smaller in clover treatments than it was in bare ground, which could signify competition with clovers and weeds (Bruce et al. 2022). This can be a concern for growers interested in living mulches because it can decrease cash crop yields and produce smaller broccoli heads. 2023 broccoli biomass was similar to 2022 outcomes; however, RC showed the greatest competition with broccoli dried biomass. As speculated earlier, red clover can be very competitive for cash crops and showed the competitive nature with broccoli plant biomass.

In 2022, soil management treatments did not show any differences between treatments for broccoli plant biomass, however, differences were shown in 2023 broccoli. TF and NTF plots performed the same compared to NT and T treatments. NT treatments showed high competition with broccoli plants compared to the other treatments and produced the lightest dried broccoli plants. Broccoli in conventional and stripped tilled systems showed similar weights for dried broccoli plants in Iowa (Jokela and Nair 2016). More research studies should consider broccoli dried biomass in the future since there are little studies that contain this information.

Broccoli Harvest. 2023 broccoli produced more total broccoli heads compared to 2022 which could be due to the longer growing season. BG whole plots produced larger broccoli plants due to less competition for light and space with clovers and weeds (Bruce et al. 2022; Tarrant et al. 2020). More heads were harvested in the BG plots compared to the clover treatments which shows that clovers created a negative relationship with cash crop harvest performance (Bruce et al. 2022). Since broccoli plants were noticeably larger in BG plots, heads were also heavier in the bare ground than the clover treatments which means less competition with clovers and weeds interrupted head formation during the growing season. Broccoli heads in BG plots were harvested early in the season due to little competition with weeds and loose soils. NT treatments produced less broccoli heads compared to the other management treatments due to competition with clovers and weeds

(Jokela and Nair 2016). Broccoli plants in the TF treatments produced the most amount of total broccoli heads which is comparable to (Theriault et al. 2009). TF broccoli plants also had the highest presence of non-marketable broccoli heads in both seasons, which isn't surprising due to the soil being less compacted from tillage events (Stein et al. 2022). Broccoli heads in the NT treatments were never able to establish in both seasons due to heavy suppression of the clover living mulch. A longer growing season would have been more adequate to receive broccoli heads in the NT treatments due to broccoli slowed growth from oats, clovers, and weeds.

Broccoli in the T treatments had noticeably more weeds compared to the NT treatments due little competition from clovers. NTF treatments did have clover species still present in the planting holes, but weeds were pulled at clover and weed biomass collection events which still could have caused delayed head formation and high presence of non-marketable broccoli. Heatwaves caused broccoli heads to become puffy and bolt quickly after crop maturity (Jokela and Nair 2016; Pfeiffer et al. 2016). Due to labor constraints, broccoli harvest occurred once a week which could have resulted in non-marketable broccoli heads forming.

Clover whole plots did not result in many differences between treatments for marketable and non-marketable broccoli head formation in 2022. Only two harvest events occurred in 2022 which caused more broccoli heads to bolt at maturity compared to 2023. In 2023, there were differences between clover treatments for broccoli head formation. There were more total broccoli heads in WC plots than there were in KC and RC plots, which is surprising due to its stoloniferous roots (Sparks et al. 2015). RC and KC performed relative to each other in 2023 for broccoli head formation, but KC plots had more non-marketable broccoli heads compared to RC treatments. As shown on the East coast (Farnham and Bjorkman 2011), broccoli is a heat sensitive crop and can maintain yield reductions during heat spikes.

CONCLUSION

During the first year of establishment, clover living mulch showed negative effects on broccoli cash crop yield and plant health data. Weed suppression was promising throughout the season and clovers suppressed weeds by the end of the season. Limited rainfall affected clover growth throughout the season which was not a major concern in other studies (Pfeiffer et al. 2016; Tarrant et al. 2020). Tillage and landscape fabric applications still show little protection against yield loss, which specialty crop farmers should consider if they are interested in incorporating living mulches into their systems. Broccoli health and harvest data was negatively affected by weather and suppression of clover, oat and weed populations which was noticed in Wisconsin (Pfieffer et al. 2016).

Farmers who are considering integrating living mulches into their can see positive benefits such as improved soil health (Theriault et al. 2009) and may act as a beneficial green manure. Farmers should also consider the benefits of weed suppression (Puka-Beals and Gramig 2021; Rylander et al. 2020) from living mulches as well as the possibility of welcoming pollinators to the area (Splawski et al. 2014).

This research confirms that early season clover cover crops as a living mulch negatively impacts broccoli cash crop establishment in the Northern great plains. Future research should consider increased early season irrigation and supplemented irrigation throughout the season to encourage clover growth and further weed suppression. Cash crops should be correctly fertilized for better competition and overall healthy plant mass; higher than recommended fertility rates may be needed. Future research should explore higher fertility rates in combination with clover living mulches. Further studies should also consider evaluating clover and weed establishment over multiple years to evaluate clovers needs as a living mulch overtime for vegetable producers. Similar crops to broccoli such sprouting broccoli or broccolini that are better suited for warm summers should be investigated in future research, given the heat sensitivity concern with traditional broccoli crops shown in this research.

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APPENDIX B

Table B.1: Dates events occurred throughout the 2022 and 2023 research season

Activity	2022 Dates	2023 Dates
Seeded Oats Cover Crops	26-Apr	27-Apr
Seeded Transplants in Greenhouse	7-Jun	2-Jun
Mowed CC, Tilled, Pinned Fabric	17-Jul	27-Jun
Broccoli Planted in the Field	18-Jul	27-Jun
Fertigated	19-Jul; 3-Aug; 15-Aug; 31-Aug	29-Jun; 26-Jul; 26-Aug
Installed ProtekNet Row Cover	15-Aug	29-Jun
Collected Whole plot Clover and Weed Biomass	30-Jun; 13-Jul; 1-Aug; 9-Sep; 5-Oct	26-Jun; 12-Jul; 4-Aug; 7-Sep; 4-Oct
Collected in-row Clover and Weed Biomass	30-Jun; 13-Jul; 1-Aug; 9-Sep; 5-Oct	11-Jul; 3-Aug; 6-Sep
Mowed CC / Weeded Subplots	30-Jun; 13-Jul; 1-Aug; 9-Sep	12-Jul; 4-Aug; 7-Sep
Collected Mid-season Plant Height, Canopy and SPAD	NA	11-Aug, 28-Sep
Harvested Broccoli	21-Sep; 3-Oct	31-Aug; 8-Sep; 14-Sep; 21-Sep
Collected Final Plant Height, Canopy, SPAD and Broccoli Biomass	4&5-Oct	28-Sep

Table B.2. Mean monthly total precipitation and monthly average minimum and maximum temperature for the 2022 and 2023 research seasons at the Specialty Crop Research Field, Brookings, SD.

Year	Month	Minimum Air Temperature (°C)	Maximum Air Temperature (°C)	Average Temperature (°C)	Total Precipitation (cm)
2022	*April*	11.3	5.3	-0.2	4.7
	May	21.5	15.4	9.4	8.1
	June	28.7	22.8	16.0	4.3
	July	30.2	24.3	18.4	8.1
	August	28.2	22.0	15.8	6.7
	September	27.0	18.9	11.5	1.7
	October	18.6	10.4	2.9	2.4
2023	*April*	-10.3	-1.0	-5.3	2.8
	May	-0.3	11.7	5.7	2.8
	June	9.4	23.8	17.0	5.3
	July	15.9	28.1	22.1	3.9
	August	14.2	27.1	21.0	5.1
	September	15.3	28.3	21.8	2.0
	October	11.8	25.5	18.4	6.8

Table B.3. Total average precipitation and average maximum and minimum daily air temperature collected from 1993-2022 in Brookings, SD.

Month	Minimum Air Temperature (°C)	Maximum Air Temperature (°C)	Average Temperature (°C)	Total Precipitation (cm)
April	-0.1	12.2	-	5.4
May	7.2	19.3	-	8.9
June	13.6	25.2	-	10.0
July	15.8	27.8	-	9.1
August	14.2	26.5	-	8.1
September	9.1	22.5	-	7.8
October	1.5	14.5	-	5.3

Table B.4. Clover and weed whole plot (pathway) height accumulation collected from alleyways between planting 'Imperial' broccoli rows throughout 2022 and 2023 research seasons at the Specialty Crop Research Field, Brookings, SD.[z]

2022										
	Weed Height (cm)					Clover Height (cm)				
Date	**Jun. 30**	**Jul. 13**	**Aug. 1**	**Sep. 9**	**Oct. 5**	**Jun. 30**	**Jul. 13**	**Aug. 1**	**Sep. 9**	**Oct. 5**
BG[y]	11 Bab[x]	17 Aa	9 Cb	22 Ba	0 Bc	0 Cb	0 Cb	0 Cb	0 Cb	7 Ba
KC	14 Ab	13 Bb	34 Aa	31 Aa	4 Bc	11 Ab	12 Ab	13 Bb	18 Ba	13 Bb
RC	11 Bb	15 Ab	21 Ba	38 Aa	12 Ab	15 Ab	17 Ab	22 Aab	35 Aa	27Aa
WC	14 Ab	18 Aab	31 Aa	39 Aa	12 Ab	11 Ab	11 ABb	13 Bb	23 ABa	14 BAb
2023										
	Weed Height (cm)					Clover Height (cm)				
Date	**Jun. 26**	**Jul. 12**	**Aug. 4**	**Sep .7**	**Oct. 4**	**Jun. 26**	**Jul. 12**	**Aug. 4**	**Sep .7**	**Oct. 4**
BG	9 a	4 Bb	9 Ba	12 Ba	4 Bb	0	0 B	0 C	0 C	0 C
KC	12 b	12 Ab	21 Aa	21 Aa	16 Aab	4 b	12 Aa	7 Bb	10 Ba	13 Ba
RC	11 b	18 Aa	17 Aa	19 Aa	19 Aa	6 c	14 Ab	12 Ab	21 Aa	28 Aa
WC	10 b	14 Aab	20 Aa	26 Aa	16 Ab	2 c	8 Ab	6 Bb	13 Ba	15 Ba

[z]Uppercase letters represent differences among treatments within a single date column. Lowercase letters represent differences among dates within rows for single treatment type.
[y]BG= bare ground, RC= red clover, KC= white x kura clover, WC= white clover

[x]Values within the same column and treatment followed by the same letter are not statistically different according to Fisher's protected least significant difference ($P \leq 0.05$). Data are presented as management (M) within clover (C) treatments due to multiple response variables with M x C interactions.

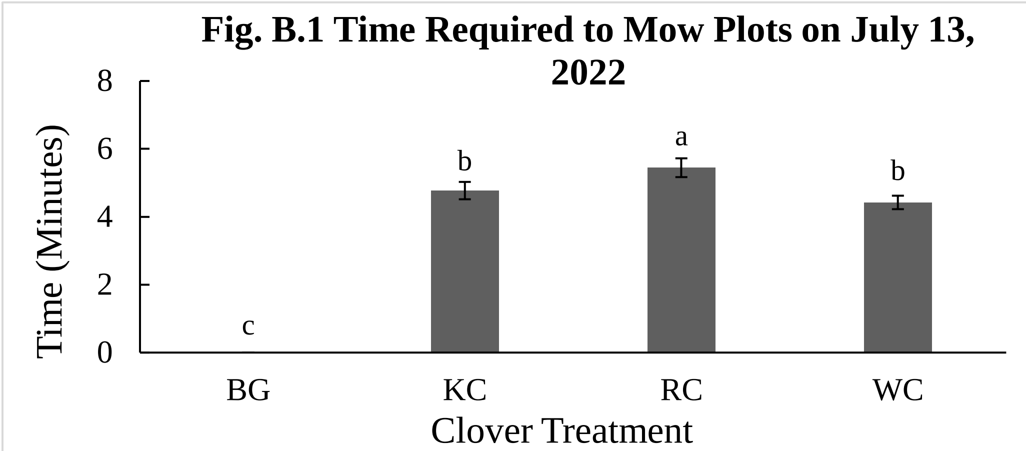
Table B.5. Clover and weed whole plot (pathway) biomass accumulation collected from alleyways between planting 'Imperial' broccoli rows throughout 2022 and 2023 research seasons at the Specialty Crop Research Field, Brookings, SD.[z]

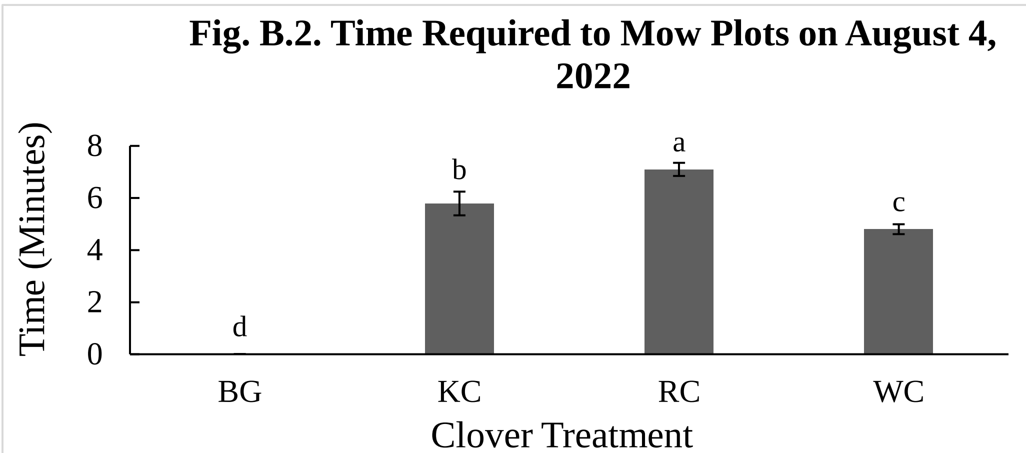
			2022							
	Weed Biomass (Kg/h)					**Clover Biomass (Kg/h)**				
Date	**Jun. 30**	**Jul. 13**	**Aug. 1**	**Sep. 9**	**Oct. 5**	**Jun. 30**	**Jul. 13**	**Aug. 1**	**Sep. 9**	**Oct. 5**
BG[y]	34 Bbc[x]	66 Bb	91 Ca	212 Aa	9 Bc	0 C	0 C	0 B	0 C	0 C
KC	91 Abc	116 Ab	355 Aa	133 Bb	8 Bc	27 Bc	109 ABbc	237 Ab	353 Bb	1184 Aa
RC	20 Bc	147 Ab	183 Bab	279 Aa	13 Bc	58 Ad	189 Ac	300 Ab	547 Ab	868 Ba
WC	35 Bc	112 Ab	208 Ba	144 Ba	45 Ac	21 Bc	85 Bc	310 Ab	585 Ab	1411 Aa
			2023							
	Weed Biomass (Kg/h)					**Clover Biomass (Kg/h)**				
Date	**Jun. 26**	**Jul. 12**	**Aug. 4**	**Sep .7**	**Oct. 4**	**Jun. 26**	**July 12**	**Aug. 4**	**Sep .7**	**Oct. 4**
BG	115 Ab	66 Bbc	557 Aa	291 Ba	20 Bc	0	0 B	0 C	0 C	0 C
KC	100 Ab	374 Aa	311 Aa	375 ABa	91 Ab	6 d	62 Ac	49 Bc	314 Bb	386 Ba
RC	67 Bc	352 Aa	259 Bb	433 Aa	75 Ac	6 c	66 Ab	70 Ab	533 Aa	616 Aa
WC	68 Bc	277 Ab	256 Bb	524 Aa	106 Abc	5 c	51 Ab	25 BCc	301 Ba	412 Ba

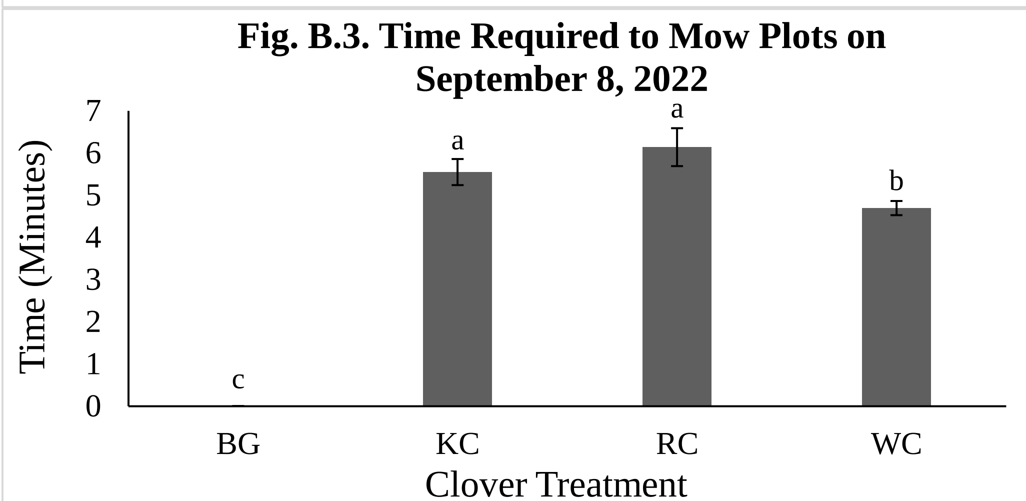
[z]Uppercase letters represent differences among treatments within a single date column. Lowercase letters represent differences among dates within rows for single treatment type.

[y]BG= bare ground, RC= red clover, KC= white x kura clover, WC= white clover

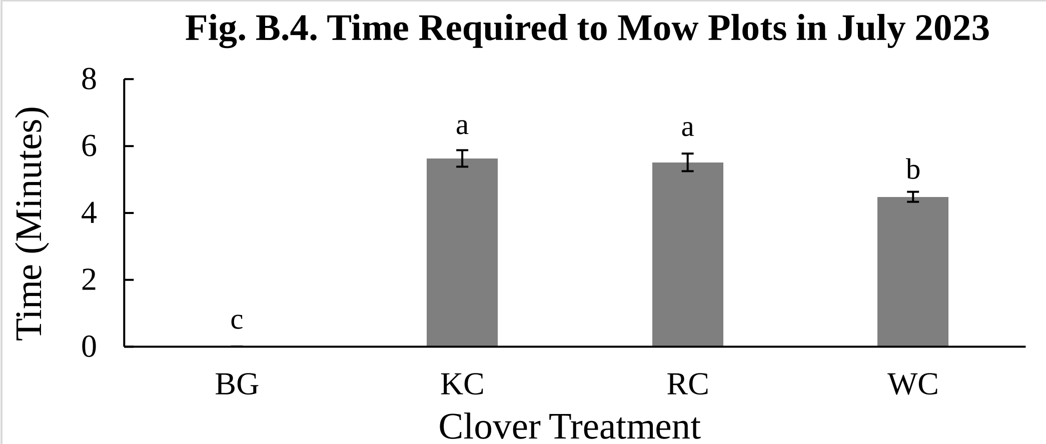
[x]Values within the same column and treatment followed by the same letter are not statistically different according to Fisher's protected least significant difference ($P \leq 0.05$). Data are presented as management (M) within clover (C) treatments due to multiple response variables with M x C interactions.

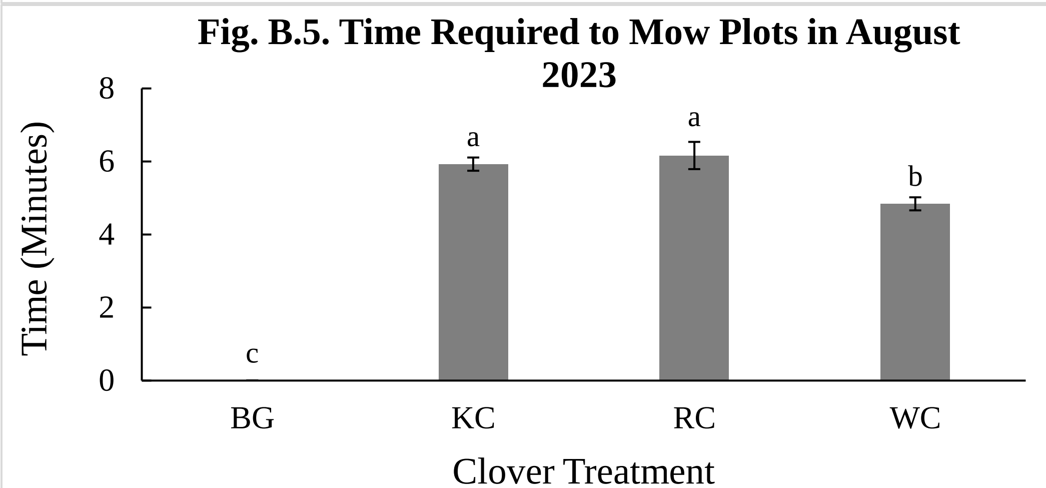


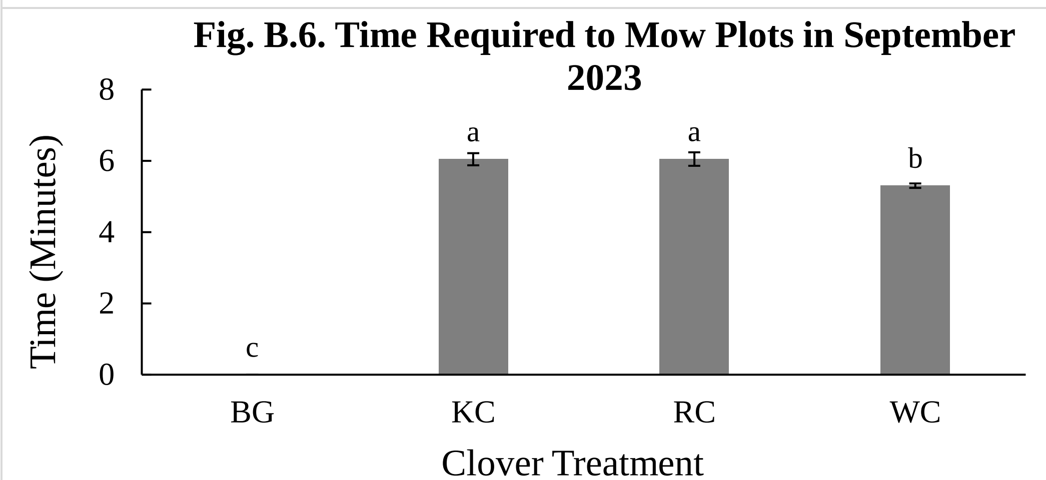




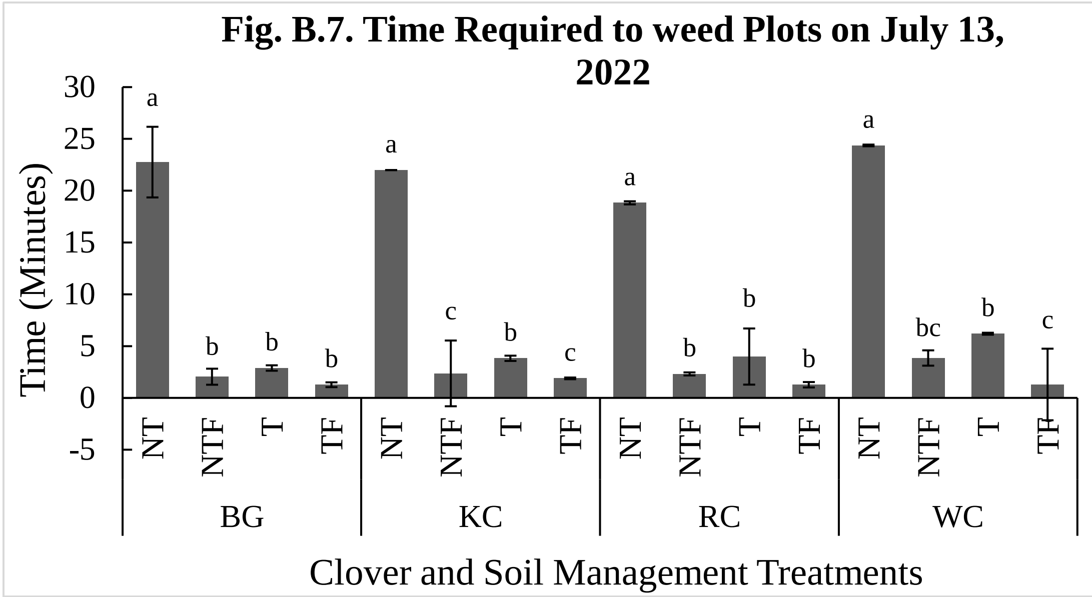
Figs. B.1., B.2., B.3. Time required to mow 3.6 m clover pathways with two people in July, August and September 2022. BG: bare ground, KC: white x kura clover, RC: red clover, WC: white clover. Means with common letters within response variables are not different according to Fisher's unrestricted least significant difference procedure (α = 0.05).

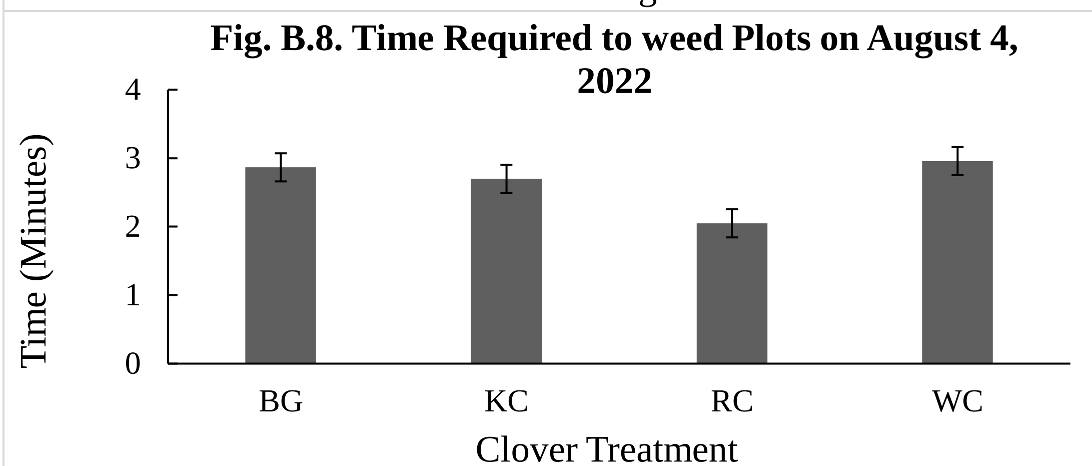


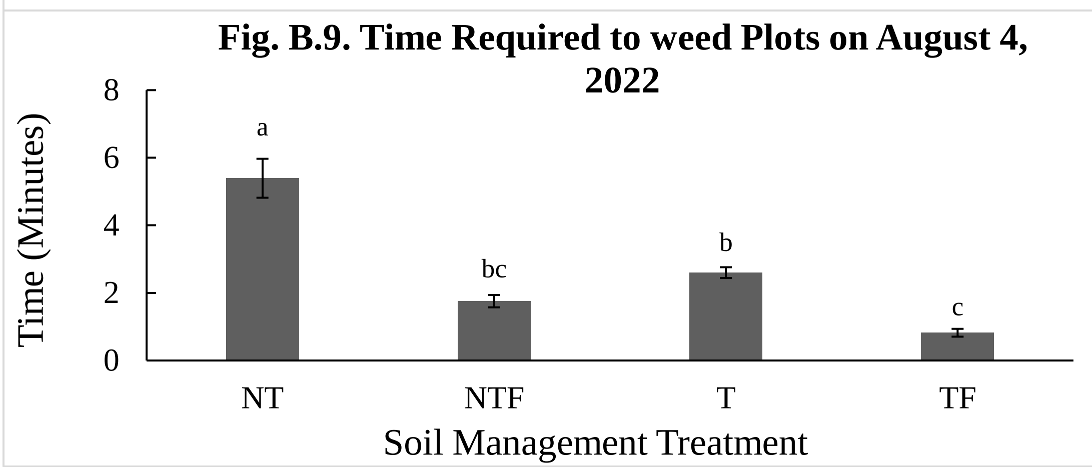




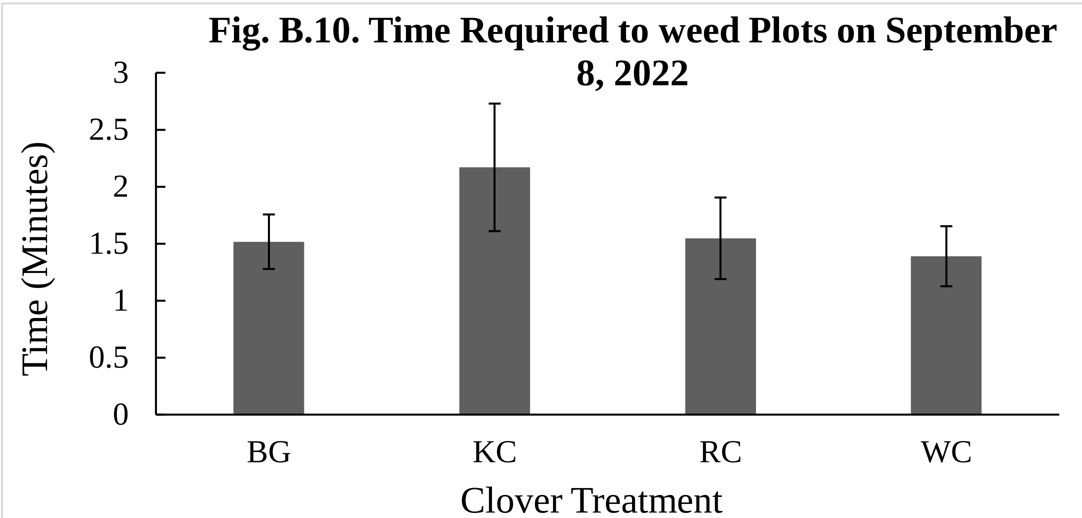
Figs. B.4., B.5., B.6. Time required to mow 3.6 m clover pathways with two people in July, August and September 2023. BG: bare ground, KC: white x kura clover, RC: red clover, WC: white clover. Means with common letters within response variables are not different according to Fisher's unrestricted least significant difference procedure (α = 0.05).

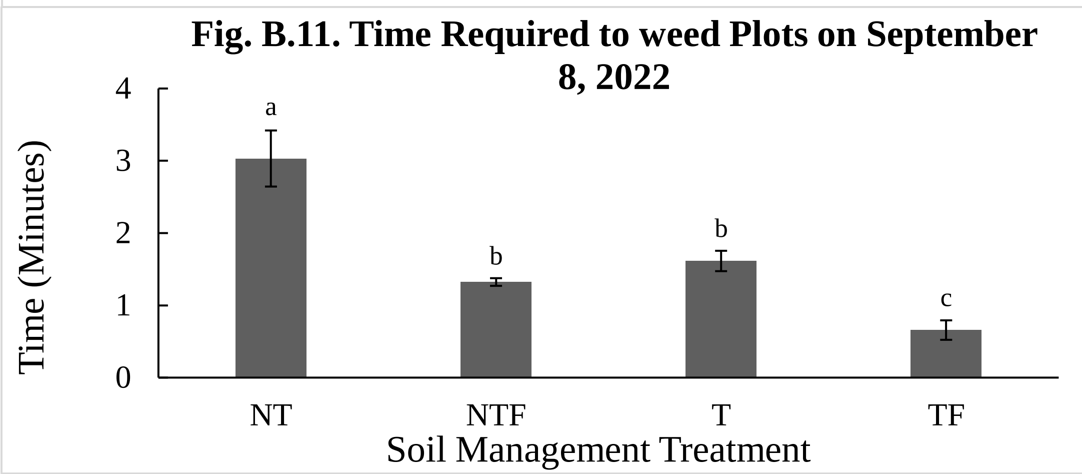






Figs. B.7., B.8., B.9. Time required to weed 3.6 m clover and management planting beds with two people in July, and August 2022. BG: bare ground, KC: white x kura clover, RC: red clover, WC: white clover. NT: no-till, NTF: No-till + fabric, TF: tilled + fabric, T: tilled. Means with common letters within response variables are not different according to Fisher's unrestricted least significant difference procedure (α = 0.05).





Figs. B.10., B.11. Time required to weed 3.6 m clover and management planting beds with two people in September 2022. BG: bare ground, KC: white x kura clover, RC: red clover, WC: white clover. NT: no-till, NTF: No-till + fabric, TF: tilled + fabric, T: tilled. Means with common letters within response variables are not different according to Fisher's unrestricted least significant difference procedure (α = 0.05).

Fig. B.12. Time Required to weed Plots in July 2023

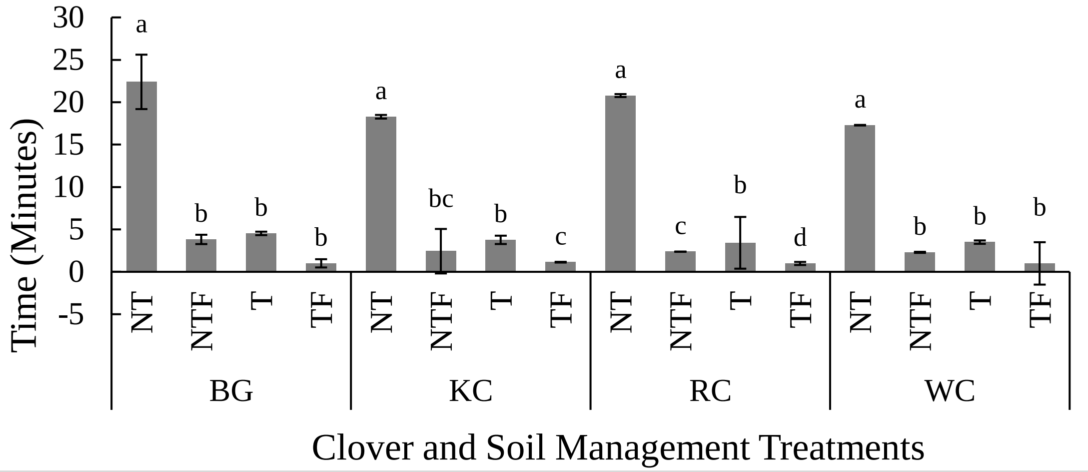


Fig. B.13. Time Required to weed Plots in August 2023

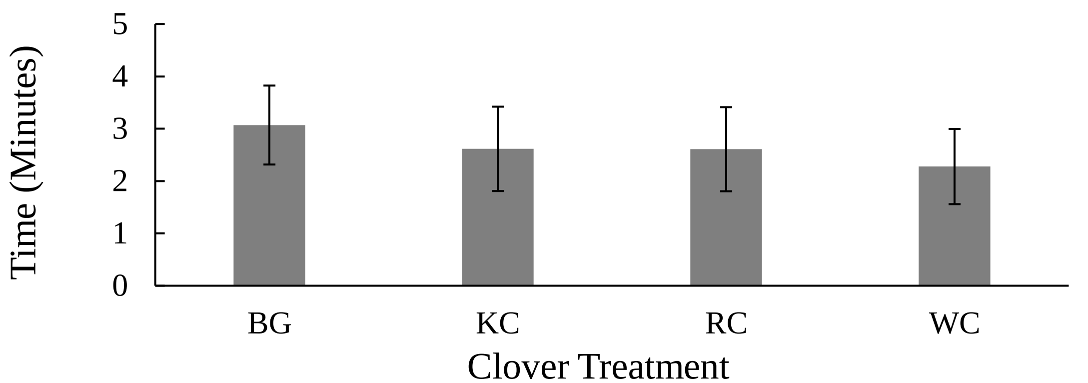
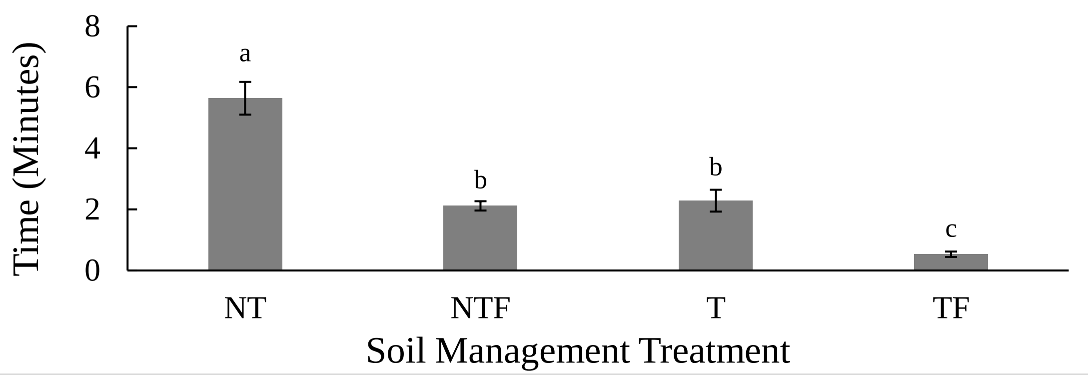
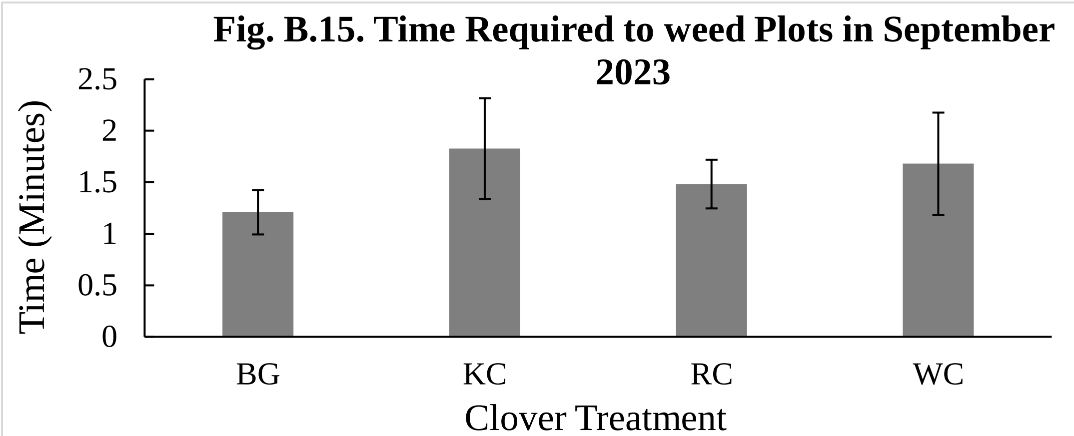
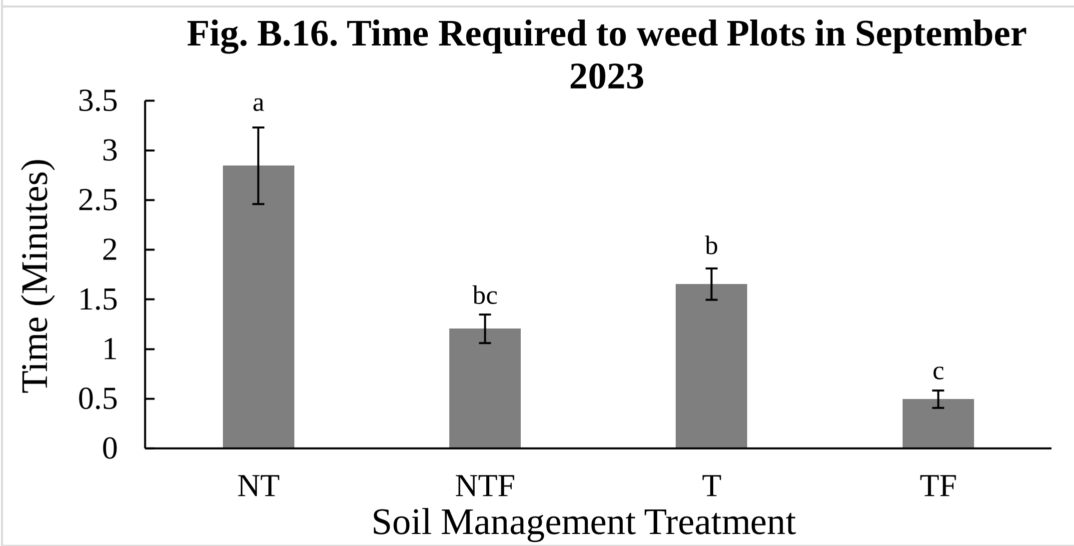


Fig. B.14. Time Required to weed Plots in August 2023

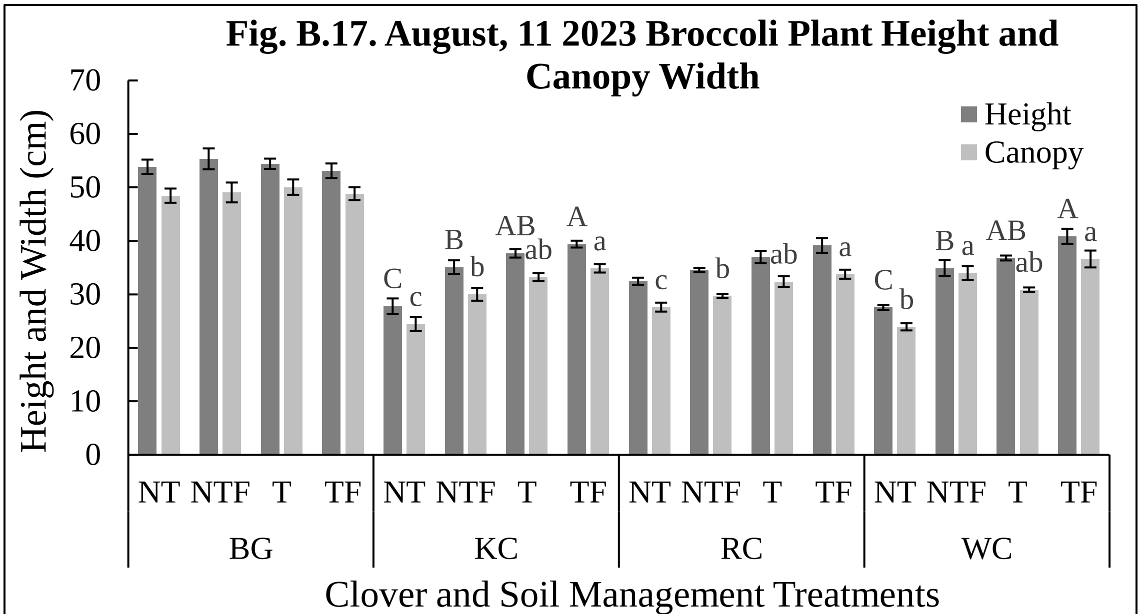


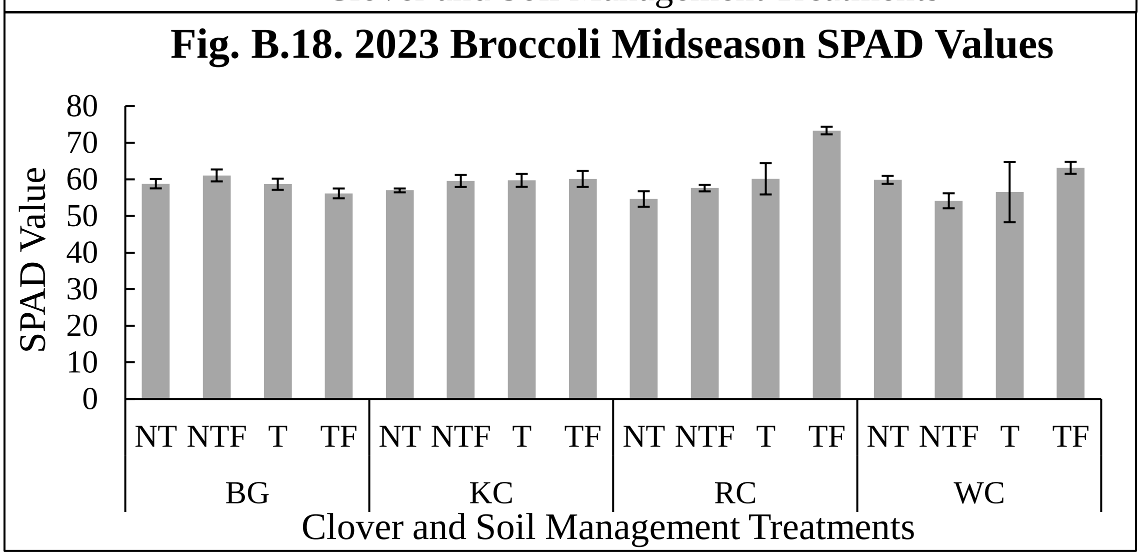
Figs. B.12., B.13., B.14. Time required to weed 3.6 m clover and management planting beds with two people in July and August 2023. BG: bare ground, KC: white x kura clover, RC: red clover, WC: white clover. NT: no-till, NTF: no-till + fabric, TF: tilled + fabric, T: tilled. Means with common letters within response variables are not different according to Fisher’s unrestricted least significant difference procedure ($\alpha = 0.05$).



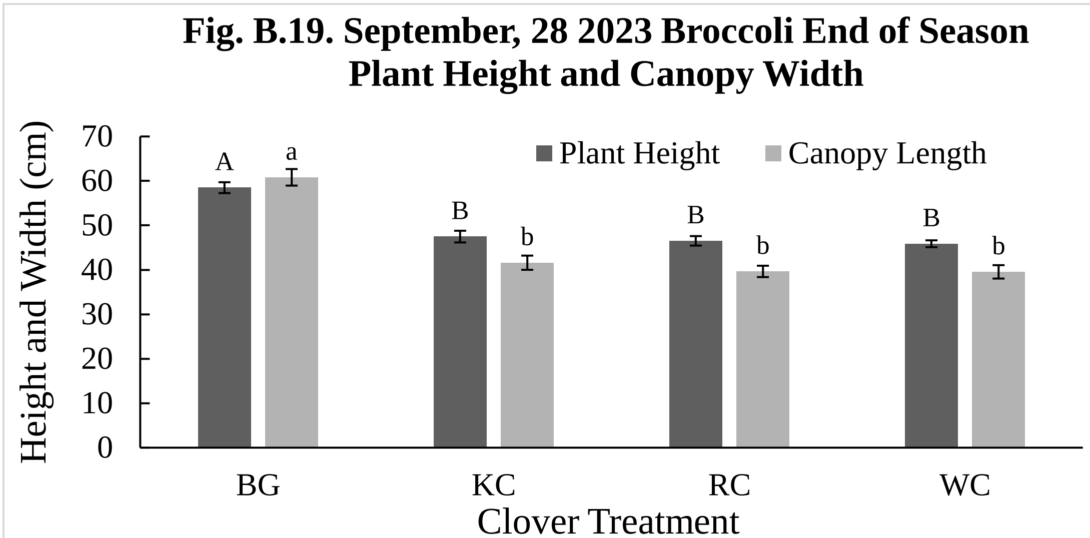


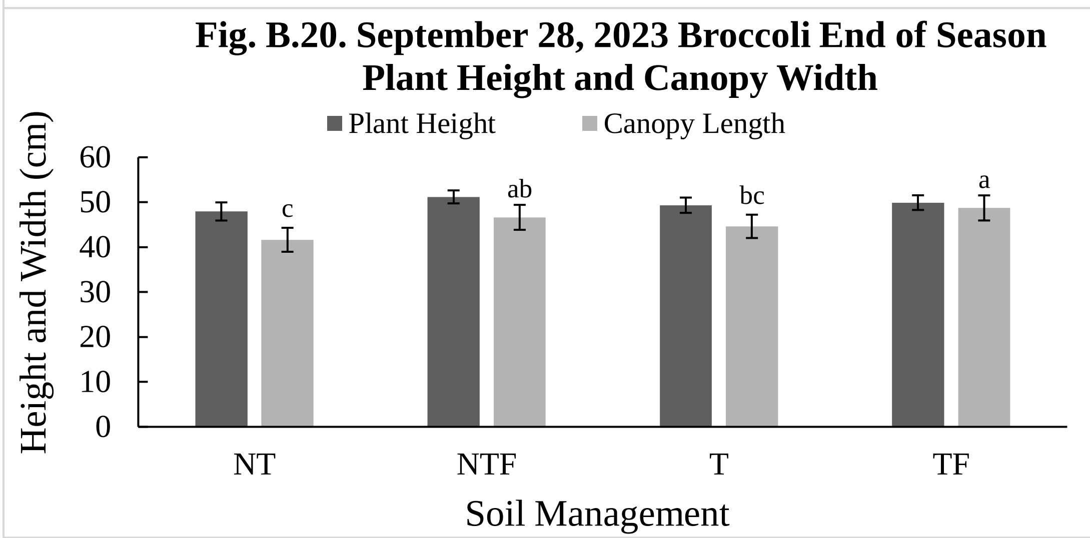
Figs. B.15., B.16. Time required to weed 3.6 m clover and management planting beds with two people in September, 202. BG: bare ground, KC: white x kura clover, RC: red clover, WC: white clover. NT: no-till, NTF: No-till + fabric, TF: tilled + fabric, T: tilled. Means with common letters within response variables are not different according to Fisher's unrestricted least significant difference procedure ($\alpha = 0.05$).





Figs. B.17., B.18. Broccoli midseason SPAD values, canopy width and plant height collected on August 11, 2023. BG: bare ground, KC: white x kura clover, RC: red clover, WC: white clover. NT: no-till, NTF: No-till + fabric, TF: tilled + fabric, T: tilled. Means with common letters within response variables are not different according to Fisher's unrestricted least significant difference procedure ($\alpha = 0.05$). Lowercase letters represent mean separations for canopy; uppercase letters represent mean separations for height.





Figs. B.19., B.20. Broccoli canopy width and plant height collected on September 28, 2023 within clover and management rows. BG: bare ground, KC: white x kura clover, RC: red clover, WC: white clover. NT: no-till, NTF: No-till + fabric, TF: tilled + fabric, T: tilled. Means with common letters within response variables are not different according to Fisher's unrestricted least significant difference procedure (α = 0.05). Lowercase letters represent mean separations for canopy; uppercase letters represent mean separations for height.

Fig. B.21. September 28, 2023 Broccoli End of Season SPAD Readings

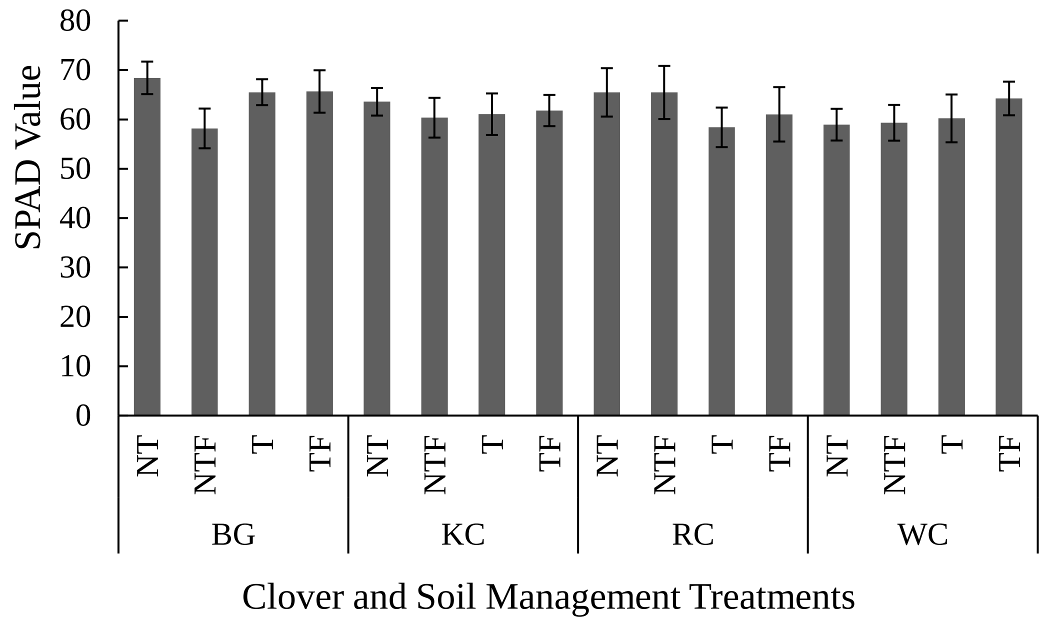
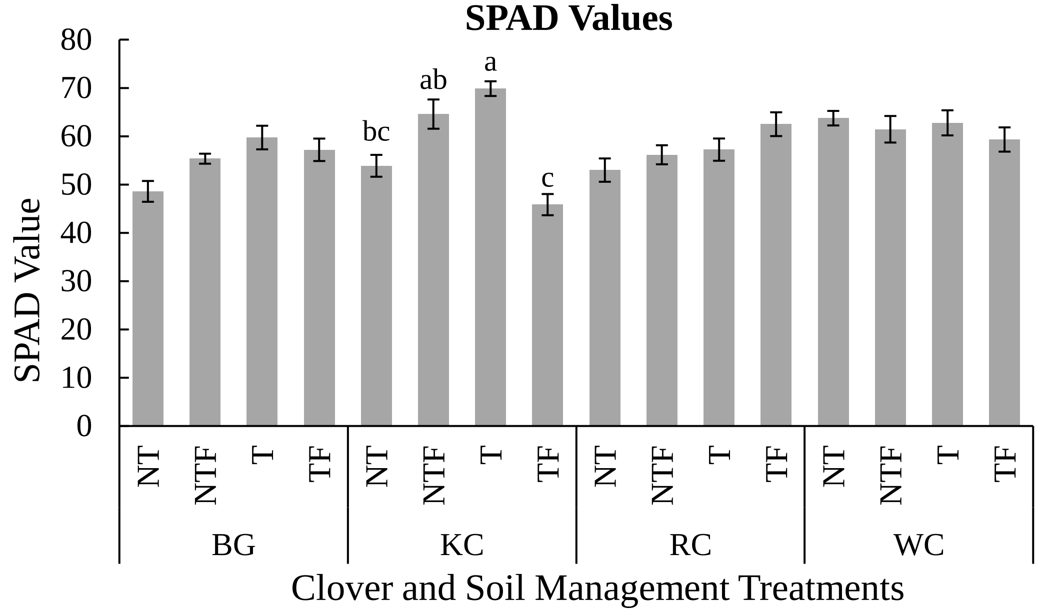


Fig. B.22. October 5, 2022 Broccoli End of Season SPAD Values



Figs. B.21., B.22. Broccoli SPAD measurements collected on September 28, 2023 and October 5, 2022 within clover and management rows. BG: bare ground, KC: white x kura clover, RC: red clover, WC: white clover. NT: no-till, NTF: No-till + fabric, TF: tilled + fabric, T: tilled. Means with common letters within response variables are not different according to Fisher's unrestricted least significant difference procedure ($\alpha = 0.05$).

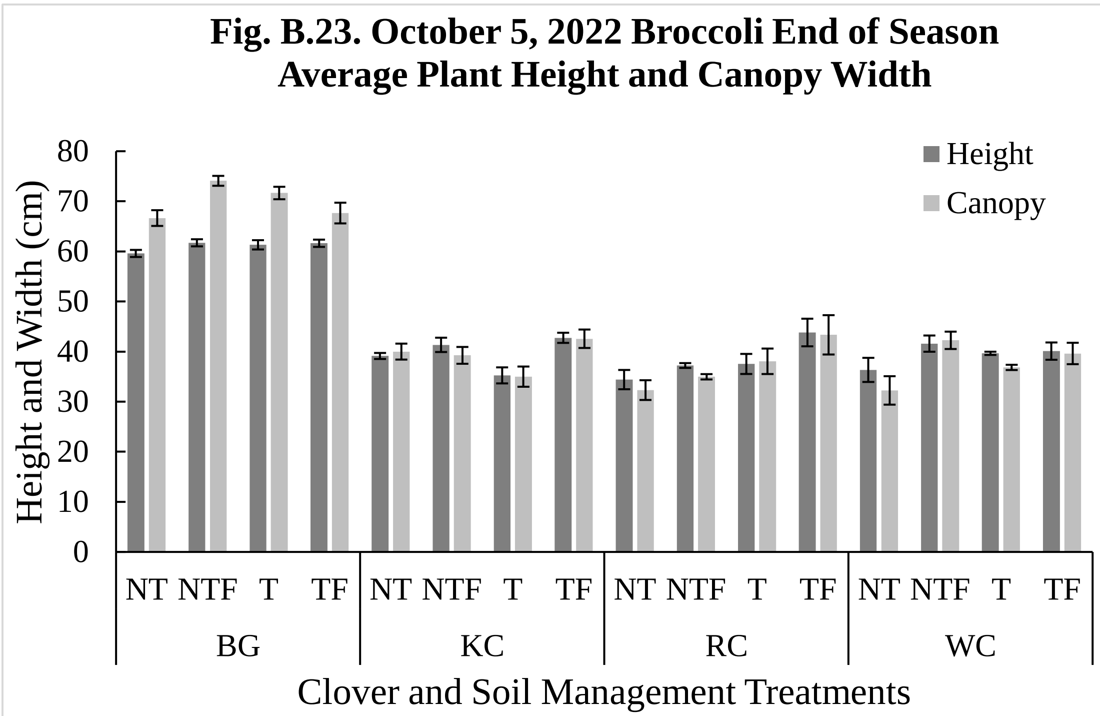


Fig. B. 23. Broccoli canopy width and plant height collected on October 5, 2022 within clover and management rows. BG: bare ground, KC: white x kura clover, RC: red clover, WC: white clover. NT: no-till, NTF: No-till + fabric, TF: tilled + fabric, T: tilled. Means with common letters within response variables are not different according to Fisher's unrestricted least significant difference procedure ($\alpha = 0.05$).

Table B.6. Mean dried plant biomass data collected on October 2, 2022 and September 28, 2023 for 'Imperial' broccoli plants grown in 2022 and 2023 at the Specialty Crop Research Field, Brookings, SD.

Treatment	**2022**	**2023**
Clover (C)[z]		
BG	163 a[y]	152 a
KC	42 b	78 b
RC	36 b	58 c
WC	40 b	69 bc
p-value[x]	*0.01*	*0.01*
Management (M)[w]		
T	71	85 b
NT	64	57 c
TF	73	108 a
NTF	74	105 a
p-value	*0.6*	*0.01*
C x M		
p-value	*0.7*	*0.6*

[z]Clover treatments were: bare ground (BG), red clover (RC), white clover, (WC), and white x kura clover (KC)

[y]Values within the same column and treatment followed by the same letter are not statistically different according to Fisher’s protected least significant difference ($P \leq 0.05$).

[x]*p-values* based on *F* test.

[w]Management treatments were tillage (T), no-till (NT), tillage + fabric (TF), and no-till + fabric (NTF)

Table B.7. Average number of broccoli heads harvested per 20 plants on September 21 and October 3, 2022 from 'Imperial' broccoli grown in 2022 at the Specialty Crop Research Field, Brookings, SD. Data includes marketable and non-marketable head count and weight.

2022	**Marketable**		**Non-marketable**	
Treatment	**Head Count**	**Head Weight (Kg)**	**Head Count**	**Head Weight (Kg)**
Clover (C)[z]				
BG	11.0 a[y]	3.0 a	7.0 a	3.0 a
KC	5.0 b	0.4 b	0.4 b	0.1 b
RC	3.0 b	0.3 b	0.2 b	0.1 b
WC	5.0 b	0.2 b	0.3 b	0.1 b
p-value[x]	*0.01*	*0.01*	*0.01*	*0.01*
Management (M)[w]				
T	6.0	1.0	2.0	1.0
NT	4.0	1.0	2.0	1.0
TF	8.0	1.0	2.0	1.0
NTF	5.0	1.0	2.0	1.0
p-value	*0.2*	*0.5*	*0.8*	*0.8*
C x M				
p-value	*0.4*	*0.9*	*0.9*	*0.9*

[z]Clover treatments were: bare ground (BG), red clover (RC), white clover, (WC), and white x kura clover (KC)

[y]Values within the same column and treatment followed by the same letter are not statistically different according to Fisher's protected least significant difference ($P \leq 0.05$).

[x]*p-values* based on *F* test.

[w]Management treatments were tillage (T), no-till (NT), tillage + fabric (TF), and no-till + fabric (NTF)

Fig. B.24. 2023 Number of Broccoli Heads Harvested from 20 Plants

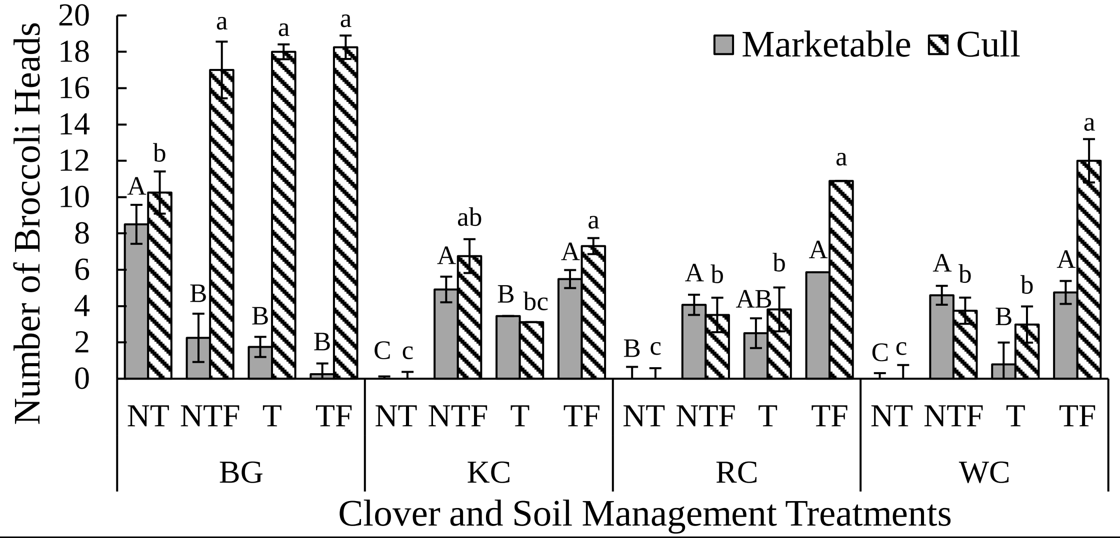
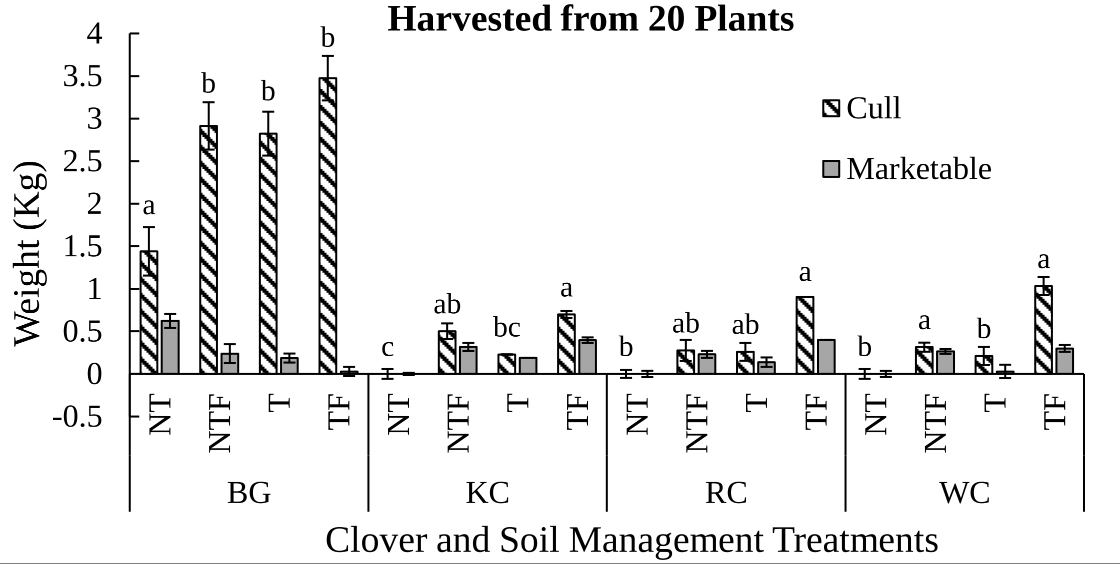


Fig. B.25. 2023 Average Weight of Broccoli Heads Harvested from 20 Plants



Figs. B.24., B.25. Average broccoli head count and head weight harvested on August 31, September 8, September 14 and September 21, 2023. BG: bare ground, KC: white x kura clover, RC: red clover, WC: white clover. NT: no-till, NTF: No-till + fabric, TF: tilled + fabric, T: tilled. Means with common letters within response variables (clover) are not different according to Fisher's unrestricted least significant difference procedure ($\alpha = 0.05$). Lowercase letters represent mean separations for cull broccoli heads; uppercase letters represent mean separations for marketable broccoli heads.

CHAPTER 4: CONCLUSION

Living mulches may aid in weed suppression, soil erosion reduction and nitrogen fixation within and along cash crop rows (Thériault et al. 2019). WC plots produced the most clover biomass in 2022 for both systems but saw a drastic decline in 2023 plots. Weed biomass was also lowest in WC plots in 2022 but was lower in RC plots in 2023 for both systems. RC plots produced the most biomass in 2023 compared to the clover treatments which is surprising due to its woody stem (Pfeiffer et al. 2016). Though clover living mulches can suppress weeds, it can suppress cash crop yields which hurt vegetable producers in the long run (Bruce et al. 2022; Strader et al. 2017). Broccoli and squash plants in the clover treatments were noticeably smaller in the clover treatments compared to the BG plots, especially NT plots which produced a drastic yield decrease.

Year one establishment of early season clovers as a living mulch has resulted in negative effects on broccoli and winter squash cash crop yields and plant health. Squash plants produced more fruit in 2022 compared to 2023, which was caused by the longer season in 2022. Squash vine borer was also present in both seasons and completely wilted 75% of squash plants in 2022 and 60% in 2023 (Tillman et al. 2015). Broccoli plants in the NT plots never reached maturity in the clover treatments except for the BG plots due to no competition with oats and clovers (Pfeiffer et al. 2016).

South Dakota and midwestern vegetable farmers are seeking natural alternatives to black plastic mulch, however, long term studies about perennial living mulches are needed to answer continued questions (Tarrant et al. 2020). Current studies evaluate first year establishment of living mulches, but more research is needed to understand the benefits of long-term perennial living mulch production systems in the Midwest. More living mulch studies that incorporate different management methods should also be considered for farmers considering no-till or organic production (Jokela and Nair 2016).

This work highlights the need for other tillage alternatives since the first year of living mulches may not be a great substitute for tillage. This work shows farmers that bare ground plots performed better in weed management overtime compared to clover treatments. It also shows that living mulches can suppress cash crop yields, which is concerning since farmers do want a sustainable alternative to tillage and plastic mulch. Broccoli and winter squash plants were smaller in living mulch plots than they were in bare ground plots, which shows there may competition issues for cash crops with clovers for light, space and nutrients which can be a concern for first year establishment for farmers interested in living mulches. This highlights the importance of the ability to test multiple clover treatments, whereas a farmer may not have that ability due to seed cost or living availability to implement due to space on farm systems. This also proves that studies like this are important because researchers can evaluate multiple clovers and cash crops combinations to show the best outcome for specialty crop farmers.

Northern plains farmers should consider supplemental irrigation if rainfall is not adequate for their systems. Living mulches will not establish well early in the season if there is not enough rainfall received, which was noticed in 2023 in Beresford, South Dakota for the winter squash living mulch project. Another implementation farmers should consider is the amount of time needed to weed and mow living mulch plots. Running a walk-behind tiller along bare ground plots takes less time than mowing (Pfeiffer et al. 2016), which can impact farmers income and may not be beneficial in long run with increased labor times over all as well as struggles with finding employees. It also takes a significant amount of time to hand weed living mulch plots after two months of establishing living mulches, which relates back to the previous concerns of labor costs and the ability to hire enough employees. Yield reductions are also important considering results in this study did not always see marketable cash crop yields and saw a yield reduction in all living mulch plots. This can be concerning for CSA shares and farmers markets when farmers are trying to meet a yield goal and sell enough produce to local consumers.

Based on the results of this study, future research should consider rainfall, temperatures, pest pressures and weed identification. The rainfall and temperature vary in the Great Plains every season, and that is very important for specialty crops, especially brassica crops that are heat sensitive and tend to bolt. This study observed ongoing concerns with squash vine borer, which highlights the need for adequate crop rotations and monitoring pest pressures to show growers what data we are receiving and how that's applicable to their season. Weed identification is important because farmers want to target specific weed species for management in specialty crop systems. Notice what weeds are present in specific living mulch plots and incorporate that into research and discussions to provide more management methods for small scale farming systems. Lastly, incorporating soil temperatures and measuring the amount of light under landscape fabric would be incredibly important for heat-sensitive crops like brassicas and would further elaborate on results in living mulch studies.

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