2023 Evaluation of Newly Established Clover Cover Crops as a Living Mulch for Sustainable Broccoli Production in Eastern South Dakota

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Introduction

Managing weeds, improving soil health, and reducing the use of plastic mulch continue to be priorities for vegetable farmers. South Dakota vegetable farmers have expressed an interest in incorporating cover crops into their farm systems to reduce the use of single use plastic and increase soil health benefits. Perennial legume cover crops provide nutrients to soil prior to vegetable planting and may overwinter to establish living mulches for future growing seasons (Vollmer et al. 2010). During the growing season, clover cover crops that are grown as a living mulch may suppress weeds, contribute nitrogen after establishment and prevent soil erosion. However, previous research has shown that using clovers as a living mulch or living pathway between planting rows can compete with cash crops and result in lower vegetable yields (Bruce et al. 2022 and Pfeiffer et al. 2016).

Materials and Methods

Field research was conducted April through October in 2023 at the Specialty Crop Research Field in Brookings, South Dakota. The objective of this research was to observe the performance of three different clover species used in a broccoli production system. The cash crop chosen was an 'Imperial' broccoli *(Brassica oleracea)* which was selected for its strong performance as a fall crop in prior midwestern U.S. research (Pfeiffer et al. 2016).

Field Design

Clover cultivars trialed were 'Domino' white clover *(Trifolium repens)*, 'Aberlasting' white x kura clover *(T. repens x ambiguum)*, and 'Dynamite' red clover *(T. pratense)* and a fourth treatment was a bare ground control. Clovers and an oat nurse crop were seeded on April 27 at a ½ inch depth with a 5 ft. no-till drill pulled by a tractor. Oats were seeded at 30 lbs./A and each clover type was seeded at the industry recommended rate for that cultivar (Table 1). The clovers were planted in a split plot design replicated across four blocks. Within each whole plot of clover, four soil management treatments (subplots) were randomized. The soil management treatments were: No-till + fabric (NTF), no-till without fabric (NT), tilled + fabric (TF) and tilled without fabric (T). Details of the soil management treatments are explained below.

Table 1. Seeding rates and additional details of clover cultivars planted in 2023 for the Specialty Crop Research Field in Brookings, SD. All seeds were provided by GoSeed (Salem, OR).

Clover Cultivars	Field Planting Rate (lbs./A)	Germ. Rate	Seeds per pound (based on actual count)	Estimated Plants per Sq. Foot
'Aberlasting' White x Kura Clover	11.9	85%	403,242	75
'Domino' White Clover	7.6	85%	632,916	75
'Dynamite' Red Clover	12.3	85%	275,329	53

Field Preparation and Broccoli Planting

Prior to broccoli planting in May and June, supplemental sprinkler irrigation was applied on each replicated block to aid in clover germination and growth when one inch of rainfall per week was not achieved. On June 27, soil management strips were tilled with two passes with a BCS walk-behind tiller (30-inch) to a depth of approximately six inches. Black woven landscape fabric strips that were 36 inches wide and 12 feet long had planting holes cauterized with a butane burner prior to installation. Landscape fabric was installed with 6-inch landscape staples every two feet to prevent fabric from blowing away due to high South Dakota winds (Table 2).

Table 2. Field activities and data collection events that occurred throughout the 2023 season for broccoli production at the SDSU Specialty Crop Research Field, Brookings, SD.

Activity	Dates
Seeded Oats and Cover Crops	27-Apr
Seeded Transplants in Greenhouse	2-Jun
Mowed Cover Crops, Tilled, Pinned Fabric, Installed Drip Tape	27-Jun
Broccoli Planted in the Field	28-Jun
Fertigated with 10-4-3 Nature's Source via Drip Tape	29-Jun; 26-Jul; 26-Aug
Installed ProtekNet Row Cover	29-Jun
Collected Whole plot Clover Biomass	1-Jun; 26-Jun; 12-Jul; 4-Aug; 7-Sep; 4-Oct
Mowed Cover Crops/Weeded Subplots	12-Jul; 4-Aug; 7-Sep Oct-4
Collected Mid-season Plant Height, Canopy and SPAD	11-Aug
Harvested Broccoli	31-Aug; 8-Sep; 14-Sep; 21-Sep
Collected Final Plant Height, Canopy, SPAD and Broccoli Biomass	28-Sep

Broccoli was seeded in a greenhouse on the SDSU campus June 2 (Table 2) and moved outside on June 23 to harden-off prior to planting. On June 28, the broccoli was transplanted into the Specialty Crop Research Field in Brookings, South Dakota (Table 2). Within each 12-foot sub-plot, twenty broccoli transplants were hand planted in staggered, double rows, 18 inches apart from each other with 12 inches between plants within each row. The time required to transplant broccoli was recorded in two out of the four research blocks to analyze labor needed for planting in different clover and soil management treatments. Seven-foot-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 (Figure 1) (Table 2) (Nelson and Gleason 2019). Grasshopper pressure was persistent throughout the season but decreased as temperatures cooled down in the fall.

Figure 1. Broccoli plants on July 27 under a ProtekNet row cover to prevent pest and rodent damage. Courtesy: Alexis Barnes

Data Collection Procedures

Clover whole plot (pathway) Biomass Collection.

Clover performance was assessed five times over the course of the growing season (Table 2). A 25 x 25-centimeter quadrat was randomly tossed three times within each clover whole plot pathway (between crop rows) and two times in each in-row clover x management subplot (within planting row) to analyze the relationship between weeds and clover species (Tarrant et al., 2020). The tallest clover, weed and oat in each quadrat were measured from the base of the stem to the tallest leaf point. All oats, clovers and weeds present in the quadrat were cut at the base of the stem, separated, and kept in brown paper sample bags for biomass drying. Samples were then dried for approximately four days at 110°F. Dried samples were weighed to the nearest 0.1 grams to determine plant biomass.

After data was collected, the clover pathways were mowed in the three clover species whole plots, and weeds were hand cultivated in the bare ground treatments; time spent for these events was recorded (Table 2). The mowing height was set at approximately three inches from the ground using a weed eater to prevent damage to the ProtekNet row cover. Timed weeding events also occurred for in-row (subplot) weed management events and consisted of hand pulling and using a stirrup hoe when appropriate (Table 2).

Broccoli Plant Health Data Collection

Eight broccoli plants from the middle of each sub-plot were measured for height, canopy width and estimated leaf chlorophyll content (with a SPAD meter) at the middle and end of the season (Table 2). At the end of the season, broccoli plant biomass was collected after harvest to determine total plant mass (without the broccoli heads) (Table 2). Four plants in each subplot were trimmed at the base of the stem and dried for five days at 110 degrees F. Dried broccoli biomass was weighed to the nearest 0.1 grams.

Yield

Broccoli harvest occurred once a week for four weeks (Table 2); only mature broccoli heads were harvested, weighed, and graded into distinct categories based on the USDA size and quality standards (Table 2). All broccoli heads were harvested on the final harvest date regardless of size. For each harvest, broccoli heads were weighed and graded into distinct categories for count and weight. Marketable categories included U.S. 1 (free of imperfections and a head diameter between 4-6 inches) (Figure 2), and U.S. 2 (free of imperfections and a head diameter of 3 inches) (Figure 3). Head diameter size for broccoli heads was in addition to the stem diameter requirements from the USDA (USDA AMS Standards). Non-marketable categories included any heads below 3 inches in diameter as well as puffiness (Figure 4), bolting (Figure 5), and hollow stem (Figure 6).

Figure 2. U.S. 1 marketable broccoli head found in September shows compact bead heads and a uniform head formation of 5 inches in diameter. Courtesy: Alexis Barnes

Figure 3. Small marketable broccoli head found in September shows compact bead heads and uniform head formation of 3 inches in diameter. Courtesy: Alexis Barnes

Figure 4. A puffy broccoli head found in August shows the shoots starting to elongate and bead heads are starting to open due to unexpected August heat. Courtesy: Alexis Barnes

Figure 5. Bolting broccoli head found in September shows the buds have flowered and shoots are irregularly shaped typically caused by fluctuating hot temperatures. Courtesy: Alexis Barnes

Figure 6. Hollow stem found in August which can be caused by insufficient N, soil moisture or warm weather. Courtesy: Alexis Barnes

Data Analysis

All data were analyzed using PROC GLIMMIX of SAS (version 9.4) for analysis of variance with clover and management treatments as fixed effects and block as a random effect. If no clover x management interactions were found for a response variable, main effects were presented. When interactions occurred, data were analyzed for differences among management within each clover treatment. Means separations were performed using a Fisher's protected least significant difference (alpha = 0.05).

Results and Discussion

Clover whole plot (pathway) Biomass

Clover biomass in the broccoli walkways increased throughout the season (Figure 7). Clovers slowly increased from June 1 to July 12 and notably increased in August due to increased rainfall compared to early Spring (Figure 7). Red clover (RC) biomass increased the most throughout the season compared to the other clover treatments, most likely due to its tall growing potential (Figure 7). White clover (WC) and White x Kura clover (KC) biomass grew the same throughout the season (Figure 7).

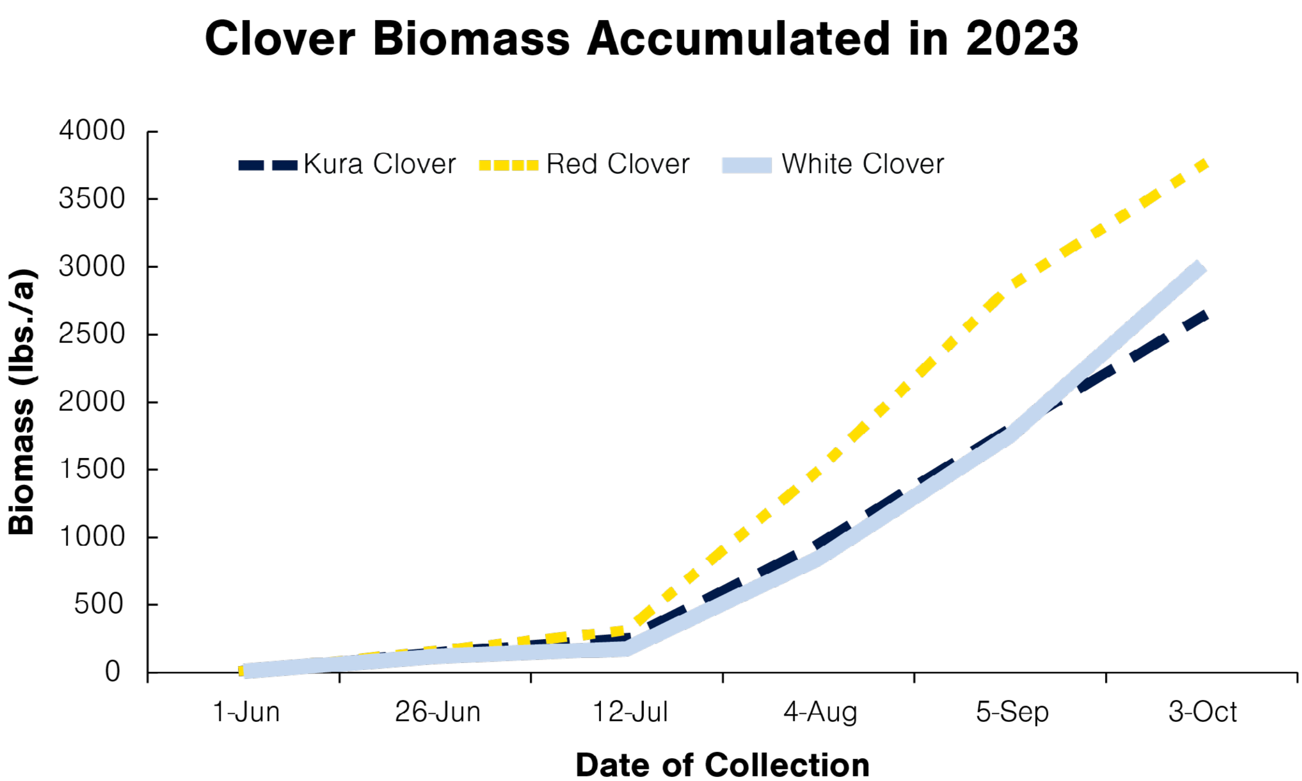

Figure 7. Broccoli whole plot (walk-way) clover biomass accumulated during the 2023 growing season.

Weed biomass increased throughout the season and began to plateau in August due to competition with the clover treatments (Figure 8). Weed biomass in the bare ground (BG) plots performed similarly to RC and WC plots throughout the season (Figure 8). KC, RC, and WC plots accumulated similar amounts of weed biomass throughout the season (Figure 8). Weed biomass accumulated in the KC treatments showed increased differences compared to BG plots which could indicate heavy weed competition in the KC plots for the first year of establishment (Figure 8).

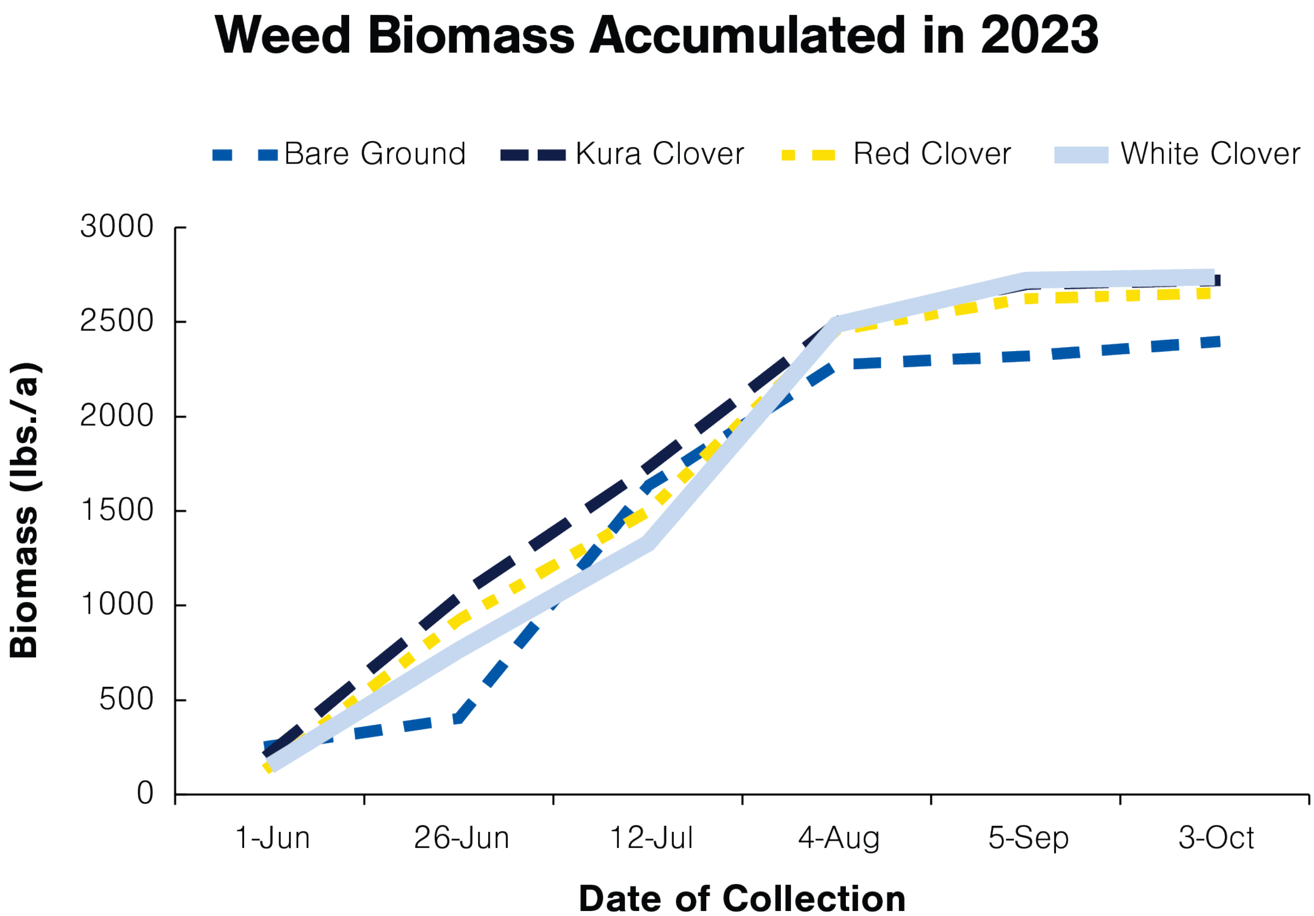

Figure 8. Broccoli whole plot (walk-way) weed biomass accumulated during the 2023 growing season.

Mid-Season Broccoli Plant Health

Mid-season SPAD readings did not differ among clover or management treatments, indicating that nitrogen levels within plant tissues were not negatively impacted by any treatment (Figures 9 and 10).

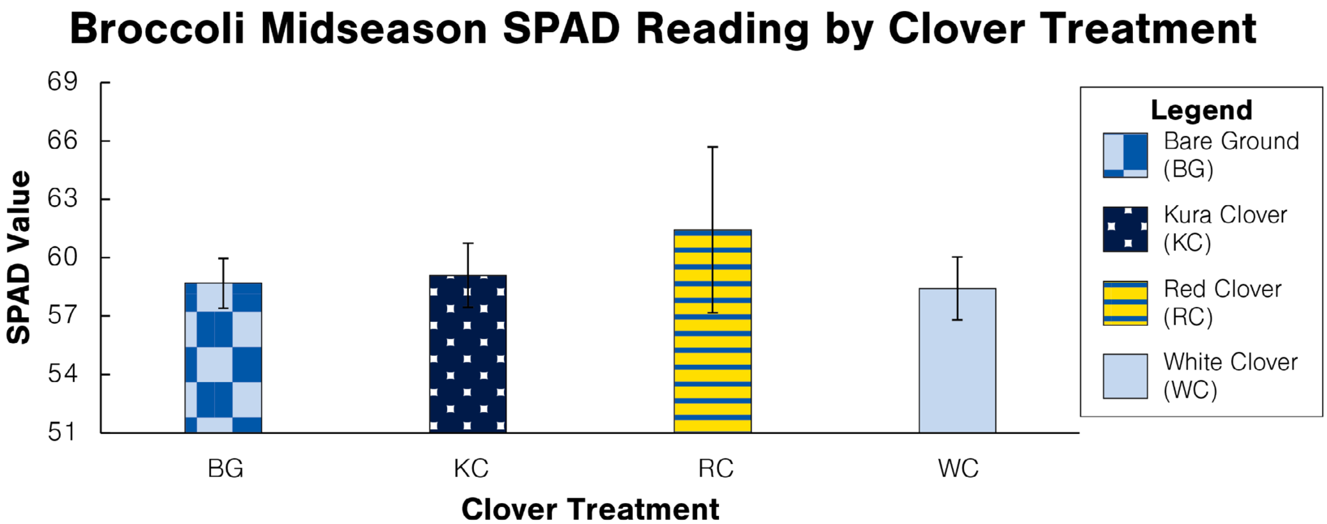

Figure 9. Average SPAD reading for chlorophyll content taken mid-season on eight broccoli plants per row. Clover cultivar did not affect midseason broccoli SPAD readings per 20 plants ($p = 0.83$) for the 2023 trial.

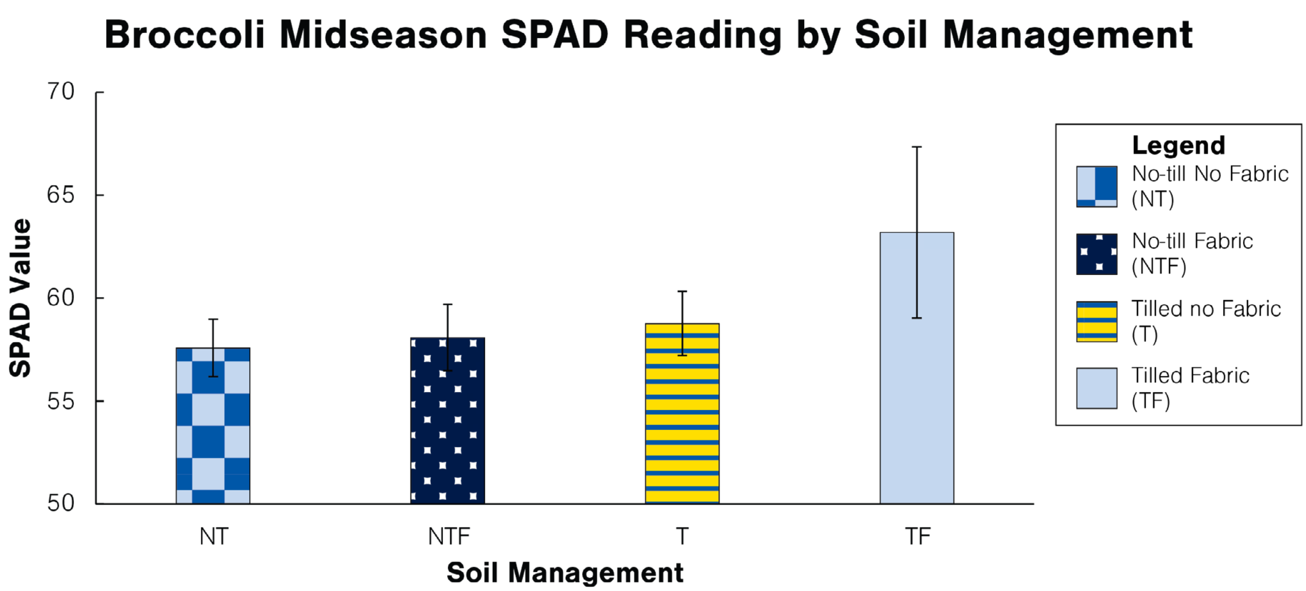

Figure 10. Average SPAD reading for chlorophyll content taken mid-season on eight broccoli plants per row. Management treatment did not affect midseason broccoli SPAD readings per 20 plants ($p = 0.29$) for the 2023 trial.

There was a significant interaction between clover and management treatments for plant height (p = 0.01) and canopy width (p = 0.02) (Figures 11 and 12). Broccoli plants were shortest in NT plots in KC and WC treatments (Figure 11). Broccoli was the tallest when grown in TF in KC and in WC (Figure 11). Within BG and RC plots, soil management did not affect broccoli height (Figure 11).

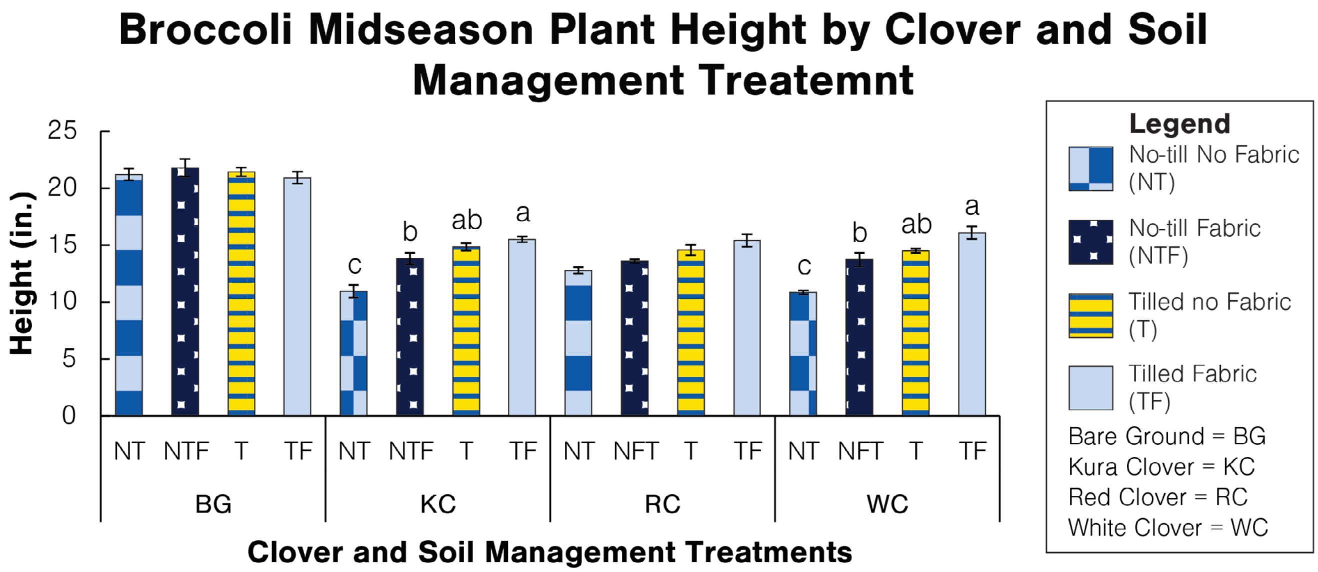

Figure 11. Average broccoli plant height collected mid-season, 2023. Clover cultivar and management treatment used affected (p = 0.01) midseason broccoli plant height. Mean separations are affected within each clover treatment, RC (p = 0.2), WC (p = 0.01), KC (p = 0.006) and BG (p = 0.5). Capital letters represent Fisher's protected least significant differences (p ≤ 0.05) for management responses within clover cultivars.

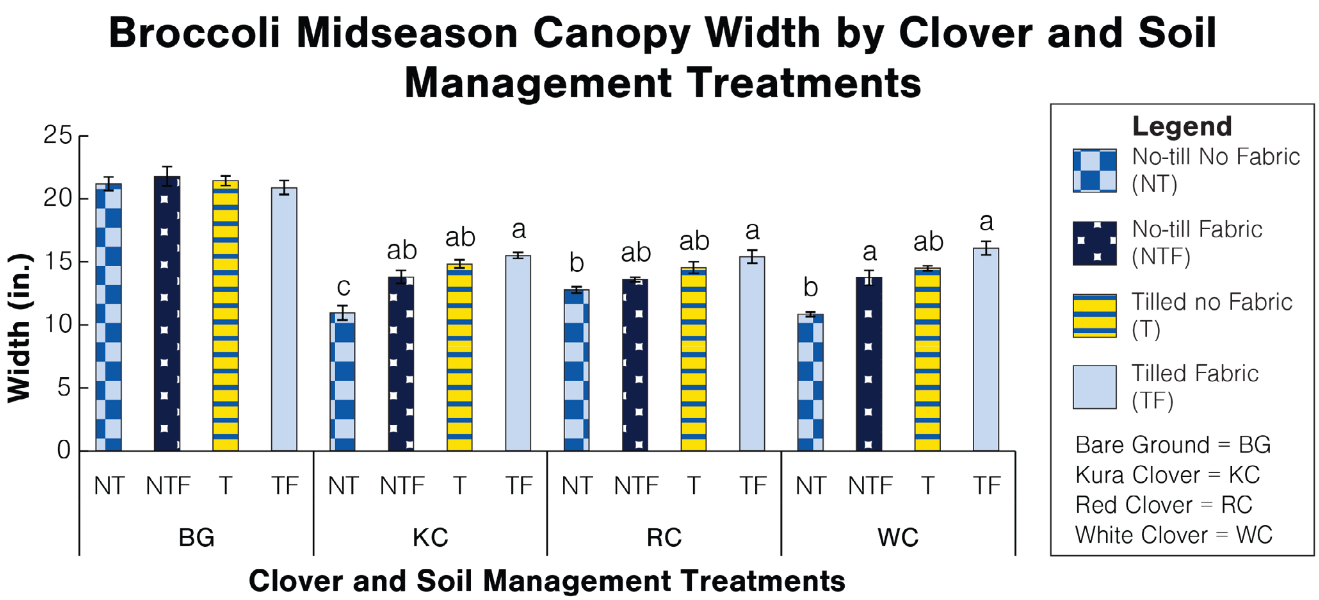

Figure 12. Average broccoli plant canopy width collected mid-season. Clover cultivar and management treatment used affected (p = 0.02) midseason broccoli canopy width. Mean separations are affected within each clover treatment, RC (p = 0.02), WC (p = 0.01), KC (p = 0.02) and BG (p = 0.4). Capital and lowercase letters represent Fisher's protected least significant differences (p ≤ 0.05) for clover cultivar response variables, respectively.

In-row soil management had no effect on the canopy width of broccoli grown in BG conditions (Figure 12). Within KC, RC, and WC plots, NTF, T, and TF conditions resulted in similar broccoli canopy widths (Figure 12). Not surprisingly, broccoli plants had a wider canopy in TF plots compared to NT conditions when grown in all three clover cultivars

(Figure 12). NT broccoli plants were small mid-season compared to TF due to competition from the clover and the weeds (Figure 12).

End of Season Broccoli Plant Health

End of season SPAD readings showed no differences among clover and management treatments (Figures 13 & 14). There were interactions between clover (p = 0.01) and soil management responses (p = 0.05) for plant height. Broccoli plant height in BG plots was taller compared to the other clover treatments due to decreased competition between clovers and weeds (Figures 15). KC, RC, and WC plots performed similarly for end of season plant height compared to BG plots (Figure 15). T and TF treatments produced a similar plant height around 19.5 in. (Figure 16). NT plots produced the lowest plant height out of all treatments at 18.8 in.; likely due to the competition of establishing living mulches (Figure 16).

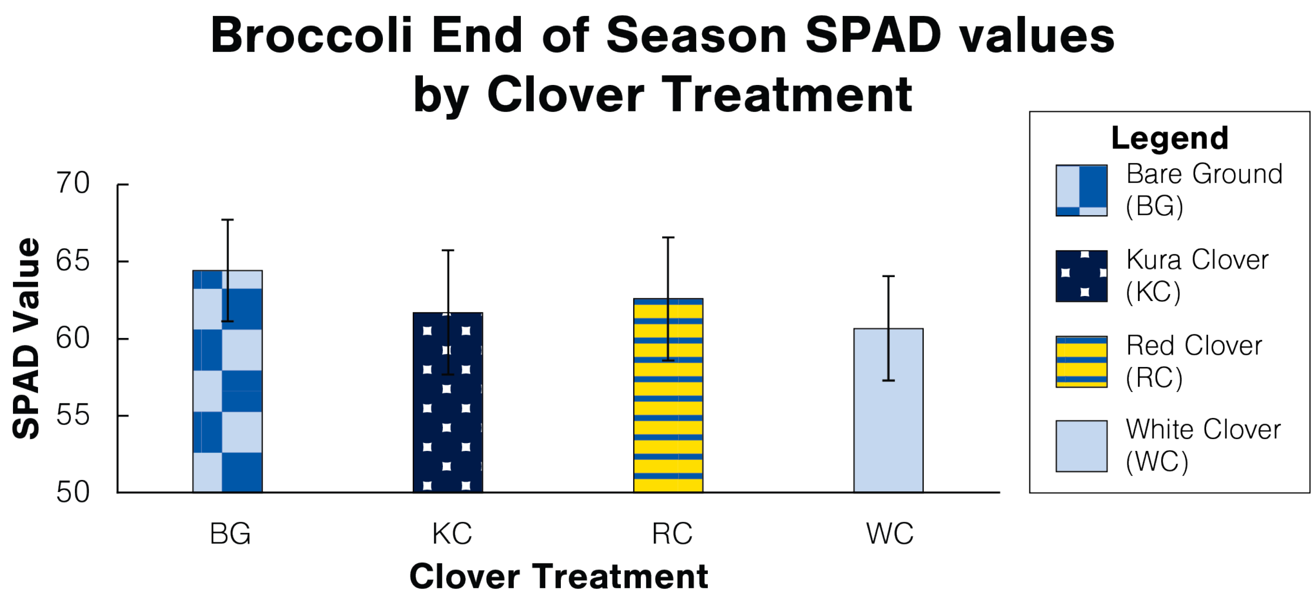

Figure 13. Average SPAD reading for chlorophyll content taken at the end of the season on eight broccoli plants per row. Clover cultivar did not affect end of season broccoli SPAD readings per 20 plants (p = 0.70) for the 2023 trial.

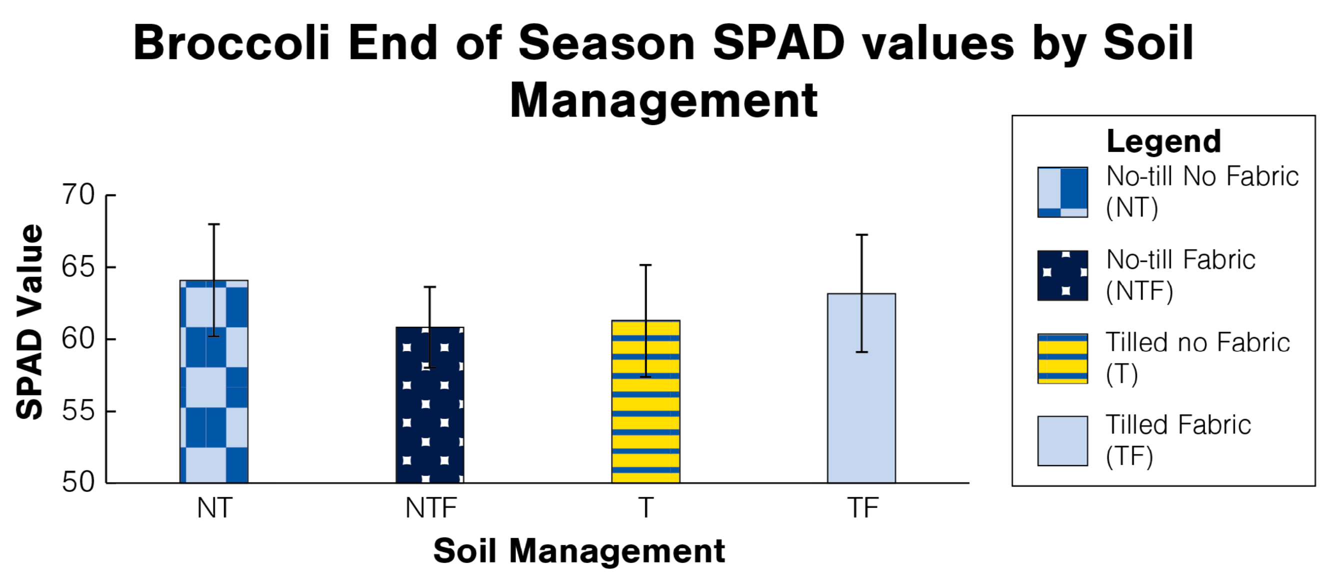

Figure 14. Average SPAD reading for chlorophyll content taken at the end of the season on eight broccoli plants per row. Management treatment did not affect end of season broccoli SPAD readings per 20 plant (p = 0.57) for the 2023 trial.

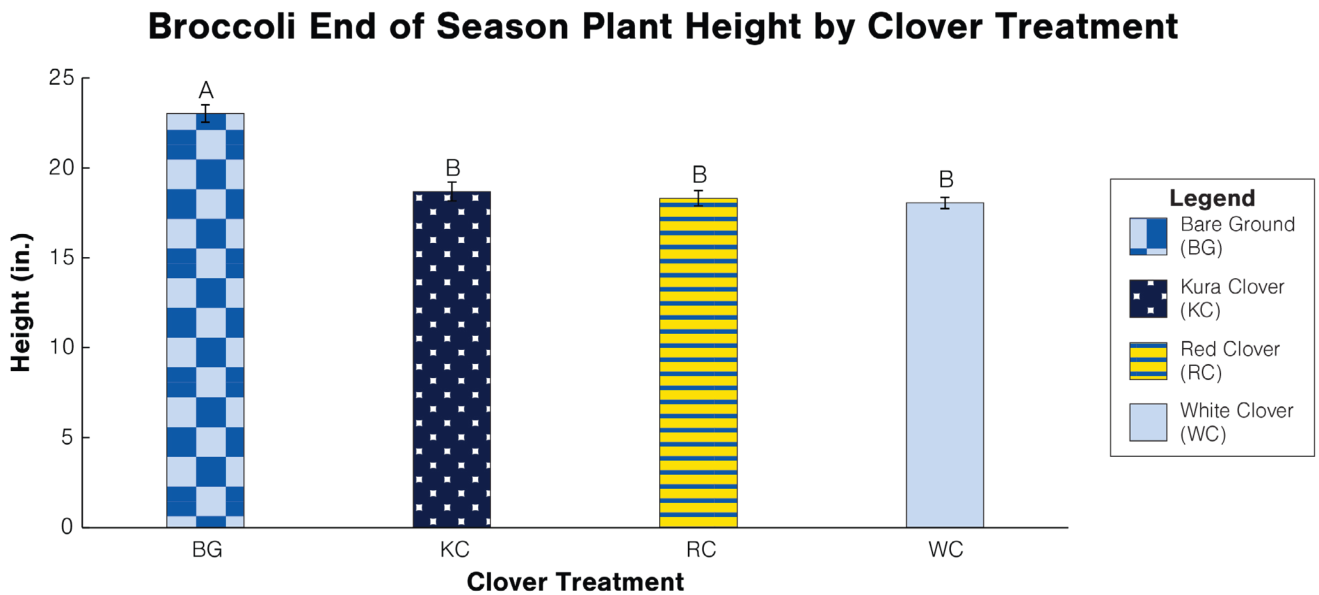

Figure 15. Average broccoli plant height collected at the end of the season. Clover cultivar used affected (p = 0.01) end of season broccoli plant height. Capital and lowercase letters represent Fisher's protected least significant differences (p ≤ 0.05) for clover cultivar response variables, respectively.

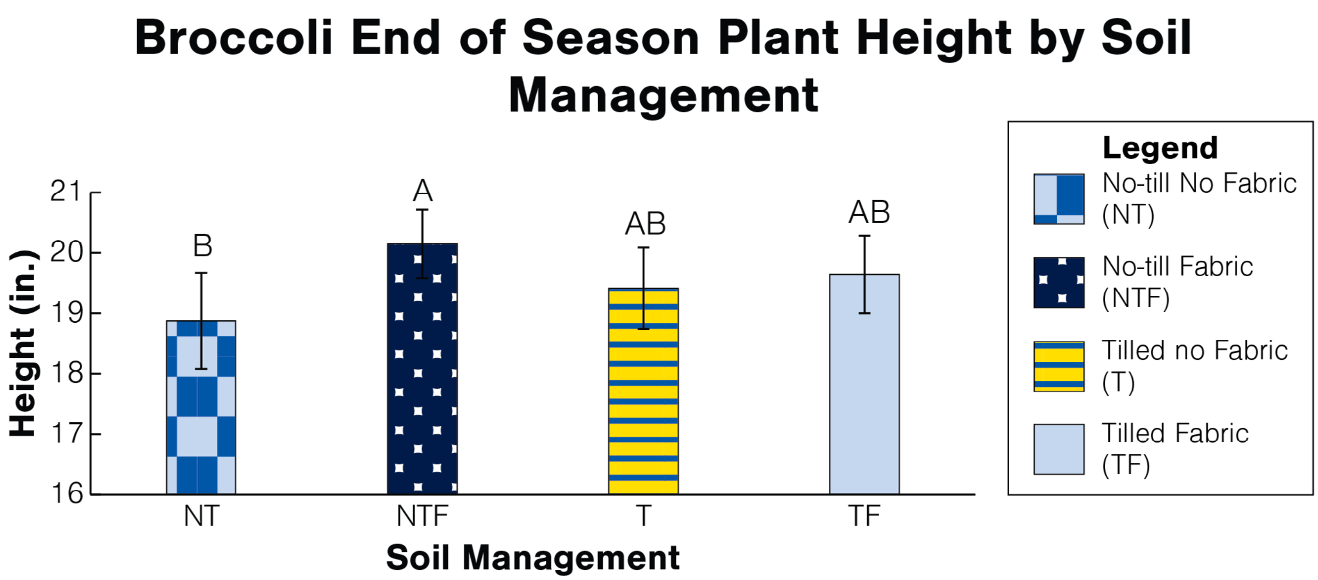

Figure 16. Average broccoli plant height collected at the end of the season. Management treatment used affected (p = 0.05) end of season broccoli plant height. Capital and lowercase letters represent Fisher's protected least significant differences (p ≤ 0.05) for clover cultivar response variables, respectively.

The broccoli canopy was wider in the BG plots compared to the clover treatments (Figures 17 & 18). KC, RC, and WC plots showed no differences among canopy height compared to the BG plots (Figure 17). TF subplots produced the widest canopy width of 19 inches compared to NT and T treatments when grown in the clover plots (Figure 18). Unsurprisingly, NT subplots produced the smallest width of 15.3 inches due to the rapid growth of clovers and competition for light and space with broccoli plants (Figure 18).

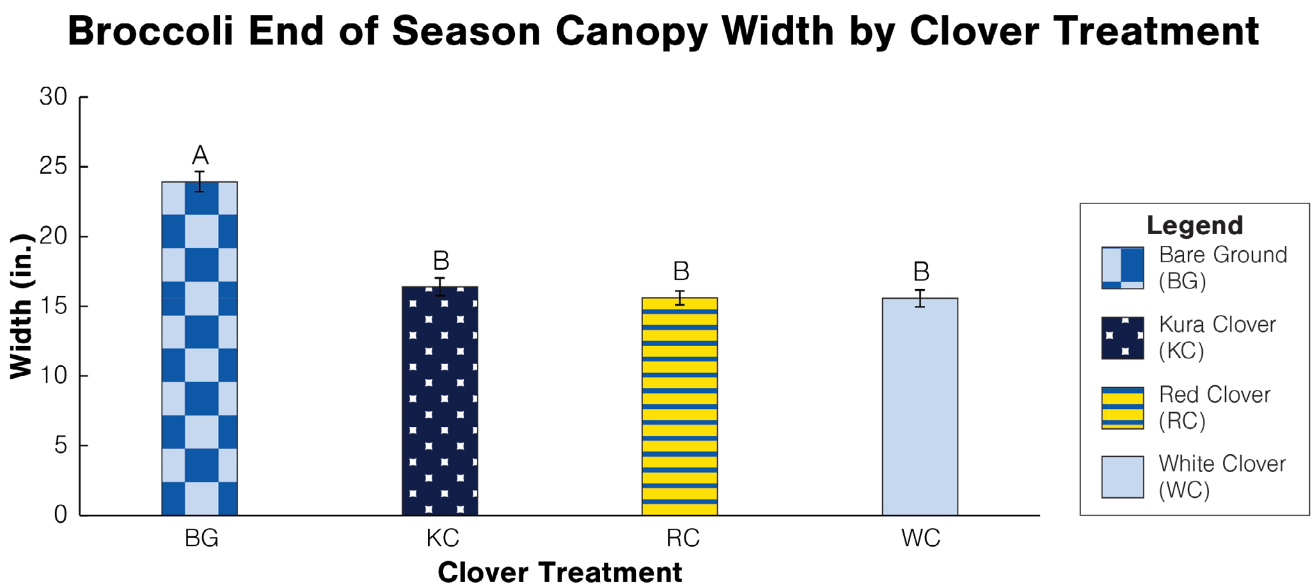

Figure 17. Average broccoli canopy width collected at the end of the season. Clover cultivar used affected (p = 0.01) end of season broccoli canopy width. Capital and lowercase letters represent Fisher's protected least significant differences (p ≤ 0.05) for soil management response variables, respectively.

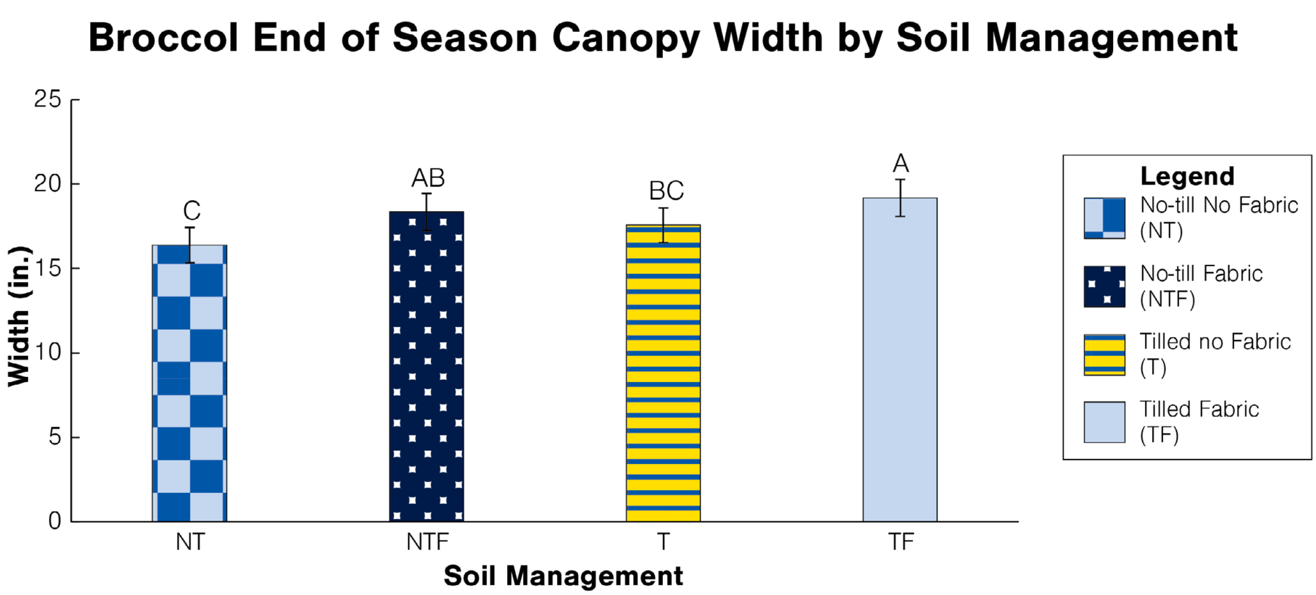

Figure 18. Average broccoli canopy width collected at the end of the season. Management treatment used affected (p = 0.009) end of season broccoli canopy width. Capital and lowercase letters represent Fisher's protected least significant differences (p ≤ 0.05) for soil management response variables, respectively.

Broccoli plant biomass showed differences among soil management and clover treatments (Figures 19 & 20). BG plots produced the heaviest broccoli dry biomass, at an average weight of 0.33 lbs., compared to the other clover treatments due to limited competition with weeds in BG plots (Figure 19). RC plots produced the lowest broccoli average dry weight of 0.13 lbs. compared to KC and BG (Figure 19). NTF and TF produced the heaviest average dry weights, 0.23 and 0.24 lbs., respectively, compared to T and NT (Figure 20). NT produced the lowest average broccoli dry weight of 0.13 lbs., most likely due to competition between the establishing clover and broccoli plants (Figure 20).

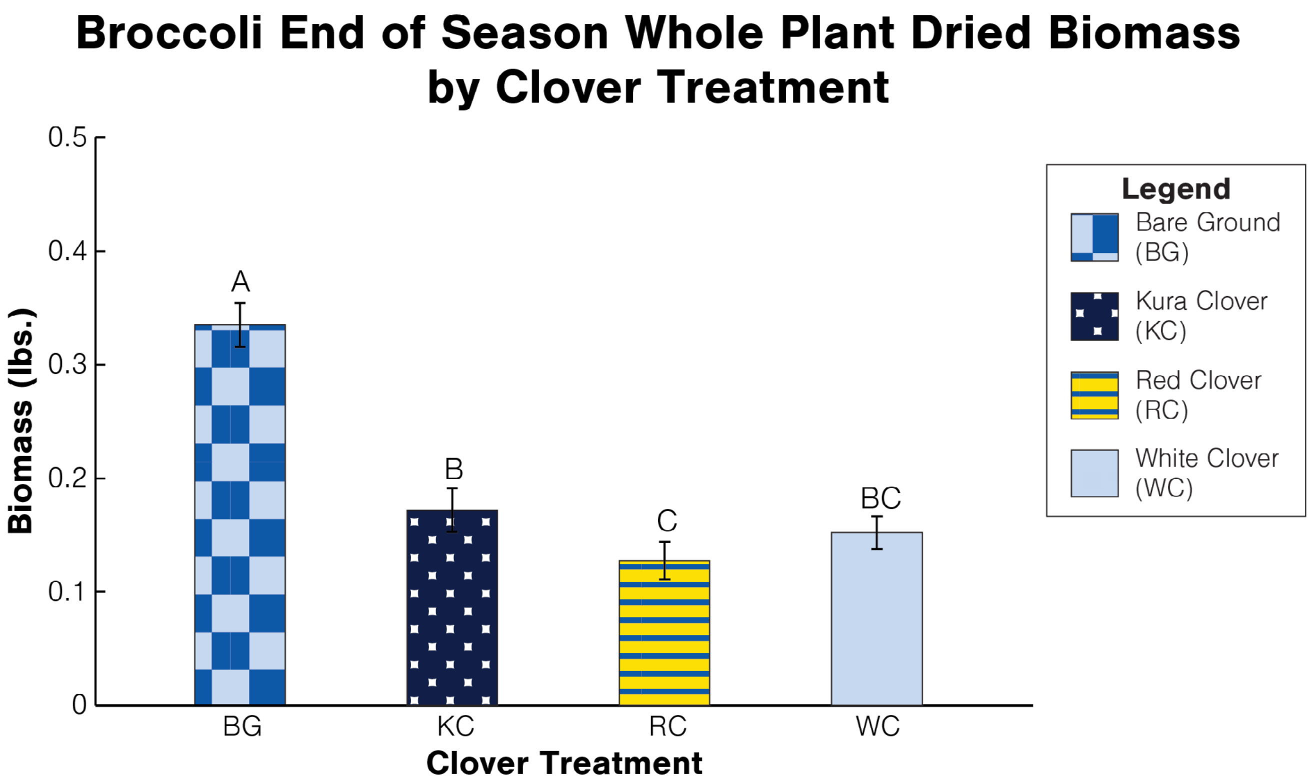

Figure 19. Average dry broccoli plant biomass collected at the end of the season. Clover cultivar used affected ($p = 0.01$) broccoli dried plant biomass. Capital and lowercase letters represent Fisher's protected least significant differences ($p \leq 0.05$) for clover cultivar response variables, respectively.

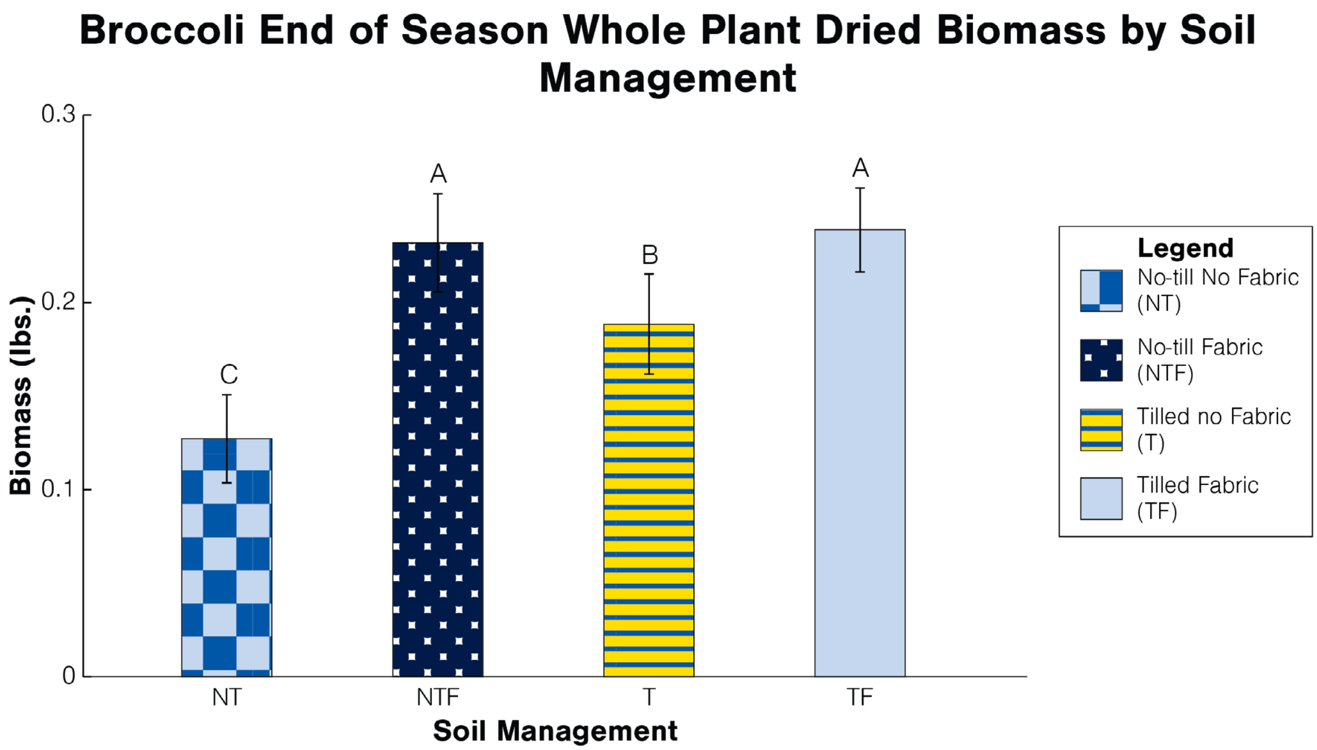

Figure 20. Average dry broccoli plant biomass collected at the end of the season. Management treatment used affected ($p = 0.007$) broccoli dried plant biomass. Capital and lowercase letters represent Fisher's protected least significant differences ($p \leq 0.05$) for soil management response variables, respectively.

Yield

There was an interaction (p = 0.01) between clover and soil management for the yield response. TF in RC and WC resulted in higher marketable broccoli yields than any other soil management treatment (Figure 21). Within KC plots, there were more marketable broccoli heads collected from TF versus T plots, but TF and NTF plots were similar (Figure 21). This shows some potential for the use of 36-wide fabric in conjunction with tilled planting strips to guard against yield losses of living pathways. However, yields in BG plots did trend higher than marketable yields collected from any of the BG x soil management plots (Figure 21). Only 29% of total harvested broccoli heads were marketable across all soil treatments and clover cultivars (Figure 21). Late season heat waves in August and September caused 71% of broccoli heads to bolt or become puffy (Figures 3 & 21). BG broccoli was ready to harvest in August due to less competition between weeds and broccoli plants.

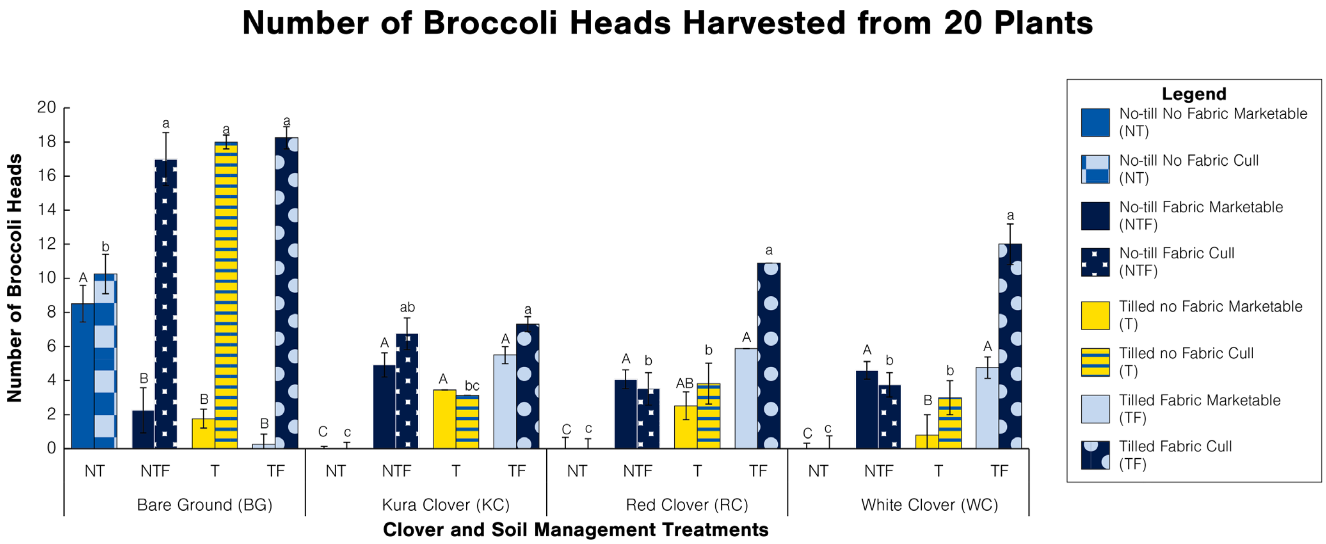

Figure 21. Average broccoli heads harvested from 20 plants; data includes marketable and cull head count. Cultivar used affected marketable (alpha = 0.01) and cull (p = 0.02) count per 20 plants. Mean separations are affected within each clover treatment for marketable broccoli: RC (p = 0.002), WC (p = 0.007), KC (p = 0.001) and BG (p = 0.001). Mean separations are affected within each clover treatment for cull broccoli: RC (p = 0.03), WC (p = 0.02), KC (p = 0.04) and BG (p = 0.01). Cultivar used affected marketable squash (p = 0.01). Capital and lowercase letters represent Fisher's protected least significant differences ($p \leq 0.05$) for marketable and cull response variables, respectively.

What to Consider Before Using Clover Living Mulch in SD

Though they were slow to establish in the spring, clover plots were filling out by the end of the first growing season. Red clover, while taller, had patchier growth, and less soil coverage; it does have a tap root which could provide increased water infiltration and decreased soil erosion as a pathway plant, but it is not showing as much promise for a no-till living mulch. While weeds trended lower across all plots by the end of the season, the clovers did not positively impact weed suppression within field pathways. It's likely that mowing of weeds in clover pathways and cultivation of weeds in BG treatments meant that weed resources were reduced by two different mechanisms but resulted in similar outcomes. As expected, broccoli plant performance was severely impacted when grown in NT plots; this aligns with prior findings in 2022 and we do not advise that broccoli be planted directly into KC, RC, or WC living mulches used in this study. 71% of broccoli heads harvested were non-marketable, which was due to fluctuating temperatures in late summer, and labor constraints limiting daily harvest. Had harvest been timelier when broccoli was maturing rapidly, it's likely we could have observed larger differences in marketable broccoli heads among soil management treatments x clover cultivars. We learned that broccoli in BG plots was ready to harvest earlier in the season, so delays in broccoli head production should be taken into consideration if clover living mulch pathways are used.

South Dakota specialty crop producers who are interested in incorporating clover living mulches into their farm system should be prepared for yield decreases in the first year of clover establishment, as demonstrated by our work. The use of tilled strips in 36-inch-wide woven landscape fabric can provide some protection against poor plant health and yield losses, but there will still be trade-offs. Mowing living mulch pathways was faster than cultivating bare-ground pathways, and we observed a reduction in dust during high winds, and reduced muddiness when rain occurred.

Supplemental moisture may be necessary early in the season to ensure strong establishment of the clover living mulch pathways if there is a lack of timely rainfall. Additional irrigation may be needed if drought conditions persist in July and August of the first growing season. Diligence in pest scouting, increased fertilizer applications, increased moisture and selecting competitive cash crops may be necessary to make the use of living mulches successful. Additional data analysis from this work and consecutive years of data collection are ongoing to get a deeper understanding of soil health benefits that may make plant performance trade-offs easier to accept, as farmers incorporate more sustainable practices into their farming system.

Acknowledgments

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USDA AMS Standards. ams.usda.gov/grades-standards/broccoli-processing-grades-and-standards

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