The Ceres Trust
Final Report (2013-2016)

Project Title:
Evaluation of Soil Quality in Vegetables Planted in Plastic Mulch vs. No-Till in Polyculture Cover Crop.

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Abstract:

This project's main objective was to determine the effects of a polyculture cover crop, no-till, tillage, and straw, polyethylene and fabric mulch on soil quality, weed control and yield of seven growing systems. Overall, no-till treatments yielded less than tilled treatment and only in the tomato cropping system was there even moderate success with using organic no-till for weed control. In lettuce and broccoli, the timing of cover crop growth stages did not match well with crop planting, leading to the cover crop competing for resources with the cash crop. No-till systems conserved moisture better than tilled systems but using a cover crop and no-till did not have an effect on most soil health indicators during the three year study, with the exception being increased soil microbial biomass under no-till with a cover crop.

Introduction:

Organic vegetable production in the Midwest relies heavily on tillage and the use of polyethylene film for weed control. Both of these practices have been implicated in the degradation of soil quality. Both tillage (Jackson et al., 2003; Doran, 1980; Creamer and Baldwin, 2000) and the use of polyethylene film (Rice et al., 2001; Li et al., 2004; Moreno and Moreno, 2008) can lead to increased soil erosion, losses in soil organic matter and microbial biomass, and a decline in nutrient availability. The utilization of cover crops in vegetable production can lead to a reduction in tillage and reduced need for polyethylene film. When paired with no-till practices, growing cover crops can lead to improved soil organic matter content, increased microbial diversity, increased water holding capacity, reduced soil erosion, lower weed competition, and a reduced need for nutrient amendments (Gunapala and Scow, 1998; Jackson et al., 2003; Moreno and Moreno, 2008). The high management requirement that characterizes organic vegetable production fits well into sustainable practices using cover crops. Improvements to soil quality brought about through use of cover crops, no-till and good crop rotations can lead to improved productivity and yields (Kelly et al., 1995; Abdul-Baki et al., 1996; Carrera et al., 2007; Creamer et al., 1996).

Still, even with the soil quality benefits, no-till practices are challenging to implement on organic vegetable farms because of the issue of weed control. In this experiment, we examined seven organic growing systems that utilized either a polyculture cover crop, no-till, or tillage and polyethylene, straw, or fabric mulch to determine which systems provide best practices for weed control, soil quality, and profitability. We also studied which vegetable crops had the best germination and growth when transplanted or direct-seeded into no-till cover crop residue. Our goal was to develop a production plan that will help organic vegetable producers decide when they can feasibly use no-till practices and how they can successfully reduce use of tillage and polyethylene film without hurting their crop yield. The specific objectives of this project were:

- Compare the effects of 7 vegetable growing systems on soil quality, weed control and crop yield. These systems will utilize no-till with rolled or mowed cover crops or tillage with plastic, fabric or hay mulch.
- Determine if germination and growth of direct seeded and transplanted vegetables are affected by planting into cover crop residue.
- Develop a production plan that will help organic vegetable producers decide when they can feasibly use no-till and cover crops and how they can best reduce use of tillage and polyethylene film.
- Integrate research results into organic and extension publications, presentations and conferences.

Materials and Methods:

This research was conducted on land certified organic through QCS at the Bradford Research Center, located 5 miles east of Columbia, MO. Soils at this site are Mexico silt loam (fine, smectitic, mesic Vertic Epiaqualfs) and are on the central glacial till claypan plain. Elements of this study were conducted concurrently on two certified organic farmers' fields as described in the organic farmer section.

Polyculture cover crops: The winter mix was cereal rye, oats, crimson clover, Austrian winter pea, and hairy vetch. The summer mix was sorghum, cowpea and sunn hemp.

Crops and Planting: Lettuce (Adriana) was planted in the spring (mid-May) in two rows with 12 inch in-row spacing, tomato (Charger) in the summer (early June) in one row with two inch in-row spacing and broccoli (Arcadia) was planted in the fall (mid-August) in two rows with two inch in-row spacing. Winter cover crops were planted in mid-October and summer cover crops were planted in mid-June. Direct seeded crops were planted in early June. Cash crops were chosen based on their value and demand in the market. Four replications of each treatment were grown. Plots in Experiment 1 were 5 feet wide and 10 feet long. Crops in the mulch experiment (part A) were transplants. Crops in the non-mulch experiment (part B) were planted with a grain crop planter in 30 inch rows. In experiment 2 of the study, both direct-seeded and transplanted crops were planted into three treatments: 1) no-till in rolled cover crop; 2) cover crop mowed and tilled; and 3) bare ground tilled. Both early and mid-season crops were tested in winter cover crop mixes. Direct-seeded, early-season plots were

5 feet wide by 10 feet long, and seeds were planted with a 6-row drill, three crops per plot. Transplanted plots were 12 feet wide by 20 feet long. Direct-seeded mid-season plots were 5 feet wide and 7.5 feet long and were planted with a 2-row cone planter at 30” apart. Transplanted plots were 12 feet wide by 20 feet long, with 8 rows of transplants.

Experiment One. Improving soil quality in organic vegetable production

<table>
<tr><th>Treatment</th><th>Tillage</th><th>Mulch</th><th>early season crop</th><th>mid season crop</th><th>late season crop</th></tr>
<tr><td colspan="6">Crops normally grown with plastic (Part A)</td></tr>
<tr><td>Winter cover crop polyculture</td><td>no</td><td>mowed cc, straw</td><td rowspan="7">head lettuce</td><td rowspan="7">tomato</td><td rowspan="5"></td></tr>
<tr><td>Winter cover crop polyculture</td><td>no</td><td>rolled cc</td></tr>
<tr><td>Winter cover crop polyculture</td><td>yes</td><td>mowed cc, plastic film</td></tr>
<tr><td>Winter cover crop polyculture</td><td>yes</td><td>mowed cc, fabric</td></tr>
<tr><td>No cover crop</td><td>yes</td><td>straw</td></tr>
<tr><td>No cover crop</td><td>yes</td><td>plastic film</td><td rowspan="6">broccoli</td></tr>
<tr><td>No cover crop</td><td>yes</td><td>fabric</td></tr>
<tr><td>Summer cover crop polyculture</td><td>no</td><td>mowed cc, straw</td><td rowspan="4"></td><td rowspan="4"></td></tr>
<tr><td>Summer cover crop polyculture</td><td>no</td><td>rolled cc</td></tr>
<tr><td>Summer cover crop polyculture</td><td>yes</td><td>mowed cc, plastic film</td></tr>
<tr><td>Summer cover crop polyculture</td><td>yes</td><td>mowed cc, fabric</td></tr>
<tr><td colspan="6">Crops normally grown without plastic (Part B)</td></tr>
<tr><td>Winter cover crop polyculture</td><td>no</td><td>rolled cc</td><td colspan="2" rowspan="3">sweet corn, melons</td><td rowspan="3"></td></tr>
<tr><td>Winter cover crop polyculture</td><td>yes</td><td>mowed cc</td></tr>
<tr><td>No cover crop</td><td>yes</td><td>none</td></tr>
<tr><td>Summer cover crop polyculture</td><td>no</td><td>rolled cc</td><td rowspan="3"></td><td colspan="2" rowspan="3">sweet corn, green beans</td></tr>
<tr><td>Summer cover crop polyculture</td><td>yes</td><td>mowed cc</td></tr>
<tr><td>No cover crop</td><td>yes</td><td>none</td></tr>
</table>

Experiment Two. Germination and growth in cover crop mulch

Planting method	Season	Crops
direct seeded	early	carrot, onion, pea, spinach, radish, turnip, beet
	mid	cucumber, eggplant, beans, melon, sweet corn, okra, squash, pumpkin
transplant	early	broccoli, Brussel sprouts, cabbage, cauliflower, lettuce, onion, potato, leek
	mid	cucumbers, eggplant, melon, okra, pepper, squash, sweet potato, tomato

Fertility: Composted poultry manure was applied to each plot at 2 tons/acre.

Soil Analyses:

Wet aggregate stability was determined using the method of Nimmo and Perkins (2002). After air drying, a soil sample was passed through a 2 mm sieve and retained on a 1 mm sieve. Pre-weighed sieves of 0.5 mm were placed in plastic dishes filled with two liters of deionized water and 3.00 grams of the >1 to <2 mm soil fraction was evenly dispersed on the sieves and left to soak for 16 hours. Samples were agitated using 20 up and down strokes, then sieves and soil were removed from water, placed on pre-weighed metal plates, and dried at 110° C for one hour. Sand and iron-manganese nodules were then separated from soil aggregates by adding a solution of sodium hexametaphosphate (35.7 g L^{-1}) and sodium bicarbonate (7.94 g L^{-1}) then triturating the dispersing solution with fingers to remove soil particles left on the sieve. The samples and sieves were again dried at 110° C and weighed.

Soil microbial analysis samples were collected at the end of each crop season. Microbial community diversity was measured using the phospholipid fatty acid analysis of Buyer and Sasser (2012). In brief, samples were placed in test tubes and dried overnight. After a Bligh-Dyer lipid extraction was performed the extract was dried, dissolved in chloroform, and placed into a 96 well extraction plate. Phospholipids were then eluted into vials, dried and transesterified. The fatty acid methyl esters produced by this process were then analyzed in a GC using MIDI Sherlock software (MIDI Inc., Newark, DE).

Total soil organic carbon (TOC) and total nitrogen (TN) were determined on sieved (< 2 mm), air-dried, ground soil samples by dry combustion at 900° C using a LECO® Tru-Spec C/N Analyzer (Nelson and Sommers, 1996).

The active soil carbon fraction was analyzed colorimetrically using the method of Weil et al. (2003) and modified by Culman et al. (2012). A 2.5 g soil sample was added to 2.0 ml of potassium permanganate ($KMnO_4$) and 18.0 ml of DI water then shaken for 2 minutes. After settling for 10 minutes, a 0.5 ml sample of the supernatant was extracted, added to 49.5 ml of DI water and read at 550 nm on a spectrophotometer (Pharmacia LKB Ultrospec).

Samples from each treatment were tested at the onset of the experiment and annually for macronutrients as described in Nathan et al., 2006. Daily soil temperatures in mulch vs. plastic treatments were monitored using a HOBO data logger.

Harvest: Cover crops were rolled using an I&J roller/crimper or were flail mowed. Vegetable crops were hand harvested, weighed and seasonal yields calculated on a weight/area basis.

Organic Farmer Involvement:

Two certified organic farmers participated in the tomato production part of this research on their farms. David Gray of Greyson Organics in Montgomery City, MO planted Mountain Delight tomatoes into: 1) No cover crop- tilled-plastic; 2) Cover crop-rolled/crimped; 3) Cover crop-mowed-straw mulch. He found that the treatment of a cover crop with straw mulch produced the best yields, although he noted that three treatments yielded less than his usual due to late timing of planting. Mr. Gray took a hiatus from farming in 2014 to concentrate on his construction business. Liberty Hunter of the Salad Garden in Ashland, MO transplanted Big Beef tomatoes into the same three treatments. She found that the treatment with no cover crop and plastic mulch yielded highest. Unfortunately, Ms. Hunter also quit farming in 2014 to take a paying job with benefits.

<u>Outreach and Extension:</u>

Organic Field days were held at the University of Missouri Bradford Research Center in early August of 2013-2016. Attendance at these field days ranged from 90 to 175 people. Food served at the field day was prepared from organic vegetables harvested from the research plots and other produce and grains organically grown at Bradford.

The no-till vegetable research plots were also mentioned and visited during numerous field days held at Bradford Research Center including the annual September Tomato Festival (attendance 800), NRCS and Extension Cover Crop Field Days in 2013 and 2014 (attendance 25), the Future Farmers of America Ag Education Field Day in 2013-2016 (attendance 2000), and the Crop Injury and Diagnostic Clinic in 2014 (attendance 75). Additionally, the research field was a regular tour stop for the 3000 schoolchildren who receive educational tours at the research center each fall.

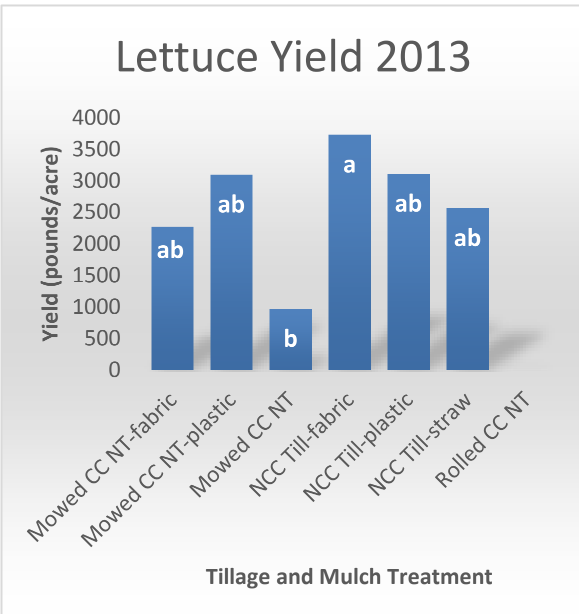
Presentations on our research were made at the Great Plains Commercial Vegetable Growers Conference in 2013 and 2014 (attendance 350), and at the Missouri Organic Association Conference in 2014 and 2016 (total attendance 600). Research posters were presented at the MOSES Organic Farming Conference in February 2014 (attendance 2000) and at the American Society of Agronomy annual conferences in 2014 and 2015 (attendance 4000).

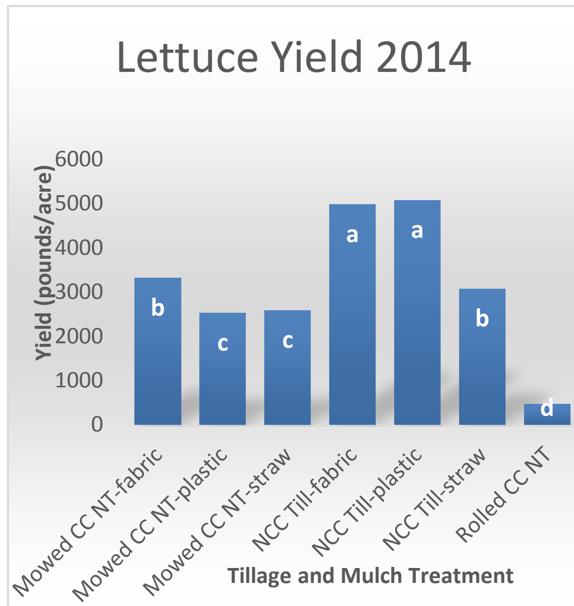
The research was also a focal point for interaction with the student group, Tigers for Community Agriculture. Our research specialist became a co-instructor for the Sustainable Agriculture Advanced Practicum class at the University of Missouri and held weekly training sessions for the TCA student group in organic vegetable production. The produce harvested from the research plots was donated to Tiger Pantry, an on-campus, student-run food pantry, and sold to Campus Dining for use in the campus dining halls. This effort has been well publicized in numerous online publications by the College of Agriculture Communications Office and featured on the MU website (audience 250,000).

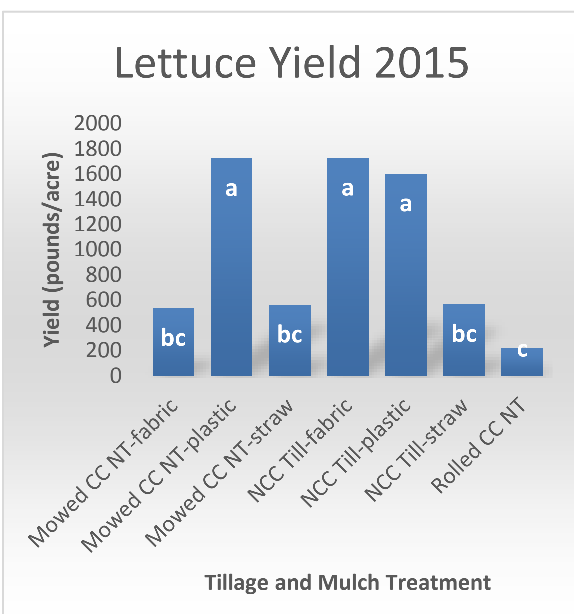
We are currently writing a publication on the research that will be submitted to a per-reviewed journal and an extension guide sheet on no-till organic vegetable production in Missouri is being prepared.

Results and Discussion:

Experiment One: We have determined that a winter-planted cover crop that is terminated in early to mid-May is not at the proper stage for successful rolling/crimping and needs to be more mature for complete termination. It is possible that spring-grown vegetables like lettuce may not be feasible in a no-till system for organic growers without using a mulch other than the crimped cover crop. In 2013, the crimped cover crop produced no lettuce crop while in 2014 and 2015 it led to severely reduced yields, largely due to weed competition from the still growing cover

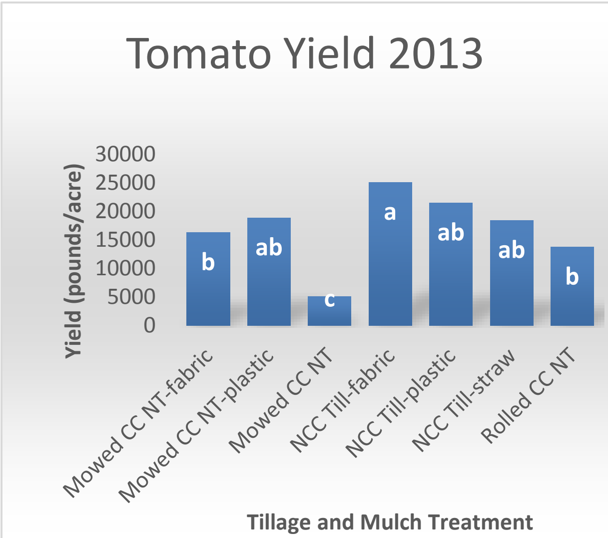


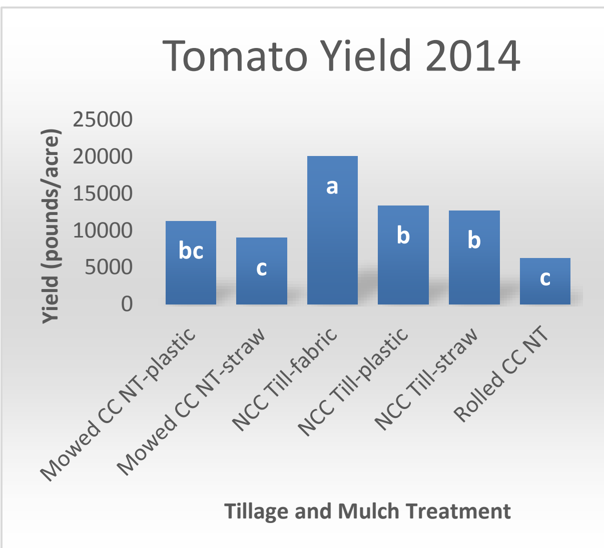




crop. Although lettuce yields were consistently highest in the no cover crop, tilled plots with fabric and plastic mulch, adverse weather conditions (very high spring precipitation) led to poor overall lettuce yields in this experiment.

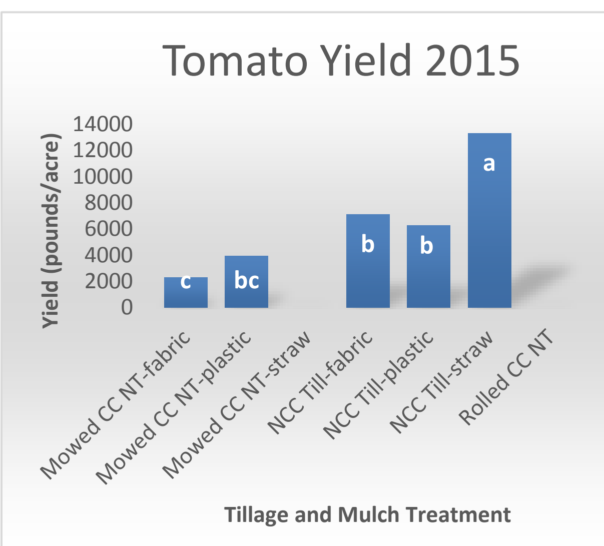
In 2013 and 2014, the soil was so difficult to work with in the no-till plots that we had to use a soil auger to make holes for transplanting. This took significantly more time and energy and may be a challenge for organic growers using no-till practices. Two weeks after transplanting, the

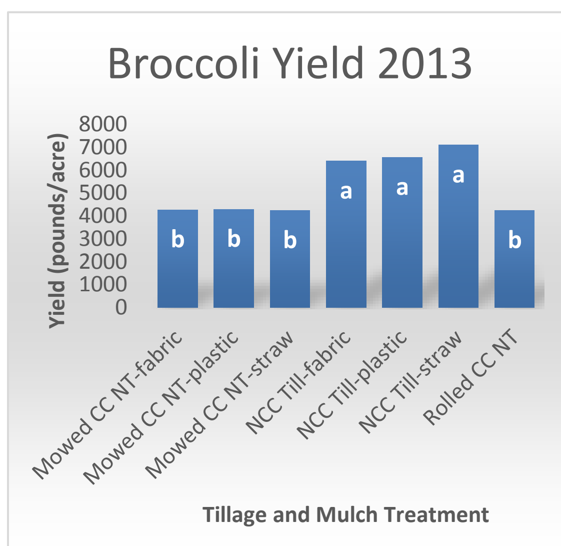




tomatoes were staked using the Florida weave method. Excessive rainfall in early summer in 2015 led to very poor results in the tomato plots. The highest yields were in the no cover crop, tilled with fabric mulch treatment in 2013 and 2014. Planting into the no-till plots seemed to lead to slowed growth immediately after planting, probably due to root restrictions in the non-tilled topsoil. Most of Missouri's agricultural soils are very high in smectitic clays, which can cause reduced growth of vegetable crops compared to crops grown in areas of higher loess deposits and less clay. For this reason, most vegetable growers in Missouri have better success growing in alluvial soils where sand and silt content is higher or in the Mollisols of west central Missouri where topography is more limiting for row crops.

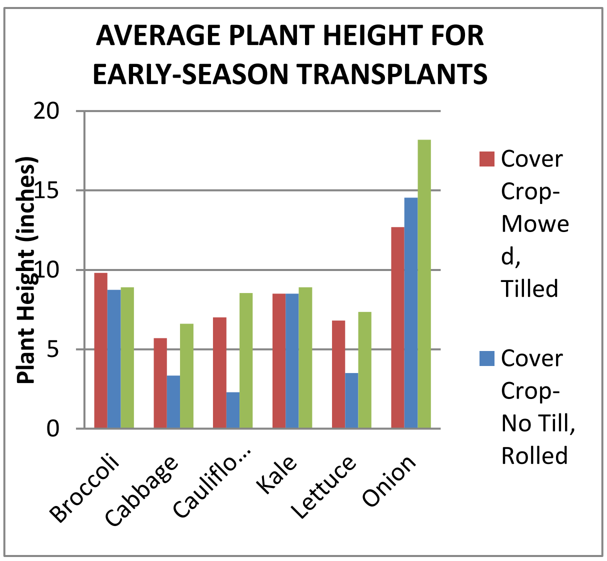
Broccoli production in 2014 and 2015 was severely hampered by extremely wet autumn weather and yields were not reportable. In 2013, the summer cover crop was crimped before

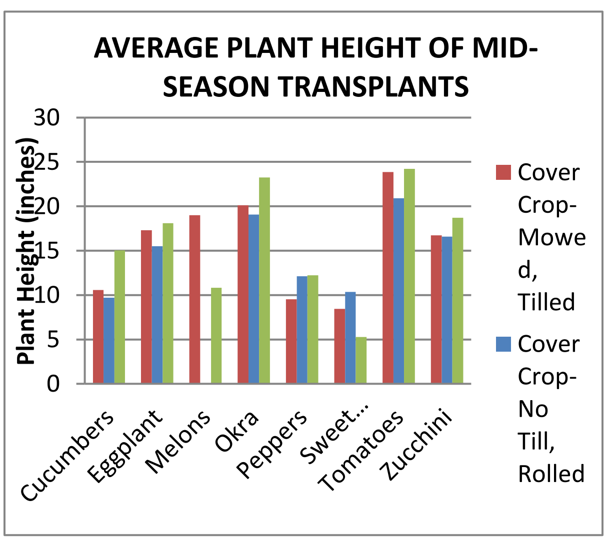




reaching a mature enough stage for crimping to significantly set it back, thus weed competition from the cover crop was an issue in the cover crop mulched treatment. The three tilled treatments led to the highest broccoli yields in 2013.

In part B of this experiment, crops normally direct seeded, weed control in the organic no-till treatments was such a big issue that it was decided to not proceed with the experiment until alternative weed control could be found. We used this experience to write and obtain a $950,000 grant from the USDA to determine new weed control methods in organic no-till. Currently we are discovering that in row crops, the use of a crimped cover crop as primary weed control pairs very well with between-row mowing for secondary weed control. We recently have added an agricultural engineering MS student to our project to design and build a prototype three-point hitch tractor-mounted mower.



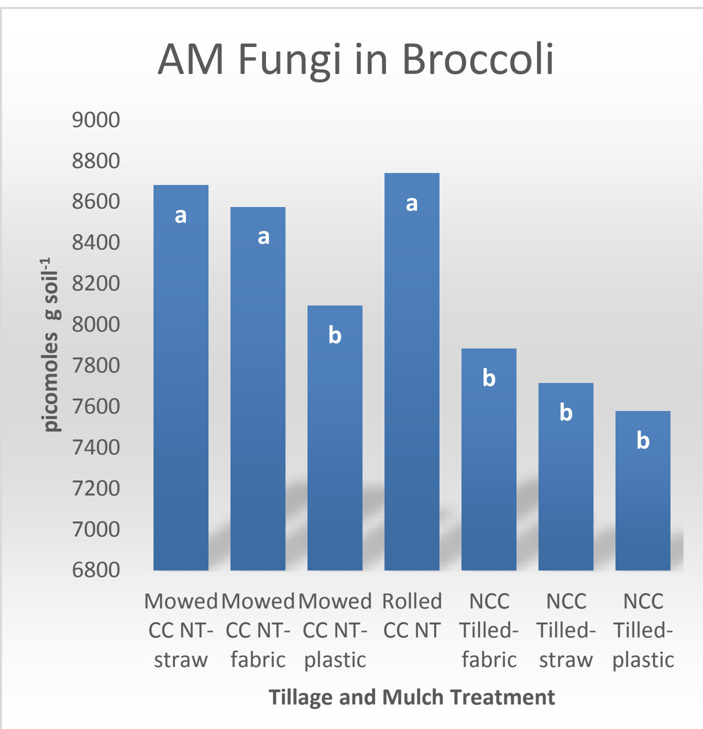


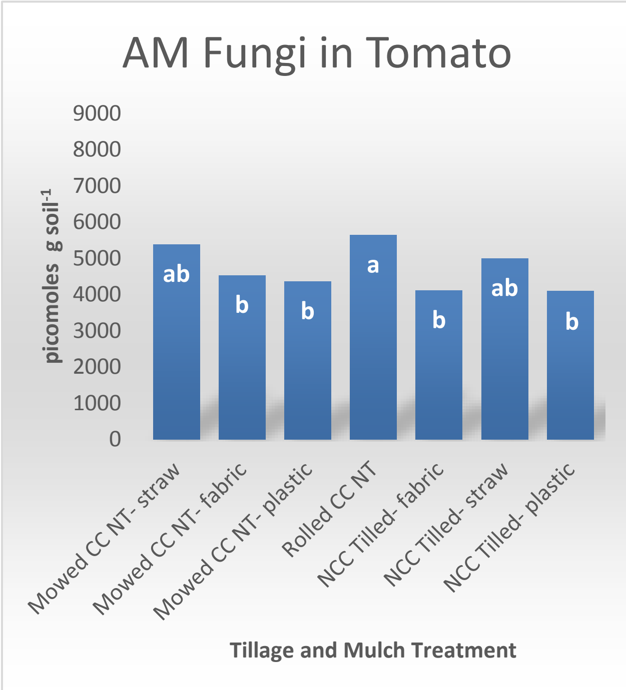
Experiment 2: The objective of Experiment 2 was to determine if germination and growth of direct seeded and transplanted vegetables are affected by planting into cover crop residue. Early and mid-season transplanted vegetables were measured for crop height in inches at one month after planting. Crops planted in mid-season rolled cover crops were comparatively more vigorous and healthy than crops planted in early-season rolled cover crops, most likely because the cover crop was more mature and properly crimped in the later part of the season. For vegetables like eggplant, okra, peppers, and zucchini, plantings in rolled cover crops were almost as successful as those planted into a tilled system. However, weed control in the crimped cover crop was rarely sufficient thus after weed influence increased, growth of the tilled crops exceeded no-till crops (data not shown).

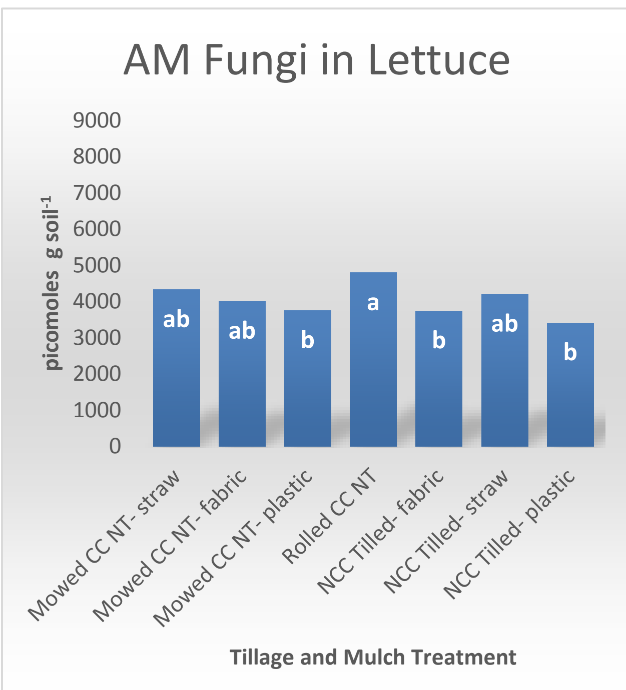
Germination counts were taken on early-season and mid-season direct-seeded crops. Early season vegetables included many small seeded, slow germinating varieties like carrots, onions, and spinach. These crops showed very poor germination, most likely due to insufficient seed-soil contact in the no-till plots as well as weed competition due to their slow germination time. Seeds planted in the mid-season trials were more successful. The cover crop mix was more mature at time of planting in mid-season, and therefore the cover crop had more biomass and it crimped more successfully. Furthermore, mid-season vegetables had larger seeds and made better seed-soil contact.

Soil Health

Several soil health indicators, including active carbon, aggregate stability, total organic carbon and N:C ratio were not affected by the tillage or mulch treatments used in this experiment. Although we hypothesized that tillage and mulch would influence soil health based on published research, only in the biomass of soil microorganisms were significant differences between treatments observed (see following tables for arbuscular mycorrhizal fungi (AMF) levels). AMF levels were highest after the late fall broccoli harvest compared to summer lettuce harvest and early fall tomato harvest. In other organic research using no-till and cover crops conducted at Bradford we have also observed that little change to soil health indicators occurs as a result of different treatments in the three year period of the research. We have not seen increases in active carbon or total organic C or N from increased cover crop residue and reduced tillage in any three-year period. We have observed improved aggregate stability in row crops with no-till and cover crops and increased soil microbial biomass. It is possible that climatic fluctuations within this short research period are affecting cover crop breakdown in a way that is not leading to quick, measurable changes in active C. It is also possible that weed



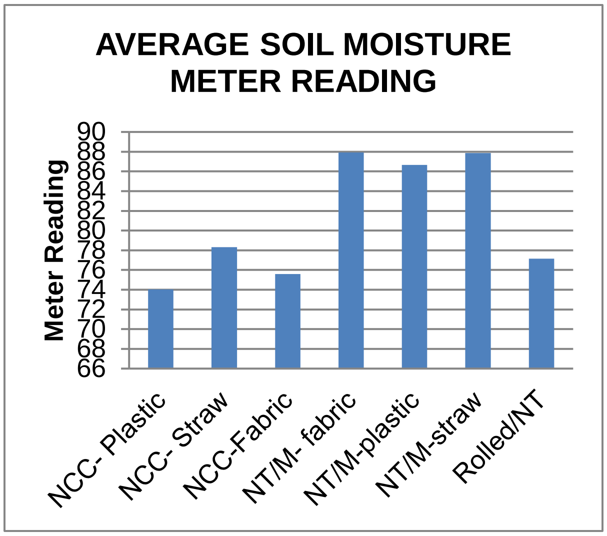




biomass in some organic situations can lead to increases in active C along with changes caused by addition of cover crops. However, weeds within the plots of this organic study were relatively low due to the presence of mulches. We believe that management capable of changing soil productivity and sustainability is ultimately a result of long-term changes, such as cumulative years of cover cropping combined with long rotations employing forages and other high residue crops. While adding cover crops to existing rotations can add to improved soil health via increased microbial biomass and improved aggregate stability, those changes need to be coupled with broader system changes that can more greatly impact soil health over time. For many farmers, managing for soil health may need to lead to greater economic impact in a shorter timer period than soil changes can actually occur. Limiting erosion is one facet of soil health that can be immediately affected by the use of cover crops and reduction of tillage but erosion must be viewed as a problem by a farmer for this to be reason enough for implementing management changes.

Soil Moisture

Soil moisture readings were taken in Experiment 1: Part A by burying gypsum soil blocks in the soil around each plot. Each day, moisture readings were taken using a Delmhorst Model KS-D1 moisture tester. Available soil moisture is measured in percent of the total potential reserve. Meter readings range from 3.0 to 99.0. Higher meter readings indicate higher available



moisture. Results showed that the no-till treatments had the highest average meter readings and most successfully conserved soil moisture. Although irrigation was by drip line laid under the mulches, the plastic mulch with no cover crop likely had the lowest moisture due to its impermeability to rainfall. The cover crop in the rolled treatments had less ground cover than the three mulches so would have lost more moisture to evapotranspiration.

Conclusions

Using a rolled/crimped cover crop for weed control did not work well except for moderate success in the tomato crop. Only in this system did the timing of the cover crop crimping and the crop planting match well enough to get adequate kill in the cover crop. In the lettuce and broccoli systems, the cover crop did not crimp well due to still being in vegetative stages, thus leading to the cover crop becoming competitive for resources needed by the cash crop. It was also very difficult to hand transplant into the no-till plots, especially in dryer years.

We found that several species of cover crops in our polyculture mix either did not overwinter reliably or led to too much crop competition if not completely killed in the spring. Hairy vetch has great potential to become a pervasive weed in an organic system. While cereal rye is necessary for good weed control in organic no-till, it is very competitive against legumes planted for N fixation thus the crimson clover was often shaded by the accompanying rye, leading to stunted or no growth in the clover. Austrian winter pea is more competitive with rye than crimson clover and less likely to become weedy than hairy vetch. However, in a wet cold winter with little snow cover, winter kill in this species may be very high.

Although the rolled cover crop did lead to improved microbial biomass, it had little effect on other soil health parameters. No-till conserved moisture better than tillage but tillage led to improved yields in all crops. Straw as a mulch inhibited lettuce growth by partially covering the small lettuce plants while a fabric mulch was used in the highest yielding tomatoes in two of the three years. Overall, adverse weather conditions during the study probably had far greater impact on yields than did any of the individual treatments. When trying to navigate around rainy, cold spring days, having a cover crop in the field can seem like an additional hurdle to jump over.

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