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Promoting soil integrity: the use of cover crops and a microorganism stimulant on a strip-till corn field in southeastern Minnesota

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ABSTRACT

A recent increase in collective knowledge concerning harmful environmental impacts of agricultural processes has prompted much research in agriculture to focus on sustainable practices. Two such practices are the use of cover crops and microorganism stimulants. Both contribute to building healthier soil and provide long term benefits for land quality. The purpose of this study was to determine the effects of a commercially available microorganism stimulant, AgZyme, and a mix of cover crops on soil characteristics, crop yield, and profit in a strip-tilled cornfield in Northfield, Minnesota. Soil core samples were taken three times throughout the growing season of 2015. Soil variables measured included ammonia, nitrates, orthophosphates, percent organic matter, percent moisture, bulk density, CO2 respiration, and microbial and fungal biomass and diversity. Soil nutrient analyses showed concentrations of nitrates, ammonia, and phosphates did not vary with addition of AgZyme or a cover crop, but nitrate and ammonia concentrations significantly varied over the growing season. Soil microbial biomass and CO2 respiration were higher in the AgZyme area, suggesting an increase in microorganism presence and better nutrient mobilization. Yields were not significantly different among the AgZyme, cover crop and control treatments. Profits were highest in the control treatment. While profits decreased slightly with use of a microorganism stimulant and more with the cost of planting a cover crop, benefits in terms of soil health and continued high yield are likely in the long term.

INTRODUCTION

The increase in collective knowledge about the harmful environmental impacts of conventional farming processes, such as excess nitrogen fertilizer runoff and soil erosion, has gained the attention of farmers and scientists alike. For agriculture to be environmentally sound, it must be sustainable, in this case meaning that cropland should be as productive and workable as it is today for generations to come. Research in agriculture is beginning to focus more on practices that can maintain and build soil integrity without compromising productivity, such as the use of cover crops, and perhaps less common, the use of microorganism stimulants. Even though it is known that current practices will lead to loss of productivity for the land in the future (Reganold 1987), it can be difficult to take action to change course without monetary incentive or decreased input costs to the farmer. Maintaining productivity is an imperative for farmers of commodity crops because decreased yields usually lead to decreased profits.

Implementing ecologically and economically sound practices is becoming increasingly important in Minnesota as concerns arise about soil erosion and nutrient runoff into streams and ground water. As of 2014, Minnesota farmland makes up 25.9 million acres, approximately half of all land in the state (USDA 2015). This means the practices that commodity farmers use influence the landscape to a high degree and improving those practices deserves immediate attention. In 2015 the Minnesota state legislature passed a buffer bill that requires perennial vegetation buffers of up to 50 feet and at a minimum of 16.5 feet along rivers, streams, and ditches with the goal of bettering filtering of phosphorus, nitrogen, and sediment (Minnesota Board of Soil and Water Resources 2015). These buffers will provide similar the benefits of preventing loss of soil by erosion and nutrient runoff, similar to what cover crops provide. That Minnesota is recognizing the value of conserving soil and resources and putting it into law is a step towards the mainstreaming of soil conservation.

One management goal for decreasing the impact of conventional practice is to focus on improving soil health and quality. Factors that are important in evaluating soil quality include physical and chemical properties and microorganism content. Microorganisms are gaining importance in the evaluation of soil quality (Paz-Ferreiro and Fu 2016).Their role in providing vital ecosystem services is only beginning to be understood. Soil type can also affect factors from nutrient uptake to soil moisture, and is therefore also important in considering soil quality.

Soil improvement can be achieved through the use of cover crops and other methods for enhancing microbial activity in the soil. Cover crops are a crop or a mix of crops that are planted alongside a cash crop during growing season, in a fallow field in an off season, or during the winter. Many different crops and combinations can be used as a cover crop; each make unique contributions to soil, for example, legume cover crops provide nitrogen fixation and the long tap roots of grasses bring up nutrients from lower soil depths while breaking up soil compaction (Blanco-Canqui 2015).

Commercial microorganism stimulants are one way to increase microbial activity in the soil. The product used in this project was AgZyme. Essentially food for microorganisms, it is touted to increase microorganism activity in soil and increase crop yields. The goal of AgZyme is to harness soil microbial potential and allow for optimal movement of nutrients (Ag Concepts 2012).

Microorganisms are encouraged by the presence of cover crops as well; the microorganisms that are supported by the presence of cover crops provide benefits of their own, including enhanced uptake of phosphorus (PO_4-P). Enhanced uptake of ammonia and nitrates (NH4+ and NO3-), are also promoted by cover crops, especially in low fertility soil. Microorganisms also create biomass and regulate carbon sequestration, N availability, and P in the soil (Drinkwater and Snapp 2007). Efficient uptake of nutrients and increased soil fertility are other benefits of the increased presence of microorganisms (Higa and Wididana 1991). Some microorganisms can even help soil suppress disease (Calvo 2014).

Cover crops are only used on 1.5 percent of Minnesota farmland (Meersman 2015), which is unfortunate because they provide a host of ecological benefits and the land could benefit from their implementation. Cover crops can break up soil compaction, which improves soil aggregation, reduce erosion and runoff, suppress weeds, regulate pests, and maintain biodiversity in the soil (Schipanski 2013). With cover crops, runoff decreases up to 80 percent and sediment is reduced by half (Blanco-Canqui 2015). Cover crops can moderate soil temperature, leading to an increase in moisture retention (Blanco-Canqui 2015). The use of cover crops is not a new concept, but one that is not in fashion. The more learned about the host of benefits they provide, the more policy can reflect the value of ecosystem services the soil provides and the more palatable their use might become for farmers.

One concern of many farmers is what this all will cost, that is, what effects it will have on their profitability. Cover crops can vary in the cost per acre depending on seed and spreading method, which can done aerially or with equipment on the ground, such as a high wheel box spreader, which allows the machinery to pass over the main crop. Some reports have estimated $25-35/acre, one farmer spent about $44/acre (Merersman 2015).These prices include the amount and type of seed and how it was applied. These costs may pay off, though. Cover crops, in some cases show an improvement in yield. Yield varies by climate, precipitation, management practices, and type of cover crop used, but using cover crops often leads to no change or improvement in yield in the long run (Robertson et al. 2014). An eventual decrease in the need for inorganic nitrogen inputs will lead to decreased costs as well (Blanco-Canqui 2015).

Today farmers rely on many chemical strategies and inputs, but a nutrient management strategy that takes into account soil and ecology awaits wide adoption (Drinkwater and Snapp 2007). The goal of this research is to examine the use of cover crops and a microorganism stimulant on a strip-till corn field to provide additional information for farmers who are considering or have not considered using soil protecting and enhancing practices. Specific objectives for this study were to determine 1) If cover crops can be grown effectively alongside corn in a strip-till field; 2) If cover crops and/or microorganisms stimulants contribute to increased soil health and quality; 3) If agricultural productivity and economic viability can be maintained while reducing impacts through the use of the new ecological inputs observed.

METHODS

Experiment and Field Design

Data were collected from an agricultural field in Northfield in southeastern Minnesota (44^{0}N, 93^{0}W) on St. Olaf College land just north of the campus (Figure 1a). The field is a strip-tilled corn (*Zea mays*) field that was planted with DeKalb Refuge-in-a-bag seed. This seed mix is a GMO variety that contains seed with the B.t. resistant gene along with other changes, which makes it resistant to pests like the corn borer and rootworm. Five percent of the seed is not resistant to ensure that insect populations do not become resistant to the gene. Strip tilling is a method of tillage where only a small strip along where the seed will be planted is turned up. In this method, discs turn up the soil about 8 inches into the ground. The remaining land in between the rows remains undisturbed. The field has been under strip-till management since 2005. The current crop was planted following a year of soybeans.

Soil types were taken note of throughout the study. The soil types in the area of interest were 106C: Lester Loam with 6 to 10 percent slopes, 382B: Blooming Silt Loam with 1 to 6 percent slopes, 377B: Merton Silt Loam with 1 to 6 percent slopes, and 239: Le Sueur Loam (Figure 1a).

The field was divided into three treatment areas: a microorganism stimulant (AgZyme by Ag Concepts), no treatment, and cover crops. The cover crops took up most of the field, covering about 8.1 ha, while the areas treated with AgZyme and no treatment were smaller and roughly equal in area, each about 1.6 ha (4 acre) (see Figure 1a and Figure 1b for location of study site and specific sample locations).

Within the untreated area, fertilizer and herbicide were applied as the farmer would under normal circumstances for his practices (Table 1). In the area treated with a microorganism stimulant, usual practices were carried out alongside the addition of AgZyme. The microorganism stimulant was applied on June 30th at a rate of 1 kg/ha (0.9 lbs/acre). For the application it was combined with liquid nitrogen fertilizer (containing 4lbs N/gal). Actual N was applied at a rate of 67.25 kg/ha (60 lbs/acre). Cover crops were spread on July 9th using a high wheel box spreader. A mix of four types of cover crop seeds was spread: 272.2 kg (600 lbs) assist annual rye grass (*Lolium multiflorum*), 54.4 kg (120 lbs) bayou kale (*Brassica oleracea*), 22.7 kg (50 lbs) enrich radish (*Raphanus sativus*), and 6.8 kg (15 lbs) crimson clover (*Trifolium incarnatum*). The cover crop seeds were combined with potash before spreading in order to carry the lighter ryegrass seeds. This resulted in adding 90.9 kg/ha (81.9 lbs/acre) potash along with 44kg/ha (39.25 lbs/acre) cover crop seed.

Soil Collection

Soil samples were collected on three dates throughout the duration of the project: June 23, July 14, and October 4. There were three sampling sites in the area treated with AgZyme, three sites in the untreated area, and one sampling site in the cover crop area that had a consistent location throughout the three sampling rounds (Figure 1b). Samples were taken in other locations for sampling rounds two and three for cover crops to attempt to capture the influence of soil type on the outcome. Two samples were taken at each sampling site. Shallow samples (15-30 cm) were taken at all sites. Additional deep samples (15-30 cm) were taken at two sampling sites, one in AgZyme and one in no treatment, each round. There was a total of 18 samples in round one, 20 samples in round two, and 26 samples in round three.

Soil Physical Properties

Soil samples were all taken with a corer of known volume and analyzed for percent moisture, organic matter, and bulk density. Each core was weighed to get a wet weight, dried in an oven at a temperature of 105^0C for 48 hours, then and reweighed to obtain a dry weight. Soil percent moisture was then calculated with the equation $\left(\frac{Mw-Md}{Md}\right)\times 100$, where *Mw* = wet mass and *Md* = dry weight. Organic matter was found by using 1.19 mm sieve on the dry soil samples to obtain sieved samples weighing 5-10 grams. Then each sample was weighed and placed in a 500^0C muffle oven for four hours, and then reweighing the samples. Percent organic matter was then calculated using the equation $\left(\frac{Md-Ma}{Md}\right)\times 100$, where *Md* = dry weight of sample and *Ma* = mass of sample after being in the furnace. Bulk density was calculated using the equation $\left(\frac{Md}{V}\right)$, where *Md* = dry weight and *V* = volume of the soil corer.

Soil Nutrients

To obtain concentration of phosphates in the soil, 5 grams of each sample was extracted in 25mL Mehlich 3 solution. To determine the concentration of nitrates and ammonium, 5 grams of each soil sample was extracted in 25mL KCL solution. Each extracted sample was then analyzed using the SmartChem 200, an automated chemical analysis machine.

Plant Properties

Cover crop density was measured on September 22. Density was observed in 29 evenly spaced $33cm^2$ plots. Within each plot the type of cover crop growing and the number of each type of cover crop was recorded.

Stalk nitrate information was obtained by sending stalk samples to Minnesota Valley Testing Lab (MVTL) in New Ulm, MN. Stalk sections 20 cm long starting 15 cm above the soil surface, as instructed by the lab. Ten sections were taken from five different areas to be analyzed. Information was obtained on stalk nitrates in covers crop soil types 382B, 106C, and 239. In the area treated with AgZyme and the area with no treatment, stalks were collected to represent soil type 382B.

Soil Health

Additional samples were sent to WARD lab in Kearney, NE to be analyzed for nutrient availability, composition of the microbial community, and other indicators of overall soil health and quality. Samples were collected and combined to represent seven different situations regarding treatment and soil type. Three samples represented the area treated with AgZyme and soil types 377B, 382B, and 106C; three samples represented the area with no treatment and the same soil types as the AgZyme samples. The last sample was from the cover crop area in soil type 239. Two tests were performed by the lab: the Haney Soil Test and the PLFA Soil Test. The PLFA test examines phospholipid fatty acids to determine soil microbial community characteristics such as community composition and abundance (Ward Labs 2015). The Haney Soil Test provides information on many soil characteristics, including organic matter, nutrient availability, organic C:N ratio, and a soil health calculation, which examines the balance of soil C and N and in relation to microbial activity (Ward Labs 2015).

Respiration was recorded in mid-October. CO_2 respiration (ppm/sec) was found using a LiCor -820, an infrared gas analyzer, connected to 25x25 cm respiration chambers, Respiration was measured at five sites throughout the field: AgZyme soil type 382B, no treatment soil type

382B, and cover crops on soil types 382B, 106C, and 239. The readings were translated into slopes to find the rate of CO_2 increase.

Data Analysis

Soil properties and soil nutrients were compared between treatments and soil types statistically. Summary statistics and one-way and two-way analysis of variance (ANOVA) tests were performed using the commander module of R version 3.1.1 (2014). Microsoft Excel version 14 (2010) was used to organize and graphically present all data. Bar graphs show means with standard error bars.

Yield and Profit Analysis

Harvest took place on November 7th. During harvest, yield information was collected for individual passes using data collected by the combine. Two separate passes were collected for each treatment. A pass is the distance from one end of the field to the other that the combine drives before turning around to go back. The combine used for this study collected eight rows of corn in each pass. Profit per hectare was calculated using the equation

$$Revenue\ \ (\$\,income\ /ha) - Costs\ \ (\$\,input\ cost/ha) = Profit\ (\$/ha)$$

Revenue per hectare was determined for each treatment using the yield data (bu/ha) and the price of corn at the elevator as of December 2nd ($3.07/bu). Cost per hectare was found using the cost of cover crop seed and AgZyme when appropriate and fertilizer and herbicide costs along with fuel and transportation costs. Cover crop costs also included the rental cost of the high wheel box spreader. Cover crop seed costs were $0.70/lb for Rye Grass, $1.95/lb for Tillage Radish, $1.85/lb for Bayou Kale, and $1.85/lb for Crimson Clover.

RESULTS

Soil Nutrients

Ammonium (NH_4+) concentrations in the cover crop study varied significantly among sampling times (p=4.944e-05). Concentrations decreased in both the cover crops and no treatment areas over time. There was no significant variation between treatments and in the interaction between treatment and sampling time (Figure 2a). In the AgZyme study NH_4^+ concentrations varied significantly over time (p= 2.162e-05), but there was no significant variation between treatments or in the interaction between treatment and sampling time (Figure 2b).

Nitrate (NO_3-N) concentrations in the cover crop study varied significantly among sampling times (p= 0.002666). There was no significant variation between treatments or between treatment and sampling time (Figure 3a). In the AgZyme study NO_3-N concentrations also varied with sampling time (p= 0.002114), but not between AgZyme and no AgZyme areas. There was no significant interaction between treatment and sampling time (Figure 3b).

Phosphate (PO4-P) concentrations in the cover crop study varied significantly among sampling times (p= 0.03491). There was no significant differences between treatments. There was no significant interaction between treatment and sampling time (Figure 4a). In the AgZyme study concentrations also varied among sampling times (p= 0.04864) but not between treatments. There was also no significant interaction between sampling time and treatment (Figure 4b).

Soil Physical Properties

Bulk density showed no significant variation with the addition of cover crops between treatment, sampling round, and the interaction between treatment and sampling round (Figure 5a). In the AgZyme study there was also no significant variation with the addition of AgZyme between treatment and no treatment, sampling round, and the interaction between treatment and sampling round (Figure 5b). Although insignificant, overall bulk density shows a decreasing trend throughout time for all treatments.

Percent soil moisture showed no significant variation with the addition of cover crops between treatment, sampling round, and the interaction between treatment and sampling round (Figure 6a). In the AgZyme study, there was no significance between treatment, sampling round, and the interaction between treatment and sampling round (Figure 6b).

Percent organic matter in the cover crop study did not vary significantly between treatment, sampling round, and in the interaction between treatment and sampling round (Figure 7a). In the AgZyme study, percent organic matter also did not vary significantly between treatment, sampling round, and in the interaction between treatment and sampling round (Figure 7b).

Combining all the data collected for the AgZyme study (treated and no treatment samples), there were significant differences among soil types for the three physical soil properties (Figure 8). Bulk density was lowest in soil type 377B ($p=0.000473$). Soil moisture was highest in soil type 377B ($p= 6.87E-11$). Percent organic matter was highest in soil type 377B ($p=1.96E-07$). There was no significant variation in nutrients among the different soil types.

Soil Health

The Haney soil test and the PLFA soil test reveal an overall higher total biomass, percent organic matter, and soil health calculation for the AgZyme area compared the no treatment area. The no treatment area shows a higher diversity index and C:N ratio (Table 2). By soil type, 106C had the highest biomass, diversity index, and C:N ratio, 382B had the highest soil health calculation, and 377B had the highest percent organic matter (Table 3).

CO_2 respiration results reveal higher rates of respiration in the AgZyme and cover crops, but not significantly (Figure 9). Within the cover crops, there is higher respiration, but not significantly, in the soil type 382B, the same soil type in which the AgZyme and no treatment respiration rates were measured.

Plant Properties

Stalk nitrates reveal low levels for all treatments (Table 4).

Cover crop density shows rye grass as the most commonly found variety in each plot by far, followed, but not closely, by Bayou kale (Figure 10).

Yield and Profit

The yield in the area with no treatment was 495.03 bu/ha (200.33 bu/acre), the yield in the AgZyme was 476.91 bu/ha (193 bu/acre), and in the cover crops was 476.91 bu/ha (193 bu/acre) (Figure 11). There was no significant variation between treatment and yield. Profits were highest in the area with no treatment at $866.49/ha ($350.66/acre). Profit from the AgZyme was $794.17/ha ($321.40/acre) and from the cover crops was $548.18/ha ($221.85/acre) (Figure 12).

DISCUSSION

Soil Nutrients

Ammonium (NH_4^+) concentrations did not vary significantly between treatments in the cover crop study (Figure 2a).The concentrations did decrease in both treatments over sampling times. An increase in the presence of bacteria can act as a nutrient sink and can take up NH_4^+ and immobilize it, then convert it into nitrates through nitrification (Paul 2014); the decrease of NH_4^+ in the soil throughout indicates microorganism presence performing this process.

In the AgZyme study NH_4^+ concentrations varied across time, but not between treatments or in the interaction between treatment and sampling time. Over time there was a decrease in ammonia concentrations in both AgZyme and no AgZyme. As explained above for the cover crop study, this is due to nitrification in both areas. Because there is no significant difference between treatments, AgZyme had little effectiveness for this one season study.

Nitrate (NO_3-N) concentrations varied significantly across time. The increase in N availability at the end of the growing season may be attributed to higher availability of nitrates for plants to take up due to higher levels of mineralization and activity in the soil. The lower concentration in the cover crops than in no treatment in the later months might be due to its immobilization by cover crop roots, increasing the capacity for internal nutrient cycling (Schipanski 2014).

In the AgZyme study, there was significant variation in nitrates across sampling times, however there was no significant variation between treatments or in the interaction between sampling time and treatment. The concentrations decreased from June to July and increased from July to October. The higher concentrations for both treatments signal a lack of more nitrogen immobilization in one area compared to another, showing that AgZyme may have displayed little of its purported effects. The Ward Lab tests revealed a lower C:N ratio in the AgZyme area compared to the no treatment area, which means greater mineralization was able to occur and more N is available for plants to take up. Abbott et al. (2015) noted an increase in microbial activity can contribute to greater loss of nutrients from soil for some management practices, including use of cover crops. This may help explain the observed, but insignificant, slightly lower presence of nutrients between AgZyme and no treatment and across sampling times.

Phosphate (PO_4-P) concentrations in the cover crops varied significantly between sampling times, but not between treatments or in the interaction between treatment and sampling time. In the AgZyme study, there was also significant variation among sampling times, but not between treatments and the interaction between treatment and sampling time. The differences were small between treatment (both cover crops and AgZyme) and no treatment the first two sampling times, but in October, the treated are shows much higher levels of P. Microorganisms can mobilize P, increasing its potential for plant use (Richardson 2011). Using microorganisms as a way to make P available is important because it is a limiting nutrient in plant growth and success.

Soil Physical Properties

Bulk density did not vary significantly between treatments or sampling times. It does show a small decrease throughout time for both treatments, indicating that soil compaction decreased between June and October. It is also slightly lower in the AgZyme and cover crop areas. This would hold up the idea that roots of cover crops and microbial activity reduce soil compaction. Also strip-tillage reduces soil compaction. Reduced compaction overall will also lead to an increase in the ability for root growth and water uptake (Hamza 2005). Bulk density among soil types did vary significantly. It was lowest in 377B, indicating that soil texture due to composition plays a role in bulk density.

Soil moisture revealed no significant differences between treatments or over time. This could be due to the short time frame of the experiment and that the field is strip-tilled, which maintains and retains soil moisture well. Variation in soil moisture can be attributed to time of year and rainfall. The significant differences between soil type and moisture come from the natural variation in moisture among soil types due to their composition, which affects compaction and drainage ability.

No significant differences were found between treatments and sampling times for organic matter. Overall organic matter on this field in 2011 was 5.36 percent (Wieme 2011). Today at an average of 5.54 percent, it is just slightly higher. This shows that strip-tilling, like other conservation practices, builds up benefits over time. Organic matter did vary significantly between soil types. It was highest in soil type 377B, which relates to its low bulk density. Soils with a lower bulk density tend to have a higher organic matter due to increased porosity (USDA Soil Bulk Density 2015).

Overall no significant differences were found between physical soil properties and treatments, however there were differences in physical properties with soil type (Figure 8). This reveals that soil type can largely influence the outcomes of a sample. This study aimed to have a representation of the common soil types in the field to make reasonable comparisons between treatments. All farms have different soil types and in turn compositions that make up their field, meaning there are differences in outcomes for management practices field by field. This calls for specific research for individual fields rather than only general management standards for all farms.

Soil Health

Overall, the Haney soil test and the PLFA soil test revealed an overall higher total biomass, percent organic matter, and soil health calculation for the AgZyme area compared the no treatment area. The no treatment area showed a higher diversity index and C:N ratio. By soil type, 106C had the highest biomass, diversity index, and C:N ratio, 382B had the highest soil health calculation, and 377B had the highest percent organic matter. No statistical tests were done on the Haney and PLFA soil tests results because of the low number of samples collected. The top three factors that affect soil microbial community and composition are soil type, time of year, and management practices, such as the use of cover crops or addition of a microorganism stimulant (Bossio et al. 1998), which this what this research examined. The appearance of increased microbial biomass in the AgZyme study can in part be considered due to the importance of management practices and their often large and positive impact on soil microbial community size and benefits. The PLFA soil indicators are lower in conventional fields compared to organic (Bossio et al. 1998). The field of study for this research was a field that grew commodity crops, but it is no till, which means it is not a conventional field and may have more positive indicators than a conventional field even with no additional treatment.

The higher diversity index in the no treatment area invites asking what type of microorganisms AgZyme aims to feed, whether the nutrients in the solution are better for some microorganisms than others. This study was only one season, and additional years of AgZyme spread on the same field might result in the expected outcomes from the product that reports to take a few years to show real measurable outcomes.

Although the C:N ratio was slightly, both AgZyme and no treatment areas had a ratio lower than the 24:1 ratio that microorganisms require, which means excess nitrogen will be left in the soil and will be available for plants (USDA 2011). This lower ratio allows for a quicker decomposition of organic matter compared to a system with a C:N ratio higher than 24:1. The best condition is a more balanced ratio (USDA 2011). A lower ratio indicates that more nitrogen is available for plants to use.

The soil health calculation, a tool for gauging the effects of management practices, was higher in the AgZyme than no treatment area. Soil health calculation can range from a value of 0 to over 50. The number is best if above seven, and should increase over time as soil quality improves under conservation management. All soil health calculation numbers were over seven for the tested areas, indicating a healthy soil is present, but there is room for improvement.

CO_2 respiration directly reveals the level of microbial activity in the soil, indicating organic matter content and its decomposition (USDA 2012). Low rates reveal little activity. Respiration showed higher rates of respiration in the AgZyme and cover crops, both with the soil type 382B. The next highest respiration report came from the same soil type in the untreated area. These higher rates are in the areas expected to produce more microbial potential due to the addition of microorganism stimulant and crops that promote microbial community growth. Although no significance was found because there were too few samples, this reveals that soil type as well as treatment may have an impact on respiration. The effect of soil type can be attributed to effects of the properties such as soil moisture and aeration on respiration. As this research shows, there are significant differences between soil types and their physical properties, which is in accordance with the differences found in respiration. Because the field is strip-till with high organic matter, this organic matter in addition to the treatments used in the experiment contribute to enhanced respiration and are indicative of healthy nutrient cycling. In the case of tilled fields, large amounts of CO_2 are released from the soil all at once and is lost, which contributes in part to the issues of global warming and climate change (Reicosky 1997).

Plant Properties

The outcome of cover crop density can be explained both by the individual properties of the different varieties and how much was planted. rye grass was the most commonly found crop. More rye grass seed planted than the other types of cover crop seed, so this could be expected. Also, rye grass is an annual grass and establishes rapidly (SARE 2012). Due to the size of each individual plant, which takes up less space above ground, many can be found directly adjacent to one another like grass on a lawn. The other two crops found, but in far less abundance were bayou kale and tillage radish. These two crops are both non-leguminous broadleaf plants that have root systems that help break up soil compaction. When cover crop density was observed among the rows, all plants were quite small and more abundant in some areas than others. This could be due to the timing of the seeding of cover crops, which occurred when the corn plants were already a few feet tall. The shade of the corn plants may have contributed to the inhibition of their growth. Where there were open spaces near the edges of the field, kale and radish in full size were in abundance, so establishment in this field was possible, but it was not as well done within the rows. Although the plants within the rows were small, when the seed dealers visited the field, they noted that this field looks like the average well-established cover crop field.

Crimson clover, a leguminous cover crop, was not found in any of the plots. This can be attributed to this variety being best suited for the southeastern United States. It is not a winter hardy crop and suffers in areas with significant frosts (SARE 2012). However, this should not have been a hindrance to its growth as the first frost this year came late and temperatures this fall and early winter have been the warmest on record (Douglas 2015). The primary barrier to establishment of the clover was likely that it is recommended to establish the variety in early spring (SARE 2012). Different cover crops establish best at different times of the year and in different climates. Some cover crops are best used for over the winter and some are planted alongside crops. These factors can have significant implications for the cover crop mix chosen and its success.

Stalk nitrates, which reports late season nitrogen uptake, were reported as low for all samples and were well below the optimal 1200 ppm level for all samples. However they have been reported as low in previous studies for the same field at a similar fertilizer rate (Wieme 2011).

Yield and Profit

Yields and profits were lower in both the AgZyme and cover crops compared to the area with no treatment. Yields in the AgZyme and cover crop treatment areas both produced an average of 476.91 bu/ha (193 bu/acre) and an average of 495.03 bu/ha (200.33 bu/acre) was harvested in the no treatment area. All treatment areas yielded higher than the average for Rice County, Minnesota, which in 2014 was 388.2 bu/ha (157.1 bu/acre) (USDA 2015). Although not significant, soil and organic matter appear higher across all sampling times in the no treatment area compared to the other two treated areas. Ammonia and nitrates were lower in the cover crops and AgZyme area than in the no treatment area, too. This observed lower quality in the treated soil shows that a positive connection can be made between yield and healthy soil indicators. There is also the chance that the cover crops interfered with nutrient uptake, indicating a trade-off (Larsen et al. 2014) of this ecologically sound practice, however that is one of many factors that affect yields. It also reveals that the nutrient level may have been too low due to higher microbial activity, which can cause nutrient loss when practices such as no till and cover crops are implemented (Abbott 2015). Both are practices used in this study.

The AgZyme product itself was a minimal cost, but it had no added effects. AgZyme yields may not have had any significant effect on increasing yields because it was the first year of application. Most studies that have examined to the use of AgZyme on corn fields have examined its use over a five year period (Ag Concepts 2012). Cover crop profitability was reported as lower than no treatment because a majority of the samples and the combine passes that were used to calculate yields were in soil type 106C on a slope. Slopes contribute to the erosion of nutrients, especially if the soil is exposed. The field's farmer mentioned the rough shape this area was in when he began farming it. The corn in this cover crop area was also shorter than corn in other parts of the field of study. Cover crops were specifically planted on this part of the field because of the need for erosion control and retention of nutrients for the cash crop trying to grow in the area. Because of this use of a degraded portion of the field for cover crops, there was likely underestimation of the positive effects that cover crops can have on yields.

Cover crops were reported as more expensive than they would usually be because this research was supported by a company interested in showing what cover crops can do, and they provided twice the Bayou Kale seed, one of the more expensive seeds, than they would typically recommend. Potash was also used to carry the seeds, especially the ryegrass, which has a very light seed. The potash costs were more expensive than the cover crop seeds alone. There are other ways to carry the seed besides potash. There also different ways to seed a cover crop. This research used the high wheel box spreader, but many also use aerial seeding, which can drive up the cost. What must be considered in the costs and benefits of cover crops is the future reductions in cost that can come from using nitrogen fixing cover crops in place of inorganic inputs and higher yields in the long run.

When considering cover crops, it is common to think that those plants might be in competition for nutrients with the main cash crop. However, this is likely not the case. Yield drag is another caution that farmers keep in mind when choosing whether or not to use cover crops. It occurs when a new input, in this case cover crops and AgZyme, lowers yields for the first year or so before showing positive returns and higher yields from improved soil health, showing losses in the short term. Most reports indicate that yield drag is for the most part, nonexistent (Wilde 2014), but may be a factor in the case of severely degraded soil, as seen in this research. One year is not enough to get a clear picture of what cover crops can do for soil health and organic matter. Return from cover crops takes more than one year, but the expected benefits are worth it.

CONCLUSIONS

It is not yet clear whether the addition of AgZyme and cover crops provides any environmental benefits. Results did not show an increase in soil health did not show significance or a difference in yield in the two treatments. As the components of this research show, there are many factors at work when it comes to measuring and improving the health of the soil. This includes soil type, combinations of management practices, and field history. Beyond this research, consideration of the effect of different varieties of cover crops, such as legumes or grains, on soil nutrient changes will be an important step in aiding farmers in their decision about what type of cover crops to plant. Also, more research on soil microbial communities between different treatments can be elaborated on. Diversity as well as abundance are critical factors in assessing healthy soils. Cover crops contribute to soil microbial community abundance and composition among other benefits, while AgZyme is purported to do the job of building microbial communities. This begs the question of whether microbial communities can be built on the application of nutrients without plants that host and nurture them.

The use of management practices such as cover crops that improve the integrity of the land are investments in the future, not a year-by year profitability scheme. Building soil health is going be on nature's time, aided by farmers who are committed to conservation practices. This commitment to practices that build soil integrity will likely require governmental assistance. Higher institutions can create laws that must be followed, such as Governor Mark Dayton's new buffer law, and can create financial incentives and assistance regimes that allow farmers to implement cover crops and other practices that build soil health without the concern of a bad year taking a toll. Research that spans more than one year of study can dig into the realization of the benefits that cover crops provide when it comes to building soil integrity and promoting an ethic that ensures that the land will be farmable and productive for the benefit of the earth and the next generation.

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Thank you to Kathy Shea for her guidance throughout this project. Thank you to Diane Angell for her support as well. Thank you to fellow students Corey Ruder for helping analyze soil samples with the SmartChem, Magill Schumm for aiding in soil sampling and collecting GPS data for sampling sites, and Connor McCormick for sharing CO_2 respiration data. Thanks is due to Jason Menard for putting together maps of soil sampling sites and to TJ Kartes from Saddle Butte who provided cover crop seed free of charge. Last, a special thanks to Dave Legvold for enthusiastically welcoming research onto his fields from yet another St. Olaf student and teaching me that driving a combine can be part of a liberal arts education.

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FIGURES AND TABLES

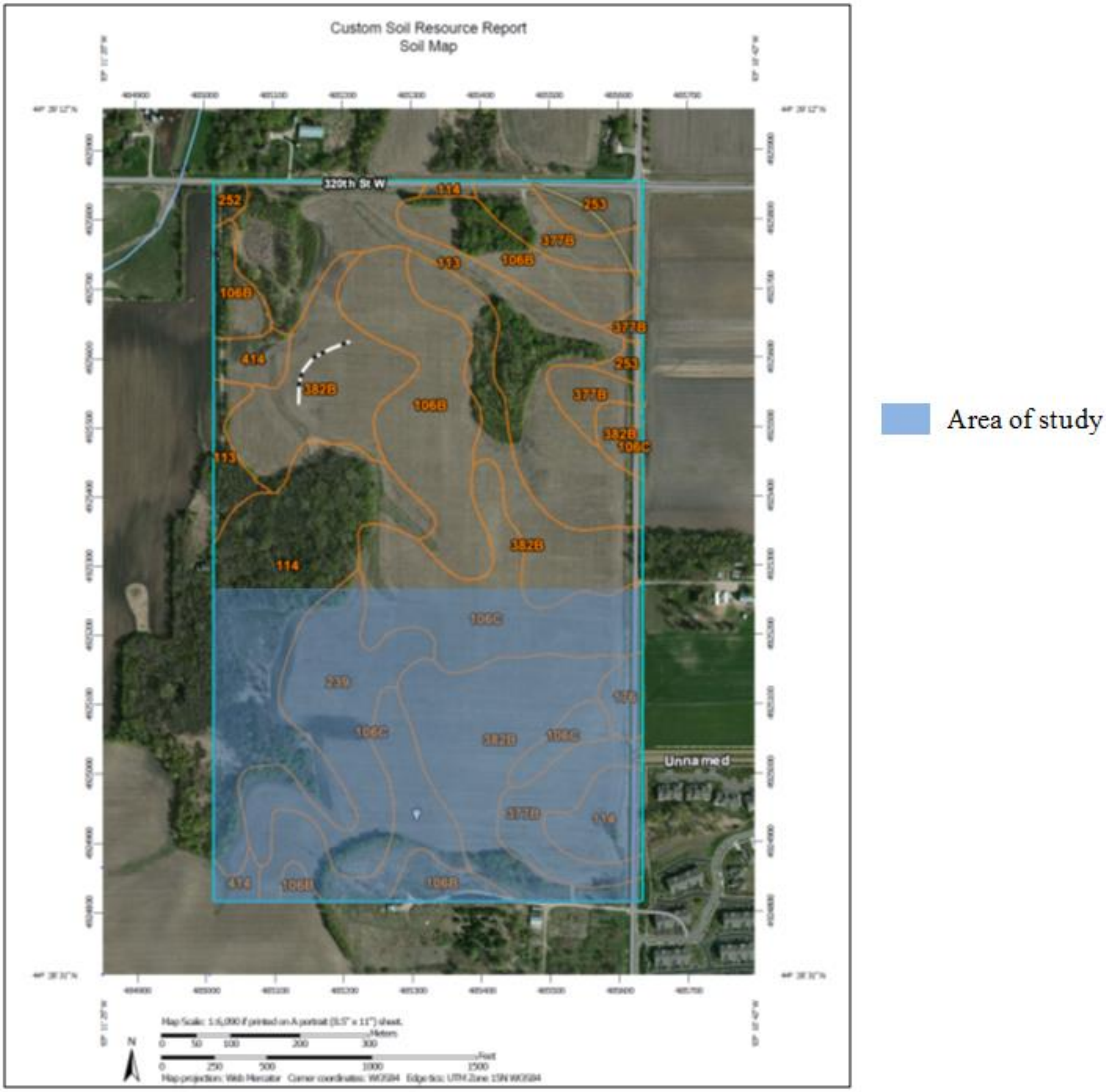


Figure 1a. Map of field studied (USDA NRCS 2015). Soil type is indicated by orange lines and numbers. Area of study for all three treatments is indicated by blue shading. The soil types in the area of study were 106C: Lester Loam with 6 to 10 percent slopes, 382B: Blooming Silt Loam with 1 to 6 percent slopes, 377B: Merton Silt Loam with 1 to 6 percent slopes, and 239: Le Sueur Loam.

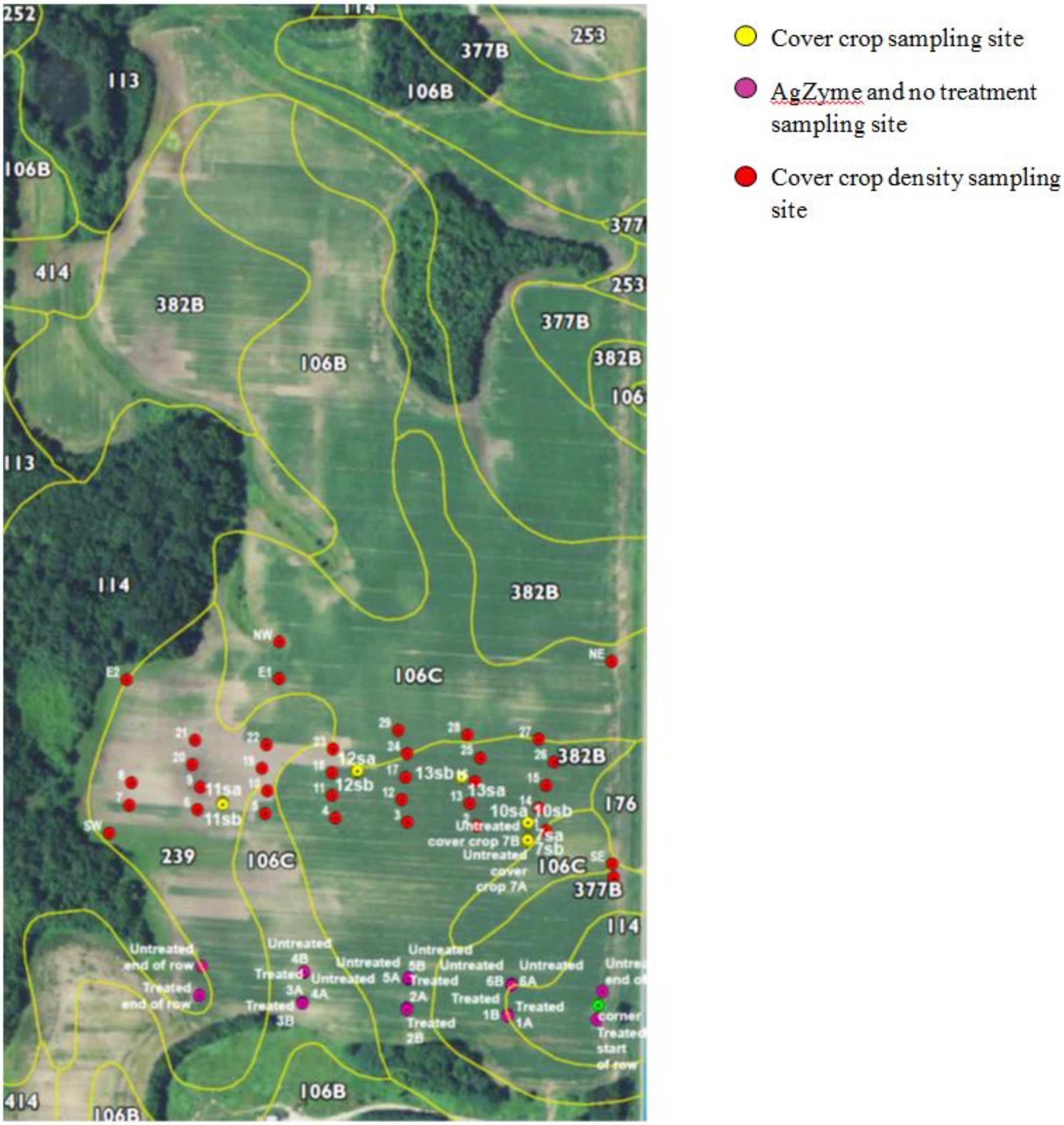


Figure 1b. Map of field studied with points of sampling shown by what type of sampling was performed.

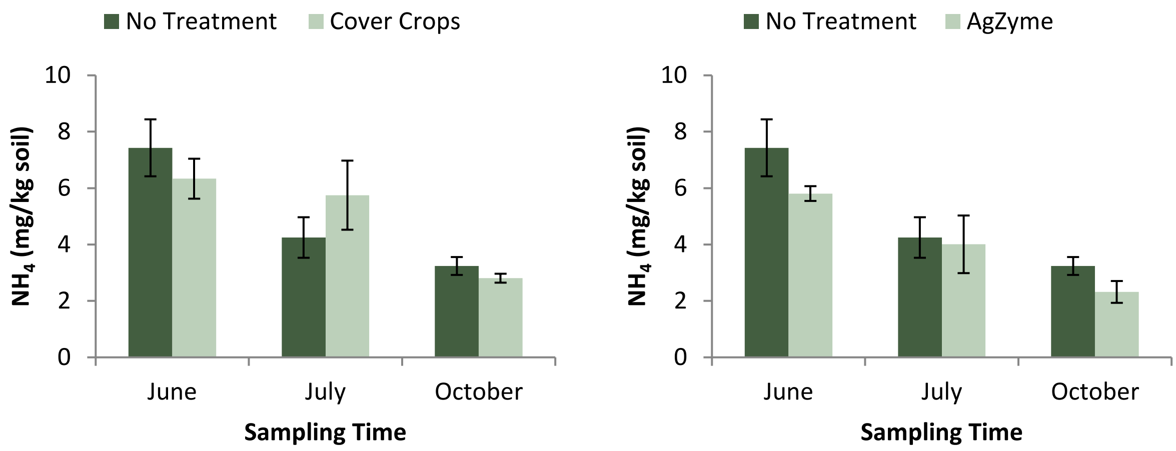


Figure 2a. NH4+ concentrations varied significantly among sampling times (p=4.944e-05). There was no significant variation between treatments or in the interaction between treatment and sampling time (cover crops June n=2, July n=10, October n=6; no treatment n=6).

Figure 2b. NH4+ varied significantly among sampling times (p=2.162e-05). There was no significant variation within treatments and no significant interaction between treatment and sampling time (AgZyme n=6; no treatment n=6).

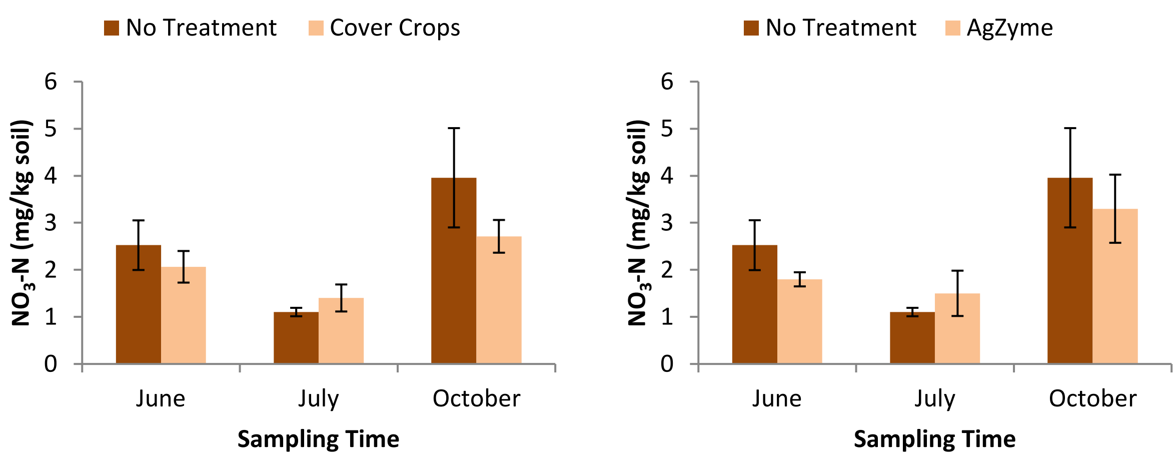
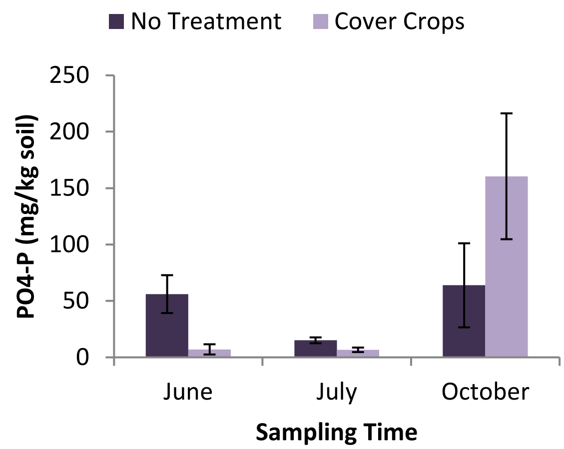


Figure 3a. NO_3-N concentrations varied significantly among sampling times (p=0.002666). There was no significant variation between treatments or in the interaction between treatment and sampling time (cover crops June n=2, July n=10, October n=6; no treatment all times n=6).

Figure 3b. NO_3-N concentrations varied significantly among sampling times (p= 0.002114). There was no significant variation between treatments or in the interaction between treatment and sampling time (AgZyme n=6; no treatment n=6).



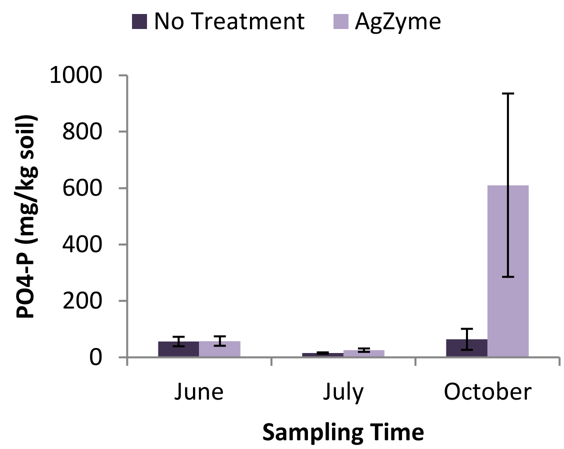
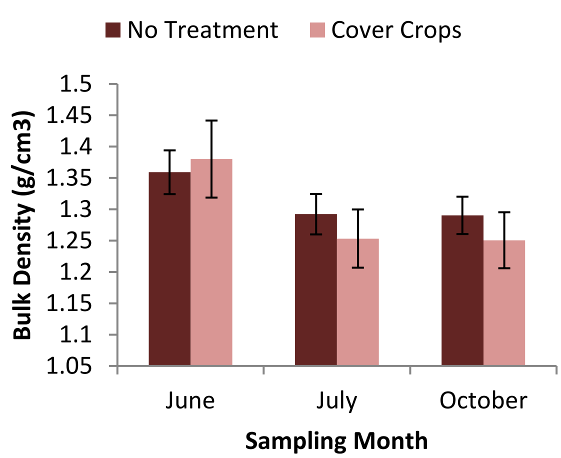


Figure 4a. PO_4-P concentrations varied significantly among sampling times (p=0.03491). There was no significant variation between treatments or in the interaction between treatment and sampling time (cover crops June n=2, July n=10, October n=6; no treatment all times n=6).

Figure 4b. Significant variation in PO_4-P concentrations was found among sampling times (p=0.04864). There was no significant variation between treatments or in the interaction between treatment and sampling time (AgZyme n=6; no treatment n=6).



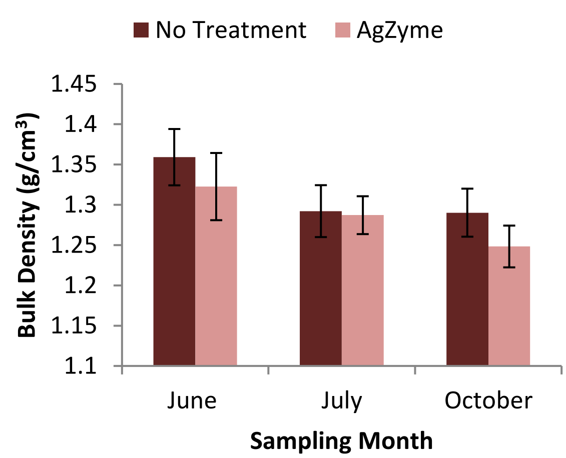
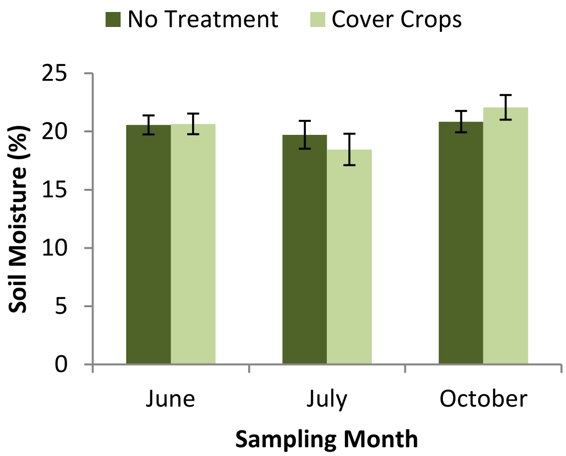


Figure 5a. The effect of treatment and sampling time on bulk density. Bulk density did not vary significantly among treatments or sampling time (cover crops June n=2, July n=10, October n=6; no treatment n=6 all sampling times).

Figure 5b. The effect of treatment and sampling time on bulk density. Bulk density did not vary significantly with treatments or sampling time (n=6 for each sampling time for both treatments).



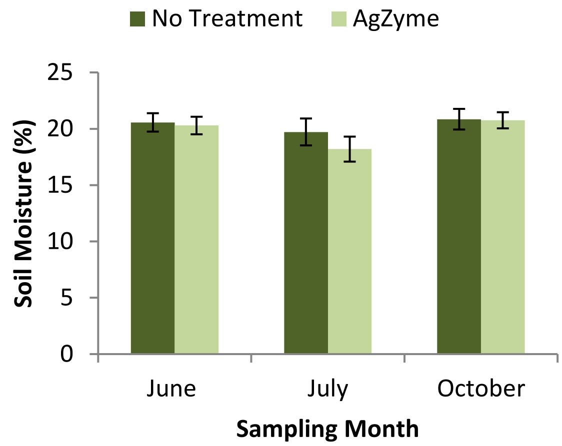
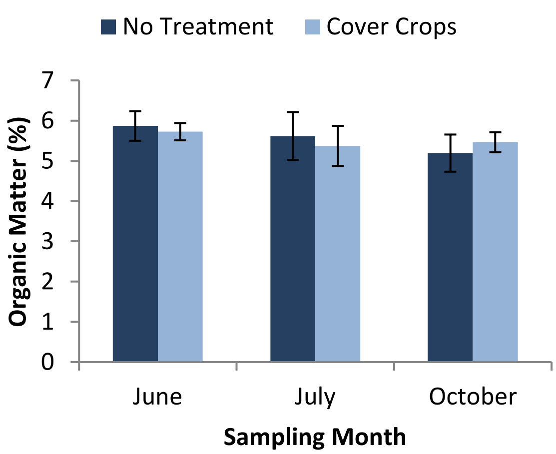


Figure 6a. The effect of treatment on percent soil moisture in no treatment (n=6 each round) and cover crops (June n=2, July n=10, October n=6). Soil moisture did not vary significantly within treatments, among sampling rounds, or in the interaction between treatment and sampling round.

Figure 6b. The effect of treatment on percent soil moisture in no treatment (n=6 each round) and AgZyme (n=6 each round). Soil moisture did not vary significantly within treatments, between sampling times, or in the interaction between treatment and sampling time.



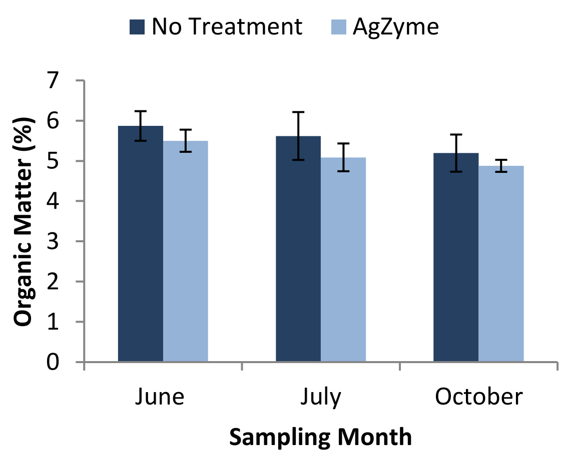


Figure 4a. The effect of treatment on percent organic matter in no treatment (n=6 each round) and cover crops (June n=2, July n=10, October n=6). Organic matter did not vary significantly within treatments, among sampling times, or in the interaction between treatment and sampling time.

Figure 4b. The effect of treatment on percent organic matter in no treatment (n=6 each round) and AgZyme (n=6 each round). Organic matter did not vary significantly within treatments, among sampling times, or in the interaction between treatment and sampling time.

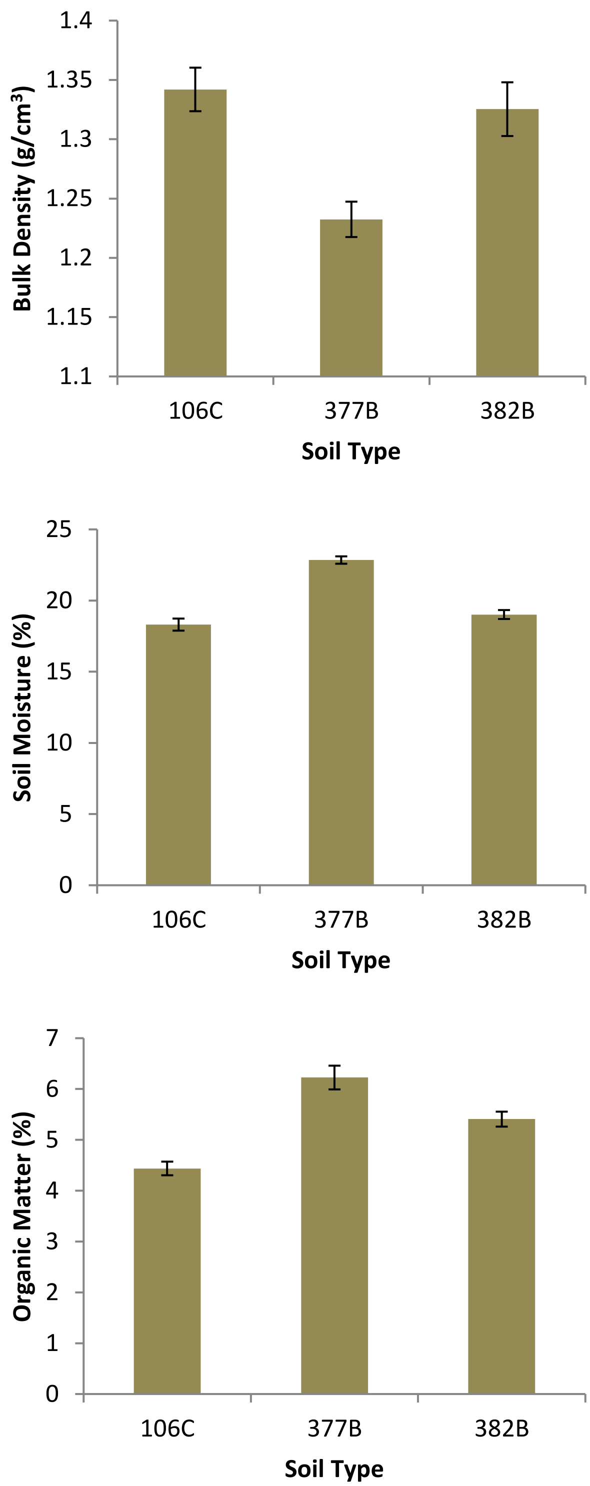


Figure 8. The effects of soil type of soil physical properties for both AgZyme and no treatment areas and across all sampling rounds. There was significant variation among soil types for all three properties: bulk density (p=0.000473), percent soil moisture (p= 6.87E-11) and percent organic matter (p=1.96E-07). There was no significant variation among nutrients and soil types .

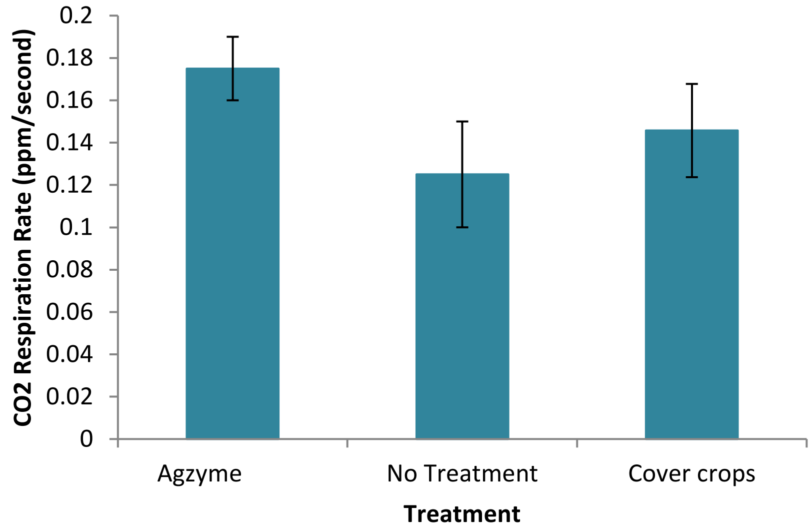


Figure 9. Mean CO_2 respiration rates for between treatments (Agzyme n=2, cover crops n=7, no treatment n=2). AgZyme and cover crops show higher respiration rates, but are not statistically significant.

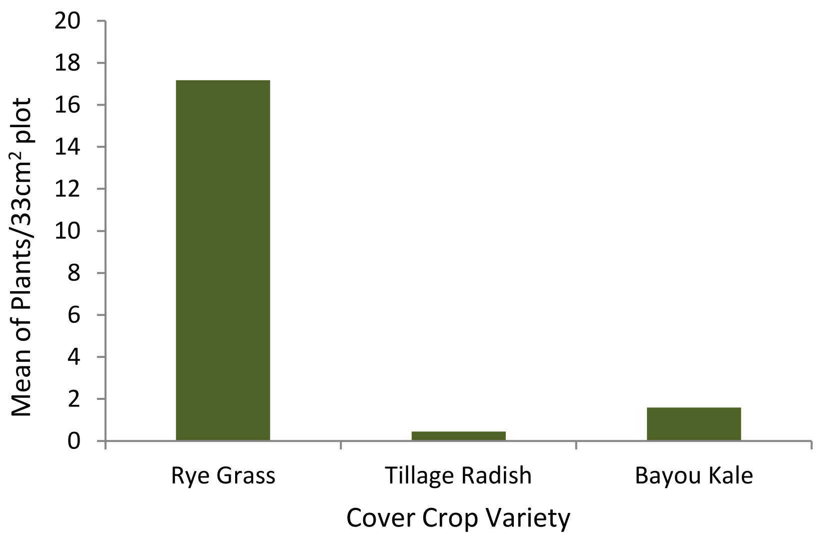


Figure 10. Mean number of cover crop plants found per 33cm^2 plot (n=29). Rye grass was the most common followed by kale. No clover was found.

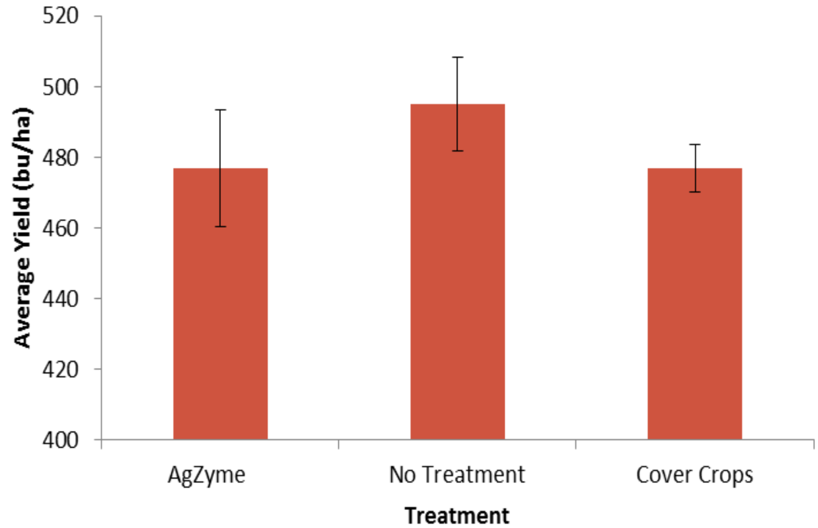


Figure 11. Average yield (bu/ha) for each treatment. The yield in the area with no treatment was 495.03 bu/ha (200.33 bu/acre). The yield in the AgZyme was 476.91 bu/ha (193 bu/acre) and in the cover crops was 476.91 bu/ha (193 bu/acre). No significant variation was found between treatment and yield.

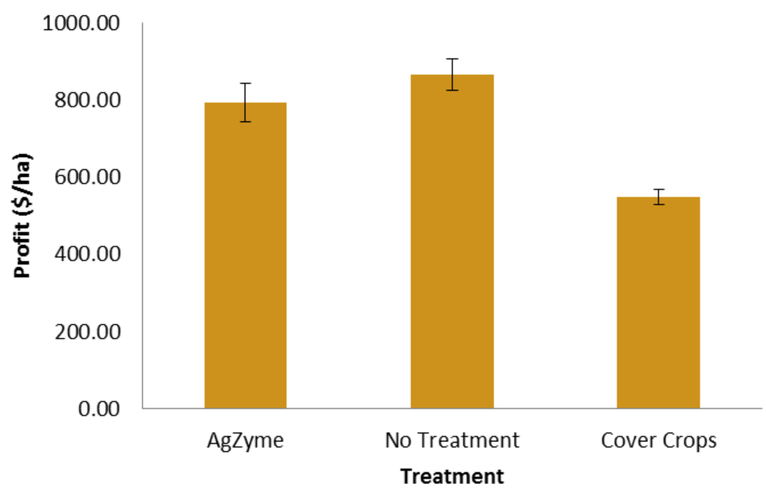


Figure 12. Profit ($/ha) for each treatment. AgZyme profits were $794.17/ha ($321.40/acre), cover crop profits were $548.18/ha ($221.84/acre), and the area with no treatment profits were $866.49/ha ($350.66/acre).

Table 1. Fertilizer and herbicide application rates.

Fertilizer application	Time of Addition	Fertilizer	Application Rate
	Preplanting	dry urea	355.31 kg/ha (317 lbs/acre)
	Side-Dress	liquid ammonium nitrate solution	67.27 kg/ha (60 lbs/acre)
Herbicide Application	**Date**	**Herbicide**	**Application Rate**
	6/25/15	Roundup	1.54 kg/ha (22 oz/acre)
	6/25/15	Strut	1.12 kg/ha (16 oz/acre)

Table 2. Means of Haney soil test and PLFA soil test results by treatment (AgZyme n=2; cover crops n=2). Although not analyzed statistically, samples from the AgZyme treatment showed overall higher biomass, organic matter, and soil health calculation.

Treatment	AgZyme	No Treatment
Total Biomass	2336.46	2060.02
Diversity Index	1.59	1.63
Bacteria %	57.92	57.37
Total Bacteria Biomass	1353.74	1174.76
Total Fungi %	11.78	12.38
Total Fungi Biomass	277.48	260.59
Fungi:Bacteria	0.20	0.22
Predator:Prey	0.02	0.02
Organic Matter %	3.40	3.23
Organic C:N	11.80	12.50
Soil Health Calculation	9.91	8.83

Table 3. Means of Haney soil test and PLFA soil test results by soil type (n=2 all types). Although not analyzed statistically soil type 106C showed the highest biomass and 382B showed the highest soil health calculation.

Soil Type	**377B**	**382B**	**106C**
Total Biomass	1836.68	2331.95	2426.09
Diversity Index	1.60	1.59	1.64
Bacteria %	59.38	57.28	56.28
Total Bacteria Biomass	1089.25	1339.48	1364.03
Total Fungi %	11.23	11.60	13.41
Total Fungi Biomass	202.74	276.15	328.22
Fungi:Bacteria	0.19	0.20	0.24
Predator:Prey	0.02	0.02	0.02
Organic Matter %	3.55	3.50	2.90
Organic C:N	11.90	11.75	12.80
Soil Health Calculation	8.81	11.27	8.04

Table 4. Stalk nitrate values received from the lab. All nitrate concentrations were reported as very low for all treatments and soil types.

Treatment	Soil Type	Nitrate (ppm)	Interpretation
Cover Crops	239	74	low
Cover Crops	106C	<50	low
Cover Crops	382B	<50	low
AgZyme	382B	58	low
No Treatment	382B	54	low