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Impact of Cover Crop Use on a Southern Minnesota Soybean and Corn Field: An Analysis of Soil Health and Macroinvertebrate Communities

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Abstract:

Cover crops provide a multitude of ecosystem services, but are becoming increasingly overlooked and underutilized in the face of large-scale conventional agriculture. The purpose of this study was to understand the impact of cover cropping on physical and chemical soil characteristics and macroinvertebrate communities over time in a southern Minnesota strip-tilled agricultural field growing soybeans and corn in rotation. Using my own and previously collected data, I analyzed percent moisture, bulk density, percent organic matter, and nitrate and ammonia concentrations on cover crop and control plots at three sampling times over a year and a half to analyze differences between plots and variations over time. I also compared the diversity and composition of macroinvertebrate communities between the cover crop and control plots. My results showed that more significant differences in physical soil characteristics occurred between plots, while chemical characteristics varied more over time. There were statistically significant differences in percent soil moisture and bulk density between cover crop and control plots and significant variation in soil bulk density, and nitrate and ammonia concentrations over time. Soil percent moisture was consistently higher and bulk density consistently lower in the cover crop plot, which indicates a trend toward increased soil health in response to cover crop planting. Although there was no significant difference in macroinvertebrate diversity between the two plots, they varied greatly in species composition. The higher moisture and lower bulk density seen in the cover crop plot provided a healthy environment for invasive earthworms, which were seen in higher numbers throughout the cover crop plot.

Introduction:

Both conventional and organic farmers have to make hard decisions, balancing economic realities with sustainability and definite short-term gains with possible long-term losses. When struggling with rising functioning costs and fluctuating prices in the face of large-scale conventional agriculture, farmers are often forced or choose to forgo sustainable options and make decisions based on short-term profitability (Schipanski et al. 2014). One sustainable strategy that too many famers are not taking advantage of is the use of cover crops to conserve soil health and in some cases, increase yield. The underutilization of cover crops is a huge loss to agricultural systems because over time, cover crops provide a multitude of ecosystem services.

Cover crops are plants grown on agricultural fields either alongside the year’s main crop or between crop plantings in the off season to maintain or even increase soil health, diminish land degradation, and increase crop yields (Reicosky and Forcella 1998). The specific ecosystem services associated with cover crops include the reduction of wind and water erosion, prevention of nitrate leaching, moderation of soil temperature fluctuations, sequestration of carbon, regulation of pests and weeds, and addition of nutrition sources for beneficial pollinators (Reicosky and Forcella 1998, De Bruin et al. 2005, Schipanski et al. 2014). Cover crops range in abilities and include legumes, such as clover, peas, vetch, and beans and non-legumes, such as cereals, forage grasses, and broadleaf species. Legumes are especially known for fixing nitrogen, while non-legumes are most useful for scavenging nutrients and increasing a soil's organic matter. Often, a combination of legume and non-legume species are applied to achieve multiple objectives at once (Clark 2015). A recent study in Iowa found that the utilization of cover crops following a soybean crop is especially important for the retention of soil nutrients. Due to soybean's low evapotranspiration during the growing seasons and high nitrogen content in the left over residue, fields often experience increased nitrogen leaching. This leaching can greatly be reduced through the use of cover crops (Betts 2016).

Cover crops have the ability to provide so many beneficial ecosystem services due to their relationship with soil. It has been shown that cover crop growth positively affects the health of the surrounding soil, which in turn, has direct and indirect effects on the health of the plants and other living organisms dependent on that soil (De Bruin et al. 2005). In a highly compact field in Maryland, for example, the use of rye and radish positively affected the soil's compaction, which led to increased soybean yields (Williams and Weil 2004). A soil's health is determined by a number of interacting physical, chemical, and biological characteristics. In general, a healthy soil has the ability to retain water and essential biologically available nutrients, support a high diversity of microbial and fungal life, and successfully infiltrate water (Cardoso et al. 2013). Consistent cover cropping over time can help maintain or increase these properties of healthy soil.

Analyzing physical and chemical soil characteristics is one way of understanding soil health, however macroinvertebrates and nematodes are also excellent indicators of soil quality and plant productivity (Stork and Eggleton 1992, Blanchart et al. 2006). Their abundance and diversity are dependent on soil health (Stork and Eggleton 1992). In a study done in cornfields of southern Benin, it was discovered that plots with velvet bean cover crop plantings had a two to four- fold increase in macroinvertebrate density and biomass compared to control and fertilized plots (Blanchart et al. 2006). In this case, the increased soil quality due to the cover crop planting could be seen through observations of macroinvertebrates. Macroinvertebrates are not only indicators of soil health, but promoters of it as well. Many macroinvertebrate species aid in soil formation, nutrient cycling and primary production (Lavelle et al. 2006). Although invasive in North America, earthworms are especially recognized for aerating soil and increasing water holding capacity (Stork and Eggleton 1992).

In Minnesota, discussion of agriculture, cover crops, and macroinvertebrates is especially prevalent and necessary because in 2014, farmland took up 25.9 million acres of land, which is nearly half of all land in the state (USDA 2015). Soybean and corn fields are especially common. According to a report on Agricultural Exports, soybeans are Minnesota's top agricultural export, followed by corn together contributing to about 40% of the state's total exports (Ye 2016). Unfortunately, these crops are often not produced using sustainable methods. For example, a 2012 estimate stated that cover crops are only grown on 1.5% of Minnesota farmland (Meersman 2015).

The focus of my project was on the impact of cover crops on the soil and macroinvertebrate communities of a corn and soybean field in southern Minnesota. Cover crops were first planted on this field on July 9, 2015 during a corn crop. The cover crops included rye, kale, tillage radish, and clover, however a density analysis completed by Kendra Klenz showed there was no to very low germination of the clover species (Klenz 2015). The specific objectives of my study were to a) examine differences in soil health between cover crop and control plots, b) perform a comprehensive analysis of soil health over time using data collected during the fall 2015 and summer and fall of 2016, and c) understand the impact of cover crop planting on macroinvertebrate diversity and composition.

Methods and Materials:

Site Description:

The area of focus for my study was an agricultural field in Southern Minnesota, just north of St. Olaf College's campus in the town of Northfield (44^0N, 93^0W) (Fig. 1). The land is owned by the college and farmed by Dave Legvold, who grows corn and soybeans in annual rotation. Strip-till management has been practiced since 2005 and the field has been the site of many student ecology projects over the years. There are a variety of soil types throughout the field and changes in topography within the sampling area. The soil types present in my sample area include Lester Loam, Blooming Silt Loam, Merton Silt Loam, and Le Sueur Loam.

Soil Samples-

At the start of this project in 2015, six distinct locations throughout the agricultural field were identified as sample sites, three within the control plot and three within the cover crop plot. At each location, two points within close proximity to each other were selected, totaling 12 sampling points. On October 22, 2016, I used a pre-programmed GPS to locate these 12 points and took two soil cores at each, using a shallow soil sampler with a cutaway (Fig. 2). I took the cores from the top 15 cm of soil, using the line on the soil sampler to keep volumes consistent among the samples. I paid very close attention to the soil volume on one of my replicates, whereas the other volume was only an approximation.

Soil Analysis-

In the lab, I analyzed both the physical and chemical characteristics of all soil samples. I determined the moisture content of the soil by drying the exact volume cores from each site in an over for approximately 48 hours at 105^0C. After the samples had dried completely I weighed the soil again to get it's dry weight. I used the following formula to calculate percent equation:

$$\% \text{ moisture} = \frac{\text{□□□□}h\text{□ □□ □□□□□□}}{\text{□□□ □□□□}h\text{□ □□ □□□□}} * 100$$

Knowing that the volume of the soil corer was 47.7522 cm^3, I was then able to calculate bulk density using the soil's dry weight and the following equation:

$$\text{Bulk density } (g/cm^3) = \frac{\text{□□□ □□□□}h\text{□ □□ □□□□}}{\text{□□□□□□ □□ □□□□□□ }(47.7522)}$$

To analyze organic matter in the soil, I sifted the oven-dried samples through a 1.19 mm sieve and weighed out 5-10g of soil to the nearest thousandth of a gram. I placed all the weighed soil samples in a muffle furnace at 500^0C and left them in the furnace for four hours before weighing them a second time after they had cooled. I could then calculate percent organic matter using the equation:

$$\% \text{ organic matter} = \frac{\text{□□□□}h\text{□ □□ □□□□ □□□□□□ }105^0\text{C} - \text{□□□□}h\text{□ □□□□□□ }500^0\text{C}}{\text{□□□□}h\text{□ □□ □□□□ □□□□□□ }105^0\text{C}} * 100$$

To determine nitrate and ammonium concentrations in the soil, I performed a KCl extraction using 5g of soil (measured to the nearest thousandth of a gram) and 25mL KCL solution. I followed the methodology provided by Professor Shea. The extractions were analyzed for nitrate and ammonium using an automated chemical analysis machine, the SmartChem 200.

Macroinvertebrates-

I sampled macroinvertebrates at the six locations I took soil samples. To do this, I placed a 25 x 25 cm plot and dug down the depth of my trowel (approximately 12cm) and then sorted through the unearthed soil, placing all organisms I saw in a zip lock bag. I spent at least 15 minutes at each sample site hand-picking macroinvertebrates. Once in lab, I preserved the specimens in 70% ethanol and identified them to the best of my ability using mostly online resources. I used the three ecological groups – anecic, epigeic, and endogeic – for separating earthworms and identified all the other organisms down to at least order, sometimes going further to family, genus, or species.

Statistical Analysis-

I ran statistical tests using R, version 3.2.4 with XQuartz 2.7.8 and created graphs to accompany this analysis in Excel for Mac 2011 version 14.5.7. To analyze differences in physical and chemical soil characteristics variation between plots and over time, I used two-way analysis of variance tests. For the analysis of my macroinvertebrate findings, I calculated species richness, Shannon diversity index, and Simpson diversity index. Lastly, I created a contingency table containing the four most common groups of organisms seen between both sites: earthworms, pot worms, millipedes, and centipedes. The contingency table results helped me understand differences in macroinvertebrate composition between plot types.

Results:

Physical Soil Characteristics-

Over three sampling periods in the fall of 2015 and the summer and fall of 2016, the cover crop plot had consistently higher percent soil moisture with means ranging from 23.97 +/- 0.78% in 2015 to 26.51 +/- 2.11% in 2016. The control plot, where no cover crops were planted, had lower percentages ranging from 20.85 +/- 2.24% in 2015 to 22.14 +/- 3.11% in 2016 (Table

1). The higher mean percentages measured in the cover plot were significantly different from the mean percentages observed the control plot (p-value=1.654e-05), but I observed no significant variation in moisture over time (p-value=0.135) (Fig. 3).

The cover crop plot not only had more moisture than the control plot, but also a lower bulk density that increased among all samples over time (Fig. 4). The control plot had mean bulk densities of 1.29 +/- 0.07 g/cm^3 in 2015 and 1.37 +/- 0.06 and 1.37 +/- 0.09 g/cm^3 in 2016, whereas the cover crop plot bulk densities were generally lower with measurements of 1.17 +/- 0.02 g/cm^3 in 2015 and 1.28 +/- 0.06 and 1.28 +/- 0.05 g/cm^3 in 2016 (Table 1). The differences in bulk densities observed between plots were statistically significant (p-value=3.861e-05) and the overall increase in bulk density across all samples over time was also significant (p-value=0.001). Although plot type and time both influenced bulk density, there was no significant interaction between the two variables (p-value=0.824).

There was no observable trend in the percent organic matter over time (p-value=0.135), but organic matter measurements were consistently higher in the cover crop plot compared to the control (Fig. 5). For example, in the fall of 2016, when the percent organic matter was 5.45 +/- 1.07% in the control plot, a higher percentage was measured in the cover crop plot: 6.26 +/- 0.71% (Table 1). The same trend was seen during the summer of 2016 and the fall of the previous year. These observed differences between plots did not prove to be statistically significant (p-value=0.097), but it is possible that with continued replications, this trend would become further accentuated.

Chemical Soil Characteristics-

The nitrate concentration among all plots varied greatly over time, showing a steady decrease from the first sample to the last (Fig. 6). In the fall of 2015, NO_3-N levels varied greatly among samples, measuring 3.96 +/- 2.59 mg/kg soil in the control plot and 3.10 +/- 1.29 mg/kg soil in the cover crop plot. A half a year later in July of 2016, NO_3-N levels had stabilized and decreased to 2.36 +/- 0.24 mg/kg soil in the control plot and 2.19 +/- 0.36 mg/kg soil in the cover crop plot. When I sampled again in the fall of 2016, the levels had decreased even more with concentrations of 1.34 +/- 0.55 mg/kg soil in the control and 1.48 +/- 0.45 mg/kg soil in the cover crop plot (Table 2). There was significant variation in the nitrate concentration means over time (p-value=0.001), but no significant differences seen between plot types (p-value=0.487).

Ammonium (NH_4+) concentrations also varied with time, but instead of a steady decrease over time, ammonium concentrations appeared to differ based on the month of sampling (Fig. 7). I observed dramatically higher concentrations in the summer compared with the fall. For example, in the summer of 2016, the ammonium concentration ranged from 6.65 +/- 2.45 mg/kg soil in the control to 5.68 +/- 0.87 mg/kg soil in the cover crop plot. During fall sampling times in 2015-16, ammonium concentrations never rose above 3.24 +/- 0.78 mg/kg soil (Table 2).

Macroinvertebrates-

Within the three 25 x 25cm plots I sampled in the control plot, I found 80 organisms and 10 different species. Using the same procedure in the cover crop plot, I found noticeably fewer organisms (n=47) and two fewer species. The Shannon index of diversity showed the control plot to be slightly more diverse than the cover crop plot, with a value of 0.727, compared to the cover crop's 0.631. The Simpson index showed the same trend, however the difference observed was not statistically significant (Table 3).

Although diversity didn't vary between plots (1.399), the composition of macroinvertebrates did (p-value=2.282e-05). Earthworms were found in high abundance throughout the cover crop plot, while the proportion of organisms was shared more equally among earthworms, millipedes, and pot worms in the control plot. Including endogeic, epigeic, and juvenile worms, 70% of the total organisms found in the cover crop plot were earthworms. Contrastingly, earthworms only made up 23% of the organisms in the control plot (Fig. 8). Considering the four major categories of organisms I found: earthworms, pot worms, millipedes, and centipedes, the compositional differences between the plot types were significant (p-value=2.282e-05) (Table 4).

Discussion:

Plot type differences-

Under no-till and strip-till management, soil compaction often increases due to the fact that the soil remains mostly undisturbed, however my bulk density measurements throughout both control and cover crop plots show values less than 1.4 g/cm^3. Values below this are considered ideal for plant growth (NRCS 2011). Although bulk density measurements from the control and cover crop plot were both within this ideal zone, I found significantly lower bulk densities in the cover crop plot. These lower bulk density measurements were encouraging because lower values indicate less soil compaction and less compaction leads to increased root and plant growth, beneficial soil infiltration movement, and ultimately less erosion (NRCS 2011). During the 2015 season when cover crops were initially planted, it is likely that lower bulk densities were observed due to the increased aeration of the soil by the cover crop roots. However, low bulk density was maintained during the next year, which means the initial cover crop planting had lasting effects long after their death. A study in 2004 found that soybeans were able to use soil channels created by decomposing cover crop roots to find subsoil water more easily and grow with decreased resistance (Williams and Weil 2004). It is possible that the soybeans grown on Dave's land were also able to do this, which may explain why bulk density remained low in cover crop plots even after the plants had died.

The persistence of lower bulk density in cover crop plots after cover crop death may also be explained within the context of other soil characteristics. My hypothesis is that initially, the cover crop roots provided added aeration to the soil, which increased space between soil particles, allowing the soil to hold more water. As water filled these new spaces, the soil's percent moisture increased, which is why my data showed consistently higher moisture content within cover cropped areas. The increased moisture soil content provided a more suitable environment for earthworms, which thrive in moist soils (Stork and Eggleton 1992). Although no macroinvertebrate data was taken before the fall of 2016 to act as a comparison, I hypothesize that after the cover crops were planted, earthworm abundance increased due to the higher soil moisture content. The samples I took this fall indicated a significantly higher percentage of earthworms throughout the cover crop samples, which supports this claim. Ultimately, I propose that this potential earthworm increase helped sustain the initial beneficial soil changes, namely increased moisture and decreased bulk density initiated by the cover crops. This proposed sequence of events may be incorrect, but the idea that moisture content, bulk density, and earthworm abundance are interrelated is likely correct, according to previous studies (Stork and Eggleton 1992, Blanchart et al. 2006, Clark 2015). My only finding clearly inconsistent with the current literature was the lower abundance of organisms and species within the cover crop plot. Previous research has shown that cover crops act to increase macroinvertebrate density and biomass and while I did not specifically test for these parameters, this did not appear to be the case with my data (Blanchart et al. 2006).

Overall, physical characteristics and macroinvertebrate composition significantly varied with plot type. Compared to the control plot, the area where cover crops had been planted showed consistently lower bulk density, higher moisture content, a greater abundance of earthworms, and a possible trend toward higher levels of organic matter. These trends prove beneficial to overall health of the soil, which provides evidence for the importance of cover crop use. From my results it is clear that the planting of cover crops did not negatively impact the soil in any way and possibly improved its overall quality. Unfortunately, there are no usable samples from before the cover crop was planted that could be used as a means of comparison. While it appears that cover crops did play a role in the changes I observed between sites, there are numerous confounding variables. For examples, differences in soil type and topography may have influenced my measurements.

Variation over time-

Unlike the physical soil characteristics, which significantly varied between plot types, the soil's chemical characteristics varied more dramatically over time due to differences in corn and soybean needs and changes in nutrient processing throughout the growing season. Whereas corn needs an abundant amount of nitrogen to grow, soybeans are able to form symbiotic relationships with rhizobia bacteria and fix most of the nitrogen they need to grow (Freeman 2016). While farmers often apply nitrogen fertilizer to corn fields, they often refrain from adding additional nitrogen during soybean growth because it has been shown to inhibit natural nitrogen fixation.

My data showed a steady decrease over time in nitrate concentration (NO_3-N). A significantly higher concentration was seen during the first sampling time in the fall of 2015, which is likely due to the fact that nitrogen fertilizer had been applied to the corn crop that year. No nitrogen fertilizer was added this year in 2016, which is likely why the nitrate concentrations are lower. The decrease in nitrate concentrations from July 2016 to October 2016 may indicate that some nitrates were lost to leaching or were taken up by the soybean plants toward the end of the growing season. According to a study done in Iowa, it is more likely that leaching was the cause of the decrease. While most people assume nitrogen fertilizer used for corn is the main reason excess nitrates enter water systems, these researchers found evidence for the contrary, leading them to propose that water nitrate levels (due to leaching) are less dependent on corn production and more related to soybean decomposition (Betts 2016).

Ammonium concentrations also varied significantly over time, but I observed a different trend; ammonium appeared to be related more to the month or season of sampling. The ammonium concentrations in July of 2016 were nearly double what was observed in the two fall samples. This shows that there was more nitrogen in the soil during the soybean's peak season, when the plants needed it most. It's likely that the high ammonium concentration observed in July was also a result of the soybean and rhizobia's ability to fix nitrogen. It is curious however, that the high concentrations of ammonium in July were not matched with higher concentrations of nitrates. This could indicate that the soybean plants were actually fixing more nitrogen than could be converted to nitrites and nitrates through the process of nitrification.

Although the results of this study were promising, it will be very important to continue planting cover crops and analyzing soil health to get a more comprehensive idea of cover crop's effect on agricultural land. The full impact of cover cropping on soil may take numerous years to become fully realized. This study solely focused on the biological impact of cover crops, but the economic impact of cover crops is equally important and should be considered before making a decision about the long-term use of cover crops.

Conclusions:

Overall, physical characteristics differed more between plot types and chemical characteristics varied more significantly over time. The cover crop plot had higher percent moisture, lower bulk density, higher abundance of earthworms, and a possible trend toward more organic matter compared with the control. These changes are all indicative of a trend toward higher soil quality and health, supporting the use of cover crops.

Acknowledgements:

This project was made possible through the help of numerous people. Firstly, I would like to thank both Kendra Klenz and Tom Knee for their previous hard work on this project and for allowing me to use their data for comparison in this study. I was humbled to have to opportunity to continue such an important project. I would also like to thank Tom Knee, again, for his help with the nutrient analysis. I want to express my appreciation for Dave Legvold, who has continuously supported ecology projects over the years by allowing complete access to his farms. Last but not least, I want to express my deep gratitude to Professor Shea, who introduced me to this project and supported me throughout the semester.

Literature Cited

Betts, L. 2016. Cropping system changes may mean reduced nitrates. Corn + Soybean Digest.

Blanchart, E., C. Villenave, A. Viallatoux, B. Barthès, C. Girardin, A. Azontonde, and C. Feller. 2006. Long-term effect of a legume cover crop (Mucuna pruriens var. utilis) on the communities of soil macrofauna and nematofauna, under maize cultivation, in southern Benin. European Journal of Soil Biology **42, Supplement 1**:S136-S144.

Cardoso, E. J. B. N., R. L. F. Vasconcellos, D. Bini, M. Y. H. Miyauchi, C. A. d. Santos, P. R. L. Alves, A. M. d. Paula, A. S. Nakatani, J. d. M. Pereira, and M. A. Nogueira. 2013. Soil health: looking for suitable indicators. What should be considered to assess the effects of use and management on soil health? Scientia Agricola **70**:274-289.

Clark, A. 2015. Cover Crops for Sustainable Crop Rotations. Topic Room Series. Sustainable Agriculture Research and Educatoin.

De Bruin, J. L., P. M. Porter, and N. R. Jordan. 2005. Use of a Rye Cover Crop following Corn in Rotation with Soybean in the Upper Midwest. Agronomy Journal **97**:587-598.

Freeman, K., M. Clover, R. Bender, and C. Woolfold. 2016. Nitrogen. Crop Nutrition. The Mosaic Company.

Klenz, K., T. Knee, M. Schumm, J. Porterfield, K. Shea. 2015. Effects of a Microorganism Stimulant and Cover Crops on Soil Quality in a Strip-till Corn Field in Southeastern Minnesota. St. Olaf College.

Lavelle, P., T. Decaëns, M. Aubert, S. Barot, M. Blouin, F. Bureau, P. Margerie, P. Mora, and J. P. Rossi. 2006. Soil invertebrates and ecosystem services. European Journal of Soil Biology **42, Supplement 1**:S3-S15.

Meersman, T. 2015. Cover crops provide benefits but are a tricky proposition for Minnesota farmers Star Tribune.

NRCS. 2011. Bulk Density. Soil Quality for Environmental Health. NRCS East National Technology Support Center.

Reicosky, D. C., and F. Forcella. 1998. Cover crop and soil quality interactions in agroecosystems. Journal of Soil and Water Conservation **53**:224-229.

Schipanski, M. E., M. Barbercheck, M. R. Douglas, D. M. Finney, K. Haider, J. P. Kaye, A. R. Kemanian, D. A. Mortensen, M. R. Ryan, J. Tooker, and C. White. 2014. A framework for evaluating ecosystem services provided by cover crops in agroecosystems. Agricultural Systems **125**:12-22.

Stork, N. E., and P. Eggleton. 1992. Invertebrates as determinants and indicators of soil quality. American Journal of Alternative Agriculture **7**:38-47.

USDA. 2015. Minnesota Ag News - Farms and Land in Farms. Minnesota Department of Agriculture, St. Paul, MN.

Williams, S. M., and R. R. Weil. 2004. Crop Cover Root Channels May Alleviate Soil Compaction Effects On Soybean Crop. Soil Science Society of America Journal **68**:1403-1409.

Ye, S. 2016. Minnesota Agricultural Exports. Minnesota Department of Agriculture.

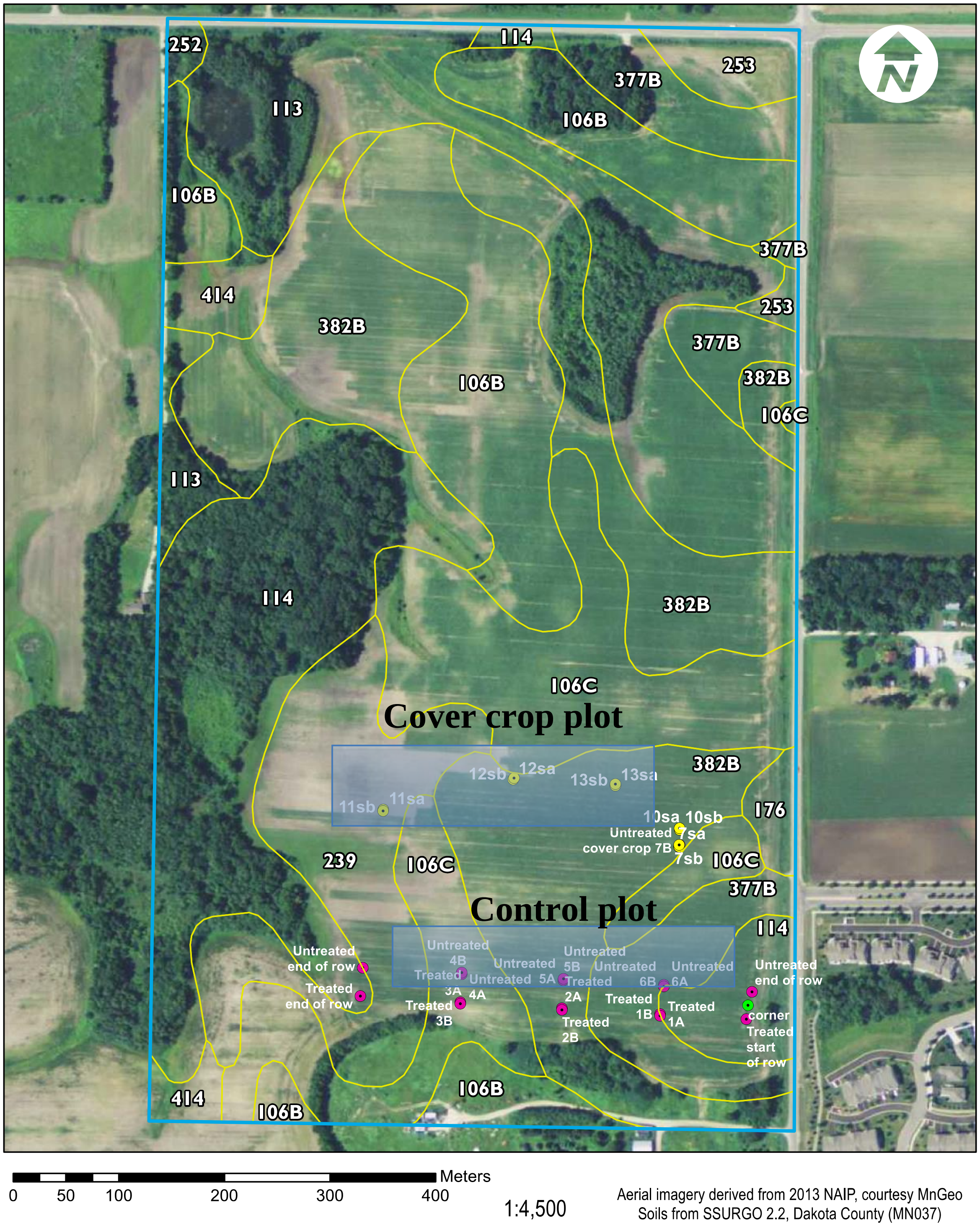

Fig. 1: An aerial map of the agricultural field created by Kendra Klenz in 2015, showing my sample locations. The yellow lines demarcate boundaries between different soil types and the white numbers correspond to soil types defined by the USDA NCRS. The yellow dots within the top blue box show my cover crop plot sampling sites and the pink dots in the second blue box show where I sampled in the control plot.

Fig. 2: Taking soil core samples on October 22, 2016. The yellow GPS used to locate sample sites can be seen in the foreground of the photo.

Table 1: Results of three two-way ANOVAs showing the variation in physical soil characteristics between plot type and over time. Percent moisture and bulk density were significantly different between plot types and bulk density varied significantly over time.

Plot Type	**Date**	**Number of Samples**	**Mean % moisture +/- SD**	**% moisture p-values**	**Mean bulk density +/- SD (mg/kg soil)**	**Bulk density p-values**	**Mean % organic matter +/- SD (mg/kg soil)**	**% organic matter p-values**
Control	10/15	6	20.85 +/- 2.24	**Plot type** = 1.654e-05 **Date** = 0.135 **Interaction** = 0.777	1.29 +/- 0.07	**Plot type** = 3.861e-05 **Date** = 0.001 **Interaction** = 0.824	5.19 +/- 1.07	**Plot type** = 0.097 **Date** = 0.112 **Interaction** = 0.813
	7/16	6	21.42 +/- 2.16		1.37 +/- 0.06		4.82 +/- 0.97	
	10/16	6	22.14 +/- 3.11		1.37 +/- 0.09		5.45 +/- 1.13	
Cover crop	10/15	6	23.97 +/- 0.78		1.17 +/- 0.02		5.85 +/- 0.44	
	7/16	6	25.59 +/- 2.58		1.28 +/- 0.06		5.11 +/- 1.46	
	10/16	6	26.51 +/- 2.11		1.28 +/- 0.05		6.26 +/- 0.71	

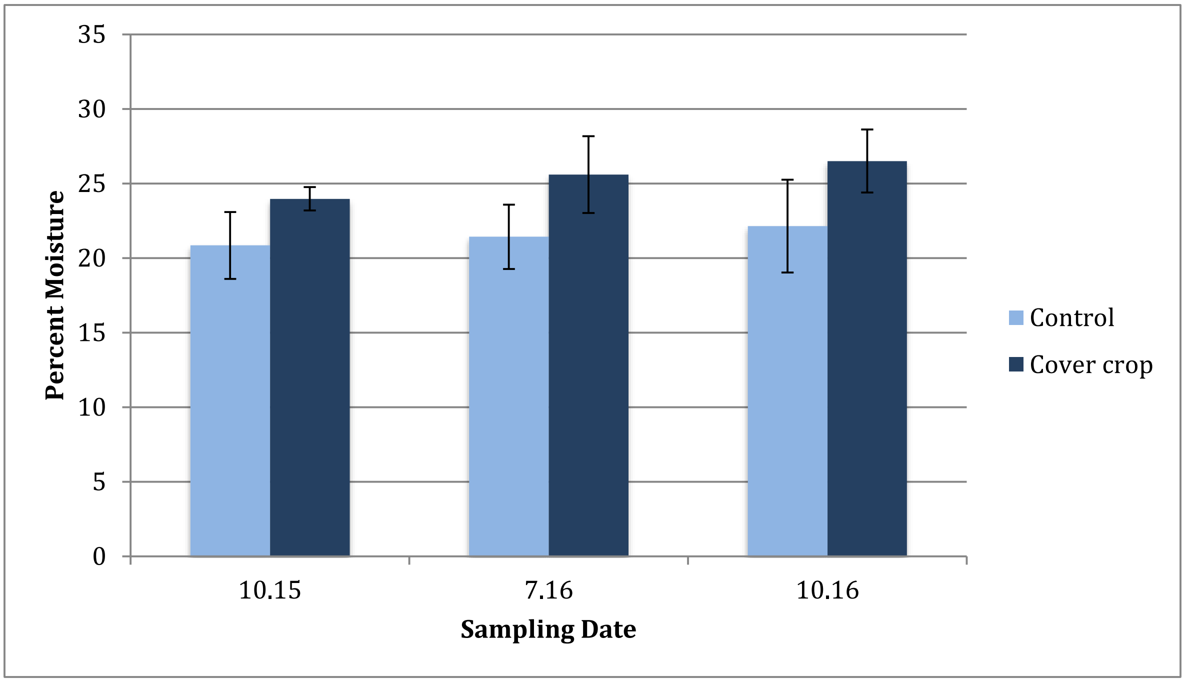

Fig. 3: Mean percent moisture in cover crop and control plots over time. Samples were taken in October of 2015 and July and October of 2016 (n=6 for each sampling event). There was no variation over time (p-value=0.135), but the cover crop plot had significantly higher percent moisture than the control plot (p-value=1.654e-05). The interaction between plot type and date was not significant (p-value=0.777)

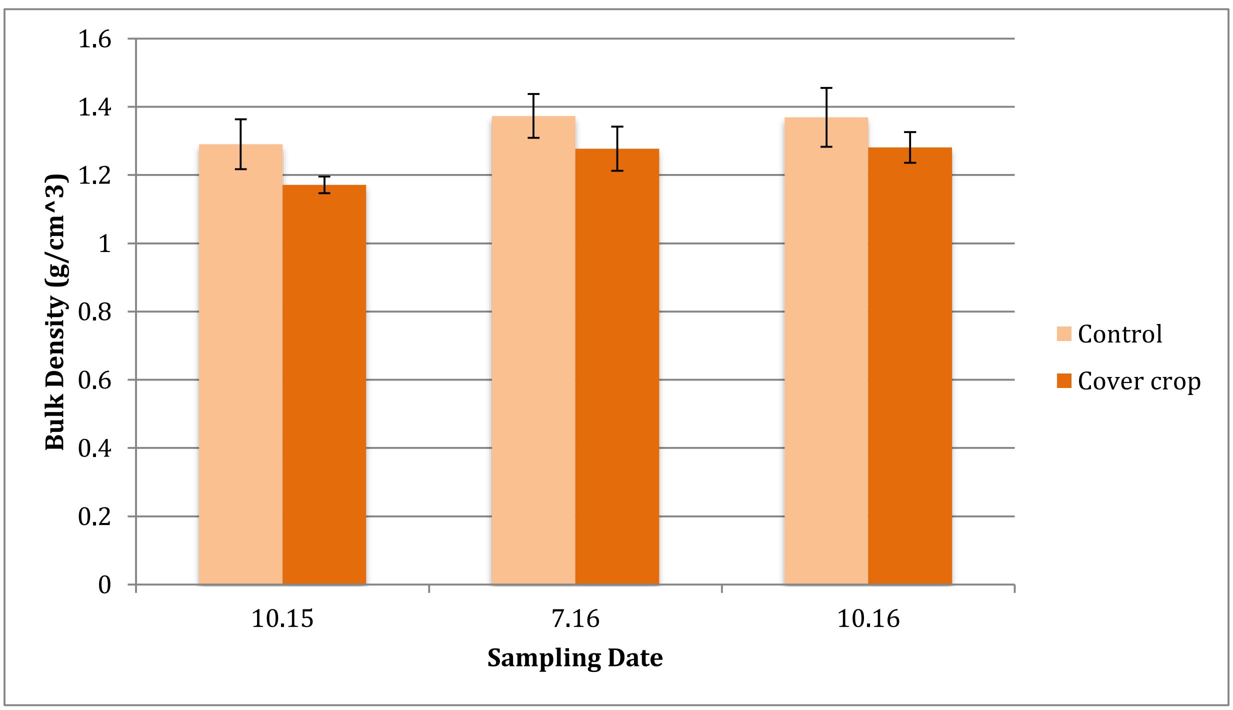

Fig. 4: Mean bulk density in cover crop and control plots over time. Samples were taken in October of 2015 and July and October of 2016 (n=6 for each sampling event). There was significant variation between plots, with control having consistently higher bulk densities (p-value=3.861e-05) and a significant increase over time (p-value=0.001), however there was no interaction between the variables (p-value=0.824).

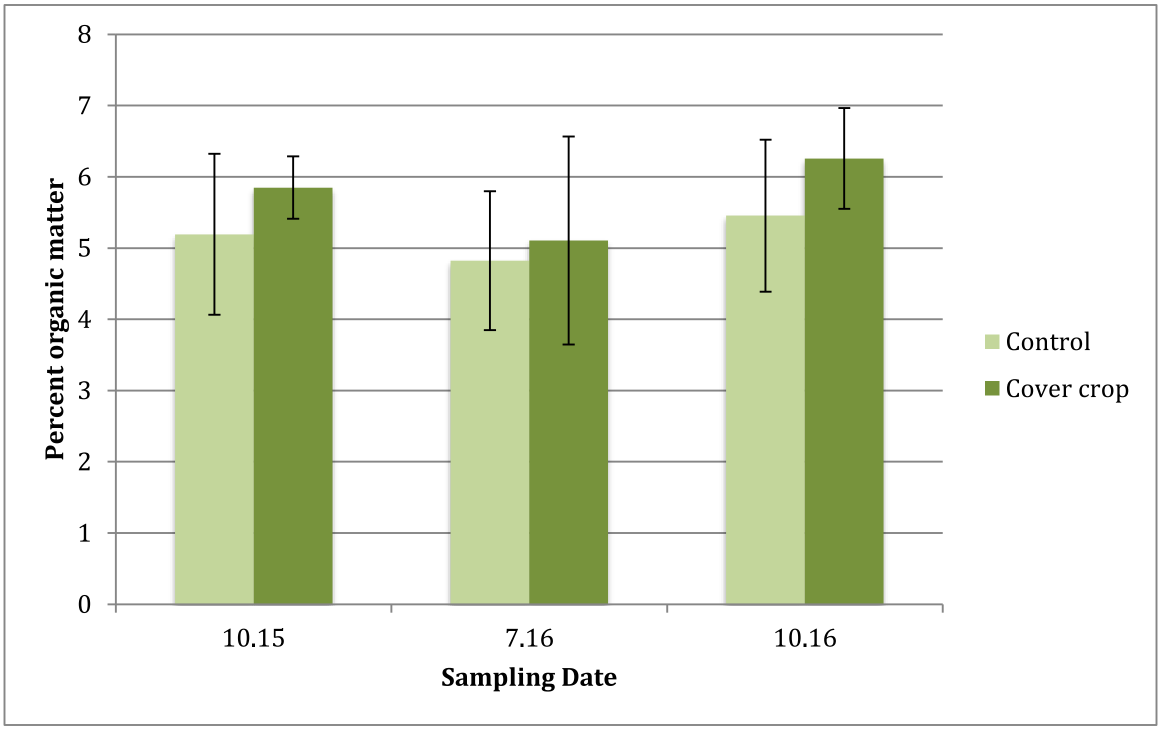

Fig. 5: Mean percent organic matter in cover crop and control plots over time. Samples were taken in October of 2015 and July and October of 2016 (n=6 for each sampling event). There was no significant variation between plots (p-value=0.097) or over time (p-value=0.112), however the graph shows that there might be a trend toward higher organic matter in the cover crop plots.

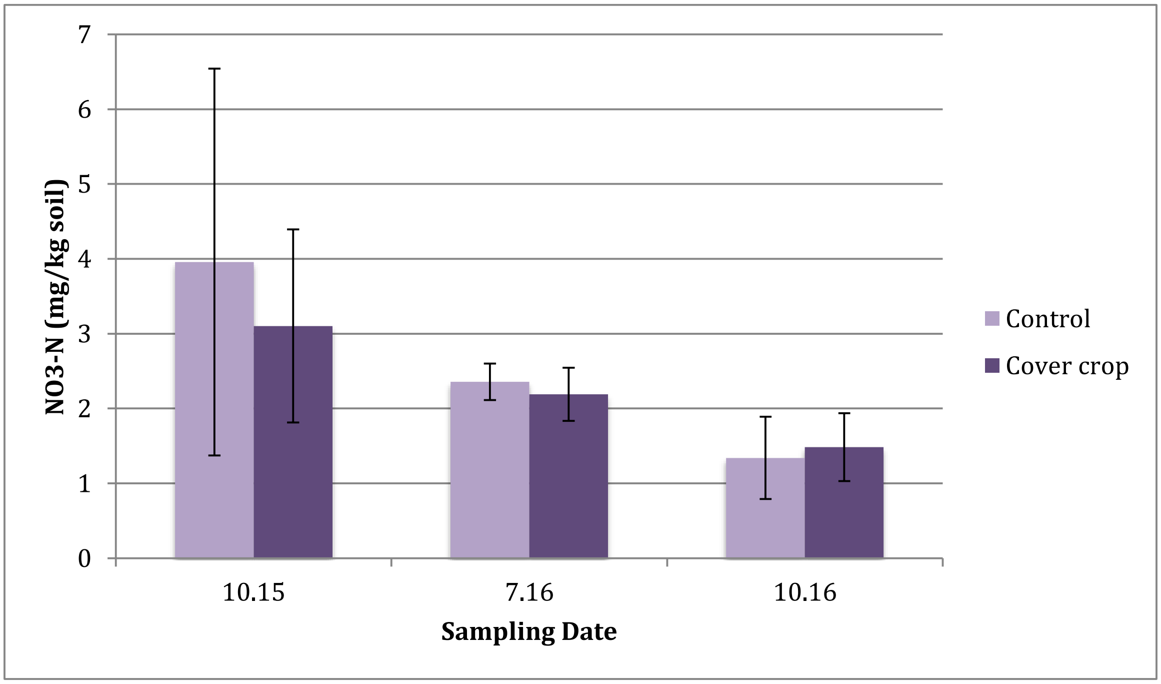

Fig. 6: Mean nitrogen-nitrate concentrations in cover crop and control plots over time. Samples were taken in October of 2015 and July and October of 2016 (n=6 for each sampling event). There was no significant variation between plot types (p-value=0.487), but an obvious decrease over time (p-value=0.001).

Table 2: Results of two two-way ANOVAs showing the variation in chemical soil characteristics between plot type and over time. Both nitrate and ammonium soil concentrations varied significantly over time.

Plot Type	Date	Number of Samples	Mean [N-NO_3] +/- SD (mg/kg soil)	[N-NO_3] p-values	Mean [NH_4+] +/- SD (mg/ kg soil)	[NH_4+] p-values
Control	10/15	6	3.96 +/- 2.59	**Plot type** = 0.487 **Date** = 0.001 **Interaction** = 0.612	3.24 +/- 0.78	**Plot type** = 3.861e-05 **Date** = 0.001 **Interaction** = 0.824
	7/16	6	2.36 +/- 0.24		6.65 +/- 2.45	
	10/16	6	1.34 +/- 0.55		2.24 +/- 1.20	
Cover crop	10/15	6	3.10 +/- 1.29		2.86 +/- 0.37	
	7/16	6	2.19 +/- 0.36		5.68 +/- 0.87	
	10/16	6	1.48 +/- 0.45		1.86 +/- 0.79	

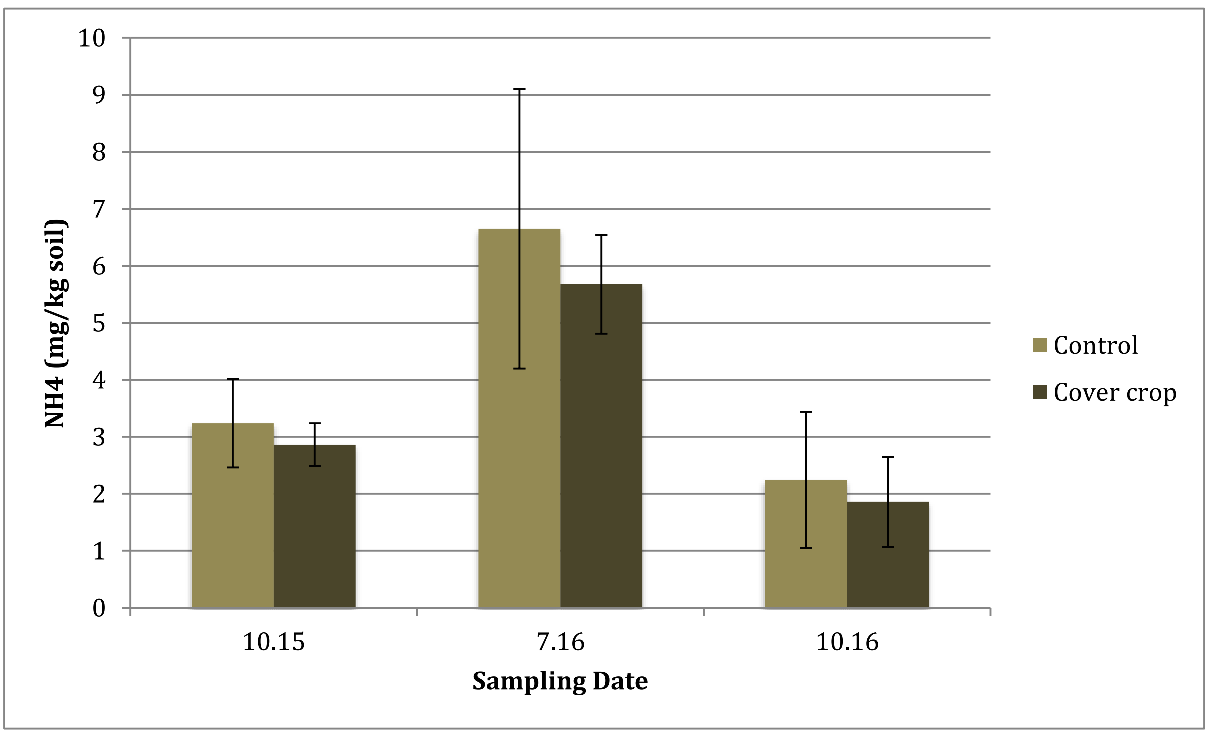

Fig. 7: Mean ammonium concentrations in cover crop and control plots over time. Samples were taken in October of 2015 and July and October of 2016 (n=6 for each sampling event). There was no significant variation between plot types (p-value=0.174), but obvious variation based on season (p-value=1.453e-08).

Table 3: Diversity indexes for the macroinvertebrate diversity between control and cover crop plots. Eighty organisms were collected in the control plot and 47 in the cover crop plot. Although both indexes showed slightly higher diversity in the control plot, the difference was no significant (1.399).

	Control	Cover crop	Significance
Richness	10	8	1.399
Shannon (H')	0.727	0.631	
Simpson (Ds)	0.766	0.666	
Variation of Ds	0.001	0.005	

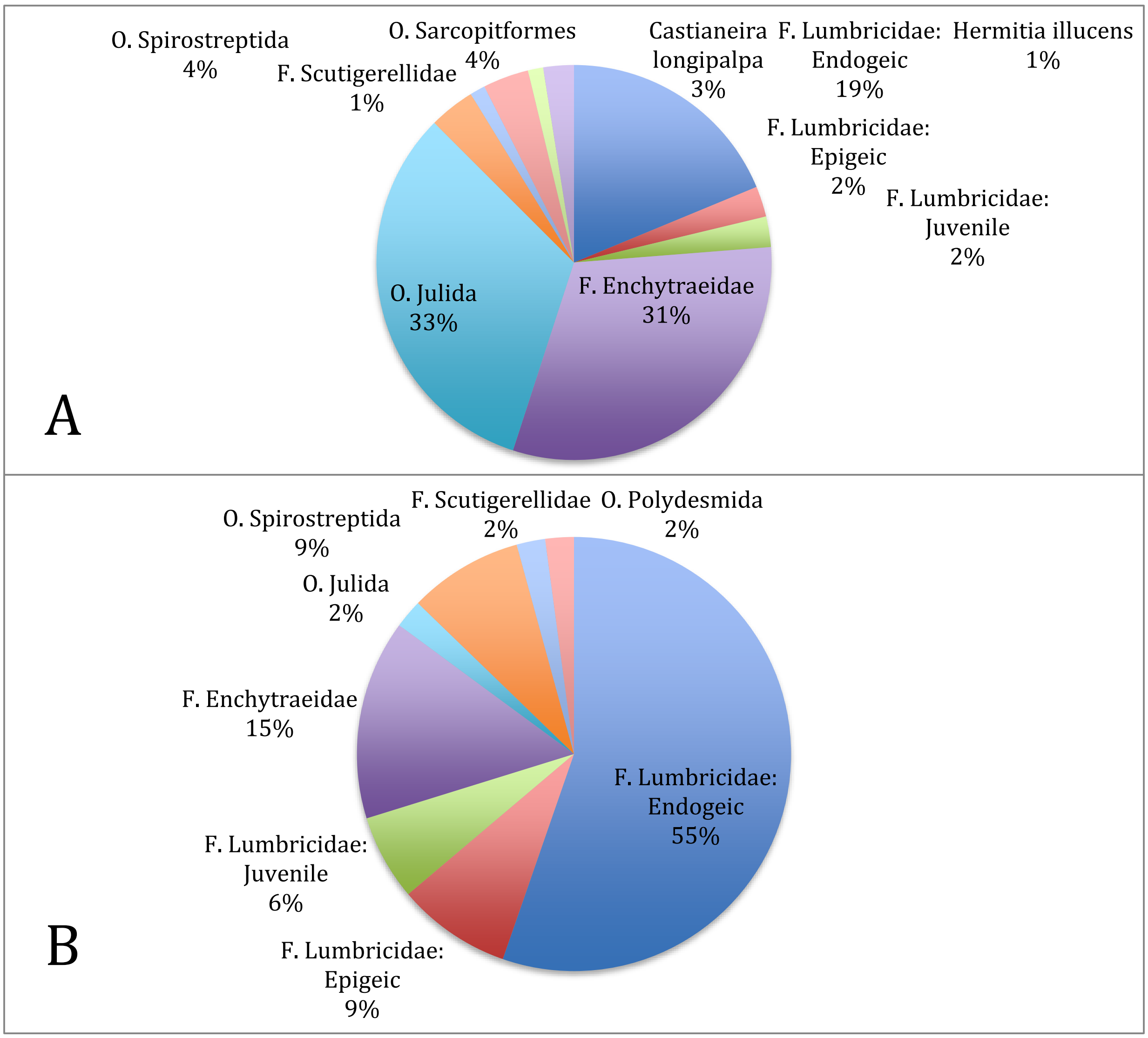

Fig. 8: Species composition in the control plot (A) and cover crop plot (B). In the above names, O stands for order and F stands for family. The composition varied greatly between plots, with earthworms having greater abundance in the cover crop plot.

Table 4: The results of a contingency table constructed based on the four major organism groups common between the control and cover crop plots. The cover crop plot contained a majority of earthworms, whereas there was nearly an equal abundance of earthworms, pot worms, and millipedes in the control plot. The compositional differences seen between the plot types were significant (p-value = 2.282e-05).

	Control		**Cover crop**	
	Count	Column percentages	Count	Column percentages
Earthworms (epigeic, endogeic, and juveniles included)	19	25.7%	33	70.2%
Pot worms	25	33.8%	7	14.9%
Millipedes (Orders Julida, Spirostreptida, and Polydesmida included)	29	39.2%	6	12.8%
Centipedes (Family Scutigerellidae included)	1	1.4%	1	2.1%