The Various Effects of Various Tilling Practices on Long-Term Soil Health in the Capital Region of New York

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Abstract

Agricultural soils account for more than 10% of total carbon stored in terrestrial ecosystems. Current conventional management practices such as moldboard plowing and disc tillage undermine soils ability to store and sequester atmospheric CO_2 as well as degrade the health of soils and subsequently their ability to provide essential ecosystem services. It has been previously shown that no-till agriculture techniques can support C sequestration while simultaneously improving soil health. Evaluating soil health characteristics such as percent aggregation, percent total carbon and nitrogen, soil organic matter (SOM), and microbial metabolic activity can help us gain insight into how both conventional and no-till management practices influence the long term health of agricultural soils. Our study focused on analyzing agricultural soils managed for livestock feed production using a variety of cultivation practices in Washington County, NY. We quantified the five aforementioned soil health characteristics and compared their values across five field management regimes that utilized various forms of tilling to gain insight into which management practice would simultaneously ensure soil health as well as C sequestration. We predicted that we would see an increase across all soil health characteristics from the most disruptive tilling practice to the least while also taking into account the duration of time the field was under cultivation. The least percent aggregation was found in the moldboard plow field in both the top 0-7 cm (10.74%) and the bottom 7-15 cm (12.44%) soil layers. The highest percent aggregation was found to be in the cultivator field in the top (48.81%) and bottom (42.92%) soil layers. The least percent carbon was found in the top 0-7 cm of the long term no-till field (1.896%) and the most was found in the pasture fields (3.56%). The pasture fields had the highest average percent SOM in the top 0-7 cm (9.95%) and bottom 7-15 cm (6.98%). The fields with the lowest average SOM in the top 0-7 cm were the long term no-till fields (6.32%). We found no significant differences in average AMR and CMD values across all field types. Our results showed that management practice does indeed have an effect on all of the soil health characteristics we analyzed. Discrepancies in the statistical significance in our data could be due to the small sample size as well as high variation in the amendments applied to the various field types. Further research in this field of study should focus on the interconnectedness of these various soil health characteristics in order to understand how to optimize the potential of agricultural soils as a significant sink for atmospheric $CO_{2.}$ Understanding the interconnectedness

of various soil health characteristics could thus be the major key to optimizing our use of agricultural soils.

Introduction

Conventional agricultural tilling practices have drastically undermined the health and resiliency of soils across the globe. Degraded soils have a reduced capacity to provide vital ecosystem services such as climate mitigation, water filtration, and food production (Lal, 2013). Soils that have been subjected to conventional tilling practices, such as moldboard plowing, are more prone to compaction, emission of greenhouse gases, and erosion. Conventional tilling practices, as defined by the United States Department of Agriculture, utilize the moldboard plow or heavy disks that bury almost all previous crop residues and disturb the full area of the cultivated field (USDA, 2010). These practices cause fragmentation of soil aggregates, which are naturally occurring groups of soil particles. Soil aggregates fall into two major groups, macro- and micro-aggregates with macro-aggregates defined as soil particles greater than 250-µm (Grandy & Robertson, 2006). These consolidated soil particles are prevalent in healthy soils and help to stabilize labile soil organic matter (SOM), carbon (C) storage and microbial communities (Grandy & Robertson, 2006). No-till farming, as defined by the United States Department of Agriculture (USDA), refers to systems where crops are planted in narrow strips and disturb less than one third of the area between rows of crops (USDA, 2010). No-Till techniques thus drastically reduce the amount of disturbance to soil structure and can be implemented to increase the soils ability to help mitigate climate change and maintain long term soil health.

Macroaggregates can be key indicators of how C responds to conventional tilling practices because of their importance in protecting SOM pools. In addition to the soil's natural tendencies to flocculate due to chemical properties of soil particles, plant roots, fungal hyphal networks, and the incorporation of SOM, all contribute to macroaggregate formation and stability (Grandy & Robertson, 2006). Several studies have shown that increased SOM ultimately leads to improved soil conditions as SOM contains many cementing agents such as calcium carbonate, hummus, and oxides which all contribute to aggregate formation (Nimmo, 2004, Rhoton, 2000). Moldboard plowing immediately destroys previously established aggregates regardless of how long the land was left uncultivated and continuous tilling undermines the formation of new aggregates (Grandy & Robertson, 2006). This effect is compounded by the increase of decomposition and oxidation of soil C present in SOM made available to microbial communities within disturbed soils (Grandy & Robertson, 2006, West 2002).

Microbial communities comprised of both bacteria and fungi serve a critical role in soil food web dynamics as 90-95% of all nutrient cycling pathways pass through the metabolisms of this group of organisms (Kennedy, 1999). Often times, these microbes directly and indirectly form symbiotic relationships with crop plants as they have the ability to transform compounds from various substrates into readily absorbed plant nutrients (Kennedy, 1999). This is most easily observed in the Nitrogen (N) cycle as bacteria are able to transform molecules unavailable to plants such as ammonium to nitrates which are readily assimilated in to plant biomass (Patterson, 2003). Consequently it is important for agricultural management practices to take into account the health of these microbial communities to best support high crop yields and soil health. Studies have shown that bacteria and fungi are more abundant in no-till systems due to the lack of disturbance inflicted by the use of the moldboard plow prevalent in conventional agriculture (Helgason et al., 2007).

Many of the efforts to mitigate climate change have focused on decreasing the emission of CO_2 from the combustion of fossil fuels and the development of renewable energies, however, there has recently been a shift towards investigating how conservation focused agricultural land management can sequester atmospheric C (West, 2002). Agriculture accounts for 9% of total greenhouse gas (GHG) emissions from the United States, which primarily comes from livestock, agricultural soils, and rice production (EPA, 2018, USDA 2010 “no till”). Although most of the 1 billion hectares of agricultural land in the U.S. is cultivated with conventional tilling practices, approximately 23% have fully adopted no-till practices (USDA 2010-11).

Our study looks to investigate the effects of varied tilling practices on long-term soil health and carbon retention. We focused on dairy farms located in Washington County, New York that maintain multiple fields to grow crops to feed their livestock. These farmers have used a wide array of cultivation practices for varying lengths of time in order to increase their crops yields as well as save money. Many of the practices commonly used are determined by cost benefit analysis made by the individual farmers. We have sampled multiple fields on these farms and combined them into groups to quantify the difference in overall soil health of fields cultivated both under no-till and conventional tilling systems. All of the fields in our study had Bernardston silt loam soil and were mainly planted in crop rotations of a corn and grass/alfalfa mixture. Soil health was characterized by conducting a number of soil tests which evaluated macro and micro aggregate stability, total carbon (TC) and nitrogen (TN), soil organic matter (SOM), and microbial community metabolic activities. We chose to conduct this study on fields in current cultivation in order to observe how common cultivation practices affect soil health in a real world setting. We expect to see an increase across all soil health characteristics from the most disruptive tilling practice to the least along with length of duration of cultivation.

2. Methods

2.1 Experimental Design and Soil Sampling

We collected soil subjected to five cultivation practices within one soil type from a total of 3 farms in the Capital Region: moldboard plow, long term no-till, short term no-till, cultivator, and pasture (Figure 1). Soil type was confirmed using the Web Soil Survey (WSS) and cross-referenced with each farmer (Table 1). We collected soil cores on December 9, 13, 14, and February 25. Sample sites were determined using haphazard sampling methods by throwing a rock to select each sample site. This process was repeated twice more for a total of three times. At each of the three sites, two cores were taken in order to obtain replicates. The soil corers were made from 4-cm diameter schedule 40 PVC pipe and hammered into the soil using a rubber mallet to a depth of 15cm. The top 0-7 cm and the bottom 7-15 cm of soil from each core was placed into separate bags and stored at 1.6℃ for approximately 30 days before soil tests were conducted.

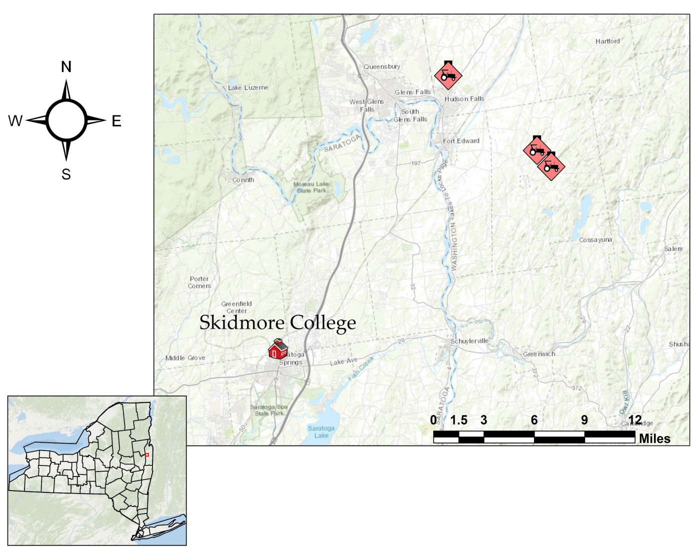

Figure 1. Dairy farms visited in Washington County, New York.

Table 1. Soils found in the Capital Region organized by years since the start of a no-till system and soil type determined by GPS and the Web Soil Survey.

	Field Name	Field Type	Time in No-Till	Field Use	Field History	Amendments
Bernardston Silt Loam	P8	Moldboard Plow	1 month	Moldboard Plow, Corn	Pasture for approximately 30 years prior cultivation. First tilled in 2016.	Cow manure and lime
	DL7	Short Term No-Till	< 1 year	Selective Row Till (SRT), 7-8-year corn and alfalfa/grass pasture rotation	Pasture for approximately 30 years prior to cultivation.	Cow manure and lime
	DL1 & F6	Long Term No-Till	5-6 years	Selective Row Till, 7-8-year corn and alfalfa/grass pasture rotation	8 year rotation between corn and an alfalfa/grass mixture for 30 years.	Cow manure and lime
	F1	Cultivator	38+ years	Surface level cultivation, 4-year corn and alfalfa/grass pasture rotation	Continuous cultivation for 38 years.	Lime and potash, no removal of crop residues
	BUP1 & P7	Pasture	30-40 years	Alfalfa/grass pasture	Over 30 years in pasture.	None

2.3 Soil Structure Analysis

Methods for wet stable aggregates were conducted similar to that of Grandy & Robertson (2006). The percentage of wet stable aggregates was determined by sieving 40 g of air dried soil in water through a series of 2000-, 250-, and 53-µm sieves. Soil was submerged in the 2000-µm sieve in a water and sodium hexametaphosphate mixture for five minutes then moved up and down over a 2 minute period with a stroke of length of 3 cm for 50 strokes. This process was repeated for the 250-µm and 53-µm sieve using the soil plus water that passed through the larger sieve.

Aggregates remaining on each sieve were dried at 60℃and weighed. We used initial total weight and the final weight of the dried soil to determine the percentage of wet stable aggregates present in the original sample (Grandy & Robertson, 2006).

2.4 Total Carbon (TC) and Total Nitrogen (TN)

20g of each soil sample was dried at 100℃, ground, and stored in glass vials. These vials were kept dry at 60℃to ensure no moisture from the air was in the sample. Two replicates of up to 10mg of each sample were packaged into tin capsules. The tin capsules were placed in well plates and kept in a desiccator for 48 hours. The samples were then sealed and sent out to Kent State University to be analyzed using an isotopic mass spectrometer. We received data including the percent nitrogen and carbon present in each sample.

2.5 Soil Organic Matter (SOM)

We used the loss-on-ignition (LOI) method to quantify SOM. We weighed 5g of soil that was previously ground and dried at 60 105℃for 12 hours. 2-5 g was transferred to crucibles and combusted in a muffle furnace at 375℃for 4 hours. Percent soil organic matter was calculated based off the initial and final sample weights:

Original weight/ (Original Weight - Final Weight) = % Soil Organic Matter

2.4 Microbial Community Physiological Profiling

We measured 5g of field moist soil into a specimen cup and added 95 ml of deionized water. After the cup was vigorously shaken for approximately 1 minute it was left to settle for 1 hour and stored overnight in a refrigerator kept at approximately 0℃. We then filtered approximately 40 ml of the settled soil slurry to remove any suspended particulate matter. We inoculated BIOLOG EcoPlates (96 well plates) with the filtrate and took an initial reading (t=0) using a BioTek Synergy HTX Multi-mode Plate Reader at an absorbance of 590 nm. The EcoPlate was incubated in the dark at room temperature (approximately 20℃) for a total of 5 days. Readings were taken every 22-26 hours. We repeated this procedure a total of 48 times to produce individual ecoplate replicates of the three sampling sites for each field for both the top

0-7 cm and bottom 7-15 cm across all field types. We calculated the average metabolic response (AMR) using the following equation.

$$AMR = \frac{\Sigma(avg\ OD\ well - OD\ neg)}{31}$$

After AMR was calculated for each ecoplate, we calculated the average AMR of the top 0-7cm and bottom 7-15 cm for each field type to produce average AMR values.

We determined community metabolic diversity by calculating the average optical density (OD) for each carbon source and subtracting it from the average OD of our negative wells. We then counted the number of carbon source averages that produced an OD value higher than the threshold of 0.25 (Adapted from Sylvia Frank-McDevitt's BI 165 Lab Protocol). After CMD was calculated for each ecoplate we calculated the average CMD of the top 0-7 cm and bottom 7-15 cm for each field type to produce average CMD values.

Statistical Analyses

We performed a One-way analysis of variance (ANOVA) to evaluate the significant differences between our data across all soil types for both the top 0-7 cm and bottom 7-15 cm, followed by a Tukey's b post hoc analysis to observe groups within the data set. Statistical analyses were performed using MS-Excel 16 and SPSS 24.

3. Results

3.1 Aggregates

We found significant differences in the 250-µm sieve in both the top 0-7 cm and bottom 7-15 cm soil layers. The least percent aggregation was found in the moldboard plow field in both the top 0-7 cm (10.74%) and the bottom 7-15 cm (12.44%) soil layers. The highest percent aggregation was found in the cultivator field in the top 0-7 cm (48.81%) and bottom 7-15 cm (42.92%) soil layers. The cultivator field had 38.07% higher percent aggregation than that of the moldboard plow field (Figure 2, 3). Tukey's B post-hoc analysis revealed significant differences between two groupings in the top 0-7 cm of the soil profile for percent aggregation in the 250-µm size class. The first group includes the moldboard plow field and the second group includes the short term no-till field, the pasture fields, and the cultivator field. The long term no till fields were not significantly different between the two groups as it was included in both groupings (Figure 2). Tukey's B post-hoc analysis also revealed significant differences between two groupings in the bottom 7-15 cm of the soil profile for percent aggregation in the 250-µm size class. The first group includes the moldboard plow field and the second group includes the pasture fields, the cultivator field, and the short term no-till field. The long term no-till fields were not significantly different between the two groups as it was included in both groupings (Figure 3).

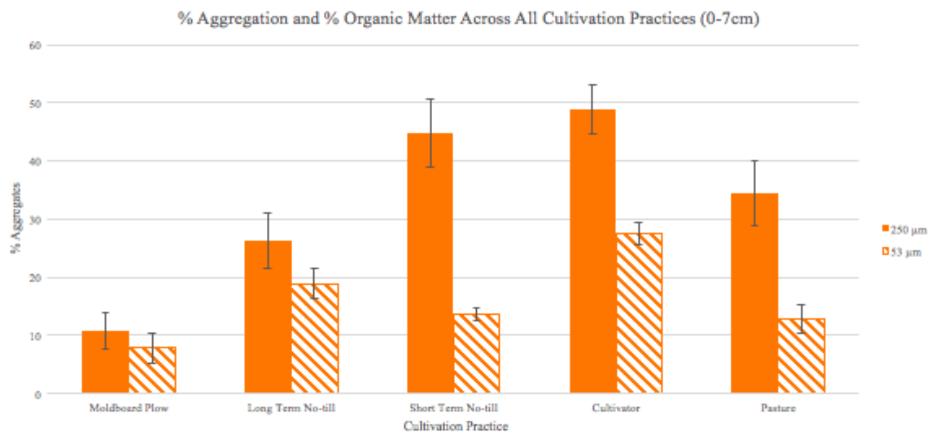

Figure 2. Percent aggregation of macro-aggregates (250 µm) and micro-aggregates (53 µm) across all cultivation practices in the top 0-7 cm. Significant values for sieves are denoted by an asterisk for the 250-µm size ($p=0.04$, $F=5.921$, $df=20$), non-significant values for sieves are not denoted by an asterisk for the 53-µm size ($p=0.079$, $F=2.552$, $df=20$).

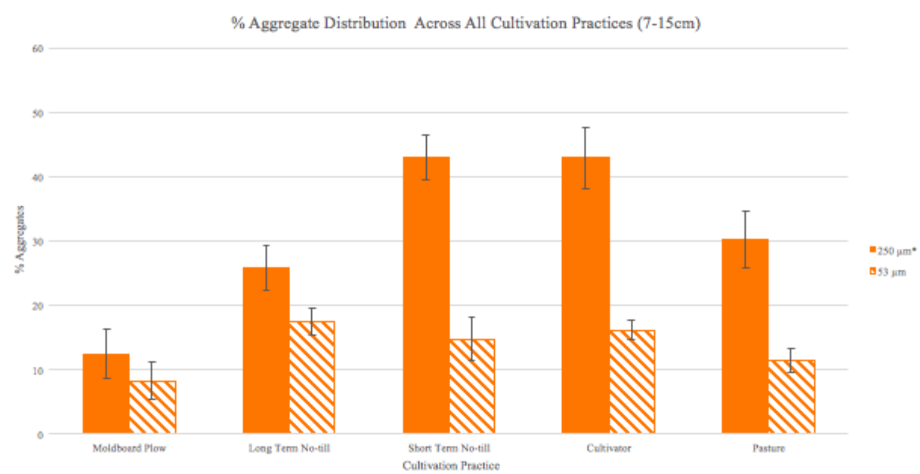

Figure 3. Percent aggregation of macro-aggregates (250 µm) and micro-aggregates (53 µm) across all cultivation practices in the bottom 7-15 cm. Significant values for sieves are denoted by an asterisk for the 250-µm size ($p=0.005$, $F=5.772$, $df=20$), non-significant values for sieves are not denoted by an asterisk for the 53-µm size ($p=0.090$, $F=2.436$, $df=20$).

3.2 Total Carbon and Nitrogen

We found significant differences in the top 0-7 cm for both percent carbon and percent nitrogen. A general increasing trend of least percent carbon to most percent carbon was found from the most disturbed to least disturbed cultivation practice for both analyses (Figure 4, 5). The least percent carbon was found in the top 0-7 cm long term no-till field (1.896%) and the most was found in top 0-7 cm in the pasture fields (3.56%) (Figure 4). There was only a 1.633% increase in percent carbon in the top 0-7 cm between the moldboard plow field and the pasture fields. In the bottom 7-15 cm of the profile, there was only a difference of 0.389% between the moldboard plow field and the pasture fields. In the bottom 7-15 cm, the least percent nitrogen was found in the moldboard plow field (0.217%) and the most was found in the pasture fields (0.359%) (Figure 5). There was not a significant difference in percent nitrogen between fields in both the top 0-7 cm and the bottom 7-15 cm of the profile. We found no significant differences in our data for the bottom 7-15 cm across all field types.

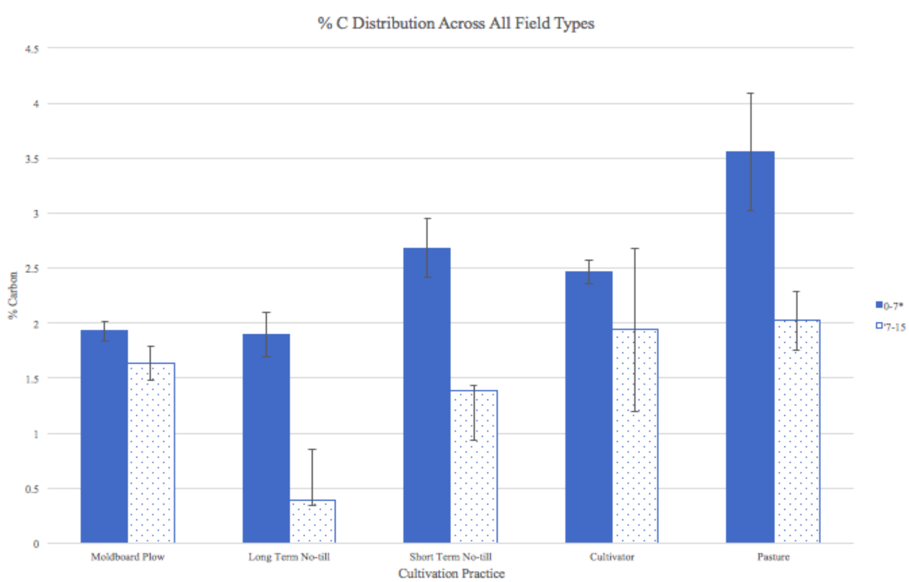

Figure 4. Percent carbon in both the top 0-7 cm and bottom 7-15 cm soil layers across all cultivation practices. Significant layers are denoted by an asterisk in the top 0-7 cm ($p=0.012$, $F=3.714$, $df=40$), non-significant values are not denoted by an asterisk in the bottom 7-15 cm ($p=0.647$, $F=0.626$, $df=40$).

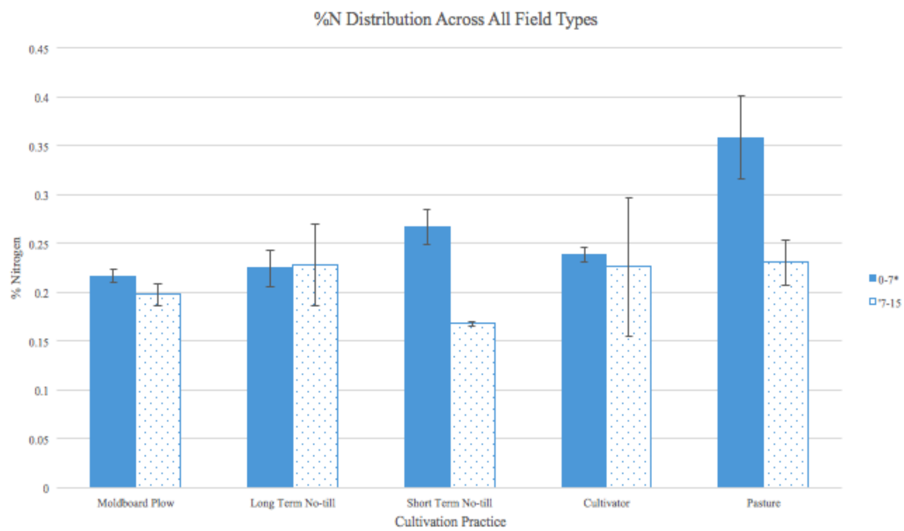

Figure 5. Percent nitrogen in both the top 0-7 cm and bottom 7-15 cm across all cultivation practices. Significant layers are denoted by an asterisk in the top 0-7 cm (p=0.005, F=4.422, df=40), non-significant values are not denoted by an asterisk in the bottom 7-15 cm (p=0.631, F=0.650, df=40).

3.3 Soil Organic Matter

The pasture fields had the highest average percent SOM in the top 0-7 cm (9.95%) and bottom 7-15 cm (6.98%). The fields with the lowest average SOM in the top 0-7 cm were the long term no-till fields (6.32%). We observed the lowest percent SOM in the bottom 7-15 cm in the cultivator field (5.03%). We found a statistically significant difference in average percent SOM values for the top 0-7 cm across all field types (Figure 6). No significant difference was found in the bottom 7-15 cm across all field types.

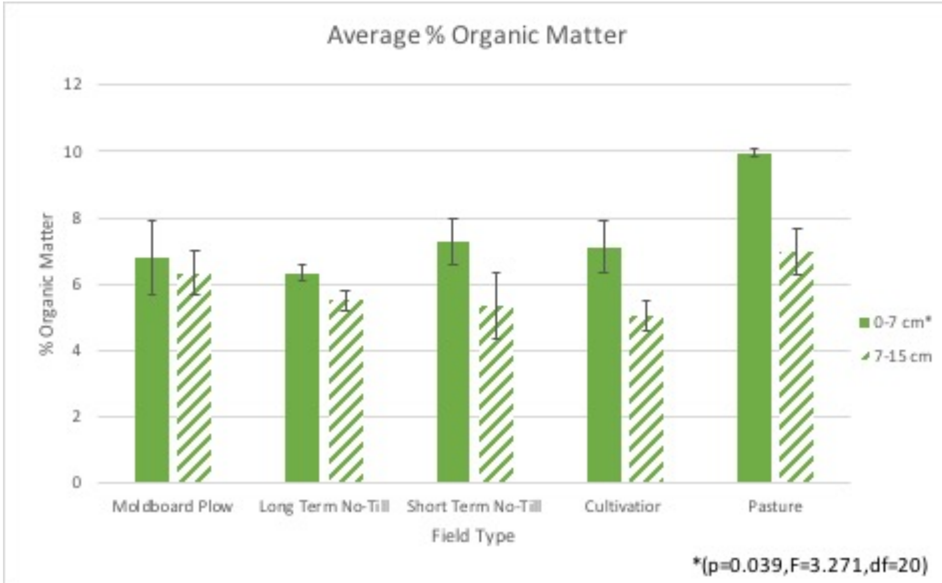

Figure 6. Average percent soil organic matter in the top 0-7 cm and bottom 7-15 cm across all field types. Statistically significant data are denoted by asterisk (p=0.039,F=3.271,df=20).

3.4 Microbial Community Physiological Profiling

The bottom 7-15cm of the long term no-till fields had the highest average of the average metabolic response (AMR) (1.04). The bottom 7-15 cm of the moldboard plow field had the lowest average AMR (.773) (Figure 7). The field type with the highest average community metabolic diversity (CMD) was the top 0-7 cm of the moldboard plow field (24.67). We observed the lowest average CMD in the top 0-7 cm of the pasture fields (19.67) (Figure 8). We found no significant differences in average AMR and CMD values across all field types (Figure 7, 8).

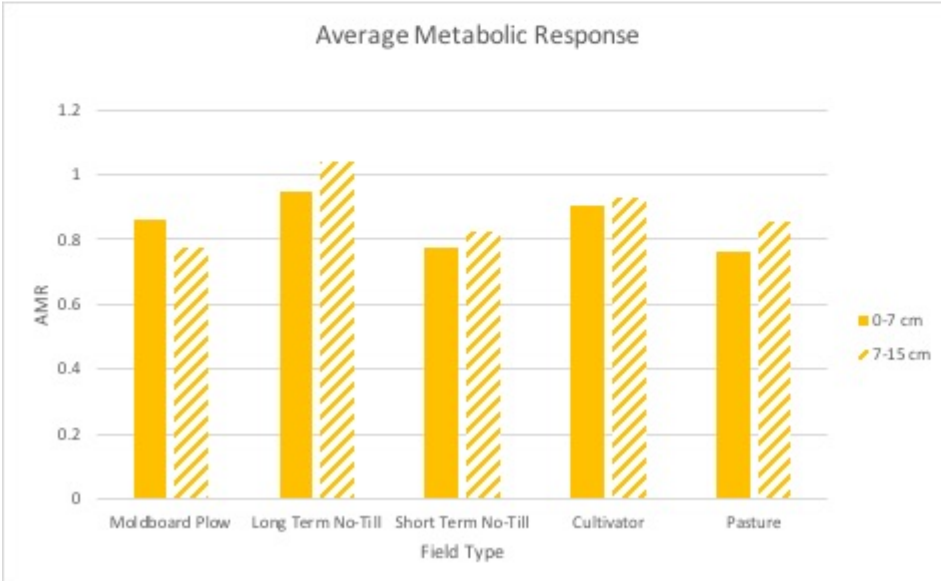

Figure 7. Average AMR values of the top 0-7 cm (p=0.588, F=0.725, df=20) and bottom 7-15 cm across all field types (p=0.161, F=1.890, df=20).

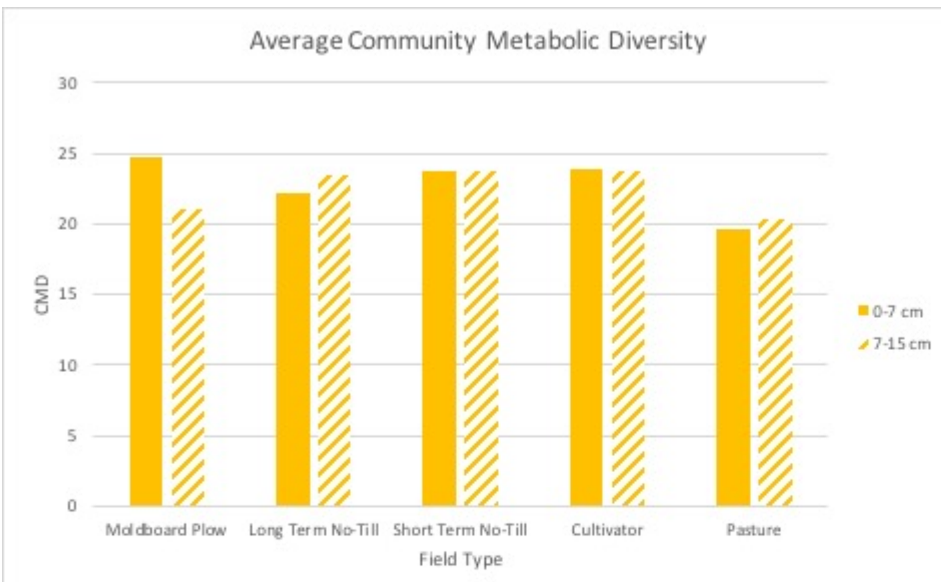

Figure 8. Average CMD values of the top 0-7 cm (p=0.143, F=2.00, df=20) and bottom 7-15 cm across all field types (p=0.155, F=1.926, df=20).

Discussion:

The objective of our study sought to holistically evaluate the long term health of soils across interconnected soil health characteristics. We found the lease percent aggregation in the 250 um size class in the moldboard plow field in both the top 0-7 cm and the bottom 7-15 cm of the soil (10.74% and 12.44%, respectively) (Figure 2,3). The highest percent aggregation in the 250 um size class was found in the cultivator field in both the top 0-7cm and bottom 7-15 cm of the soil (48.81% and 42.92%, respectively) (Figure2, 3). Although previous studies have shown that long term cultivation of soils under conventional tilling regimes greatly reduce soil aggregation, not many have compared soil health across varied cultivation practices (Grandy & Robertson, 2006). Soil disturbance is not the only factor involved in aggregation. Soil carbon, biological processes, and plant roots also assist aggregation as they cohere small soil particles which serve to capture SOM and stabilize macroaggregates (Grandy & Robertson, 2006). Nath and Lal (2017) found water stable aggregates to be greater in a no-till corn field compared to a conventionally tilled corn field. Our findings produced similar results as we found the moldboard plow field to have less percent aggregation in both the top and bottom soil layers analyzed (Figure 2, 3). Although we would have expected to see the highest percent aggregation in the fields left in pasture we found the highest percent aggregation in both the top and bottom soil layers in the cultivator field. This field was amended with lime and potash and crop residues were not removed after seasonal harvests. Decomposition of crop residue help support the formation and stabilization of aggregates (Nath & Lal, 2017). This may be why we see the highest percent aggregation in this field. The addition of line increases carbon return and crop growth which helps to bind microaggregates together into macroaggregates (Haynes & Naidu, 1998, Nath & Lal, 2017). Although lining is believed to improve soil structure Haynes and Naidu (1998) showed that the mechanism by which this happens is still unclear. The cultivator field was also amended with potash, a phosphorus additive, which results in moist loose soil that requires little plowing (Haynes & Naidu, 1998). While sampling this field we observed a noticeable difference in the soil texture and found it to be more fluffy and loose than soil samples taken from the other fields despite having the same soil type likely due to the addition of pot ash. For all other fields treated with manure, studies have found that this application adds a nutrient source and therefore improving soil physical conditions. This nutrient source addition is also likely affecting our soil organic matter, total carbon (TC), and total nitrogen (TN) data. Organic carbon content, a measure of just organic carbon, in soil increases with an increase in farmyard manure additives to the soil (Haynes & Naidu, 1998).

We found the least percent carbon in the upper 0-7 cm and the lower 7-15 cm of soil in the long term no-till fields (1.896% and 0.39%, respectively) (Figure 4). The highest percent carbon in the upper 0-7 cm and the lower 7-15 cm of soil was found in the pasture fields (3.561% and 2.023%, respectively) (Figure 4). The least percent nitrogen in the upper 0-7 cm and lower 7-15 cm of the moldboard plow and the short term no-till fields respectively (0.217% and 0.168%, respectively) (Figure 5). The highest percent nitrogen in the top 0-7 cm and the bottom 7-15 cm in the pasture fields and the long term no-till fields respectively (0.359% and 0.228%, respectively) (Figure 5). While different amendments to the soil affect the carbon and nitrogen present, aggregation is a good predictor of the potential carbon responses to disturbance events as aggregates are extremely important in protecting recently deposited and labile organic matter (Grandy & Robertson, 2006). Nath & Lal (2017) found soil organic carbon (SOC) and total nitrogen (TN) contents in their soil to be higher in the undisturbed natural forest site compared to all other sites. Similar to this, we found the highest TC and TN to be in the pasture fields compared to all other fields (Figure 4, 5). This is most likely due to a lack of disturbance occurring in pasture fields, resulting in a reduction in unnatural turnover in the soil due to cultivating machinery which brings soil carbon to the unprotected layer of the soil where it can be more easily emitted into the atmosphere as carbon dioxide (CO_2) (Six et al., 2002). Carbon is not only found inside aggregates, but it is also found throughout the soil profile. Previous studies have found that there vertical homogenization of soil C and N occurs after soil is cultivated (Grandy & Robertson, 2006). Similar to these previous studies, we found this to be true especially in our moldboard plow field for both the top 0-7 cm and bottom 7-15 cm (Figure 4, 5). The small difference observed between the top 0-7 cm and bottom 7-15 cm indicates there was vertical homogenization of TC and TN throughout the soil profile due to the use of the highly disruptive moldboard plow (Figure 4).

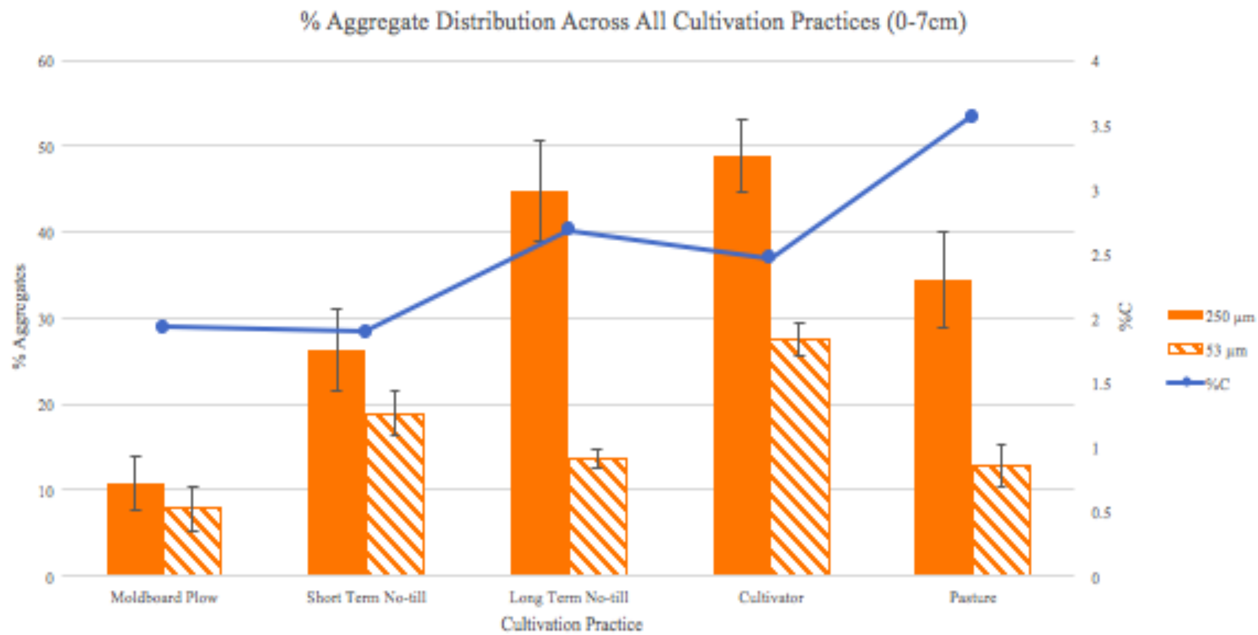

Figure 9. Comparison of percent carbon and percent aggregation in the top 0-7 cm soil layer.

In order to determine if there was any relation between the TC and aggregate data, we overlaid our TC data on top of our aggregate results (Figure 9). We don't see the trends match up exactly as we may have expected, but we do see the long-term no-till and moldboard plow field to have similar percent carbon present in their soil. The moldboard plow field was in pasture for 30 years prior to the two tilling events. The long term no-till field has been in cultivation for about 30 years with a 7-8 year rotation between corn and alfalfa/grass. Although the long term no-till field was in cultivation for much longer than the moldboard plow field, the deteriorating effects of the moldboard plow can see as it severely degraded soil characteristics even with just two tilling events. Looking at the fields with the most percent carbon in relation to percent aggregation, we would have expected the pasture fields to have the highest percent aggregation as well as percent carbon. Rather, we see the highest aggregation in the cultivator field but the highest percent carbon in the pasture fields (Figure 9). Although this is not what we expected to see, it does make sense when taking into account the field history and cultivation practices applied to the field because when macroaggregate turnover is reduced, the soil organic carbon (SOC) and total nitrogen (TN) levels increase (Nath & Lal, 2017). The cultivator field has been under cultivation for 38 or more years while the pasture has been undisturbed for just as long. Due to the disturbance that has occurred in the cultivator field for a number of years, carbon is being moved throughout the top 0-7 cm of the soil profile. Due to the inability to directly correlate our total carbon (TC) data with our percent aggregation data, drawing upon previous studies such as Nath & Lal (2017), could provide us a better understanding of the total carbon (TC) within our aggregate data. In future studies, rather than only grinding our soil separate from our aggregate data, we can grind the dried soil obtained from our wet stable aggregate procedure to better quantify the carbon present within each specific aggregate size class. This would help us better understand the relationship between total carbon and soil aggregates.

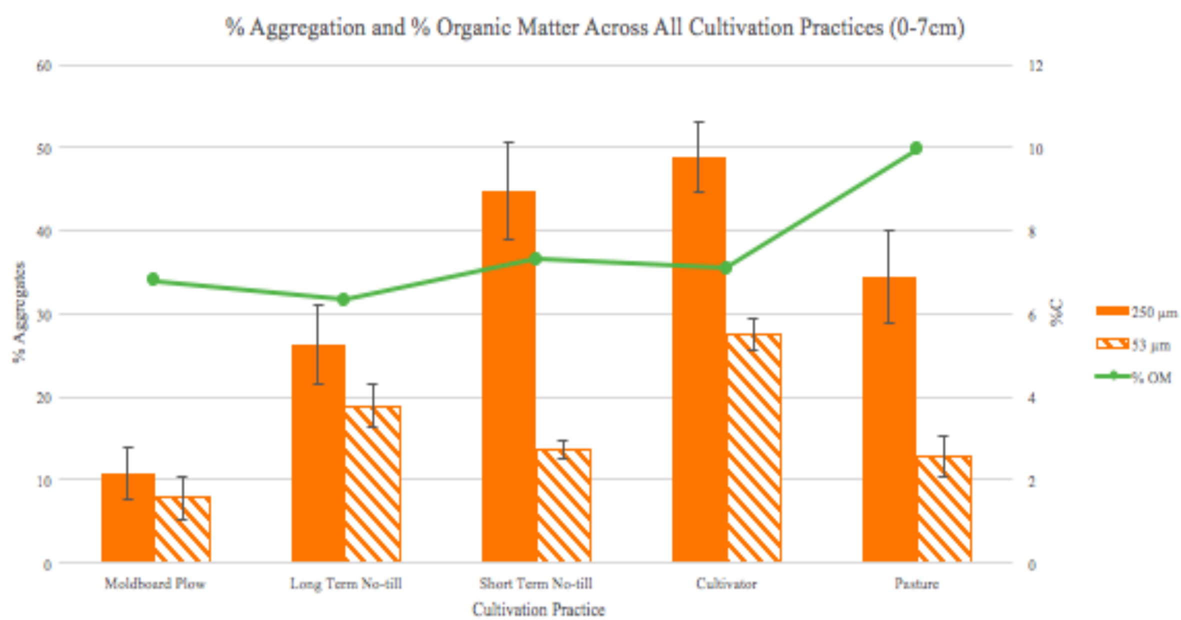

Figure 10. Comparison of percent organic matter and percent aggregation in the top 0-7 cm soil layer.

Just as TC and aggregation are extremely interconnected in terms of soil health and function, soil organic matter and aggregation are also extremely related. As mentioned previously, soil organic matter binds microaggregates together to form macroaggregates within soil (Grandy & Robertson, 2006, Nath & Lal, 2017). Without soil organic matter present in soil, it is difficult for macroaggregates to form, which are extremely important for increasing the total pore space for water to move throughout the soil profile (Haynes & Naidu, 1998). We then overlaid the percent organic matter on top of our aggregation data and found relations similar to that of the percent carbon data (Figure 10). We would have expected the pasture field to have much less percent organic matter in the soil because the moldboard plow is so destructive and the percent aggregation is so low. When considering the field history, the fact that the moldboard plow field was in pasture, indicates there may have been a lot of organic matter build up over that period of time. Again, we would have expected the highest percent organic matter to occur in the field with the highest percent aggregation, but we did not find this to be the case. We found the highest percent organic matter in the pasture field but the highest percent aggregation in the cultivator field (Figure 9). Previous studies have found disturbed soils to have the lowest percent organic matter in disturbed soils compared to undisturbed soils (Grandy & Robertson, 2006), which we also found in our study. The pasture field had the highest percent organic matter compared to any other field in our study (Figure 9). This is most likely due to the fact the pasture field was not being disturbed at all so the organic matter was not more readily available to be eroded (Six et al., 2002). Although the cultivator field has the highest percent aggregation, it doesn't have the highest percent organic matter because the soil was more disturbed, even at the surface level, exposing the organic matter to be more easily eroded (Figure 9).

We observed the highest percent SOM in the top 0-7 cm and bottom 7-15 cm of the pasture fields (9.95% and 6.98%, respectively). The field type with the lowest percent SOM in the top 0-7 cm was the long term no-till fields (6.32%). The lowest percent SOM observed in the bottom 7-15 cm was obtained from soil samples collected from the cultivator field (5.03%). We found a statistically significant difference in that the data collected from the top 0-7 cm across all field types, however, the bottom 7-15 cm did not produce statistically significant differences in the data (Figure 6). SOM accounts for more than two-thirds of total organic carbon stored terrestrial ecosystems (Six et al., 2006). This accumulation of SOM is highly influenced by the interaction between nutrients such as TC and TN, root systems, water, and organic matter within the surface soil layers (Paustian, 2000). We expected to find the lowest percent SOM in the moldboard plow field as previous studies have shown that this method of tilling has immediate deteriorating effects on the stability of SOM (Rhoton, 2000). This result was not observed as the long term no-till field type had lower percentages of SOM in both the top and bottom layers of soil. We can account for this unexpected result by considering the field histories of these two field types. The field cultivated by the moldboard plow had previously been undisturbed pasture for over 30 years prior to initial tilling. In comparison, the fields categorized as long term no-till had been cultivated in an 8 year rotation between corn and an alfalfa/grass mixture for approximately 30 years as well. Although no-till techniques have been shown to preserve the protection of SOM, the duration and frequency of disturbance of the long term no-till fields may have led to the lower values of percent SOM observed in the top 0-7 cm in comparison to the moldboard plow field (Grandy & Robertson, 2006).

Both conventional and no-till cultivation techniques have been shown to increase SOM homogenization throughout the top 20 cm of soil in agricultural fields (Grandy & Robertson, 2006). Our data has shown to be consistent with these findings. The difference in percent SOM in the top 0-7 cm and bottom 7-15 cm increased as the severity of disturbance and duration of cultivation decreased (Figure 11). Out of the fields currently in active cultivation regimes, the cultivator field showed the highest difference of percent SOM between the top and bottom soil layers (2.06%). This difference in percent SOM is significantly higher than that found between the remaining three field types under current cultivation, with the lowest difference being found between the top and bottom layers in the moldboard plow field (.43%) (Figure 11). The homogenization of SOM throughout the top 20 cm of soil proves to be problematic when considering the storage of soil C as decomposition rates of SOM at depth can be up to 105% greater than those found at the surface (Grandy & Robertson, 2006). This is partially due to the decrease of physical protection of SOM pools within macro- and micro-aggregates which protect the substrates from microbial facilitated turnover (Six et al., 2002).

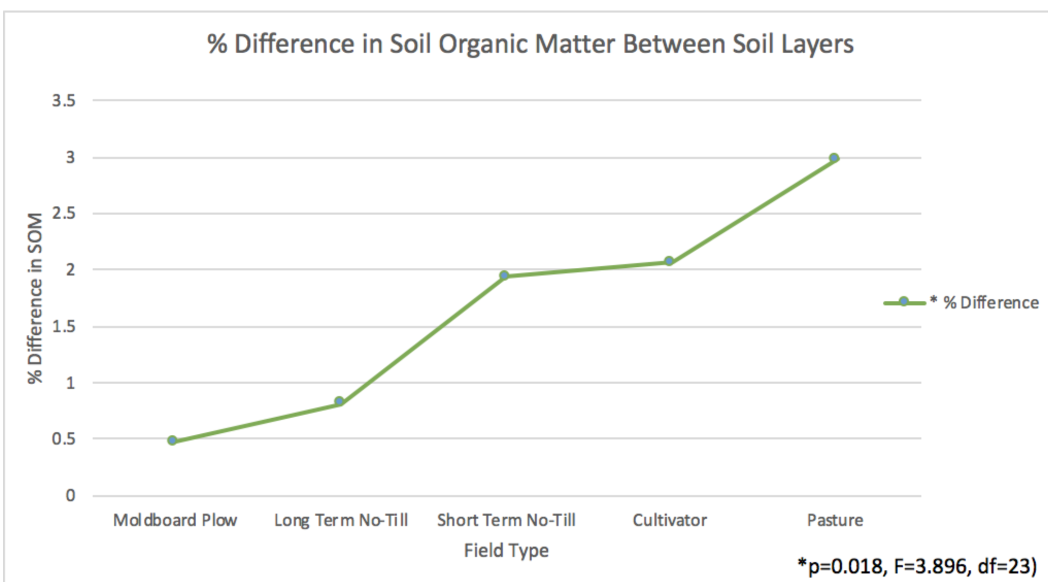

Figure 11. Percent difference of SOM in the top 0-7 cm and bottom 7-15 cm across all field types (*p=0.018, F=3.896, df=23).

We aimed to gain insight into the metabolic activity of the microbial communities present in our soil through community level physiological profiling (CLPP) using Biolog ecoplates. We found no statistically significant differences in average AMR and CMD values (Figure 7). This observation may be due to the addition of various amendments added to the soils and the subsequent effects they may have on the microbial activities in relation to SOM. Our small sample size may have also contributed to this lack of statistical significance.

The moldboard plow, long term no-till, and short term no-till fields all were subjected to annual application of dairy cow manure. A study conducted by Bucher and Lanyon (2003) on the physiological profiles of microbial communities in agricultural soils under varied management practices found that application of manure likely increase the potential of metabolic activity of microbial communities. Previous studies have shown that the ecology of bacterial present in agricultural soils will be significantly different between conventional and no-till techniques, specifically shown through the homogenization of microbial community composition, however further investigation through uncontrolled field research has shown that the influence of crop-rotation, and subsequently tilling practices, lessens when dairy manure is incorporated into the management practice (Kennedy, 1999, Bucher & Lanyon, 2005). CLPP is a useful tool when considering the roles microbes play in changing agro-ecosystems and SOM dynamics and can be more insightful that isolating specific microbial community members, however there still is some criticism on using CLPP as a definitive measure of soil microbial diversity as it is based off of arbitrary concentrations of carbon sources that may not be present in agricultural environments (Bucher & Lanyon, 2005). Future studies evaluating the metabolic activity of soils microbes may find that a multi-method approach would provide a more holistic view on the microbial community in question. Combining techniques like CLPP and analysis of fungal and bacterial abundance as well as other DNA sequencing techniques could help us better understand the unclear relationship between soil microbial diversity and function and sustainable agro-ecosystems (Bucher & Lanyon, 2005, Helgason et al., 2007).

When considering our data as a whole we can clearly see that more studies focused on the interactions between the four aforementioned soil characteristics and how they influence one another would help us gain insight into the management practices that would be most effective at stimulating soil C sequestration and preserving the long term health of soils. Although no-till agricultural practices have the capacity to support soil C sequestration farmers may face difficulties in the implementation of it due to lack of appropriate equipment, or the financial freedom needed to deviate from known crop responses (Lal, 2013). Future studies can address this issue by applying an interdisciplinary approach to analyzing farming practices which would simultaneously look at the cost, implementation and effects of agricultural management practices and their subsequent effects on soil C sequestration and long term soil health. Additionally, studies that focus on field research of actively cultivated agricultural land would also be useful in understanding what practices farmers use and what adaptations could be made to management practices to optimize these ecosystem services. As we continue to see the negative effects of global climate on change on our environment we must begin to broaden our horizons on how we can continue to reduce GHG emissions. Taking advantage of the potential of agricultural soils to be a significant sink for CO_2 could thus be just one piece of the solution to global climate change as a whole.

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