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Comparative analysis of soil quality between agricultural lands varying in farming practices and soil management techniques in southeastern MN

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ABSTRACT

An increasing concern for agricultural contributions to environmental degradation has spurred an interest in finding farming techniques that maximize the ability to grow crops while minimizing any negative environmental impacts. This can be done by maintaining good soil quality. In this study, three agricultural sites' soil quality was evaluated to assess potential productivity. The sites were divided into five field types by farming practices used in the past year (organic, conventional, or fallow) and soil management techniques (cover crops used or bare soil). It was found that there were significant differences in pH, percent moisture, organic matter, and bulk density between sites. The field type that was farmed organically and had no cover crops had the highest level of soil nutrients (NH4, NO3, and organic matter). Within the conventionally farmed field, areas that had cover crops had significantly higher pH and soil moisture. Cover crop heights were also found to be significantly different between sites suggesting that the combination of cover crop species affect plant growth. These findings reveal that soil quality with optimal nutrients and structure occurs with a combination of cover crops and organic farming techniques. The results contribute to our understanding of agricultural systems and carry implications for future farm management decisions, particularly for St. Olaf College's student-run organic farm, Stogrow.

INTRODUCTION

Consumer demand for organically produced food has been an area of rapid growth over the past few decades. This trend is reflected in the increase of cropland, rangeland, and pasture dedicated to certified organic production; 1.8 million acres in 2000 to 4.6 million acres in 2008 (Greene et al, 2010). This trend is expected to continue especially since the US organic food market is projected to have a 14% growth rate by 2018 (Daniells, 2014). Catching on with this consumer driven trend, St. Olaf College in southeastern Minnesota started a student-run organic farm, Stogrow, in 2005 designed to provide organically produced food directly to the college's cafeteria. This organic farm, which uses compost as a means of fertilization, was initially very successful. However, issues with flooding and farm management practices have severely affected yield and profitability in recent years. Due to this change in success,

students and faculty have considered moving Stogrow from its current location to an area near the Art Barn. This field would be double Stogrow's current size and be closer to campus. A concern about the change in location is soil quality, especially since the field was farmed using inorganic nitrogen fertilizers until 2013 and has laid fallow since.

Levels of nitrogen, organic matter, pH, and percent moisture all influence the amount of essential nutrients and water a plant receives and ultimately the plant's growth. Soil aggregates also influence the soil's structural stability, pore size, and water infiltration (Boyle et al, 1983). Soil macroinvertebrates are ecosystem engineers that play a role in soil structure through the creation of continuous macropores, recycling of nutrients, soil turnover, and providing ecological niches (Castellanos-Navarrete et al, 2012; Rana et al, 2010). With these variables taken into account, a comprehensive analysis of soil quality can reveal a field's ability to promote successful agricultural production.

The proposed Stogrow location was previously used as rental agricultural land for corn production. The soil was intensively used for no-till corn/soybean farming since 2005 with high input of inorganic nitrogen. While no-till farming is shown to increase soil organic matter (Jackson et al 2004), preliminary soil analyses taken March 2014 in Agroecology, ENVST 281C show that the proposed location for Stogrow is still markedly inferior to the current location (Table 1). The current Stogrow location had measurements of 7.9 mg NO_3/kg soil, 38.4% soil moisture content, and 10.7% organic matter. Because this location uses organic farming methods but no cover crops, this field type is identified as Organic_NoCC. In comparison, the proposed Stogrow location had values of 1.6 NO_3mg/kg soil, 24.3%, and 4.6% respectively (Misch, 2014). If Stogrow does decide to move to the proposed location, the site's soil quality will need to improve to ensure successful yields and profitability.

In an attempt to improve the soil quality of the proposed location, a combination of three cover crops were planted in the field last April; field radish, oat, and clover. Because of this site's use of three

cover crops and its current fallow state this field type is identified as Fallow_ROC. Cover crops are plants grown on agricultural land for the intention of managing soil quality. Studies have shown cover crops result in numerous benefits to soil quality. Rye is shown to improve soil physical structure, produce ample biomass (which adds to soil organic matter) and sequester excess nitrogen in the soil (Summers et al 2014). Increased amounts of organic matter are then associated with better plant nutrition, ease of cultivation, greater aggregate stability, reduced bulk density, and improved water holding capacity (Loveland and Webb 2003). Leguminous cover crops such as hairy vetch, clover, and alfalfa provide additional nitrogen; which also contributes to the soil's ability to support plant growth (Summers et al 2014). And forage turnips or tillage radishes have long taproot which facilitate water infiltration and break up soil compactioncontribut to improved soil moisture content (Summers et al 2014). The benefits derived from a cover crop treatment have even been shown to increase soil aggregate stability after one season (Summers et al 2014). Therefore, the use of cover crops has become an increasingly important component of soil management due to its capability to quickly improve soil quality.

Other local agricultural fields are turning towards the use of cover crops as a means of soil conservation and management. A nearby field owned by George Heinrich serves as this independent study's third site of soil quality comparison. This intensively farmed field was planted with cereal rye and tillage radishes in August following the harvest of a sweet corn crop. However, there are also patches with no cover crops planted and patches with only rye planted. Therefore, this site has three field types; Conventional_RR, Conventional_R, and Conventional_NoCC. The comparison between the Hendricks' field types, Stogrow's proposed location, and Stogrow's current location will offer an insight into the effect of cover crop combination and farming practices on overall soil quality. In addition with the measurements of soil quality mentioned previously, sites with cover crops will also be sampled for cover crop density and height.

In order to support a successful student initiative to provide organic food to St. Olaf's cafeteria, there must be good quality soil to facilitate crop growth. In this study, I compared soil quality of three agricultural sites, each varying in farming methods (organic production, fallow field, and intensively farmed) and soil management techniques (use of cover crops or bare soil). The objectives of my study were 1) to determine whether farming practice is independent of soil quality, 2) to determine whether use of cover crops as soil management is independent of soil quality 3) to explore differences in cover crop density and height between field types and 4) to assess the viability of Stogrow's relocation to the proposed site. My hypothesis was that, even with the use of cover crops, the proposed Stogrow site and conventionally farmed site would have significantly inferior soil to the current Stogrow's organically farmed land. In addition, I hypothesized that cover crop density and height was independent of field type.

METHODS

Soil Collection

Using a soil corer, 18 soil samples of exact volume (47.75 cm^2) were taken from randomly selected points within the five field types. Additional soil of inexact volume was also collected for measurements of aggregate stability. Qualitative observations were taken by digging 10 cm deep and evaluating soil in terms of texture, breakability, and pore space as well as if there were any macroinvertebrates present.

Cover Crop Data Collection

On the three field types that had cover crops present, a $1ft^2$ grid was placed in a randomly selected area. The number and species of cover crops within the grid were recorded. The height of each cover crop individual was also recorded in centimeters.

Soil Analysis

Soil was filtered immediately following collection to attain pH measurements. The soil of exact volume was weighed and placed in an oven at 105 F for 24 hours to calculate percent moisture. The same sample was then placed in a furnace muffler at 500 F for 4 hours and weighed a second time to calculate organic matterExtractions of soil were prepared for nitrate and ammonia testing Nitrate and ammonia levels were calculated by running extractions through a SmartChem to measure RFUs (relative fluorescence units) and then converted into concentrations. Aggregate stability was analyzed by air drying soil clumps completely. The dried soil samples were then placed in jars full with water, suspended by plastic mesh. The soil samples sat for 24 hours, allowing any soil deposits to settle to the bottom of the jar. The soil samples were then removed, air dried completely, and weighed once more. An index of the soil aggregate stability was calculated first by measuring the percent of soil that broke apart in the water [(Pre-soak weight – Post-soak weight/ Pre-soak weight)*100] and then subtracting the breakability from 100.

Data Analysis

Soil data and cover crop measurements were analyzed using one-way ANOVA to determine if means were statistically significant. When analyzing cover crop density, values were converted from individuals/ft^2 to individuals/m^2. All statistical tests were calculated using the R 3.1.1. statistical modelling program.

RESULTS

Soil Quality

Across the five field types, there were several significant differences in soil quality indicators. Soil pH was found to significantly differ between field types with the highest value seen in Conventional_RR (5.98) and the lowest seen in Conventional_NoCC (5.39) (Table 2, p-value=0.02).

Organic_NoCC had the significantly highest organic matter and soil moisture levels (9.72%, 24.2%; p-value=1.98E-5, 6.87E-7) of all field types while Fallow_ROC had the lowest (3.6%, 12.1%; Table 2 and Figure 1). The last significant soil quality indicator was bulk density. Fallow_ROC had the highest bulk density (1.25 gm/cm^3, p-value=6.78E-7) while Organic_NoCC had the lowest (1.0 gm/cm^3) (Table 2). Levels of NO3-N, NH4, and aggregate stability were not found to significantly differ between field types. However, the highest nitrogen levels were found in Organic_NoCC while the lowest levels were in Fallow_ROC, as seen in Figure 2.

Soil Quality in Conventional Site

When comparing the three field types within the Heinrich field (Conventional_RR, Conventional_R, and Conventional_NoCC) there was two significant differences. Soil pH (p-value=0.035) and soil moisture (p-value=0.0023) were significantly different within the Heinrich field (Table 3). Coventional_RR had the highest pH (5.98) while Conventional_NoCC (5.39) had the lowest. In terms of soil moisture, Conventional_NoCC had the highest moisture (18.56%) and Conventional_RR had the lowest (13.59%).

Macroinvertebrate Presence

There were no macroinvertebrates found in any 3 of the Conventional field types. At Fallow_ROC four macroinvertebrates were found and identified as isopods with the common name, sow bug. At Organic_NoCC, seven earthworms were found and identified as endogeic. These results are summarized in Table 4.

Cover Crops

Cover crop height, but not density, was found to significantly differ between field types. Both the rye and radish plants were taller in the Conventional_RR field (34.0 cm, 38.6 cm) than in Conventional_R (rye – 21.9 cm) or Fallow_ROC (radish – 23.5 cm) (Figure 3 and Table 5, p-value=1.37e-7, 0.011).

DISCUSSION

Soil Quality

In order to determine overall soil quality within the field sites, values measured must be compared with the optimal ranges for agricultural production. Nitrogen, an essential nutrient is often times the limiting factor in non-legume crop production. All the farming practices investigated in this study employ a supplementary form of nitrogen; cover crops, compost, or inorganic fertilizer. Therefore there is no optimal level of nitrogen in this soil analysis, but the highest level would indicate that the soil has the most nutrients to offer and less supplementary nitrogen would need to be applied. Soil organic matter has a minimum threshold of 2%, below which there is serious decline in soil quality (Loveland and Webb, 2003). Soil with the highest soil organic matter would be considered the highest quality. Since moisture content is closely linked with soil organic matter, a higher percentage is also associated with better quality soil. The ideal range for agricultural soil pH is between 5.5 and 7 although some specialty crops like potatoes grow better in more acidic soil (Splittstoesser 1990). Although optimal bulk densities depend upon soil type, typical Minnesota soils have an ideal value of 1.3 gm/cm^3; anything below this is even better. Values over 1.6 gm/cm^3 begin to restrict plants' abilities to grow (Evanylo 2009). And even though there is no optimal range for aggregate stability with the methods I used in my study, the soil that held together the best would indicate its ability to withstand wind and water stress. With these optimal ranges in mind, the five sites' soil quality can be evaluated.

Across the five field types, there were significant differences in soil pH, percent moisture, organic matter, and bulk density. Organic_NoCC had the highest levels of organic matter (9.72%), percent

moisture (24.17%), and both nitrates and ammonia levels (3.47 and 1.84 mg/kg soil). The field type had the lowest bulk density of the five field types (1.01 gm/cm^3). Lastly, Organic_NoCC's pH fell within the acceptable pH range (5.51). Therefore, this field type has superior soil quality in comparison with the rest. This finding is consistent with past studies that found higher soil fertility in organically farmed fields in comparison with conventionally farmed fields (Mader et al 2002; Glover et al 2000).

Cover Crop Height and Density

Among the three combinations of cover crops (rye and radish; radish, oat, and clover; rye), only height was found to significantly differ between sites (Table 4). The rye in the field with both rye and radish was significantly taller than the field with only rye. This is likely due to competition for sunlight between rye and the taller radish plant. The radishes were also taller in the rye and radish field than in the fallow field with radish, oat, and clover. Although the oat was much taller than the radishes in Fallow_ROC, there were fewer of them so shade on radishes was minimal. Therefore, the same competition for sunlight may have contributed to the significantly higher radish heights in Conventional_RR.

Cover Crops and Aggregate Stability

Although not a significant finding, there does appear to be a trend between aggregate strength and use of cover crops. The field types that had one, two, or three types of cover crops had higher aggregate stability than the two field types with no cover crops (Table 2). Past studies have found similar findings; use of cover crops increases the aggregate strength of agricultural soil (Hermawan and Bomke 1997; Loveland and Webb 2003). In fact, cover crops left over winter may protect soil breakdown during the winter resulting in better structure after spring tillage (Herawan and Bomke 1997). So, although

aggregate strength was not found to be significant within my study, the influence of cover crops may be more apparent following the winter months when soil breakdown is more common.

Heinrich Field Cover Crops and Plant Resource Use

The three field types within the Heinrich's field vary only in cover crop use (no cover crops, rye, or rye and radish). Therefore, the role of cover crops on soil quality can be specifically investigated by comparing these three areas, as summarized in Table 3. Conventional_NoCC had the highest percent moisture (18.56%), organic matter (7.12%), and NO_3-N levels (0.91 mg/kg soil). Conventional_RR, on the other hand, had the lowest percent moisture (13.59%), organic matter (5.45%), and NO3-N levels (0.41 mg/kg soil). Given that cover crops are supposed to improve soil quality values, these findings may seem counter-intuitive; the field type with both rye and radish should have better soil quality than the field type with bare soil. However, the lower nutrient levels in the field with cover crops are indicative that the cover crop plants are using the resources in the soil. This is especially important to the fields during winter. In a study investigating the effects of exposure during winter on agricultural fields with and without cover crops, it was found that there was a 65-70% decrease in nitrate leaching in the field that had cover crops in comparison with the field that was left bare (Wyland et al 1996). The plant roots of the cover crops were found to remove nitrates and water from the soil which would have otherwise been lost over the winter. Therefore, the lower nitrate, percent moisture, and organic matter levels within Conventional_RR indicates that the cover crops are utilizing soil resources, thus preventing nutrient and nitrate leaching over the winter. Cover crop benefits will carry beyond the winter too. When the cover crops are incorporated back into the soil in the spring there will be a sudden, large surge in N pools, microbial biomass N, and C in the surface soil (Wyland et al 1996).

Improving Soil Quality

Given the significant difference in soil quality between field types differing in farming practices (Organic_NoCC and Fallow_ROC) and use of cover crops (Conventional_RR and Conventional_NoCC), I conclude that soil quality is independent of field type. In line with my hypothesis, I observed that the organically farmed field had superior soil quality measurements. In addition, cover crops were found to be able to store essential nutrients in the Heinrich field. Therefore, the best farm management decision to ensure good soil quality would be to combine organic farming practices with the use of cover crops.

Recommendations

Due to low soil quality measurements, the proposed location for Stogrow (Fallow_ROC) does not appear to be ready for relocation. Cover crops may need to be used a second year to begin to improve the field's soil quality. However, the timing of this study may underestimate the cover crops' benefits to the soil. In Table 6, the soil quality values collected in spring 2014 between the current and proposed Stogrow sites are compared with the values I collected in fall 2014. All of the soil quality measurements are lower in the fall than in the spring. This may indicate a seasonal fluctuation in the soil quality between the beginning and end of the growing season. Therefore, to get a true sense of whether cover crops improved the proposed field's soil quality, soil data would need to be calculated again in spring 2015. If the soil does improve over that year, this would show the positive effects of cover crop and show, perhaps after one or more years of additional cover cropping, the field could be used as Stogrow's new location.

For fields like George Heinrich's, which will be unlikely to make the difficult transition to organic production, the integration of cover crops would be advantageous to continue in order to prevent nutrient leaching and wind and water erosion over the winter. The reintegration of the cover crops into the soil before planting will also provide the soil with a kick start of nitrogen and carbon biomass.

Therefore, the benefits of cover crops include better soil management over the winter and a decreased need for nutrient inputs in the beginning of the growing season.

From this study it is clear that farm management decisions have a direct impact on agricultural soil quality. Agricultural land that is farmed organically has significantly superior soil quality than conventional and fallow fields while cover crops effectively manage soil resources and contribute to soil structure. With this information, farmers can reassess their current practices and adjust for the future in order to maintain ideal and productive soil.

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LITERATURE CITED

Boyle, M., W.T. Frankenberger, and L.H. Stolzy. 1989. The influence of organic matter on soil aggregation and water infiltration. Journal of Production Agriculture 2: 290-299.

Castellanos-Navarrete, A., C. Rodríguez-Aragonés, R.G.M de Goede, M.J. Kooistra, K.D. Sayre, L. Brussaard, and M.M. Pulleman. 2012. Earthworm activity and soil structural changes under conservation agriculture in central Mexico. Soil and Tillage Research 123: 61-70

Daniells, S. 2014. US Organic Food Market to Grow 14% from 2013-18. FoodNavigator-USA.com. Web. 27 Sept. 2014.

Evanylo, G. 2009. Agricultural management practices and soil quality: measuring, assessing, and comparing laboratory and field test kit indicators of soil quality attributes. Virginia Cooperative Extension. Virginia Tech and Virginia State University.

Glover, J.D., J.P. Reganold, and P.K. Andrews. 2000. Systematic method for rating soil quality of conventional, organic, and integrated apple orchards in Washington State. Agriculture, Ecosystems, and Environment 80: 29-245.

Greene, C., E. Slattery, and W. McBride. 2010. America's Organic Farmers Face Issues and Opportunities. United States Department of Agriculture, Web. 29 Sept. 2014.

Hermawan, B. and A.A. Bomke. 1997. Effects of winter cover crops and successive spring tillage on soil aggregation. Soil and Tillage Research 44: 109-120.

Loveland, P., J. Webb. 2003. Is there a critical level of organic matter in the agricultural soils of temperate regions: a review. Soil and Tillage Research 70: 1-18.

Mader, P., A. Fiebach, D. Dubois, and L. Gunst. 2002. Soil fertility and biodiversity in organic farming. Science 296:1694-7.

Misch, L. 2014. Evaluating proposed future location of Stogrow. Unpublished data. Agroecology: ENVST 281C.

Rana, N., S.A. Rana, H.A. Khan, and A. Sohail. 2010. Assessment of possible threats to soil macro-invertebrate diversity in wheat fields from high input farming. International Journal of Agricultural Biology 12: 801-808.

Splittstoesser, W.E. 1990. Vegetable growing handbook. Avi Publishing Co., 3rd Ed.

Summers, C.F., S. Park, A.R. Dunn, X. Rong, K.L. Everts, S.L.F Meyer, S.M. Rupprecht, M.D. Kleinhenz, B.M. Gardener, and C.D. Smart. 2014. Single season effects of mixed-species cover crops on tomato health (cultivar Celebrity) in multi-state field trials. Applied Soil Ecology 77: 51-58.

Willekens, K., B. Vandecasteele, D. Buchan, and S. De Neve. 2014. Soil quality is positively affected by reduced tillage and compost in an intensive vegetable cropping system. Applied Soil Ecology 82: 61-71.

Wyland, L.J., L.E. Jackson, W.E. Chaney, K. Klonsky, S.T. Koike, and B. Kimple. 1996. Winter cover crops in a vegetable cropping system: Impacts on nitrate leaching, soil water, crop yield, pests and management costs. Agriculture, Ecosystems and Environment 59:1-17.

TABLES AND FIGURES

		STDEV
		0.18
		0.43
		0.32
		2.14
		2.52

		STDEV
		0.32
		0.08
		0.03
		0.65
		0.79

		STDEV
		0.03
		0.01
		0.01
		0.04
		0.05

Figure 1: Comparison of nitrogen levels of both NO3-N (p-value=0.097) and NH4 (p-value=0.38) including standard deviation bars across five agricultural field types in southeastern MN, USA.

Conventional_NoCC	7.12	0.39
Fallow_ROC	3.60	0.64
Organic_NoCC	9.72	1.50
p-value	**1.98E-05**	

Conventional_NoCC	1.13	
Fallow_ROC	1.25	
Organic_NoCC	1.01	
p-value	**6.78E-07**	

Field Type	Aggregate Stability (%)	STDEV
Conventional_RR	85.85	6.22
Conventional_R	84.93	1.29
Conventional_NoCC	83.32	3.84
Fallow_ROC	84.37	5.07
Organic_NoCC	74.53	14.03
p-value	**0.32**	

Table 4: Macroinvertebrates found in soil at five field types in southeastern MN, USA.

	Macroinvertebrates in Soil	
Field Type	Isopod-Pill Bug	Aporrectodea caliginosa
Conventional_RR	0	0
Conventional_R	0	0
Conventional_NoCC	0	0
Fallow_ROC	4	0
Organic_NoCC	0	7

	Spring 2014		Fall 2014	
	Current Stogrow	Proposed Stogrow	Current Stogrow	Proposed Stogrow
Organic Matter %	10.7	4.6	9.7	3.6
Soil Moisture %	38.4	24.3	24.2	12.1
NO_3-N (mg/kg soil)	7.9	1.6	3.5	1.3

Table 6: Comparison of soil quality of current and proposed location for Stogrow between values collected spring 2014 and fall 2014 in southeastern MN, USA.