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QUANTIFYING THE EFFECTS OF REGENERATIVE AGRICULTURE ON SOIL HEALTH AT THE NEW FARM

Introduction

Agricultural techniques have changed significantly over the past century. The "Green Revolution" of the 20th century - the development of high-yield crop alternatives - led to a significantly larger increase in agricultural output (Evenson & Gollin 2003). Over the past 50 years conventional agriculture, also known as industrial agriculture, has focused mainly on technological innovation, monoculture farms, pervasive use of pesticides and fertilizers, and a focus on productive cash crops (Gold 2016). Several benefits of conventional agriculture that help to justify its continued use amongst farmers and politicians include high crop yields, more efficient use of land, and reduced global hunger rates (Frison 2016). However, these modern systems have devastating effects on the ecological systems on both small and large scales (Kremen & Miles 2012). Industrial agriculture was found to destroy soil structure and quality (Reganold, Elliott, & Unger 1987), lead to diminished microbial diversity (Johansson, Paul, & Finlay 2004), increase soil carbon and N_2O emissions (Scialabba & Müller-Lindenlauf 2010), and cause an overall loss of biodiversity (Gabriel, Sait, Kunin, & Benton 2013). These techniques have been adapting for centuries with little thought being put into limiting the environmental impact of such methods. In the past, the positive outcomes of this type of farming would be enough to uphold the firmly held support of conventional agriculture, however, new implications of industrial agriculture's sustainability issues have come into question and have brought new techniques into the spotlight.

Regenerative agriculture strives to discard the somewhat archaic practices of industrial agriculture by improving the quality of soil, enhancing biodiversity, reducing pesticide use, and limiting the environmental impact of farming operations (LaCanne & Lundgren 2018). In order to be sustainable, a farm must not solely exist for the purpose of increasing the yields of a single crop but must enhance the longevity of the surrounding ecosystem while being economically profitable (Neher 2018). In doing so, it needs to provide for the needs of the general population whilst enhancing – not degrading – the natural landscape and fostering a better quality of life for farmers and the community entirely (Gold 2016). A common regenerative practice is to focus on enhancing the soil organic matter of the soil in order to limit surface erosion and runoff from the soil (Diop 1999). Farmers can do this by creating shelterbelts, planting legumes, cover-cropping, and integrating livestock with crop growth in order to stimulate the organic content of the soil and improve soil water moisture content (Diop 1999). These positive consequences do have one significant drawback, as several farmers and interest groups describe the larger amounts of land needed for integrated livestock management or polyculture fields to be more detrimental to the ecological quality of the area (Reganold & Wachter 2016).

Regenerative agriculture can sometimes go by the moniker "carbon farming" as it can increase the carbon sequestration power of the farm soil (Evans et. Al 2015). Since this form of farming is still relatively young, it is difficult to statistically represent the exact changes that have taken place. It is estimated that approximately "12-100%" of agricultural carbon emissions have been reduced by regenerative agriculture (Quarles 2018). Characterizing farms as "regenerative" is difficult due to the decentralized and non-standard nature of this form of farming (LaCanne & Lundgren 2018) which makes it difficult to numerically describe its impacts. This reduction in carbon emissions is caused by both reducing the energy needs of equipment used on the farm and by increasing the ratio of fungi to bacteria in the soil, since mycorrhizae (a form of soil fungus) can adhere organic matter to clay and other soil components to retain it in the soil (Quarles 2018).

The market for regeneratively grown food is growing rapidly due to the consumers changing demand for increased transparency in ethical farming, environmental protection, and health concerns (Morgan & Murdoch 2000). Additionally, funding available for sustainable agriculture was estimated to be around $294 million from the US government (Delonge, Miles, & Carlisle 2016) revealing interest at both an individual and governmental level.

In this study, soil from The New Farm - located near Creemore, Ontario – is being analyzed to determine the effects of regenerative agricultural practices on two main soil factors: soil organic carbon (SOC) and soil inorganic carbon (SIC). The original breadth of this study aimed at testing aggregate stability, water holding capacity, and respiration, however, was restricted due to facility limitations. The New Farm employs regenerative techniques to maintain the integrity of the surrounding ecosystem while also sustaining a profitable farm. According to Brent Preston, co-owner of the farm, the land that the farm currently sits on was farmed using conventional techniques until approximately 15 years ago – this includes the use of heavy pesticides, insecticides, and diesel-consuming machinery – to produce cash crops like corn, soy, and wheat. When the New Farm was established, they transitioned the land into the production of high cost vegetables while shifting focus to maintaining the long-term health of the soil and surrounding biodiversity. According to Mr. Preston, they use cover cropping to increase the diversity of soil microbiota, hedgerows to reduce erosion, tarps to control pests and weeds naturally, reduce tilling, and employ the integration of grazing animals to simulate the natural relations of this ecosystem. The soil at the New Farm is described as sandy loam according to the farm's owners.

Soil is an integral and often overlooked aspect in farming and climate change mitigation. The quality of soil can be described by its "fitness for use" (Larson & Pierce 1991) and how it functions to provide nutrients and support for the production of crops (Karlen et al. 1997). Soil health is related to a combination of factors, including its capability to respond to stress, microbial biodiversity, and the cycling of nutrients within the soil (Van Bruggen & Semenov 2000). Specific soil factors that are sensitive to agricultural changes and are described as being relevant to characterize the long-term health of soil are aggregate stability (Congreves et. Al 2015), soil organic carbon and inorganic carbon (Van Eerd et. Al 2014), water holding capacity (Doran 1999), and soil respiration (Mijangos, Pérez, Albizu, & Garbisu 2006).

(Lal 2016)

The amount of organic carbon in soil refers to all the organic matter that is present in the soil. Soil organic carbon (SOM) is a useful indicator of soil structure, nutrient intake, microbial activity, and water retention (Lal 2016) and thus can be used to measure the effectiveness of regenerative agriculture. SOM has also been used as a common determination of soil fertility as it can provide the plant with a primary source of nutrients (Herrick & Wander 1997). Both dry combustion (Kalembasa & Jenkinson 1973) and wet combustion (Yeomans & Bremner 1988) have been described as useful methods to test the carbon content of the soil. Currently, there are several machines capable of determine the total amount of carbon in the soil using dry combustion, making the use of dry combustion more common in recent years (Vitti et. Al 2016). Dry combustion is normally undertaken at temperatures above 1000°C with a constant supply of oxygen (Skjemstad & Baldock 2007) in order to convert the carbon into CO_2 and then detected using a non-dispersion infrared (NDIR) photometer (Vitti et. Al 2016). The Walkely-Black method is also commonly used for studies that involve the measuring of soil organic carbon (Francaviglia et. Al 2017). This involves the titration of a sample of air-dry soil, $K_2Cr_2O_7$, H_2SO_4 with low concentration of $FeSO_4$ (Walkely & Black 1934).

Soil inorganic carbon represents the carbon in soil that is present in alternate forms. These can be bicarbonate (HCO_3^-), gaseous carbon dioxide (CO_2), carbonate ions (CO_3^{2-}), and carbonate minerals (Chevallier et. Al 2016). Although soil inorganic carbon is dominant in arid or semi-arid areas (Gao et. Al 2017), it still represents an important measure of the soil's ability to sequester carbon. The measure of soil inorganic carbon can be determined through similar dry combustion methods that were used for total organic carbon content (Tiessen, Betten, & Stewart, 1981).

Aggregate stability is a very important measure of the physical structure of soil since it represents the ability of the soil to respond to mechanical stress, such as erosion or impact (Ilay & Kaydir 2018). In the long term, aggregate stability is a good measure of agricultural productivity, as its improvement can mitigate soil loss and reduce nonpoint source pollution –

assisting with several of the goals of regenerative agriculture (Amezketa 1999). Some literature has questioned the true linkage between farming practices and aggregate stability, as climatic factors like natural soil freezing and water-moisture cycles can influence these numbers (Amezketa 1999).

Water holding capacity (WHC) is an essential soil indicator that measures the soils ability to retain water and moisture (Karhu, Mattila, Bergström & Regina, K 2011). Improving the WHC of soil is commonly believed to increase the resilience of agricultural soils to climatic changes, such as variable precipitation patterns (Williams et. Al 2016). Since WHC is dependent on various other soil structure determinants, it cannot be controlled directly, however it is relatively easy to manage through regulation of several other soil factors. Soil organic matter is one such factor that can lead to an increase in WHC, and thus an increase in the efficiency of the cropland (Williams et. Al 2016).

Soil respiration is commonly referred to as being the total amount of CO_2 produced by soil microbes and plants in the soil (Yiqi & Zhou 2010). It can be used to measure the total biodiversity of microbiota in the soil (Pell, Stenstrom, & Granhall 2005). Soil respiration also has a large effect on atmospheric carbon levels, meaning that altering respiration levels can have drastic impacts on climate change (Reichstein & Beer 2008). The largest factor that affects soil respiration is water availability, since precipitation and irrigation levels can control the amount of organic carbon and oxygen that is accessible to microorganisms in the soil (Pell, Stenstrom, & Granhall 2005).

Since several soil samples will be taken from various locations for this study, it is important to ensure constant conditions for the samples to be taken. The depths at which soil the soil will be taken from can significantly influence its properties – such as organic carbon (Olson

& Al-Kaisi 2015) – due to the different chemical and material makeup of each soil horizon (Brewer et. Al 2019). Soil sampling will be performed using a 21” AMS (AMS, inc., American Falls, Idaho) Soil Probe (Pan, Boyles, White, & Heitman 2012). Sampling strategy is also an important factor to consider when executing a comparative soil test. Choosing locations with different vegetative or agricultural cover is best to produce results that will show the most statistical variance (Francaviglia et. Al 2017). Additionally, within sample sites, it is necessary to consider within-site variation in slope or overall vegetative heterogeneity while also sampling in a random manner – eliminating any potential bias (Francaviglia et. Al 2017).

According to current scientific consensus, regenerative agriculture has numerous benefits that justify its incorporation into the general agricultural industry. One of regenerative agriculture’s strengths is its ability to uphold or recover the fertility and structure of agricultural soils (LaCanne & Lundgren 2018). **Therefore, the aim of this study is to question the effects of certain agricultural practices on soil organic carbon and inorganic carbon in variably managed fields at the New Farm to establish baseline statistics for future long-term analysis.** It is **hypothesized that all soil indicators being mentioned will be weaker in the two managed fields than both the pasture and forested region as prior agricultural production on the fields will have negatively affected the soil health.** However, over the course of several years, as the regenerative agricultural practices become modified and integrated, it can be predicted that the soil health indicators will mirror those of surrounding uncultivated and naturalized land.

Methods

Sample sites were chosen for their homogenous land use history and overall vegetative and soil makeup. Four sites were chosen: Field 3 - which is currently being used as a field for cover cropping - Field 4 - for growing mixed greens – a pasture - which is being used for seasonal grazing with mixed natural vegetation - and a natural forested region. These sites were chosen for the status of their current use and the different practices that are being applied to them. Samples were taken on September 21, 2019 after approximately 1 centimeter of rainfall in the preceding week.

Within each site, samples were taken at three different locations, depending on the level of heterogeneity of the field to mitigate sampling error (Tan 2005). Field 3 samples were taken 24 meters in from the side of the field. Lengthwise, samples were taken from 9 meters in from the northern edge of the field (F3A), 34 meters in (F3B), and 55 meters in (F3C). The field was homogenous with regards to its vegetative state, so two samples were taken near each end of the field and one precisely in the middle of the field. Field 3 comprised of legumes, sunflower, flax, crimson clover, peas, phacelia, and tillage radish (Figure 1). The field is not cultivated as heavily as other areas of the farm. Approximately 10-15 soil cores (2 cups) were taken within a one meter by one-meter range and bulked for each sample in order to account for any microvariations in soil properties (Tan 2005).

Figure 1. Field 3 Vegetation

Field 4 samples were taken 18 meters in from the side of the field. Lengthwise, they were taken 30 meters in from the southern edge of the field (F4C), 113 meters in (F4B), and 196 meters in (F4A). All of field 4 was planted with rows of mixed greens throughout and a plastic tarp that covered a small portion of the crops (Figures 2 & 3). Field 4 is heavily cultivated, and its growing cycle consists of 2 years producing crops and one year with cover crops. Samples were taken in between rows of vegetation to mitigate any damage to the crops. Approximately 10-15 soil cores (2 cups) were taken within a one meter by one-meter range and bulked for each sample in order to account for any microvariations in soil properties (Tan 2005).

Figure 2. Field 4 Tarp Cover

Figure 3. Field 4 Vegetation

Samples from the pasture were taken 33 meters in from the side of the field. Lengthwise, samples were taken 49 meters in from the northern edge of the field (P1), 128 meters in (P2), and 590 meters in (P3). The pasture has three distinct areas with varying characterization, so samples were taken within each region to show the most significant within site variance (Francaviglia et. Al 2017). The sample region for P1 was level, mostly grassy, and on a lower plane than the rest of the pasture. The sample region for P2 was on a varying incline that consisted of grass and mixed shrubs. The sample region for P3 was level, mostly grass, and on a higher plane than the rest of the pasture. At the time of sampling, cattle had been grazing on the land for approximately one year at intermittent times. Approximately 10-15 soil cores (2 cups) were taken within a one meter by one-meter range and bulked for each sample in order to account for any microvariations in soil properties (Tan 2005).

The forested region sampled consisted of dense, mixed hardwood-maple forest with a shallow layer of detritus on the forest floor. The naturalized area on the farm has had no cultivation for approximately 75 years as it serves to encourage the growth of native flora and fauna. Surrounding areas of the same region can be described as a cedar-swamp and have markedly different soils, therefore they were not tested. Due to the heterogeneity and irregularity of the plot of land, three samples (N1, N2, N3) were taken using judgement sampling from the sample site in order to reduce any bias (Pennock, Yates, & Braidek 2007). Approximately 10-15 soil cores (2 cups) were taken within a one meter by one-meter range and bulked for each sample in order to account for any microvariations in soil properties (Tan 2005).

From each site, a 21” AMS (AMS, inc., American Falls, Idaho) Soil Probe (Pan, Boyles, White, & Heitman 2012) was used to collect soil cores. Soil was taken from approximately 15 cm deep to ensure an accurate representation of variations within the soil to create a composite depth sample (Crepin & Johnson 1993). Approximately 2 cups of soil were taken from each sample site to allow enough material for testing (Peters, Laboski, & Bundy 2007). Large rocks and roots were removed from the soil cores manually to reduce the amount of non-soil factors in the sample. Samples from each site were put into a sealed Ziploc bag and placed in a cooler to keep temperature constant and keep the soil conditions constant. (Pell, Stenstrom, & Granhall 2005)

After all samples were collected and labelled, the contents of each Ziploc bag were emptied and placed on sterilized baking trays to air dry. Soil was spread out thinly across each tray to ensure maximal drying. Samples were left to dry (Tuzen 2003) for approximately two weeks before being placed back into a Ziploc bag.

Samples were sent to the Guelph Agriculture and Food Laboratory for testing. Inorganic and organic carbon content was measured using the combustion method – removing organic matter using high temperature ignition. Due to time and facility restrictions, measurements for aggregate stability, water holding capacity, and soil respiration could not be obtained.

Results

Soil organic carbon is a common indicator of overall soil health and degradation. Measurements of soil organic carbon were taken on four areas located on the New Farm. The aggregated data are shown below in Figure 1. Field 4 had lower percent organic carbon than field 3, the pasture, and the naturalized area. A one-way ANOVA test was applied to the soil organic carbon data comparing each field to each other. Multiple comparisons of each field were conducted to analyse the variance and significance between each field and using both average values and raw data. Field 3 had a significantly higher percentage organic carbon than field 4 (p = .0126). Compared to the pasture (p = .3516) and naturalized land (p = .4131), field 3 did not have a significantly different percentage organic carbon. Field 4 contained a significantly lower percent organic carbon than the pasture (p = .0229), however there was no indicated significance between it and the forest (p = .0634).

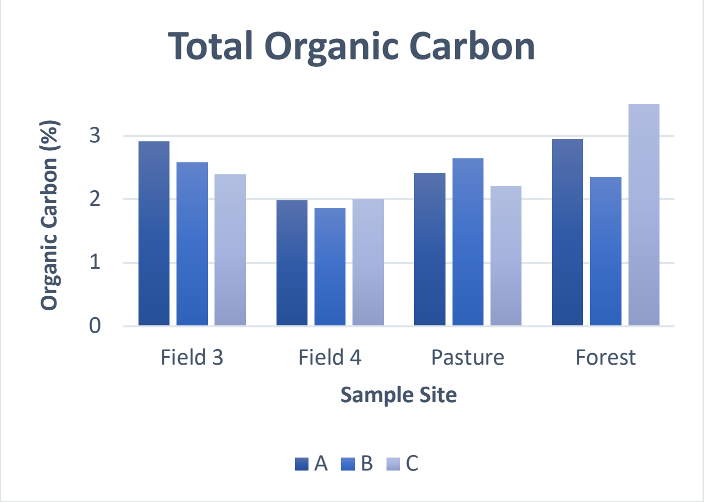

Figure 1: Total Organic Carbon percentage for each sample site. Variations within each sample site reveal the heterogeneity of each field. Field 3 and field 4 showed significant differences in the percent total organic carbon.

The average organic carbon percentage for field 3 was approximately 2.63%, while field 4 for had about 1.95% TOC. Using the average of each subsample, the mean Total Organic Carbon content was calculated for each sample site (Figure 2).

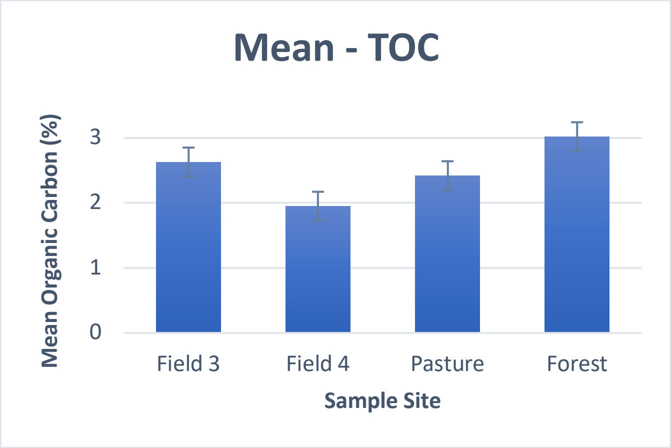

Figure 2: Mean total organic carbon percentage for each sample site. There was found to be a significant difference between field 3 and 4, as well as field 4 and the pasture.

The total inorganic carbon content of the soil was run through a one-way ANOVA test and the results applied subsequently. Field 3 and field 4 did not have a significant difference between inorganic soil carbon content (p=.416). Relative to the pasture (p=.698) and the forest (p=.388), field 3 did not have a significant difference in inorganic carbon content. Field 4 also did not have a significant difference compared to the pasture (.5008) and the forest (.3509). The compiled soil inorganic carbon data are presented in figure 3 below.

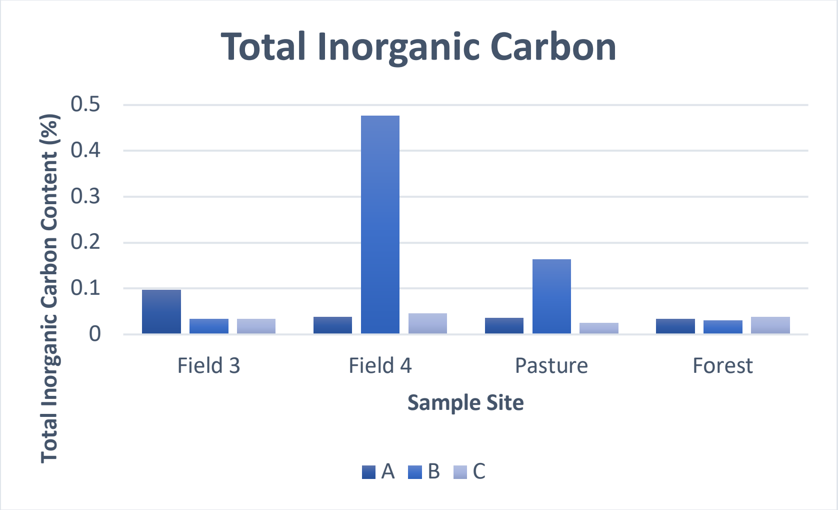

Figure 3: Total inorganic carbon content for each sample site. Strong variations within each sample site – specifically field 4 and the pasture – reveal the heterogeneity of those fields. There was no significant difference between each of the fields for inorganic carbon content.

Due to the wide variation of inorganic carbon content within each field, the mean inorganic carbon content was also plotted (Figure 4). The average inorganic carbon content for field 3 and field 4 is .055% and .187%, respectively. Although these means differ slightly, there was no significant difference between the two fields due to the high within site variability.

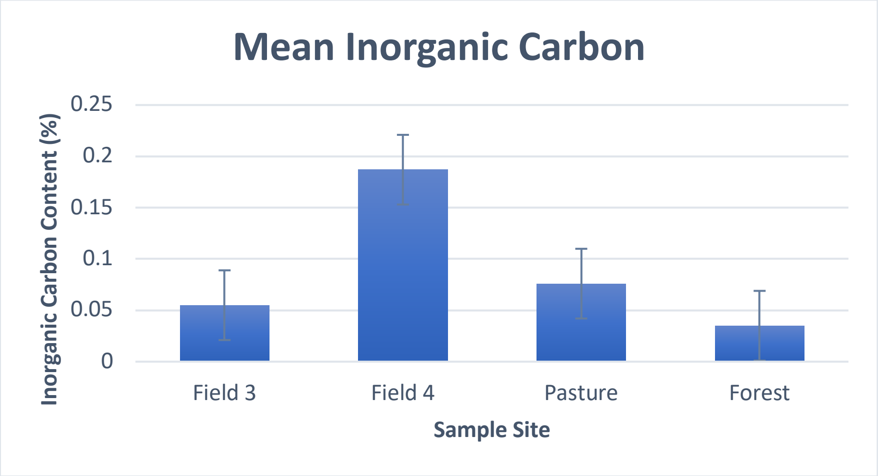

Figure 4: Mean total inorganic carbon content percentage for each site. No significant differences were

found between each sample site. Large within-field variations on each field account for the large difference of mean.

Conclusion

The purpose of this study is to determine the regenerative effects of the New Farm's agricultural practices on soil health. Soil inorganic carbon and soil organic carbon were used as an indicator of the soil's health. There was no significant difference between soil inorganic carbon between any of the fields on the New Farm. On the other hand, the study found a significant difference in soil organic carbon content between field 3 and field 4.

At the time of testing, field 3 contained cover crops and was not cultivated in the previous growing season. Field 4, at the time of testing, was the New Farm's most heavily cultivated field – growing a variety of mixed greens. Therefore, there is evidence to claim that the agricultural practices impacted the soil organic content negatively in the short term. It could be possible that adding cover crops to the fields, a regenerative technique commonly employed on the New Farm, would greatly increase the seasonal organic carbon content of the soil. This increase in soil organic carbon could be evidence that the cover crops regenerate the health of the soil over the course of the growing season. Such a conclusion must be further tested – by either replicating this study or continuing it further to understand the long-term trends of the New Farm soil.

It is important to note both the differences in cultivation patterns and their relation to the natural landscape. Field 3 presented similar measures of soil organic carbon to that of the pasture and the forest, although the forest had higher organic carbon content. This could be evidence that the soil is revitalized back to its original quality. Therefore, that means that the organic carbon content of the soil cycles between levels equal to that of the natural fields and that of other heavily cultivated fields, like field 4.

A replication study is necessary in order to further concrete the results of this study. With additional subsamples and a larger quantity of soil being taken from each field, this would allow for further testing of the soil's health. Aggregate stability, water holding capacity, and respiration – as described before – could all be tested in order to provide a more concrete conclusion. These indicators are all less impacted by seasonal variations on soil quality which would make the results more sound.

These conclusions emulate yet another necessary continuation of this study. Long term studies of the health of the New Farm soil may further develop the understanding of the effects of regenerative agriculture on the soil indicators. If possible, this would greatly improve the scientific quality of this study.

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