A COMPARISON OF THE QUALITY OF HAYFIELD AND PASTURE SOILS ON A NORTHWESTERN ONTARIO FARM

by

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Dr. Leni Meyer Major Advisor	Dr. William Wilson Second Reader

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The reader should be aware that opinions and conclusions expressed in this document are those of the student and do not necessarily reflect the opinions of the thesis supervisor, the faculty, or Lakehead University. All figures and tables are created/taken by the author unless otherwise noted. All equations used can be traced back to “The Nature and Properties of Soils” by N.C. Brady (1990).

ABSTRACT

French, B.C. 2019. A comparison of the quality of hayfield and pasture soils on a Northwestern Ontario farm.

Keywords: ANOVA, baseline data, bulk density, carbon, compaction, CNS, farm, hydrogen, kg/ha, nitrogen, Northwestern Ontario, pH, regression, soil, sulfur

This thesis examines aspects of soil quality between a hayfield and pasture site on a farm in Northwestern Ontario. Soil compaction, pH, and carbon were the main aspects looked at between the two sites. The purpose of this study is to answer how soil compaction, pH, and carbon content differ between a hayfield and pasture site, and to provide a baseline of soil quality data that can be used in determining the effect of farming practices on soil quality in the future. A one-way ANOVA was completed to determine that though the hayfield had a significantly higher percentage of carbon and sulfur, there were no significant differences ($\alpha = 0.05$) found amongst any of the other factors including carbon and sulfur amounts (kg/ha). A regression was also run to determine the strength of a linear relationship amongst CNS. These relationships were very strong with r^2 values of 0.938 (carbon v. nitrogen), 0.850 (carbon *vs.* sulfur), and 0.824 (nitrogen v. sulfur). It can be concluded from these results that though very little difference exists between the two fields, the strength of the linear relationships examined were very strong. These results are further discussed and analyzed concerning why there was a lack of significant differences amongst the fields, and it was suggested that the brevity of the research timeframe did not allow for the full representation of the effect of the current farming practices taking place on the site. Of key importance is that this data is identified as a baseline dataset that will provide an excellent foundation for future studies looking to identify how farming practices affect soil quality.

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ACKNOWLEDGEMENTS

Firstly, I would like to extend my gratitude to Jonathon Hollway and Ally Wood, owners of Corbett Creek Farm, for their generosity in allowing me to conduct my study on their farm. A special thanks is directed to Jon in particular as he was instrumental in bringing forth the idea of conducting a thesis on the farm while chaperoning our third year field school to Ecuador.

I would like to thank my thesis supervisor, Dr. Leni Meyer for his constant support, guidance, expertise, and encouragement throughout the duration of my thesis. I would also like to extend my thanks to Dr. William Wilson for acting as my second reader and providing me with an excellent wealth of knowledge surrounding the history of the study area.

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1. INTRODUCTION

The climate is far from being a static entity and as it continues to change, adaptations to the landscape and how we use it are important. Agriculture in Northern Ontario is one of the industries that look to benefit from a climate that is warming (Chapagain 2017). With a warmer climate causing an increased growing season, agricultural production in the Thunder Bay area is an intriguing opportunity to improve food security and provide new entrepreneurial opportunities.

In addition to climate however, the soil plays a quintessential role in dictating the productivity of an agricultural site. As seen in areas in the tropics, warm climates that can tolerate a vast range of species still struggle to sustainably support any kind of agricultural practice when the soil is of poor quality (Johnston *et al.* 2009). Though it is predicted that a warmer climate in the Thunder Bay area will be able to produce/sustain an increased variety of crops and animals, this change is negligible for farmers if their soil is not of high quality (Chapagain 2017). It is the importance of soil in agriculture that has driven me to examine soil quality, with a specific focus on soil compaction, pH, and carbon content.

Known historically as the McNally farm, this Thunder Bay area farm has operated since the late 19th century. The information surrounding the history of the farm was gathered from an in-person interview with Dr. Will Wilson on January 31, 2019. The farm operated as a dairy farm for much of the 20th century, before becoming a 200 sheep operation in the 1990s. Hay was a major crop for fifteen years during this latter timeframe of the farm, with most of it being sold to other farmers. In 2010, the farm decreased in scale, though sheep, pigs, and cattle all inhabited the pastures, and a hay crop was still maintained. The hay produced was mostly kept for feeding the livestock over the winter, but from 2014-2017, half of the hay crop was sold to local farmers in the region. Jonathon Hollway and Ally Wood are the current owners of what is now called the Corbett Creek Farm (5km NW of Murillo, Ontario), having farmed there since September of 2017. Situated on 109 acres, the farm's production focuses on hay, cattle and pigs. Both the cattle and pigs are pastured, but the pasture that was sampled was inhabited only by cattle. Hollway and Wood both see the importance of organic agriculture in improving productivity and ecological function of a landscape, and are looking to transition their farm to a certified organic operation in the future.

The use of machinery on the farm over the last quarter-century has been indicative of a small-scale farming operation, with a tractor, baler, mower, and manure spreader being the extent of equipment used on the fields. No synthetic fertilizers have been spread on the fields in at least 25 years, but cattle and sheep manure has been frequently spread on the fields in an effort to boost productivity.

In conducting this research, I am interested in examining the difference between soil compaction, pH, and carbon content on a hayfield and pasture site (the purpose of this research is fully outlined in the Objective section). By setting up a null hypothesis, I will be able compare these two sites to see if there are any soil difference between two parcels of land (hayfield versus pasture). The Literature Review provides an overview of existing research and publications regarding overall soil quality, with an added emphasis on the importance of soil compaction, pH, and carbon content. The structure and methodology of this research, including both field and lab work, will be outlined in the Materials and Methods section. The Results section will display raw data of soil compaction, pH levels, and carbon content percentage and amounts, as well as descriptive statistics and a one-way ANOVA displaying the comparison between the two sites. The Discussion will elaborate on the results produced, discussing the possibilities of both positive and negative implications of past, present, and future farming practices. The Conclusion will stress the importance of this data serving as a baseline for future research, and what that future research could entail.

1.1.LITERATURE REVIEW

Conserving and restoring the soil of agricultural landscapes is an important component of sustainable and productive farming practices (Johnston *et al.* 2009; Papendick and Parr 1992; Roger-Estrade *et al.* 2010). Soil quality is measured in various forms, providing different insights that contribute to determining overall soil health (Gregorich *et al.* 1994). Three indicators of soil health and their significance will be outlined in the subsequent sections. Though the improvement of soil productivity has been an area of focus for generations, it has often come at the cost of the soil's ecological integrity (Johnston *et al.* 2009). As a result, many soils have been unsustainably managed, and their lack of ecological integrity (the ability to support and maintain ecological processes and a diverse community of organisms) has resulted in an increasing reliance on synthetic fertilizers to produce a sustained yield (Tilman *et al.*2002). Matson *et al.* (1997) have shown that a reliance on these fertilizers may result in an economically viable yield, but have enormous environmental impacts that significantly hamper the long-term sustainability of the soil. Going forward, it is imperative that soil is conserved holistically, in a way that maintains or improves productivity without compromising its ecological integrity.

Many soils currently lack the most basic descriptions of physical, and chemical properties, let alone descriptions of biological aspects. This research places an emphasis on three basic soil properties: soil compaction, pH, and carbon content. This thesis will examine their elemental role for maintaining good soil health, as well as how they could have been impacted by past onsite farming practices. This research is based primarily from the results gained from soil samples collected from a farm located northwest of Murillo, Ontario, but will incorporate outside research to help parlay the importance and impact of this research.

1.1.1. Soil Compaction/Bulk Density and its Significance to Soil

Soil compaction is described by Hamza and Anderson (2005) as one of the major problems facing modern agriculture, and is described as detrimental by Ahmadi and Ghaur (2015). Soil compaction not only affects the soil's surface, but affects lower levels in the profile as well (Molnar-Irimie 2016). To measure soil compaction, bulk density (Db) may be used. Bulk density is defined as "the density of a volume of soil as it exists naturally and includes any air space and organic materials in the soil volume" (Strahler and Strahler 1997: 72). Although Db is primarily used to quantify soil compaction, it also a critical measurement for determining total nutrient contents and crop productivity.

Bulk density is also needed to calculate total water storage capacity per soil volume, and allows for soil layers to evaluate seeing if they are too compacted to allow root penetration or adequate aeration (Strahler and Strahler 1997: 72). High Db has been found to have negative effects on water permeability, crop seedling emergence, and ultimately crop yield (Ahmadi and Ghaur 2015). Furthermore, increased soil compaction leads to a decrease in crop performance (Barzegar *et al.* 2016).

Soil compaction is a result of soil layers being pressed together from an outside force (Hamza and Anderson 2005; Soane and van Ouwerkerk 1994). Overuse of machinery, intensive cropping, short crop rotations, intensive grazing, low carbon content, and poor soil management are all causes contributing towards soil compaction (Hamza and Anderson 2005; Soane and van Ouwerkerk 1994; Rowell 1994: 66). The level of compaction often depends on when the soil is heavily used by machinery or livestock; heavy grazing or machinery use on wet soils will cause more compaction, whereas the same activity on drier soils will result in less compaction (Flynn *et al.* 2018; Hamza and Anderson 2005; Rowell 1994; Willatt and Pullar 1984). Hamza and Anderson (2005) also found that soil compaction is further exacerbated by low soil organic matter content, and Willatt and Pullar (1984) found that an increase of stocking rates can lead to an increase in bulk density which in turn decreases hydraulic conductivity. Auler *et al.* (2017) in their study also found that integrated crop-livestock systems (ICLS) have potential to be damaging to soils in terms of compaction due to the intensity in which the soil is used.

Hamza and Anderson's 2005 article provides a list of ways that soil compaction can be mitigated or avoided. Reducing pressure from machinery, allowing grazing only at certain soil moistures, monitoring the intensity of machinery use and grazing, increasing soil organic matter, and planting crops with deep taproots are all methods their article puts forward as a response to reverse the harmful effects of soil compaction. Barzegar *et al.* (2016) in their study on clover growth found that sufficient water supply can also moderate adverse effects of soil compaction. Lower grazing intensities have also been found to ease the level of soil compaction, and the full cessation of grazing has been found to reverse effects of soil compaction (Mapfumo *et al.* 1999; Sharrow 2007). As a study done in Quebec shows, tilling practices have also been found to minimize compaction (Lipiec and Stepniewski 1995).

1.1.2. Soil pH and its Significance to Soil

The term pH originates from the French term *pouvoir hydrogène* (hydrogen power), and is an indication of the acidity of basicity of the soil (Miller and Gardiner 2001: 158). Soil pH is a measure of the pH of the water in equilibrium with the soil (Miller and Gardiner 2001: 158). Miller and Gardiner (2001:159) also state that most plants are best suited to a pH of 5.5 on organic soils, and 6.5 on mineral soils. Soil pH is known as the most informative simple measurement that can be made to determine soil characteristics, and affects all chemical, physical, and biological properties (Thomas 1996; Brady and Weil 2002). Thomas (1996) also states that pH can indicate the availability of essential nutrients and toxicity of other elements because of the correlation they share. Soil pH plays so much of a prominent role in determining overall soil health that Wardle (1992) suggests that soil pH carries the same importance as carbon or nitrogen concentrations in influencing the size of microbial biomass.

As previously mentioned, pH plays an extremely pivotal role in maintaining soil health. In particular, soil pH does this in two main ways. Firstly, soil pH has a profound impact on nutrient availability and cycling (Kemmitt *et al.* 2006; Robsin 1989; Xi *et al.* 2017; Prosser and Nicol 2012). Kemmitt *et al.* (2006) found that changes in soil pH significantly affect soil microbial activity and the rate of soil carbon and nitrogen cycling. Microbial activity is essential to maintaining productive soils, and regulates soil nutrient bioavailability, maintains vegetation community structure, improves plant primary productivity, and a wide range of soil processes (Robsin 1989). Carbon and nitrogen are elements that plants rely on in order to maintain productive growth rates (Batjes 1996). Ammonia-oxidizing archaea (AOA) and ammonia-oxidizing bacteria (AOB) are critical microbes in the soil that drive soil nitrification and enhance soil productivity (Prosser and Nicol 2012). Agricultural ecosystems annually receive approximately 25% of the global nitrogen input, much of which is oxidized by AOA and AOB (Jia and Conrad 2009). These AOA and AOB rely largely on the pH of the soil as it is a critical factor in dictating their abundance and community structure (Xi *et al.*2017).

Soil pH is also vital in maintaining proper decomposition rates (Pietri and Brookes 2008; Rousk *et al.* 2009; You *et al.* 1999; Miller and Gardiner 2001: 161). Decomposition relies on ergosterol (fungal and bacterial) activity, and regenerate minerals that limit productivity as well as organic matter (Rousk *et al.* 2009). Soil pH is also very important in stimulating biomass growth which increases the amount and availability of organic matter in the soil for decomposers (Pietri and Brookes 2008). Existing literature shows that soils with a neutral pH are typically much more productive in regards to microbial activity and plant growth than acidic soils. Fierer and Jackson (2006) found that bacterial diversity was low in acidic soils compared to neutral soils. This sentiment is also echoed in Miller and Gardiner's text (2001:161). You *et al.* (1999) found that an increase in pH (from acidic to more alkaline soils) resulted in an increased dissolution of organic matter. In another study, soil pH was found to be lower in minimally fertilized fields opposed to organically fertilized fields (Heinze *et al.* 2009).

1.1.3. Carbon Content and its Significance to Soil

Soil is comprised of two major components; mineral matter, and organic matter, with the latter being described by Strahler and Strahler (1997: 492) as any matter of biological origin. Soil organic matter (SOM) is largely made up of soil organic carbon (SOC), and this carbon is often used as an indicator of overall soil health (Doran and Zeiss 2000). The vast majority of the world's carbon is found in storage pools as carbon sediments below the earth's surface (Strahler and Strahler 1997: 531). Agricultural fields play a large role in storing carbon because of the large amounts of atmospheric carbon their soil is able to hold (Matsuura *et al.* 2018).

Organic matter influences physical, chemical and biological properties of soils. It serves as an abode for organisms, provides nutrients and energy material, and abets the effects of mineral colloids. It exerts a strong influence upon the formation of structural aggregates, retention of moisture, and adsorption of nutrient ions Brady 1990).

Soil organic matter is known to influence various soil properties and nutrient cycling, and there is much concern over decreasing levels of soil organic matter (SOM) resulting in a lack of productivity that would stem from the deterioration of soil physical properties and soil nutrient cycling mechanisms (Gregorich *et al.* 1994; Loveland and Webb 2003).

The levels of soil organic carbon are largely dependent on the rate of carbon input and decomposition rates (Liu *et al.* 2016). Liu *et al.* (2016) also show that soil organic carbon increases when agricultural land is used for cropping purposes, but decreases in fields that are continually grazed. Soil organic matter (and soil organic carbon by extension) has decreased historically as a result of grazing and burning (du Preez *et al.* 2011). With the large role that agricultural fields play in storing carbon and the impact that that carbon has on soil health, it is vital that agriculture practices shift towards practices that maintain SOM and SOC levels (Loveland and Webb 2003; Matsuura *et al.* 2018).

Carbon content is essential to the soil for a variety of reasons that all work together to ensure good soil health. A study done by Nwite (2017) in Nigeria found that soil organic matter (SOM) is critical to fertility maintenance and enhancement of productivity and notes that SOM is a primary attribute of soil quality assessment in regards to agricultural production. Similarly, a study done by Williams (1996) based out of the University of Aberdeen looked at the productivity of soils by adding organic materials (animal manures, green manures, and straw) to the soil and monitoring crop productivity. This study found that increasing organic content in the soil led to optimal nutrient levels, and minimized nutrient losses. Research has also shown that an increase in organic matter leads to an increase in water retention. Rawls *et al.* (2003) and Green *et al.* (2003) both found that at high organic carbon values, soils showed an increase in water retention.

The sum total of negative charge in a soil (cation exchange capacity, CEC), or the total amount of cations that a soil may potentially adsorb is also very much a function of organic matter (and clay content) as well as the effective surface area involved (Brady 1990).

The literature has also noted that too much organic matter can be detrimental to soil health (Miller and Gardiner 2001: 194). These adverse effects stem mostly from allelopathy which is defined in the same text as any beneficial or harmful effect of the chemicals produced by one plant on another plant. When organic matter in the soil becomes detrimental, this is often due to the presence of organic matter that release chemicals into the soil that are harmful to other plants (Miller 1996).

Though the literature points to carbon being a vital part of a healthy soil, there is little indication that carbon elemental levels directly have an impact on other nutrients such as nitrogen or sulfur. Manley *et al.* (1995) point out that both carbon content and nitrogen levels are affected by grazing treatments, but fail to draw a connection between the levels of one nutrient dictating the levels of another. Lawrence and Germida in their 1988 study found that sulfur oxidation in soil increased linearly with microbial biomass carbon (bacteria and fungi), and Wardle (1992) found that microbial biomass in the soil also had an impact on increasing nitrogen levels in the soil. However, the study of microbial biomass is outside the scope of this research so will not be focused on in detail.

1.2.OBJECTIVE

The purpose of this research is to establish baseline data that will aid in future research seeking to determine effects of farming practices on soil quality. This will be done by measuring soil compaction, pH, and carbon/nitrogen/sulfur (CNS) percentages and amounts. This research will also seek to determine if there are any relationships between CNS because of their known relationship in organic matter (OM). This was explored because if a strong enough relationship was found, then future research could just measure the amount of carbon in the soil to determine levels of nitrogen and sulfur. It is my hope that in carrying out this research, there will be an increased clarity in regards to the soil quality of the farm, resulting in better-informed management decisions going forward. The data obtained from this research can also be used as a baseline for future studies that delve further into the impacts of different farming practices on soil compaction, pH, and carbon content. This in turn can help utilize potential advantages of a warming climate in Thunder Bay agricultural sector.

1.3.HYPOTHESIS

My thesis has the following hypotheses (Ho & Ha):

1. Ho: There is no significant difference ($\alpha = 0.05$) in soil compaction (g cm^{-3}) in soil samples taken from a hayfield vs. samples taken from a pasture.

   Ha: There is a difference ($\alpha = 0.05$) in soil compaction (g cm^{-3}) in soil samples taken from a hayfield vs. samples taken from a pasture.

2. Ho: There is no significant difference ($\alpha = 0.05$) in pH in soil samples taken from a hayfield vs. samples taken from a pasture.

   Ha: There is a significant difference ($\alpha = 0.05$) in pH in soil samples taken from a hayfield vs. samples taken from a pasture.

3. Ho: There is no significant difference ($\alpha = 0.05$) in carbon content (kg ha^{-1}, where the ha is 10 cm deep) in soil samples taken from a hayfield vs. samples taken from a pasture.

   Ha: There is no significant difference ($\alpha = 0.05$) in carbon content (kg ha^{-1}, where the ha is 10 cm deep) in soil samples taken from a hayfield vs. samples taken from a pasture.

4. Ho: There is no significant ($\alpha = 0.05$) linear relationship between:

   a. Nitrogen (%) and Carbon (%)
   b. Sulfur (%) and Carbon (%)
   c. Sulfur (%) and Nitrogen (%)

   Ha: There is a significant ($\alpha = 0.05$) linear relationship between:

   a. Nitrogen (%) and Carbon (%)
   b. Sulfur (%) and Carbon (%)
   c. Sulfur (%) and Nitrogen (%)

If there are significant linear relationships, the R^2 will be assessed as well.

2. METHODS AND MATERIALS

2.1.SITE SELECTION AND TIME PERIOD

This study took place on Corbett Creek Farm, a local farm five kilometres northwest of Murillo, Ontario. The current owners of the farm are Jonathon Hollway and Ally Wood, who purchased the farm from William Wilson in September of 2017. This farm is currently a producer of local, pasture raised pork and beef, with the land not being pastured used for hay production.

Only a portion of the farm was sampled, with 10,000m^2 plots from both a hayfield and an adjacent pasture being sampled. Figure 1 displays the location of the farm relative to Thunder Bay with a star indicating the farm's location. Figure 2 displays the location of the farm in finer focus with the property outlined in red, and the specific study area outlined in black. The field data collection for this study began September 29, 2018, and was finished the same day. Lab analysis commenced October 1, 2018, and was completed January 21, 2019.

Figure 1. Satellite imagery displaying the farm's location (black star).

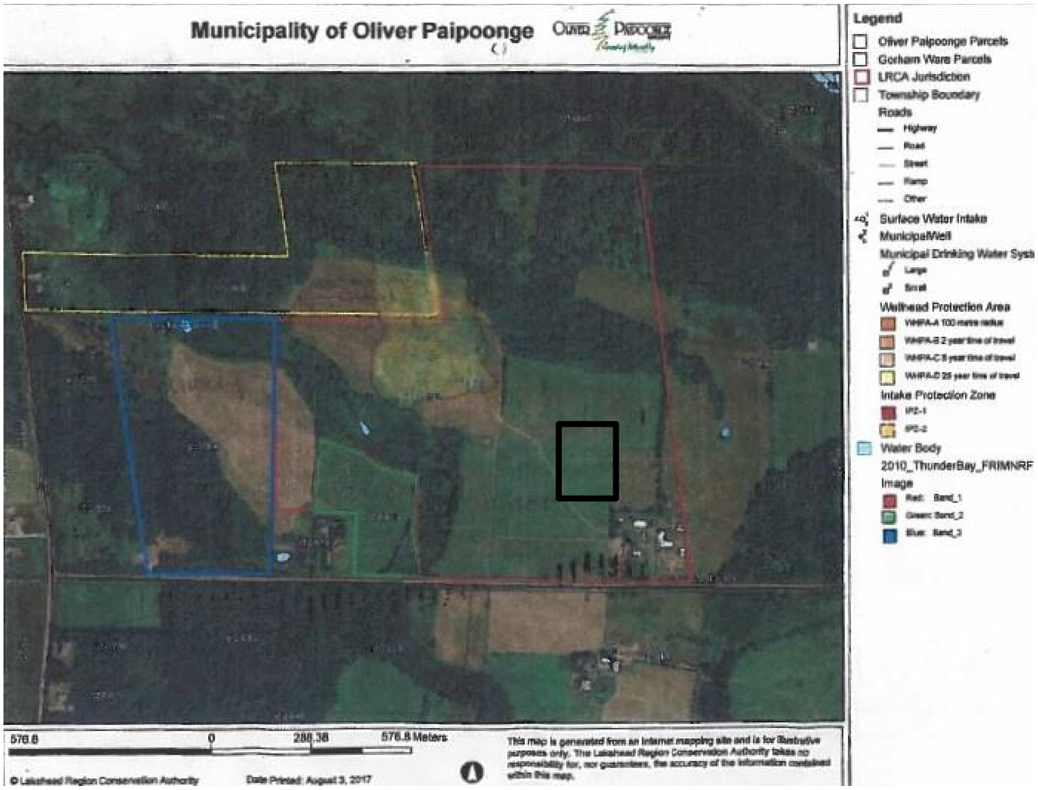

Figure 2. Map of the study area. The farm is outlined in red, and the study area outlined in black.

2.2. FIELD DATA COLLECTION

On September 29, 2018, 64 samples of soil were collected from Corbett Creek Farm. The exact location of these samples can be seen in Figure 2. The soil was classified as a Nolalu series (Nsl B/2) Orthic Eutric Brunisol sandy loam with good drainage (Anon. 1981). The area is irregular level (0.5 -2 % slope) and moderately stoney.

Thirty-two of soil samples were used to sample carbon content and pH, and the other thirty-two samples were used to measure soil compaction. Within the 10,000m^2 plots on each site, samples were collected in a grid method. Each sample was taken 25m away from previous samples, and where the two sites bordered each other a 25m buffer was given. These measurements can also be seen in Figure 3.

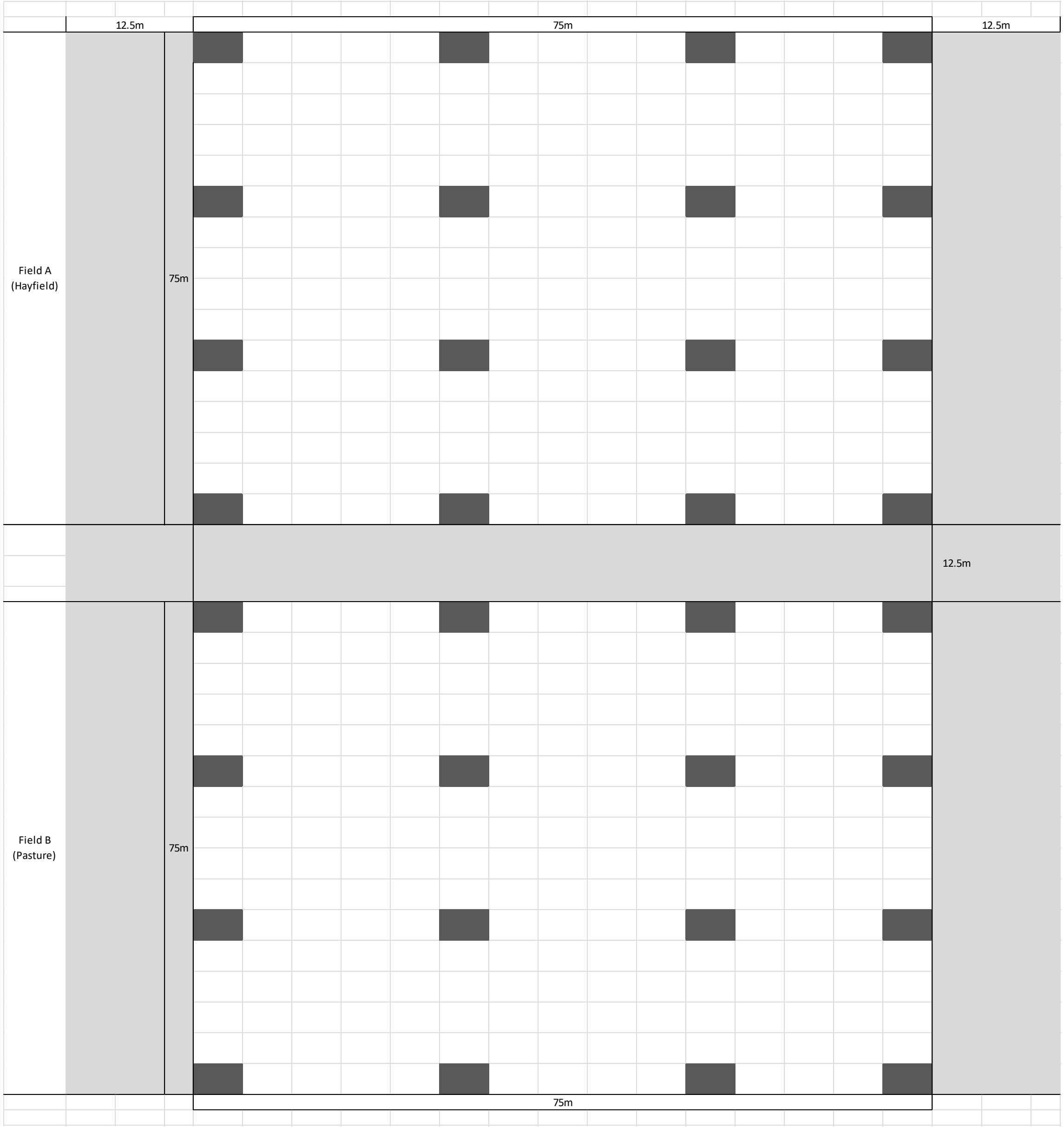

Figure 3. The study area with buffer areas (light grey), and sample areas (dark grey).

A round-pointed shovel was used to remove the sod layer, allowing for each soil sample to be taken from the A horizon at a depth of 0.10m. The soil bulk density samples were collected separately using a density drive sampler (Figure 4).

Figure 4. Density drive sampler (Source: Leni Meyer, 2019).

A standard Dutch auger was used for the collecting samples for total carbon, nitrogen, sulphur (CNS; %) and pH analyses. Soil samples used for CNS and pH were stored in plastic Ziploc bags and labelled with the respective site number. The amount of soil obtained in the field for CNS and pH measurements was not recorded as it had no effect on the study. For soil compaction, each sample volume from the density drive sampler was assumed to be that of the core: 231.7cm^3. Samples were stored in paper bags that had been weighed prior in the soils lab at Lakehead University. These paper bags were also labelled, and all samples were transported to the university where they awaited future analysis. Transportation to and from the study site was provided by Justin Goodman; a fourth year HBScF student who acted as my field assistant for this study (Figure 5).

Figure 5. Field assistant Justin Goodman and the mode of transportation for fieldwork.

2.3.LAB ANALYSIS

2.3.1. Bulk density samples

Upon returning from the field, soil samples were stored in the BB1022 to await further analysis. The paper bags containing the samples being used to measure bulk density were put into a drying oven and dried at a temperature of 105F (21C) for 48 hours, and then air dried at room temperature for an additional 48 hours. The oven in which the soil was dried in is pictured in Figure 6. Once the drying period had finished, the samples were weighed, and the weights were recorded in grams. The weight was then divided by the volume of the container (*i.e.*, 231.7cm^3) used to obtain the sample (Equation [1]):

$$\mathbf{Db = Ms/Vb} \qquad [1]$$

Where Db = Bulk density (g cm^{-3})

Ms = mass (g) of oven dry soil, and

Vb = bulk volume (cm^3) of the container

The final number for each sample was recorded and compiled into a table (refer to appendix). The bulk densities recorded from the pasture site were then compared to the bulk densities recorded from the hayfield site using an ANOVA to see if there was statistical difference ($\alpha = 0.05$) between the compaction of the two sites.

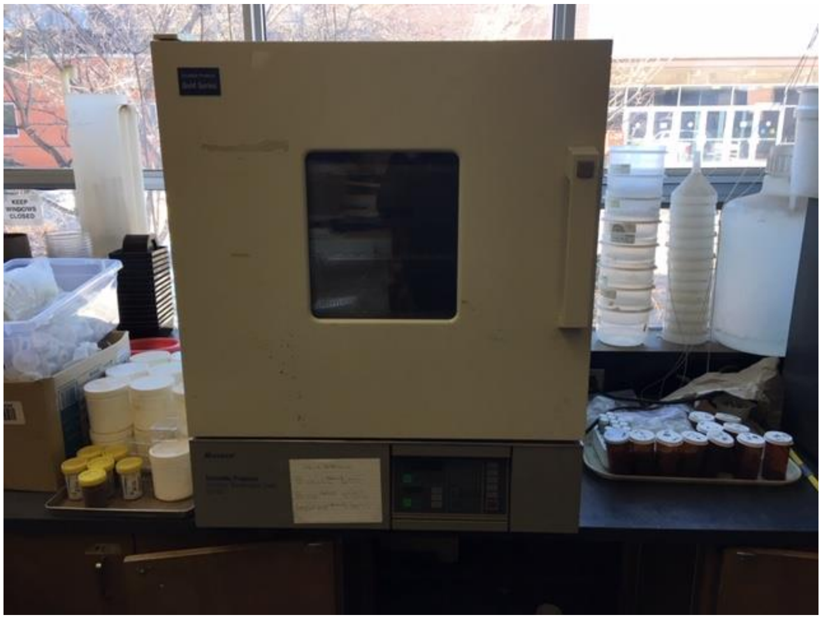

Figure 6. The drying oven that dried soil samples used to measure bulk density.

2.3.2. pH samples

Using the Ziploc bag samples of soil, the soil from each bag was air dried 48 hours at 21° C and was then was passed through a 2mm sieve using a mortar and pestle to break down the soil. The soil that passed through the sieve was returned to its respective Ziploc bag (moisture contents were calculated later on each air dry sample so all measures were on a per g Oven-Dry basis). Soil that did not pass through the sieve was discarded, and all equipment was cleaned after each sample using a paper towel to prevent contamination.

After all soil samples underwent this process, two 10g samples from each bag were weighed out into small plastic cups. For each site's soil sample, one 10g sample had 20ml of distilled H_2O added, and the other had 20 ml of 0.01M of $CaCl_2$ added. Samples were stirred every ten minutes over a thirty-minute period, before being let to rest undisturbed for one hour.

Once the allotted time had passed, each sample had its pH recorded (see Equation [2]) using an Accumet research AR20 pH/Conductivity Meter with temperature adjustment and an Orion 9165BNWP Sureflow Combination pH electrode (Figure 7).

Figure 7. Materials used to measure soil pH: 10g soil samples (far left), graduated cylinders (centre right), and the pH machine (far right).

$pH = -\log[H^+]$ and

$$[H^+] = 10^{(-pH)} \quad [2]$$

Once the machine beeped, the pH value was recorded. The sample was then removed, the machine was cleaned with distilled water and Kim-wipes, and the next sample was measured. Each value was listed into a table on Microsoft Excel and then compared by running an ANOVA to see whether there was a statistical difference ($\alpha = 0.05$) between the pH on the pasture and hayfield sites.

2.3.3. Moisture Content

Moisture content was conducted by weighing out 10g of soil from each of the Ziploc bags of soil used to measure both pH and carbon content. This soil was placed into a metal tin which was then placed into a drying oven and dried at a temperature of 105F (21C) for 48 hours. Once the samples had properly dried, samples were taken out of the oven and weighed immediately with each value being entered into Microsoft Excel. The following equation was used to correct percentage values of CNS for any moisture the samples contained when originally measured (Equation [3]):

$$\mathbf{X = \%/Sd*Sm} \quad [3]$$

Where X = Percent of CNS in the soil corrected for moisture

% = Original percentage value for CNS

Sd = Weight of dried soil (g)

Sm = Weight of undried soil (g)

2.3.4. Carbon, Nitrogen, and Sulfur (CNS) Content

To measure CNS content, soil samples from the Ziploc bags were sent to Lakehead University's LUCAS lab to be analyzed using a Elementar Vario EL Cube. The percentages of CNS were recorded by the separate lab in Microsoft Excel, corrected for moisture content and were analyzed for any significant difference using SPSS software. The raw and moisture corrected data can be found in the Appendix section.

ANOVA's were run on the percentage and actual amounts of carbon, nitrogen, and sulfur to determine any significant difference between the two fields, and regressions were run to determine whether a relationship between the nutrients existed. To calculate the actual amounts of CNS in the soil, the bulk density was multiplied by the depth at which the soil sample was obtained (0.10m), and the percentage of the nutrient found in each sample (Equation [4]):

$$\mathbf{X = Db*(Sd *10000)*(X\%/100)} \qquad [4]$$

Where X = Nutrient (C, N, or S)

Db = Bulk density (kg/m-^{3})

Sd = Soil depth (m), and

X% = Percentage of C, N, or S in the sample

2.3.5. One-way ANOVA

The dataset was tested for skewness and kurtosis (Appendix II). Skewness was considered ok if it fell between -0.8 to 0.8; Kurtosis ok if between -3 to 3 (Joanes and Gill 1998). With the exception of H+ concentration, all data was considered adequate for meeting the requirements of the CRD ANOVA. Hydrogen data, when transformed to the pH value, was normalized.

For each aspect of the soil analysis (bulk density, pH, and CNS content), a One-way ANOVA was conducted with a significance of $\alpha = 0.05$. These tests were run using IBM SPSS computer software, with percentages of CNS (response variables) serving as the dependent factor, and the field (pasture and hayfield) serving as the fixed factor. The linear model is as follows:

$$Y_{ij} = \mu + F_i + \varepsilon_{(i)j}$$

$$i = 1 = \text{pasture},\ 2 = \text{hayfield};\ j = 1, 2, \ldots, 16 \text{ replicates}$$

where:

Y_{ij} = the measured response of the j_{th} replicate of the i_{th} level of factor F

μ = the overall mean

F_i = the fixed effect of the i_{th} of 2 levels (pasture and hayfield) of factor F,

$\varepsilon_{(i)j}$ = the random effect of the j_{th} of 16 experimental units in the i_{th} treatment. The $\varepsilon_{(i)j}$ are assumed to be IID $N(0, \sigma_2)$.

The p calculated values which determine the existence of a significant difference are presented in the Results section. The averages and standard deviations of each ANOVA are presented in the Results section as figures and the raw output tables of each ANOVA are listed in the Appendix.

2.3.6. Regression

To examine the regressions between N vs. C, S vs. C, and S vs. N, linear models (simple linear regression - SLR) were run on SPSS. The p values, linear model coefficients and r^2 values were determined.

3. RESULTS

This section contains tables and figures pertaining to the seven one-way ANOVA tests that were run to determine any significant difference between various aspects of the soil on the hayfield and pasture sites. It also contains tables and figures concerning the three regressions that were carried out to determine the relationship between N vs. C, S vs. C, and S vs. N.

3.1.ANOVA RESULTS

In looking at the results from each ANOVA listed in Table 1, it can be seen that there were only two factors in which there was a significant difference ($\alpha = 0.05$) between the pasture and the hayfield: the carbon percentage, and the sulfur percentage. The hayfield was found to have a significantly higher percentage of both carbon and sulfur. It is, however, also worth noting that with a p value of 0.068, the percentage of nitrogen was also almost significantly higher in the hayfield. Apart from those factors, it can be seen that there is very little significant difference between the two fields. The following figures preceding Table 1 will display the means and standard deviations for each response variable.

Table 1. Response variable's for each ANOVA and differences between the two test sites (p calc < 0.05)

Response Variable	p calc
Db	0.126
H+ (g/kg)	0.810
C%	0.042
N%	0.068
S%	0.016
H+(kg/ha)	0.987
C(kg/ha)	0.207
N(kg/ha)	0.304
S(kg/ha)	0.091

There was no significant difference in bulk density between the hayfield and the pasture. Figure 8 shows that the average bulk density for the hayfield was 1.28 with a standard deviation of 0.12, and the pasture had an average bulk density of 1.34 with a standard deviation of 0.08.

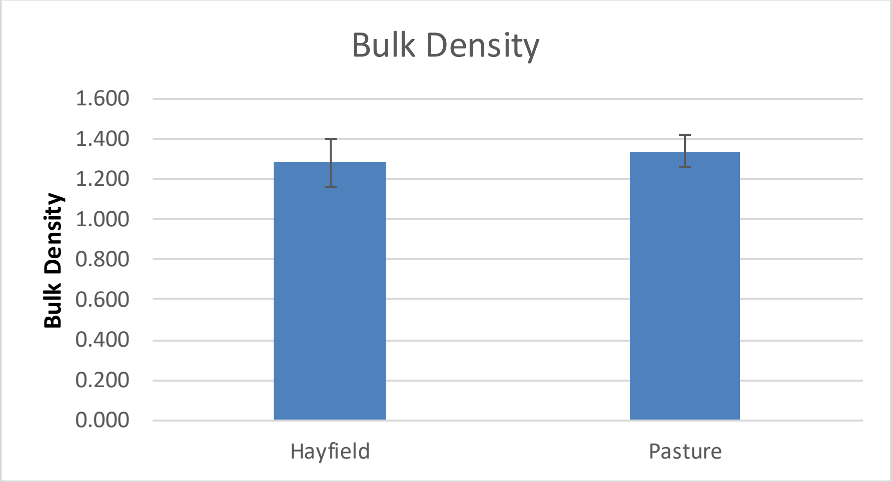

Figure 8. Means and standard deviations of bulk density (g cm-3) between hayfield and pasture sites.

The difference between H^+ (10^{-6} g/kg) in the hayfield and pasture can also be seen to be virtually nonexistent. They have average transformed H^+ values of 7.14 and 6.69 respectively, but have very large standard deviations of 6.81 and 2.97 (Figure 9).

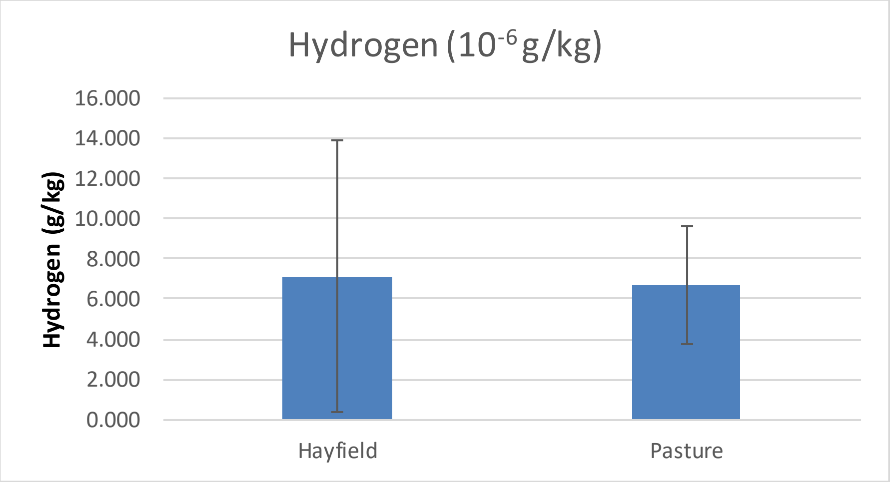

Figure 9. Hydrogen ion averages and standard deviations (g kg-1) in the hayfield and pasture sites.

The difference between the percent of carbon in the soils of the hayfield vs. pasture is documented in Table 1 as being significantly different. This difference is also presented in Figure 10 with the averages and standard deviations of both test sites being displayed. Average carbon percentage for the hayfield was 2.71% with a standard deviation of 0.29 whereas the average for the pasture was 2.38% with a standard deviation of 0.56.

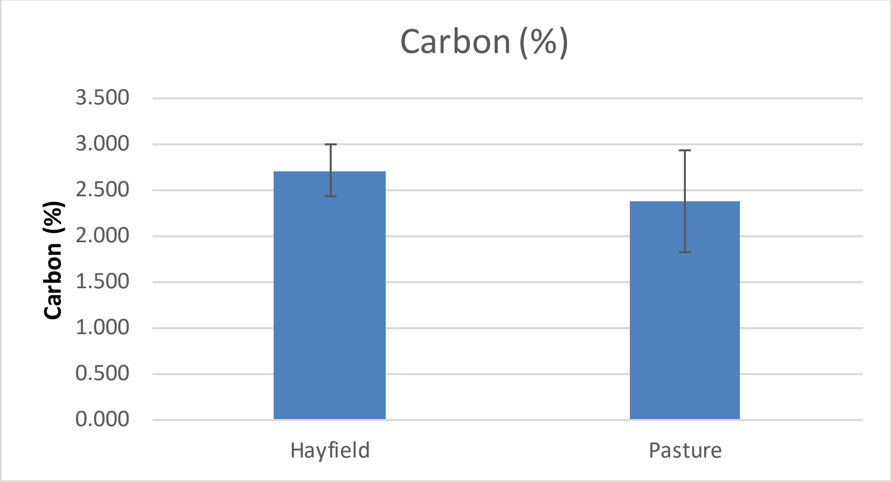

Figure 10. Carbon means and standard deviations (%) in the hayfield and pasture sites.

The percentage in nitrogen between the two fields did not prove to have a significant difference. Though there was a difference between the fields (p = 0.068), this was not enough of a difference to be deemed statistically significant (α = 0.05). The hayfield had an average nitrogen percentage of 0.25% with a standard deviation of 0.03, and the pasture had an average percentage of 0.22% with a standard deviation of 0.05. These values are displayed in Figure 11.

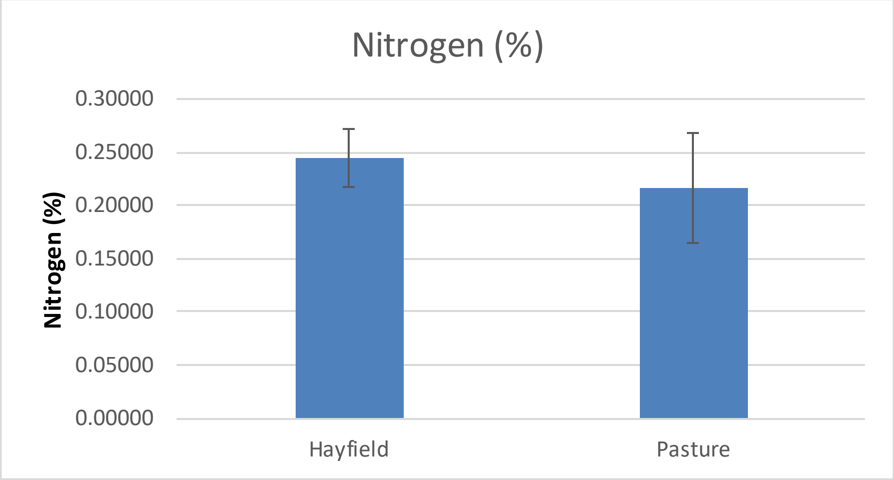

Figure 11. Nitrogen means and standard deviations (%) in the hayfield and pasture sites.

The amount of sulfur as a percentage between the two sites was the second factor to be deemed significantly different. As seen in Table 1, the p value for this response variable (0.016) was well below the significant difference threshold of 0.05. Figure 12 shows the average amounts of sulfur expressed as a percentage as well as the standard deviation for each site.

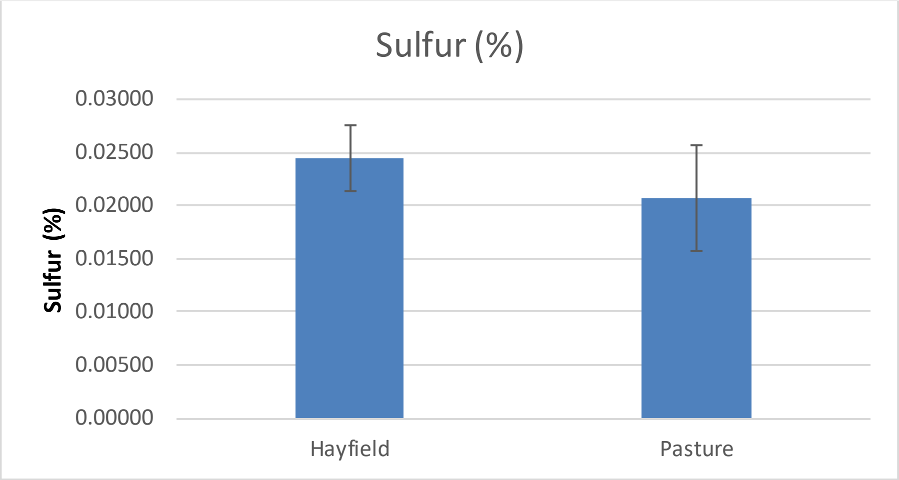

Figure 12. Sulfur means and standard deviations (%) in the hayfield and pasture sites.

When measuring hydrogen in kilograms/hectare instead of grams/kilogram, there is even less of a difference between the two sites. The amount of hydrogen in these two sites shown in Figure 13 is virtually the same, and large standard deviations further show the lack of a difference between these two sites.

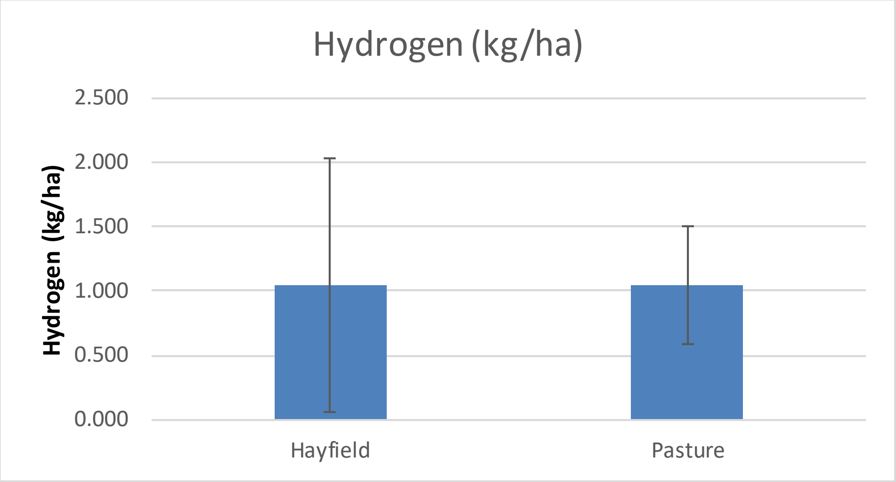

Figure 13. Hydrogen ion means and standard deviations (kg ha^{-1}) in the hayfield and pasture sites.

Though there was a significant difference in the amount of carbon as a percentage between the two sites, when bulk density is factored in to measure carbon in kilograms per hectare, there is no longer a significant difference. This can be seen in Figure 14 where it shows that the average amount of total available carbon (kg/ha) for the hayfield to be 40.16 kg, and 36.98 kg per hectare of soil for the pasture. Figure 15 shows the same test except on amounts of nitrogen (kg/ha) in both the hayfield and pasture test sites. A quick reference back to Table 1 shows that there is no significant difference, and this figure shows the averages and standard deviations that went into determining whether a significant difference was present. **Figure 16** shows the average amounts of S for the hayfield and pasture sites, and it is worth noting that though there is no significant difference, the p value of 0.09 listed in Table 1 is quite close to the significant difference value of 0.05.

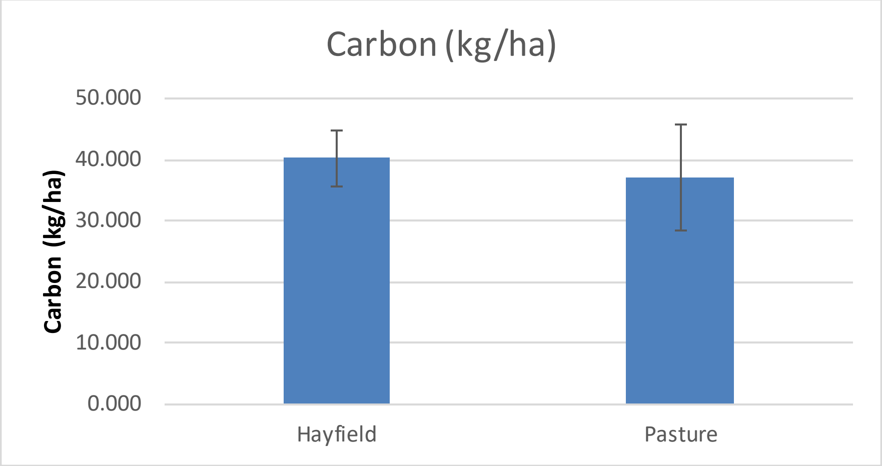

Figure 14. Carbon means and standard deviations (kg ha^{-1}) in the hayfield and pasture sites.

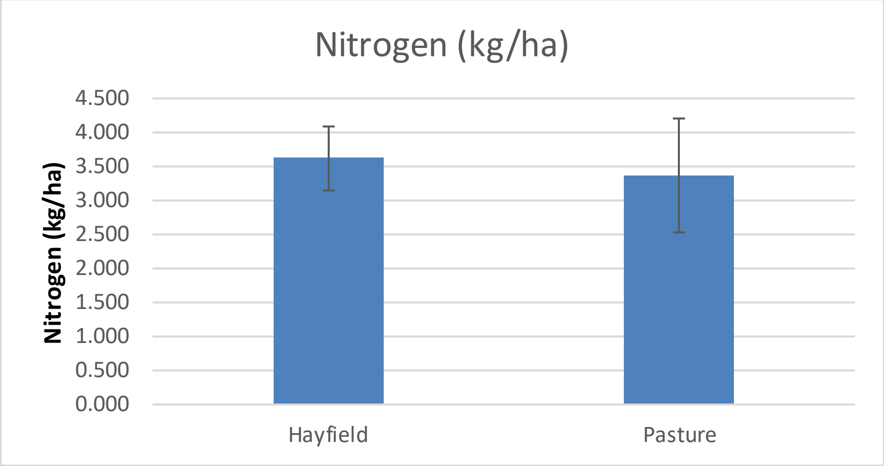

Figure 15. Nitrogen means and standard deviations (kg ha^{-1}) in the hayfield and pasture sites.

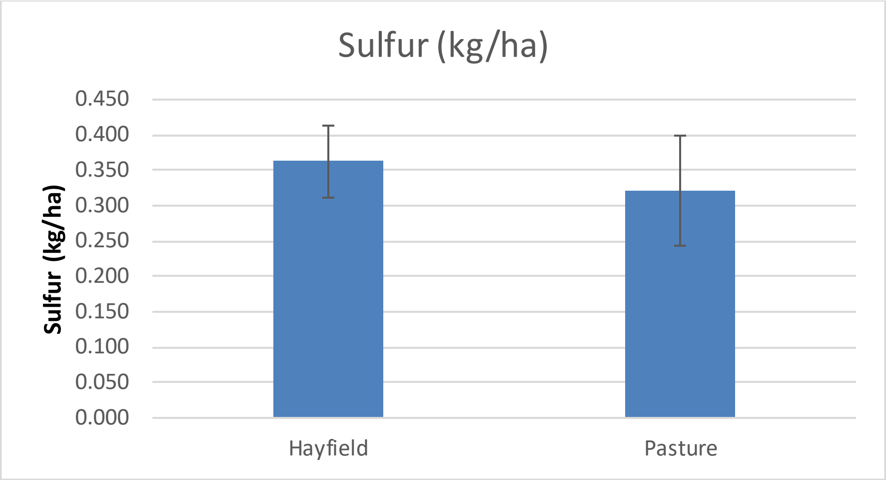

Figure 16. Sulfur means and standard deviations (kg ha^{-1}) in the hayfield and pasture sites.

In presenting these ANOVA results, there are significant differences between the two fields with respect to nutrient concentrations. That being said, it is worth noting that when bulk density is factored into these values to calculate the C, N, and S contents, there is no significant difference in actual amounts of these nutrients in the soil.

3.2.REGRESSION RESULTS

Regressions were also run on the relationships between the nutrients to gain an indication of how related the nutrients were to each other. Table 2 shows the strength of these relationships by listing the r^2 values and their p values.

Table 2. Each variable analyzed using a regression with their respective r^2 values (p values listed in brackets).

Variable	Carbon	Nitrogen	Sulfur
Carbon	-	-	-
Nitrogen	0.938 (<0.001)	-	-
Sulfur	0.850 (<0.001)	0.824 (<0.001)	-

As seen in Table 2, each regression had a very high r^2 value indicating that there are very strong relationships amongst all of the nutrients. The strongest of these 3 relationships is nitrogen's dependence on carbon levels with an r^2 value of 0.938.

From these regressions, linear models were also developed which allows researchers to determine the amount of any dependent variable provided the percentage of the independent variable is known. These equations are shown in Table 3.

Table 3. Linear models for each regression.

Dependent Variable (Y)	=	a	+	bX
N	=	0.002	+	0.090*C%
S	=	0.000	+	0.009*C%
S	=	0.001	+	0.950*N%

Figures 17, 18, and 19 show the various relationships plotted on a graph. In Figure 17, nitrogen percentages were plotted against carbon percentages, Figure 18 shows sulfur percentages plotted against carbon percentages, and Figure 19 displays the relationship between sulfur and nitrogen percentages. Trend lines are also shown on the graphs to help visually display the strength of each relationship.

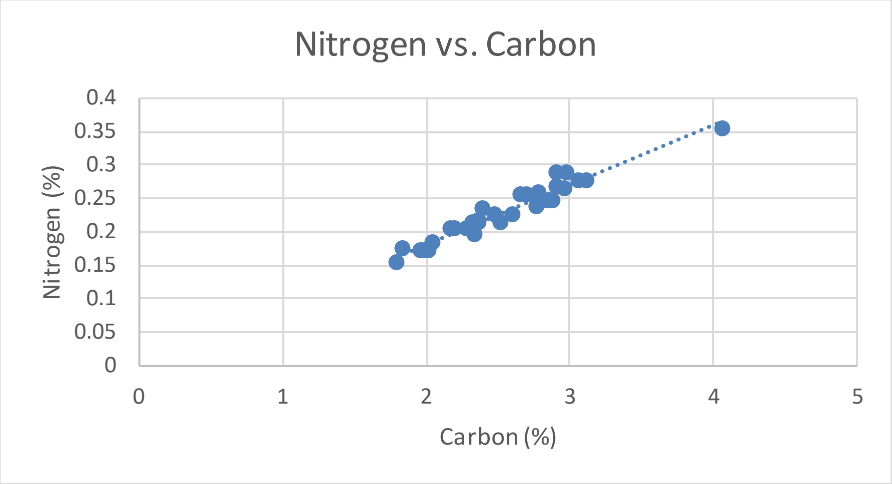

Figure 17. The relationship between N % relative to C% in the soil.

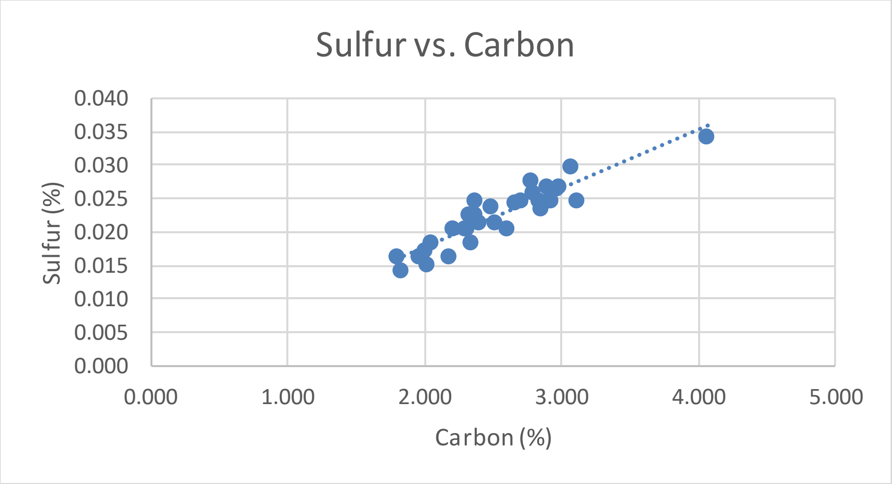

Figure 18. The relationship between S% relative to C% in the soil.

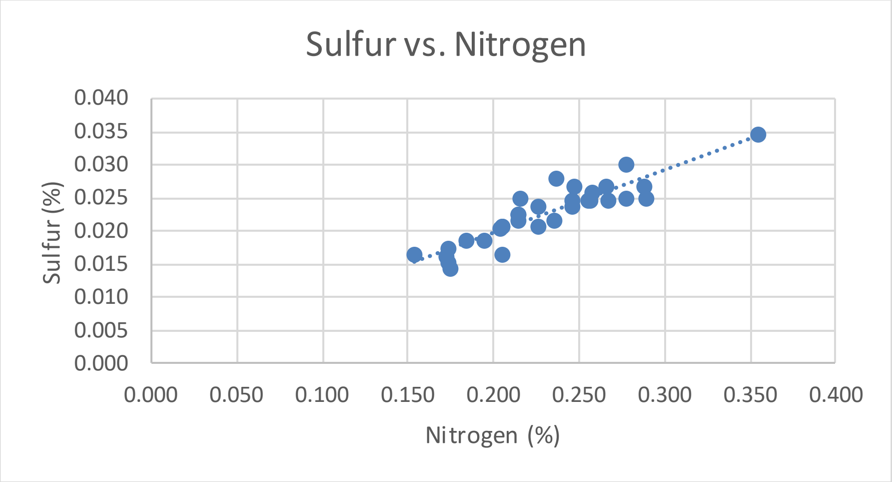

Figure 19. The relationship between S% relative to N% in the soil.

In looking at each regression graphically, it can be seen that there are very strong significant ($p < 0.001$) relationships between the amounts of these nutrients. Looking at the r^2 values in Table 2 further confirms this.

4. DISCUSSION

The results shown in the previous section portray the present conditions of the two fields on the farm. The results show that there is no significant difference between the hayfield and pasture sites. This is important because it provides knowledge to the farmer about the condition of their fields, and also provides a baseline to future researchers on the past condition of the fields. With further data collection, N and S amounts can also be calculated with knowing just carbon amounts now that an equation has been developed based on carbon's relationship with nitrogen and sulfur. This data is imperative for any future study seeking to understand how farming practices can affect soil compaction, pH, or CNS levels. With this research, a baseline is now in place that will allow for a much higher level of certainty in determining the impact of farming practices on agricultural soils in Northern Ontario.

Though there was a documented significant difference in the carbon and sulfur percentages between the two fields, when factoring in that there was no significant difference in the actual amounts of those nutrients, bulk density, or amounts of hydrogen, one can conclude that overall the two fields lack a significant overall difference in respect to the conditions analyzed in this research.

This section will document the significance of the results gathered from this research. It will compare results from this study to expected levels found in the literature to discuss the quality of the current soil conditions. In particular, it is important to take note of the significance this research has on future research.

4.1.SOIL COMPACTION

With respect to soil compaction, the results show that there is no significant difference between the hayfield and pasture sites. One possibility behind this lack of a significant difference would be the likelihood of the sites only being used for their current use in recent years. If the hayfield site were to have been previously used as a pasture, or if the pasture site were to have been previously used as a hayfield, this could have a large impact on the results. However, a conversation with Dr. Wilson (previous owner of the farm) confirmed that in his time farming the land the use of each field was the same then as it is now. This would indicate that there has been no change in how each field was used in the past nine years. Also contributing to the similarity in soil compaction could be the density at which livestock grazed the pasture, or the frequency in which machinery occupied the hayfield in years past. In speaking to Dr. Wilson, he indicated that only one cut of hay was able to be taken off a field each year on the farm, and also indicated that the density of livestock had varied over the duration of the farm. Though these variables are determined by Hamza and Anderson (2005) to be influential with regards to soil compaction levels, these variables were not measured in any quantifiable way for this study and any in depth examination of this would be pure speculation.

The Government of Manitoba (n.d.) has published typical soil compaction levels for their different types of soil throughout the province. The Newdale Clay Loam may be the soil type that is most comparable to the soil sampled in this research, and its typical bulk density value is expected to be at around 1.26. In comparing the bulk density values from the two sites measured in this experiment, it can be seen that the average bulk density value of 1.28 (hayfield) and 1.34 (pasture) are very similar to the expected values presented by the Government of Manitoba. Examining how current farming practices affect the bulk density values on these two sites has been identified as a potential area of future research.

4.2.PH/HYDROGEN AMOUNTS

The hayfield and pasture sites were also found to be equal in regards to amounts of hydrogen in the soil. With the hayfield having an average pH level of 6.2 and the pasture having an average pH of 6.1, it can be concluded that the fields have appropriate pH levels to sustain plants (Miller and Gardiner 2001:159). Unfortunately, this can be misrepresentative due to the large standard deviations in the hydrogen amounts in both fields. This indicates that amounts of hydrogen varied significantly even within each individual field. As noted in the literature review, pH has a notable impact on nutrient availability and cycling (Kemmitt *et al.* 2006; Robsin 1989; Xi *et al.* 2017; Prosser ad Nicol 2012). The results gathered in this research have shown no significant difference between hydrogen amounts in the two fields. However, should future research identify a change in pH levels, a change in nutrient amounts (kg/ha) could be confirmed by looking back to the data obtained in this research.

4.3.CARBON CONTENT

Perhaps the most interesting results of this study can be found in the results garnered form the CNS data. Though the focus of this research was aimed mostly at carbon, nitrogen and sulfur were also looked at as being major nutrients with possible relationships to carbon levels. In looking at the percentages of the fields, there was a higher percentage of carbon, nitrogen, and sulfur in the hayfield, with the differences being significant for carbon and sulfur. However, these significant differences disappear when bulk density is factored in to calculate the actual amounts of these nutrients available to the plants. This would back up Soane and van Ouwerkerk's research (1994) that indicates bulk density having a large impact on carbon content. Agriculture has long depended on maintaining high nutrient inputs in order to keep productivity at a high level. However, this research reinforces the notion presented by Soane and van Ouwerkerk (1994) that monitoring bulk density is equally important to ensuring adequate nutrient availability. With just measuring nutrient percentages, the risk arises of knowing nutrient levels in the soil but not knowing how much of those nutrients are actually available to plants.

Oldfield *et al.* (2018), determined in their study that a low carbon percentage was approximately 0.79%, medium carbon levels were about 1.54%, and high carbon levels at roughly 3.18%. In comparing the carbon percentages gathered from this experiment to the values determined by Oldfield *et al.* (2018), it appears that this soil has between a medium and high carbon percentage. As the author's point out, this high carbon percentage is positively correlated with soil organic matter (SOM). This, in turn, has a large influence in preventing the deterioration of soil physical properties and soil nutrient cycling mechanisms, which are crucial components of soil productivity (Gregorich *et al.* 1994; Loveland and Webb 2003).

This research also looked at carbon levels and the strength of the relationship towards determining nitrogen and sulfur levels. Though the literature does not suggest a strong relationship between carbon and either nitrogen or sulfur, the data collected in this research would suggest that there is a very strong relationship. This means that levels of carbon can be used to determine nitrogen or sulfur amounts with high levels of certainty. Determining the presence of these strong relationships will aid future studies as equations that only require carbon levels to determine both nitrogen and sulfur levels have now been developed. As agricultural practices continue to take place on these two test sites, measuring the nutrient levels in both fields will be important to ensure that productivity is maintained in a sustainable fashion. The results gathered from this research have the potential to aid significantly in determining the levels of change in nutrient amounts and can be used in a wide range of future research possibilities.

4.4.APPLICABILITY

Even with the lack of differences amongst the two fields, this data can still be used to determine whether farming practices should be changed. By comparing values from this study to values deemed desirable in the literature, it can be seen that compaction levels, pH levels, and carbon levels are all in line with what the literature suggests. This indicates to the farmer that the current state of the soil is productive enough to supporting agricultural production. What this does not show is whether the productivity of the soil is declining, improving, or staying the same. Opportunities to address this are outlined in the Section 4.5.

4.5.POTENTIAL FOR FUTURE RESEARCH

In order to understand fully how different farming practices impact the soil, a baseline needs to be established that future research can then be compared to. Though the hayfield and pasture examined in this study were determined as being almost identical in respect to the variables measured, this data serves as a very important baseline for any possible future research. Though this data offers minimal implications in terms of identifying the level of impacts resulting from current farming practices on the soil, future research has the potential to look at the same variables measured in this research and have a benchmark to compare their results with. This comparison between values allows research to provide the researchers and the farmers with a more thorough understanding of how the farming practices taking place on the land have an effect on soil compaction, pH and hydrogen amounts, and CNS levels. In particular, measuring carbon amounts (kg/ha) in the fields would be an interesting avenue to take in regards to future research. As the impacts of climate change continue to increasingly impact the landscape, sustainable agriculture has been identified as a way to sequester much of the carbon in the atmosphere and significantly mitigate the impacts of carbon emissions (Minasny *et al.* 2017).

5. CONCLUSION

Though the results show a lack of significant ($\alpha = 0.05$) differences amongst the two fields, the results provide an excellent inventory on the conditions of the two fields and should prove to be an excellent baseline going forward for any future studies. The results also showed that there is a strong positive relationship between carbon levels and nitrogen and sulfur levels. The relationship between carbon and nitrogen had an r^2 value of 0.938, and the relationship between carbon and sulfur had an r^2 value of 0.850. These high r^2 values suggest a possibility for obtaining nitrogen and sulfur levels by determining carbon levels opposed to measuring each individually.

This research, though valuable, needs to be expanded on in order for its full potential to be realized. This data was collected at a limited spatial scope and over a limited timeframe. Though this does not affect the quality of the samples collected or the data obtained from the samples, a greater sample size both spatially and temporally will offer more insight into how soil health can be maximized.

Ideally, this thesis would have been able to offer recommendations on how to best conduct farming practices in a way that maximizes soil health. However, recommendations can only be made when there is first a quality set of baseline data. This research has done the work of obtaining this baseline set of data, and has hopefully laid the groundwork for more extensive research going forward that will lead to recommendations on how to optimize soil health through proper farming practices. The climate in Northern Ontario is continuing to warm, and environmental degradation continues to be an issue worldwide. Thus, it is crucial to recognize and mitigate the potential negative impacts resulting from environmental degradation that have contributed to a changing climate. Sustainable agriculture has been identified as being an important vector in accomplishing this task, and should not be ignored.

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7. APPENDICES

Appendix I Raw Data

Table 1. A list of pH values for hayfield (A), and pasture samples (B). Each sample was measured twice: once in a solution of H_2O, and once in a solution of $CaCl_2$.

	A (hayfield)		B (pasture)	
Sample #	H2O	CaCl2	H2O	CaCl2
1	6.09	5.64	6.00	5.18
2	6.19	5.40	6.39	5.62
3	6.20	4.92	5.92	5.00
4	5.72	4.82	5.86	5.08
5	6.26	5.37	6.10	5.08
6	6.07	4.59	6.27	5.15
7	6.22	5.44	5.74	5.16
8	6.63	5.84	5.70	5.27
9	6.47	5.73	6.10	5.19
10	5.94	4.95	5.87	4.90
11	6.57	5.79	6.42	5.54
12	5.81	4.84	5.96	5.10
13	6.22	5.44	6.63	5.82
14	6.08	5.23	6.26	5.47
15	6.17	5.26	5.66	5.06
16	6.51	5.81	6.13	5.07

Table 2. A list of hydrogen amounts for Hayfield (A) and Pasture (B). Amounts were recorded in kg/ha.

A (Hayfield)	B (Pasture)
0.378	1.005
0.656	0.327
1.924	1.520
2.294	1.409
0.631	1.357
3.604	1.232
0.545	1.009
0.215	0.837
0.275	0.990
1.705	1.852
0.272	0.476
2.085	1.240
0.582	0.221
0.713	0.534
0.675	1.352
0.204	1.326

Table 3. Soil sample weight values (g) for the hayfield site. The number used in the bulk density calculation is the soil weight.

A (hayfield)			
Sample #	Combined Weight	Bag Weight	Soil Weight
1	338.23	7.87	330.36
2	337.49	7.82	329.67
3	327.81	7.81	320.00
4	311.02	7.83	303.19
5	303.52	7.86	295.66
6	288.20	7.81	280.39
7	307.79	7.80	299.99
8	305.63	7.84	297.79
9	303.08	7.78	295.30
10	311.66	7.80	303.86
11	343.26	7.78	335.48
12	296.36	7.85	288.51
13	328.32	7.77	320.55
14	250.00	7.82	242.18
15	253.43	7.84	245.59
16	270.76	7.83	262.93

Table 4. Soil sample weight values (g) for the pasture site. The number used in the bulk density calculation is the Soil Weight.

B (pasture)			
Sample #	Combined Weight	Bag Weight	Soil Weight
1	312.19	7.85	304.34
2	280.56	7.77	272.79
3	311.88	7.85	304.03
4	346.48	7.71	338.77
5	334.04	7.77	326.27
6	355.78	7.73	348.05
7	299.42	7.73	291.69
8	319.36	7.79	311.57
9	314.62	7.83	306.79
10	302.07	7.79	294.28
11	337.59	7.74	329.85
12	319.98	7.78	312.2
13	300.2	7.84	292.36
14	323.28	7.86	315.42
15	318.14	7.75	310.39
16	319.3	7.8	311.5

Table 5. Bulk density values for each of the plots sampled.

A (hayfield)	B (pasture)
1.65	1.52
1.65	1.36
1.60	1.52
1.52	1.69
1.48	1.63
1.40	1.74
1.50	1.46
1.49	1.56
1.48	1.53
1.52	1.47
1.68	1.65
1.44	1.56
1.60	1.46
1.21	1.58
1.23	1.55
1.31	1.56

Table 6. Hayfield CNS values showing before and after values were adjusted for moisture content.

Original Values			Adjusted for Moisture Content		
C (%)	N (%)	S (%)	C (%)	N (%)	S (%)
2.890	0.280	0.026	2.982	0.289	0.027
2.890	0.260	0.026	2.964	0.267	0.027
2.290	0.210	0.024	2.363	0.217	0.025
2.220	0.200	0.020	2.289	0.206	0.021
2.690	0.230	0.027	2.776	0.237	0.028
2.600	0.250	0.024	2.658	0.256	0.025
2.630	0.250	0.024	2.706	0.257	0.025
2.760	0.240	0.024	2.831	0.246	0.025
2.800	0.240	0.026	2.890	0.248	0.027
2.530	0.220	0.020	2.603	0.226	0.021
2.140	0.200	0.020	2.204	0.206	0.021
2.270	0.190	0.018	2.338	0.196	0.019
2.780	0.240	0.023	2.854	0.246	0.024
3.020	0.270	0.024	3.117	0.279	0.025
2.700	0.250	0.025	2.792	0.259	0.026
2.970	0.270	0.029	3.065	0.279	0.030

Table 6. Pasture CNS values showing before and after values were adjusted for moisture content.

Original Values			Adjusted for Moisture Content		
C (%)	N (%)	S (%)	C (%)	N (%)	S (%)
2.000	0.180	0.018	2.049	0.184	0.018
2.250	0.200	0.020	2.305	0.205	0.020
1.950	0.170	0.017	1.996	0.174	0.017
2.260	0.210	0.022	2.320	0.216	0.023
1.750	0.150	0.016	1.797	0.154	0.016
2.810	0.280	0.024	2.906	0.290	0.025
2.310	0.210	0.022	2.372	0.216	0.023
2.410	0.220	0.023	2.485	0.227	0.024
1.930	0.170	0.016	1.963	0.173	0.016
1.780	0.170	0.014	1.833	0.175	0.014
2.110	0.200	0.016	2.175	0.206	0.016
2.340	0.230	0.021	2.402	0.236	0.022
3.890	0.340	0.033	4.061	0.355	0.034
2.450	0.210	0.021	2.515	0.216	0.022
2.830	0.260	0.024	2.918	0.268	0.025
1.980	0.170	0.015	2.022	0.174	0.015

Table 7. Amounts (kg/ha) of carbon, nitrogen, and sulfur in the hayfield site.

C (kg/ha)	N (kg/ha)	S (kg/ha)
49.264	4.773	0.443
48.859	4.396	0.440
37.812	3.467	0.396
34.695	3.126	0.313
41.038	3.509	0.412
37.271	3.584	0.344
40.585	3.858	0.370
42.149	3.665	0.367
42.665	3.657	0.396
39.546	3.439	0.313
36.968	3.455	0.345
33.724	2.823	0.267
45.746	3.949	0.378
37.739	3.374	0.300
34.286	3.175	0.317
40.294	3.663	0.393

Table 8. Amounts (kg/ha) of carbon, nitrogen, and sulfur in the pasture site.

C (kg/ha)	N (kg/ha)	S (kg/ha)
31.182	2.806	0.281
31.444	2.795	0.279
30.341	2.645	0.265
39.303	3.652	0.383
29.311	2.512	0.268
50.570	5.039	0.432
34.590	3.145	0.329
38.705	3.533	0.369
30.117	2.653	0.250
26.973	2.576	0.212
35.875	3.401	0.272
37.502	3.686	0.337
59.357	5.188	0.504
39.670	3.400	0.340
45.279	4.160	0.384
31.500	2.705	0.239

Appendix II – Skewness and Kurtosis tests on raw data

		H x 10^6 g l-1	**Db** g/m, 3	**Db 2** g/m, 3	**N** (%)	**C** (%)	**S** (%)	**N** (kg/ha)	**C** (kg/ha)	**S)** (kg/ha)	**H+** (kg/ha)	**H+** (kg/ha)
N	Valid	32	32	32	32	32	32	32	32	32	32	32
	Missing	0	0	0	0	0	0	0	0	0	0	0
Skewness		**1.713**	**-0.72**	**-0.72**	**0.56**	**0.86**	**0.22**	**0.80**	**0.87**	**0.19**	**1.71**	**1.40**
Std. Error of Skewness		0.414	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41
Kurtosis		**4.362**	**0.75**	**0.75**	**0.73**	**2.04**	**0.23**	**0.60**	**1.15**	**-0.37**	**4.36**	**2.82**
Std. Error of Kurtosis		0.809	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81

Appendix III – ANOVA result tables and descriptive statistics for raw data.

Table 1. Bulk density ANOVA table.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	.026[a]	1	0.026	2.480	0.126
Intercept	54.968	1	54.968	5154.220	0.000
Field	0.026	1	0.026	2.480	0.126
Error	0.320	30	0.011		
Total	55.314	32			
Corrected Total	0.346	31			

a. R Squared = .076 (Adjusted R Squared = .046)

Table 2. Bulk density descriptive statistics.

Descriptive Statistics

Dependent Variable:

Field	Mean	Std. Deviation	N
Hayfield	1.282	0.122	16
Pasture	1.339	0.081	16
Total	1.311	0.106	32

Table 3. pH (g/kg) ANOVA table.

Tests of Between-Subjects Effects

Dependent Variable:

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1.617[a]	1	1.617	0.059	0.810
Intercept	1529.091	1	1529.091	55.414	0.000
Field	1.617	1	1.617	0.059	0.810
Error	827.814	30	27.594		
Total	2358.522	32			
Corrected Total	829.431	31			

a. R Squared = .002 (Adjusted R Squared = -.031)

Table 4. pH (g/kg) descriptive statistics table.

Descriptive Statistics

Dependent Variable:

Field	Mean	Std. Deviation	N
Hayfield	7.137	6.808	16
Pasture	6.688	2.973	16
Total	6.913	5.173	32

Table 5. H+ (kg/ha) ANOVA table.

Tests of Between-Subjects Effects

Dependent Variable:

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1.506E-6[a]	1	1.506E-06	0.000	0.987
Intercept	0.350	1	0.350	59.433	0.000
Field	1.506E-06	1	1.506E-06	0.000	0.987
Error	0.176	30	0.006		
Total	0.526	32			
Corrected Total	0.176	31			

a. R Squared = .000 (Adjusted R Squared = -.033)

Table 6. H+ (kg/ha) descriptive statistics.

Descriptive Statistics

Dependent Variable:

Field	Mean	Std. Deviation	N
Hayfield	1.047	0.982	16
Pasture	1.043	0.461	16
Total	1.045	0.754	32

Table 7. Carbon percentage ANOVA table

Tests of Between-Subjects Effects

Dependent Variable:

Source	Type III Sum of Squares	df	Mean Square	F	Sig.

Corrected Model	.882[a]	1	0.882	4.496	0.042
Intercept	207.832	1	207.832	1059.777	0.000
Field	0.882	1	0.882	4.496	0.042
Error	5.883	30	0.196		
Total	214.598	32			
Corrected Total	6.765	31			

a. R Squared = .130 (Adjusted R Squared = .101)

Table 8. Carbon percentage descriptive statistics table.

Descriptive Statistics

Dependent Variable:

Field	Mean	Std. Deviation	N
Hayfield	2.714	0.285	16
Pasture	2.382	0.558	16
Total	2.548	0.467	32

Table 9. Nitrogen percentage ANOVA table.

Tests of Between-Subjects Effects

Dependent Variable:

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	.006[a]	1	0.006	3.584	0.068
Intercept	1.702	1	1.702	984.634	0.000
Field	0.006	1	0.006	3.584	0.068
Error	0.052	30	0.002		
Total	1.760	32			
Corrected Total	0.058	31			

a. R Squared = .107 (Adjusted R Squared = .077)

Table 10. Nitrogen percentage descriptive statistics.

Descriptive Statistics

Dependent Variable:

Field	Mean	Std. Deviation	N
Hayfield	0.24455	0.02803	16
Pasture	0.21672	0.05169	16
Total	0.23063	0.04328	32

Table 11. Sulfur percentage ANOVA table.

Tests of Between-Subjects Effects

Dependent Variable:

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	.000[a]	1	0.000	6.490	0.016
Intercept	0.016	1	0.016	940.910	0.000
Field	0.000	1	0.000	6.490	0.016
Error	0.001	30	1.734E-05		
Total	0.017	32			
Corrected Total	0.001	31			

a. R Squared = .178 (Adjusted R Squared = .150)

Table 12. Sulfur percentage descriptive statistics.

Descriptive Statistics

Dependent Variable:

Field	Mean	Std. Deviation	N
Hayfield	0.02446	0.00306	16
Pasture	0.02071	0.00503	16
Total	0.02258	0.00452	32

Table 13. Carbon amount (kg/ha) ANOVA table.

Tests of Between-Subjects Effects

Dependent Variable:

Source	Type III Sum of Squares	df	Mean Square	F	Sig.

Corrected Model	.810[a]	1	0.810	1.667	0.207
Intercept	476.139	1	476.139	979.334	0.000
Field	0.810	1	0.810	1.667	0.207
Error	14.586	30	0.486		
Total	491.535	32			
Corrected Total	15.396	31			

a. R Squared = .053 (Adjusted R Squared = .021)

Table 14. Carbon amount (kg/ha) descriptive statistics.

Descriptive Statistics

Dependent Variable:

Field	Mean	Std. Deviation	N
Hayfield	40.165	4.740	16
Pasture	36.982	8.647	16
Total	38.574	0.705	32

Table 15. Nitrogen amount (kg/ha) ANOVA table.

Tests of Between-Subjects Effects

Dependent Variable:

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	.005[a]	1	0.005	1.095	0.304
Intercept	3.907	1	3.907	848.797	0.000
Field	0.005	1	0.005	1.095	0.304
Error	0.138	30	0.005		
Total	4.050	32			
Corrected Total	0.143	31			

a. R Squared = .035 (Adjusted R Squared = .003)

Table 16. Nitrogen amount (kg/ha) descriptive statistics.

Descriptive Statistics

Dependent Variable:

Field	Mean	Std. Deviation	N
Hayfield	3.619	0.472	16
Pasture	3.368	0.835	16
Total	3.494	0.679	32

Table 17. Sulfur amount (kg/ha) ANOVA table.

Tests of Between-Subjects Effects

Dependent Variable:

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	.000[a]	1	0.000	3.052	0.091
Intercept	0.037	1	0.037	856.693	0.000
Field	0.000	1	0.000	3.052	0.091
Error	0.001	30	4.36E-05		
Total	0.039	32			
Corrected Total	0.001	31			

a. R Squared = .092 (Adjusted R Squared = .062)

Table 18. Sulfur amount (kg/ha) descriptive statistics.

Descriptive Statistics

Dependent Variable:

Field	Mean	Std. Deviation	N
Hayfield	0.362	0.051	16
Pasture	0.321	0.078	16
Total	0.342	0.068	32

APPENDIX IV – Regression Rough Data

Table 19. Regression results for C v. N.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.968[a]	0.938	0.935	0.01100

a. Predictors: (Constant), C (%)R

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	0.054	1	0.054	450.122	.000[b]
	Residual	0.004	30	0.000		
	Total	0.058	31			

a. Dependent Variable: N (%) R

b. Predictors: (Constant), C (%)R

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	0.002	0.011		0.186	0.853
	C (%)R	0.090	0.004	0.968	21.216	0.000

a. Dependent Variable: N (%) R

Table 20. Regression results for C v. S.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.922[a]	0.850	0.845	0.00178

a. Predictors: (Constant), C (%)R

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	0.001	1	0.001	170.170	.000[b]
	Residual	0.000	30	0.000		
	Total	0.001	31			

a. Dependent Variable: S (%)R

b. Predictors: (Constant), C (%)R

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	-0.00014	0.002		-0.082	0.935
	C (%)R	0.00892	0.001	0.922	13.045	0.000

a. Dependent Variable: S (%)R

Table 21. Regression results for N v. S.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.908[a]	0.824	0.819	0.00192

a. Predictors: (Constant), N (%) R

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	0.001	1	0.001	140.900	.000[b]
	Residual	0.000	30	0.000		
	Total	0.001	31			

a. Dependent Variable: S (%)R

b. Predictors: (Constant), N (%) R

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	0.001	0.002		0.383	0.704
	N (%) R	0.095	0.008	0.908	11.870	0.000

a. Dependent Variable: S (%)R