EFFECTS OF PAST GRAZING AND TRAMPLING ON SOIL NUTRIENTS AT STANLEY HILL BISON, KAKABEKA FALLS, ONTARIO

by

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An Undergraduate Thesis Submitted in
Partial Fulfillment of the Requirements for the
Degree of Honours Bachelor of Environmental Management

Faculty of Natural Resources Management
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April 2020

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ABSTRACT

Panza, D. 2020. Effects of past grazing and trampling on soil nutrients at Stanley Hill Bison, Kakabeka Falls, Ontario. 34 pp.

Keywords: bison management, livestock management, soil quality, soil erosion, soil compaction, soil texture, carbon

Global studies indicate that ungulates can have negative influences on soil quality and directly affect soil nutrient availability. This thesis examines the effects of past cattle grazing and current bison grazing on soil quality on a small, rented farm property in Kakabeka Falls, Ontario. Three fields were chosen for comparison of a position at the top of a hill intended to be used in rotational grazing (upslope area), a heavily trampled mid-slope area, and the downslope area of the same hill near a natural watercourse used for livestock watering. Bulk density, loss on ignition (an estimate of soil organic carbon), and concentrations of soil macro-, micro-, and secondary nutrients were calculated to compare the soils. ANOVA and MANOVA tests show that there were significant differences with slope position and that, as expected from literature on seepage, higher macronutrient levels were generally downslope. The mid-slope area had lowest bulk density and highest soil organic carbon, perhaps due to high quantities of manure in the soil. Continued monitoring of soil quality at the farm is recommended as planting and rotational grazing remediate past failure to manage the pastures.

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ACKNOWLEDGEMENTS

I would like to thank my thesis supervisor, Dr. Brian McLaren for his assistance in completing my undergraduate thesis. I am grateful for Tim and Ashley Janssens at the Stanley Hill Bison farm for allowing me to collect data on their property and for assisting in any way they could. I would like to thank Dr. Lense Meyer for being my second reader. I would like to thank Johane Joncas and Greg Kepka from Lakehead University for performing soil tests for this thesis.

INTRODUCTION

Ungulate grazers can have a significant influence on grassland soil dynamics, and their negative influence on soil properties and soil erosion can decrease vegetation biomass (Frank and Groffman 1998; Augustine and Frank 2001). The North American bison (*Bison bison* L. 1758) is the largest ungulate in North America and, because of its size, has had a profound effect in altering landscapes. Heavy bison grazing can lead to decreased carbon-to-nitrogen (C:N) ratios in plants and soils, while overgrazing can result in increased defoliation, which leads to decreased root production in plants (Frank and Groffman 1998). Wallowing is a common practice for bison and results in circular soil depressions across grasslands (Coppedge *et al*. 1999). Wallows can result in soil compaction, which leads to an altered vegetation presence from that of the surrounding landscape (Knapp *et al*. 1999).

This study will take place on a bison farm, Stanley Hill Bison in Kakabeka Falls, Ontario, which has 40-45 bison at present. The farm encompasses grazing pastures, a wooded area for cover and a medium-sized stream as a water source at the southern part of the enclosed area; adjacent rented land increases the amount of pasture overall. Nevertheless, the range of the farm bison is significantly smaller than that for an average bison in the wild. Bison were historically found across most of what today is central USA, Alberta, British Columbia, and Manitoba (Soper 1941). Estimates of past population size exceed tens of millions, but due to human hunting their numbers dwindled throughout 19th century (Freese *et al.* 2007). Bison diets mainly include grasses and sedges, but they occasionally eat berries and lichen (Reynolds *et al.* 1978). Home ranges of bison differ among age classes and sex, 1,240 km^2 for females, and

1,060 km^2 for males (Larter and Gates 1994). It appears likely that, due to the small area that over 40 (mostly female) bison occupy in an area not much larger than 0.3 hectares on the Kakabeka Falls farm, without management, soil deterioration could be accelerated.

The aim of this thesis is to aid Tim and Ashley Janssens in determining the soil quality in three different areas on their farm and to help in guiding future grazing management. Objectives are to collect soil samples from these areas, to estimate from them bulk density, loss on ignition (an estimate of soil organic carbon; SOC), and concentrations of soil macro-, micro- and secondary nutrients, then to compare them using (Multivariate) Analysis of Variance, ANOVA and MANOVA.

From the work in Yellowstone National Park, like in other studies of seepage in natural soils, slope position can play an important factor in soil deterioration, as downslope areas have higher-quality soil with more carbon (C), nitrogen (N) and plant biomass, while mid- to higher slopes have much lower quality soil (Frank and Groffman 1998). So, for this study, the first hypothesis is that bison will have the strongest effect on soil quality in the mid-slope sample area. The second hypothesis is that the poorest native soil condition will be at the upslope sample area.

LITERATURE REVIEW

Soil quality is one of the most important underlying features of any ecosystem. The nutrients in soil will either help plant growth flourish or diminish it. Healthy soil is composed of organic material and minerals that contribute to nutrient cycling required to maintain soil health (Bot and Benites 2005). Organic material can be any dead plant or animal species that decomposes and returns to the soil. This decomposition process binds the soil into aggregates and improves water retention.

There are four major elements which contribute to soil quality and they are C, N, phosphorous (P), and sulfur (S) (Doran *et al*. 1999). Poor agricultural and farming practices, such as over-fertilization and tillage, can lead to decreases in these essential elements. When soil becomes unstable, it is susceptible to increased seepage, which leads to erosion, especially where a slope occurs on the landscape (Huang and Laften 1996).

Ungulate and cattle grazing play an important role in plant life and soil dynamics. It is important to properly manage soil in areas where overgrazing and soil compaction has occurred. This literature review will be focused on bison behaviour and the effects of grazing on grasslands.

BISON BEHAVIOUR

Wallowing is a unique bison behavior that is described as when the bison lie down and repeatedly roll on their sides (McMillan *et al.* 2000). Understanding the frequency of wallowing during different times is an important part of uncovering wallowing effects on soil. Wallowing occurs most frequently during the months of July and September, with males wallowing 1.7 times more per day than females and almost four times more than yearlings. In areas where bison wallow, the soil temperature is a degree warmer than areas that have not been wallowed in. Temperature variation is also much higher in areas of wallows and is 4.6 degrees Celsius lower at 3 cm depth than at the surface. The primary function of wallowing is to gain relief from biting insects, but secondary function could include play behaviours, thermoregulation, relief from shedding, social behaviour associated with conflict and rut, social behaviour associated with group cohesion, and defense from ectoparasites (McMillian *et al*. 2000).

Behaviours and spatial characteristics give a better indication of areas of preference where the bison begin to wallow. Coppedge and Shaw (2000). identified 170 wallow incidents over their 331 hours of observations. Bare soil experienced 60% of all wallows, disturbed soil 15% of all wallows, and new wallows in vegetated areas accounted for the remaining 25%. Two thirds of the observed bison preferred wallowing in areas that had a moderate slope (4-7%). Ninety-four percent of wallowing occurred in low elevations. Soils examined in wallowed areas were much coarser than reference sites. The coarse-grained soil could play an important factor in where the bison chose to wallow. Wallows play a crucial role in soil reformation sites and are an important habitat for ephemeral plant species.

Stampedes frequently occur among bison herds whenever there appears to be a threat (McHugh 1958). Stampedes could be started by small incidents, such as one bison accelerating, sudden movement by other ungulate species, or catching the scent of humans. Stampedes are significant to soil because of the trampling that occurs.

Trampling can have a negative impact on soil quality through soil compaction and lower infiltration rates (Warren *et al*. 1986). Positive correlations can be found between trampling intensity, infiltration rates and sediment production when trampling occurs on dry and moist soils.

GRAZING EFFECTS ON GRASSLANDS

Grazing management is an important part of managing wild ungulates and livestock herds. Vegetative diversity and growth are dependent on soil characteristics such as soil pH, organic matter, fertilization, and grain size structure (Glowacz and Niznikowski 2017). Season-long, continuous grazing and short duration grazing with high intensities have effects on soil water status and infiltration rates that determine soil health and vegetative diversity. Naeth and Chanasyk (1995) illustrated this point by using test sites to determine how grazing influences water retention. Soil moisture in spring was lowest in the site where continuous heavy grazing occurred. In continuous very heavy, continuous heavy, and short-duration very heavy grazing, upper slopes consistently had lower soil moisture in every season, while short-duration heavy grazing had higher soil moisture in autumn and mid-slopes had the highest soil moisture during spring and summer.

Soil moisture is an important factor to plant growth. Heavy grazing in warmer climates may not influence water content in soils but can have influences on biomass. Orodho *et al.* (1990) found there to be no significant differences in soil moisture between grazed and ungrazed sites, while there were significant differences in soil moisture with topographic position, season, and sampling depth. Hillside slope positions have higher soil moisture than hilltops and the bottoms of hills. Soil moisture is greater at increased depths, and deep-rooted vegetation have a better advantage in accessing these water resources.

C and N are two essential elements for soil health and plant production. There are concerns that overgrazing and improper management can cause deficiencies in these macronutrients, but long-term grazing in British Columbia showed that C and N generally remained unchanged after 20 years of grazing (*et al*. 2011). The most notable changes in this experimental study were in pH changes and polysaccharides. In a mixed-grass prairie environment in Wyoming, the impacts on an area where livestock grazing had occurred for 12 years were significant decreases in N and C in the above-ground biomass (Shuman *et al*. 1999). As a plant is frequently grazed, it will allocate more C into leaf production than root production (Schuster 1964). The total soil profile for C showed that there was over 13,000 more kg/ha of C at the continuous heavy grazing than at the control site in the areas observed by Shuman *et al*. (1999). Likewise, grazed areas tested for more overall N in the soil than at the control site. Soil resources appear to be enhanced with grazing in some situations and grazing can be a key component of grasslands.

On the contrary, there have been similar studies that have showed that C and N pools can decrease due to overgrazing. In tests to examine sheep grazing and its direct effect on C and N Golluscio *et al*. (2009) found that SOC was lowest on a heavily grazed site, but N content decreased by 18% from the control in the heavily grazed site. The amount of exposed soil, which can be primarily blamed on decreased herbaceous and standing dead cover, was significantly increased with heavy grazing. The reference areas were more enriched with higher stable C and N isotopes. In Northern China, a 50-

hectare natural grassland that was subject to livestock grazing for many years was compared to two areas where no grazing had occurred in five or ten years (Yong-Zhong *et al*. 2005). The control sites had soils with much more silt and clay comparing soils on the grazed site. Organic C concentrations were highest in the grazed site after 10 years, although the difference was not apparent with five years of grazing. Total N concentrations were higher in control area. The study area in Northern China is very prone to desertification and continuous overgrazing could fast-track soil nutrient depletion and soil erosion.

MATERIALS AND METHODS

STUDY SITE DESCRIPTION

The Stanley Hill Bison Farm in Kakabeka Falls, Ontario, is 24 km from Thunder Bay. The owners of the farm are Tim and Ashley Janssens and they have owned the farm for the past five years. The farm is currently being used to raise bison to produce various kinds of bison meat, which is sold to the public. Prior to the land being purchased by Tim and Ashley Janssens, the land was used as a beef cattle ranch. The total land area available to the bison is limited to just over 0.3 ha (Figure 1). The smaller rectangle on the south side of the map representing where calves and juvenile bison are held until they are strong enough to join the herd. The area on the eastern side represents a rotational grazing pasture for the bison which is especially used in the winter months.

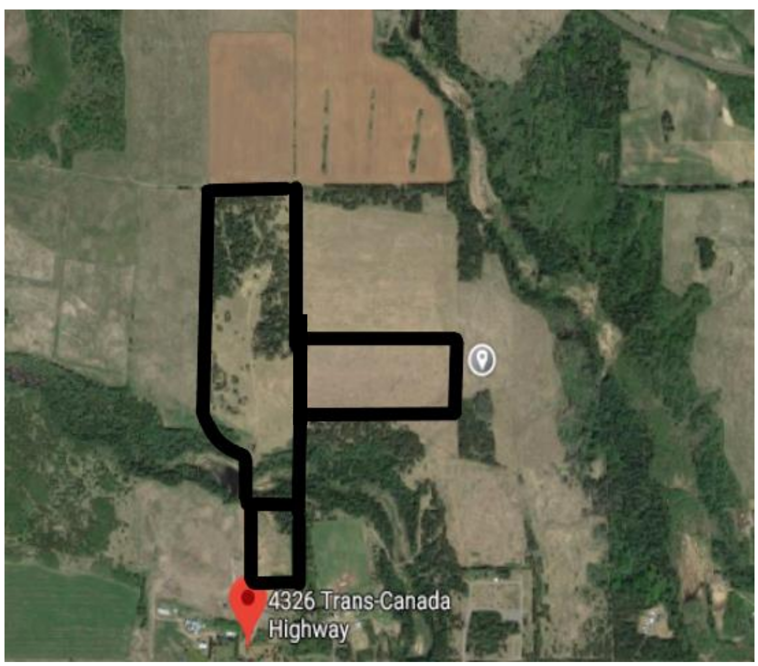

Figure 1. Satellite imagery displaying the Stanley Hill Bison farm in Kakabeka Falls, Ontario.

SAMPLING METHODS

Soil samples were collected from three main areas on the farm (Figure 2). The three areas were picked based on slope positions, including a mid-slope area (Figure 3), downslope area (Figure 4), and a rotational grazing area in an upslope area (Figure 5). Samples were collected on October 28, 2019 and sampling was completed within a 3-hour window. The soil samples were collected using a soil auger provided by Lakehead University. There were 90 samples collected from the three sampling areas, three composites of 10 auger samples in each. The subsampling locations for each composite were separated by five paces, which equated to be 8 m apart. After extraction of the soil from the auger, it was placed in large plastic bags to be transported to Lakehead University and placed in a refrigerator. Any dead organic material, such as plant roots or above ground flora, were removed and the composites were homogenized by hand stirring.

LAB METHODS

Composite samples were air dried on a metal sheet for 72 hours before sieving. Bulk density was the first test to be completed and consisted of taking three subsamples corresponding to each of the three sample areas and drying them in a conventional oven at 100°C for four hours. Soil samples were immediately weighed after being taken out of the oven. The sub-samples were then placed back into the oven and weighed again after an additional hour, to ensure that all moisture had been evaporated. If the subsample had a different weight than the first test, it was again placed in the oven for another hour until it was determined that the weights of the samples were not changing.

The weights of the soil, aluminum pans, and crucibles were measured before insertion into the oven and then immediately after the samples were taken out of the oven.

The second analysis was loss on ignition. The nine composite samples were grinded and sieved through a 110-micron filter to collect the finest particles of soil only. Four grams of fine soil were first dried in a conventional oven at 102°C for 24 hours. The samples were then weighed and then placed back in the oven for another two hours. When the samples had the same weight as the previous time, they were placed in a higher heat oven and left inside for two hours at 550°C. Following the two hours, they were weighed and then placed back in the oven at the same temperature. After four hours were up, the samples had a very minimal drop and it was determined to leave the samples in for one more hour. Upon weighing the samples after five hours, the samples displayed the same weight as when the four hours were up. The sample weights were recorded in Microsoft Excel.

Metal analysis was by Johane Joncas of the Lakehead University Environmental Laboratory. For all nine samples the sieved soil was used, and three to four grams was brought to her for metal analysis. A N test was administered by Greg Kepka, who is a technician in the CASES building at Lakehead University. Five grams of the sieved soil was brought to him in his laboratory.

ANOVA and MANOVA statistical analysis in SPSS were used to determine the significance of the differences in the soil parameters.

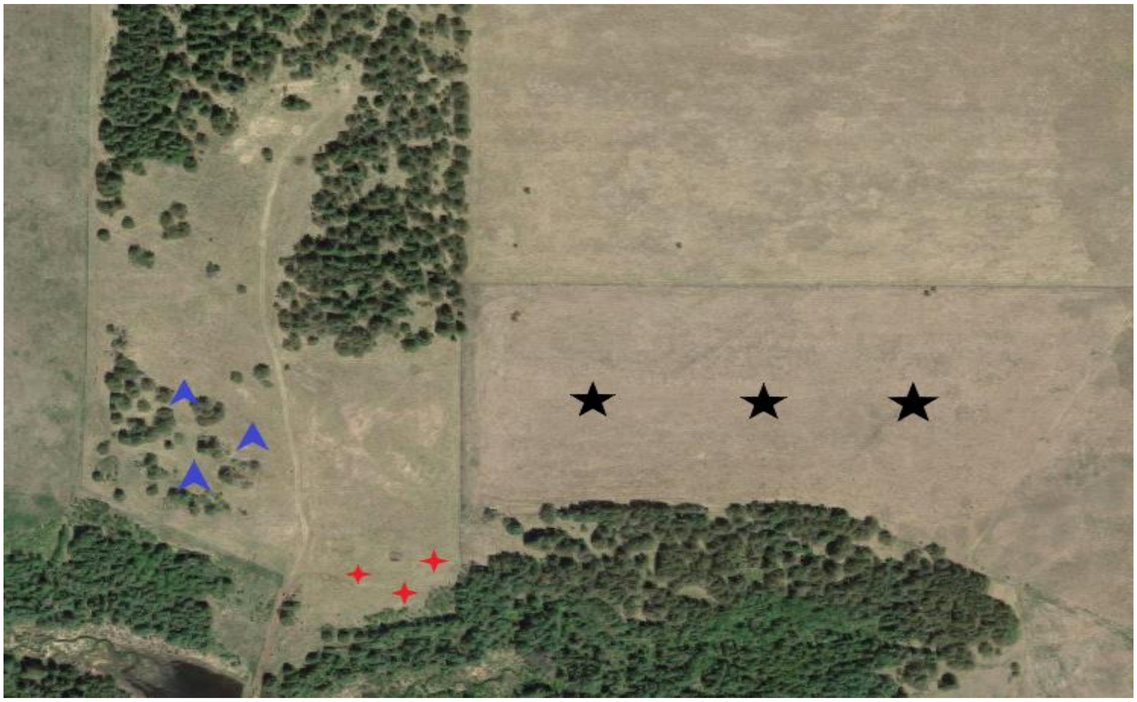

Figure 2. Sampling locations on the farmland.

Figure 3. The first sampling site, representing the mid-slope area.

Figure 4. The second sampling site, representing the downslope area.

Figure 5. The third sampling site representing the rotational grazing pasture and the upslope area.

RESULTS

The mid-slope soil had the lowest bulk density at 1.41 g/cm^3, followed by the downslope soil at 1.95 g/cm^3. The upslope area soils had a bulk density of 2.03 g/cm^3 (Table 1). The MANOVA for the macronutrients (C, N, P and K) indicated significant differences across the sample areas ($F = 14.6$; $p < 0.01$). Loss on ignition (Table 2) resulted in highest SOC estimated for the mid-slope soils and differences significant across all three sample areas. Nitrogen content was not different in the lower and middle slopes, but the upper slope soils had a lower N content. Using the estimates from loss on ignition and total N, the highest C to N ratio was on the upper slope (30.4), followed by the mid-slope (27.2), and then the downslope area (23.8; Figure 7). These estimates are significantly different (ANOVA, $F = 60.6$; $p < 0.001$). There were no differences in P concentrations (Figure 8), while potassium (K) had a higher concentration in the downslope samples (Figure 9).

Table 1. Bulk density calculations.

Sample area	Aluminum pan weight (g)	Oven dried weight (g)	Total soil weight (g)	Difference (g)	Bulk density (g/cm^3)
Low1	13.87	426.89	413.02	5.18	1.95
Low2	13.87	426.98	413.11	5.09	1.95
Low3	13.87	426.91	413.04	5.16	1.95
Mid1	10.93	310.71	299.78	5.63	1.41
Mid2	10.93	309.63	298.70	6.71	1.41
Mid3	10.93	310.50	299.57	5.84	1.41
Upper1	13.87	443.20	429.33	68.92	2.03
Upper2	13.87	445.77	431.90	66.35	2.03
Upper3	13.87	445.25	431.38	66.87	2.03

Table 2. Results from the loss on ignition analysis.

Sample area	Crucible weight (g)	Total weight (g)	2 h at 550°C (g)	4 h at 550°C (g)	5 h at 550°C (g)	Total weight (g)	Difference (g)
Low1	10.07	3.91	13.63	13.62	13.62	3.547	0.366
Low2	10.58	3.92	14.18	14.18	14.18	3.594	0.323
Low3	10.92	3.93	13.24	13.23	13.23	3.615	0.310
Mid1	10.87	3.90	14.36	14.35	14.35	3.477	0.420
Mid2	9.80	3.90	13.29	13.28	13.28	3.480	0.417
Mid3	9.87	3.92	13.44	13.43	13.43	3.556	0.363
Upper1	10.93	3.92	14.54	14.54	14.54	3.605	0.312
Upper2	11.03	3.91	14.66	14.65	14.64	3.604	0.307
Upper3	10.10	3.92	13.77	13.76	13.76	3.655	0.263

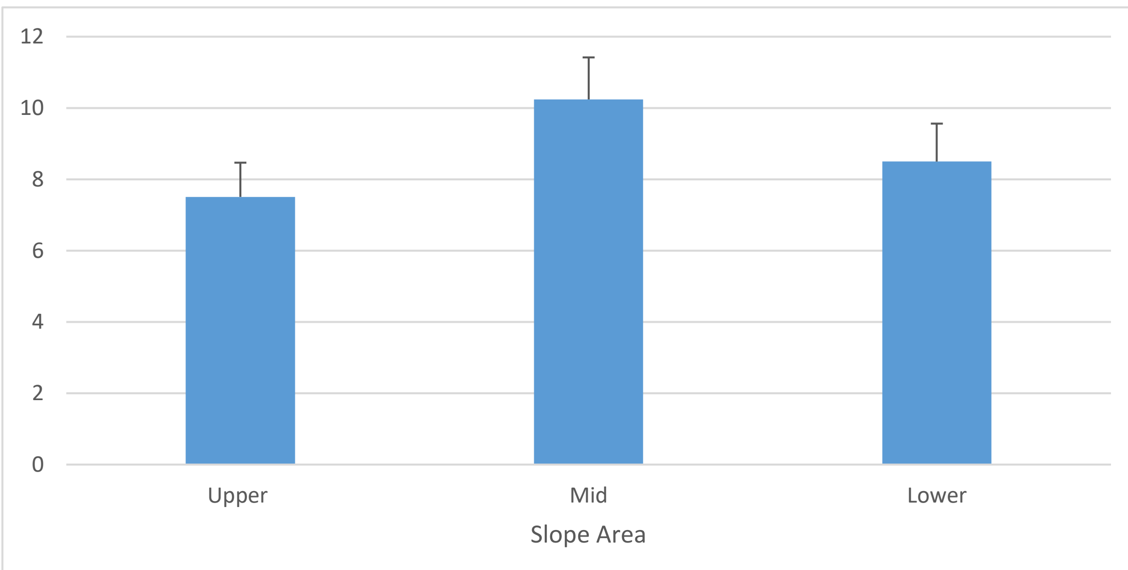

Figure 6. Soil organic carbon (%).

Secondary nutrients (Ca, Mg, S) were also significantly different across the sampling areas (MANOVA; $F = 14.6$; $p < 0.01$). Calcium (Figure 11) and Mg (Figure 12) both had lower concentrations in the upper slope areas, although the difference for Mg was only significant when compared to the mid-sloped areas. Sulfur, on the other hand was significantly lower on upper slopes, with no difference in mid- and upper slopes (Figure 13).

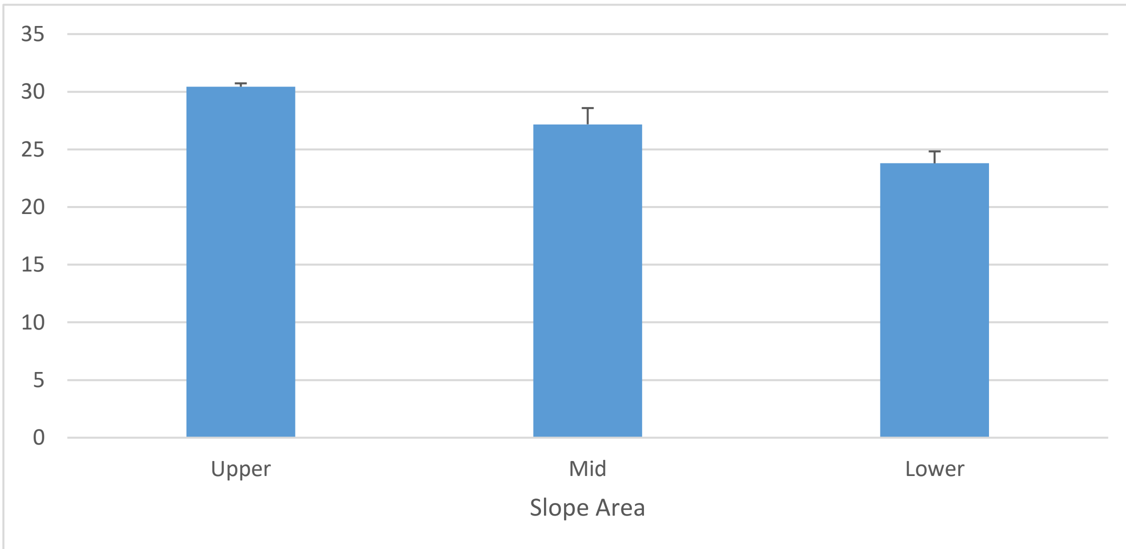

Figure 7. Carbon to nitrogen ratio (means with upper 95% confidence limits).

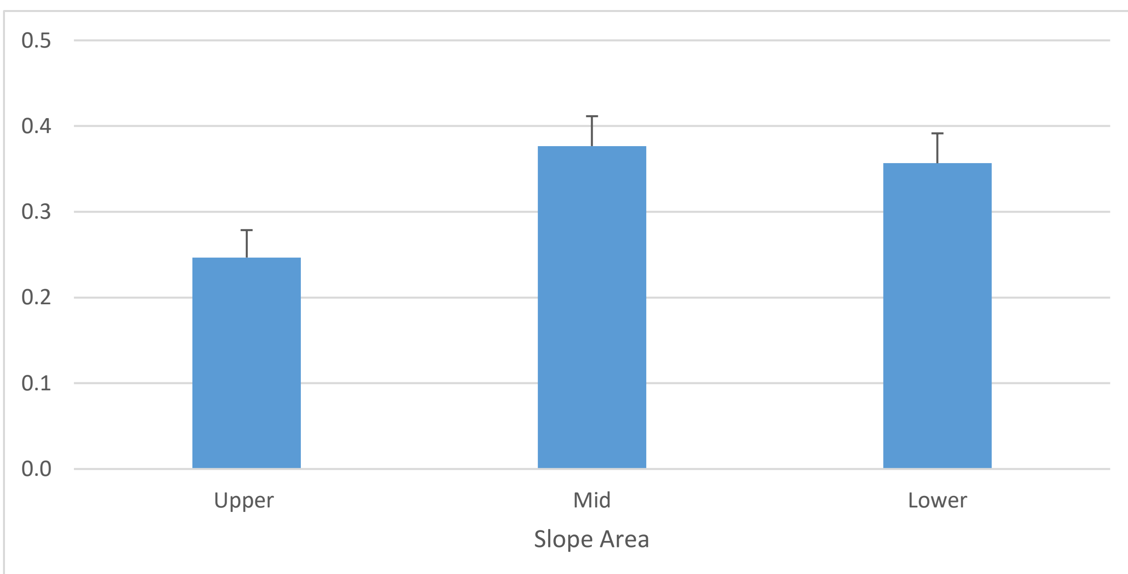

Figure 8. Nitrogen (%; means with upper 95% confidence limits).

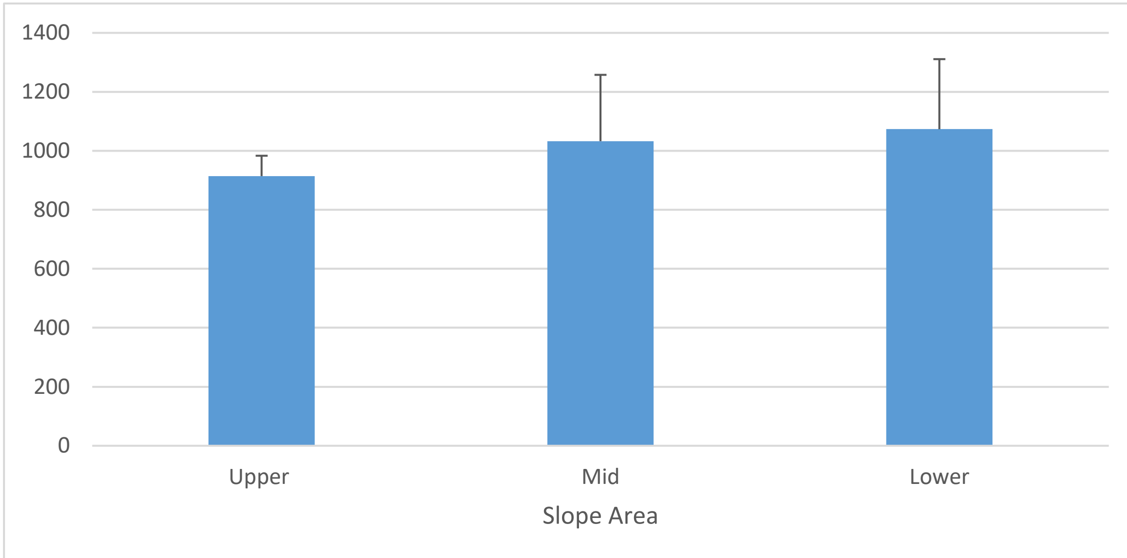

Figure 9. Phosphorus (μg/g; means with upper 95% confidence limits).

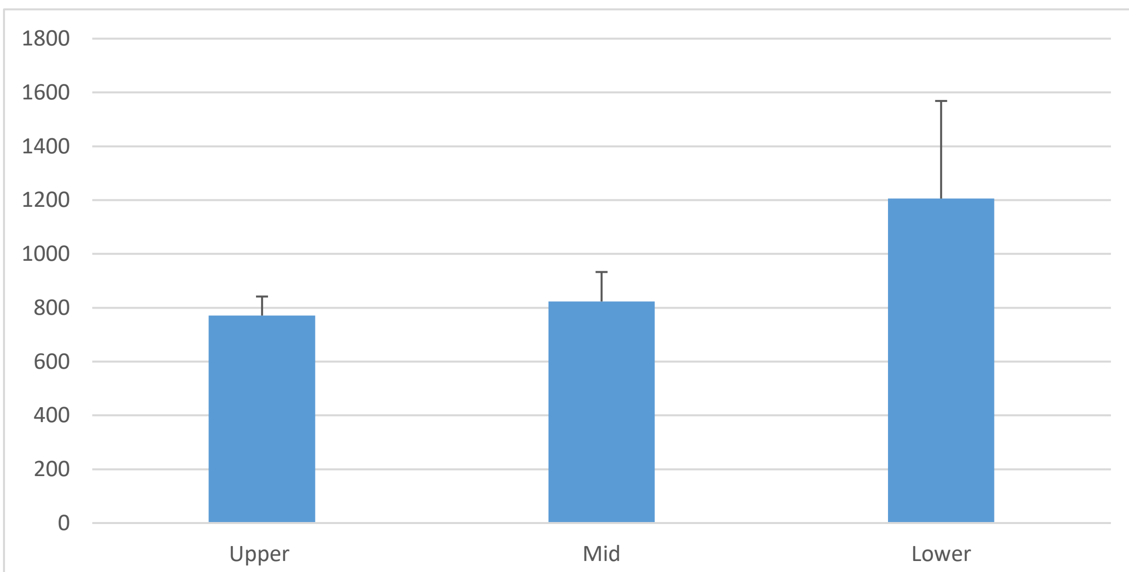

Figure 10. Potassium (μg/g; means with upper 95% confidence limits).

Considered together, there were significant differences among the micronutrients analyzed (Cu, Fe, Mn, Zn; MANOVA ($F = 4.1$, $p = 0.05$). However, none of those analyzed were different individually (Figures 14-17).

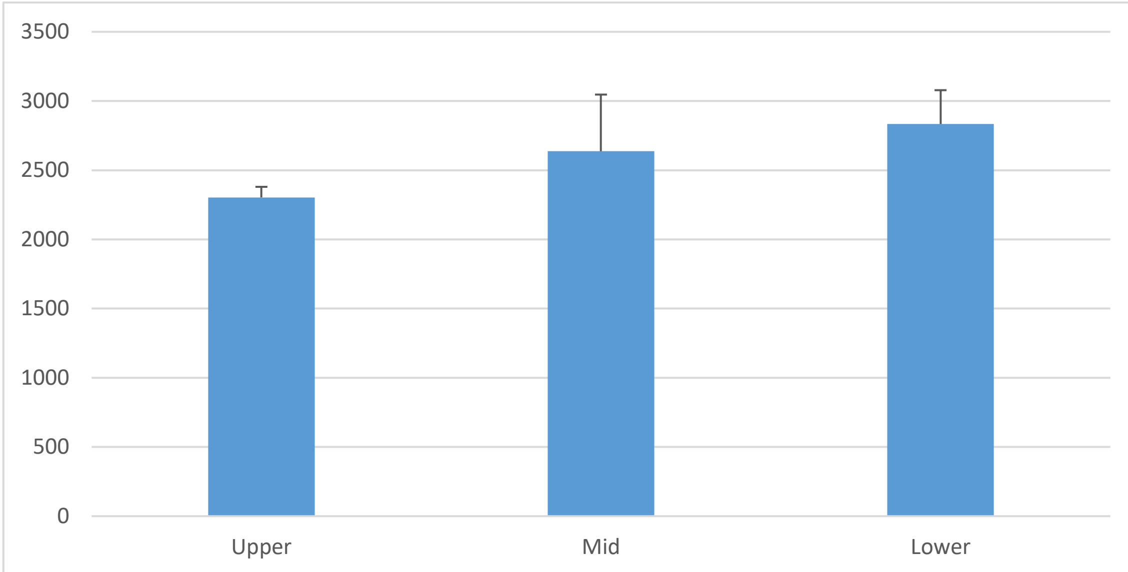

Figure 11. Calcium (µg/g; means with upper 95% confidence limits).

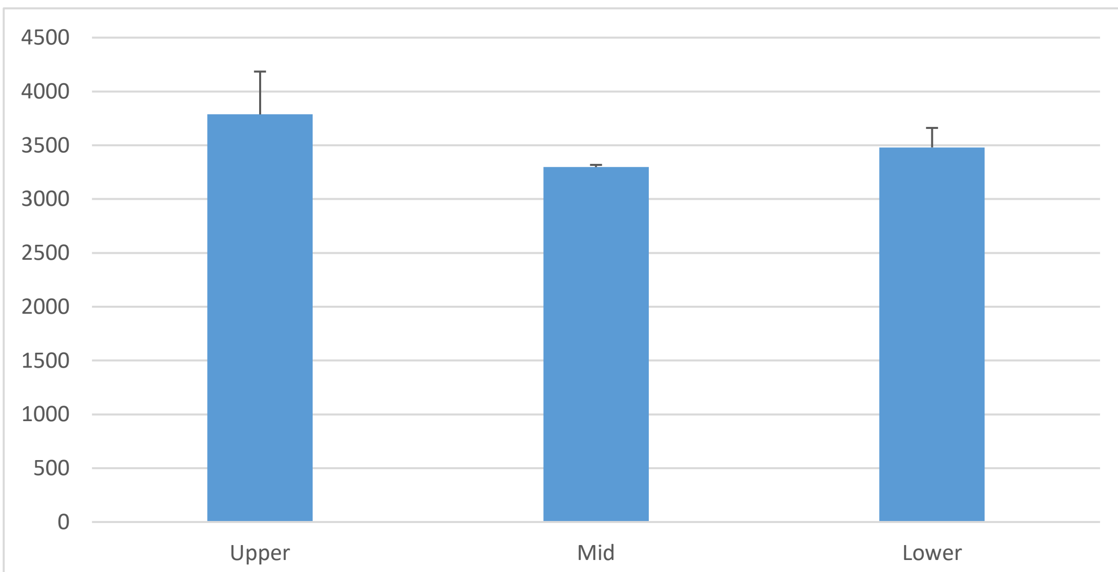

Figure 12. Magnesium (µg/g; means with upper 95% confidence limits).

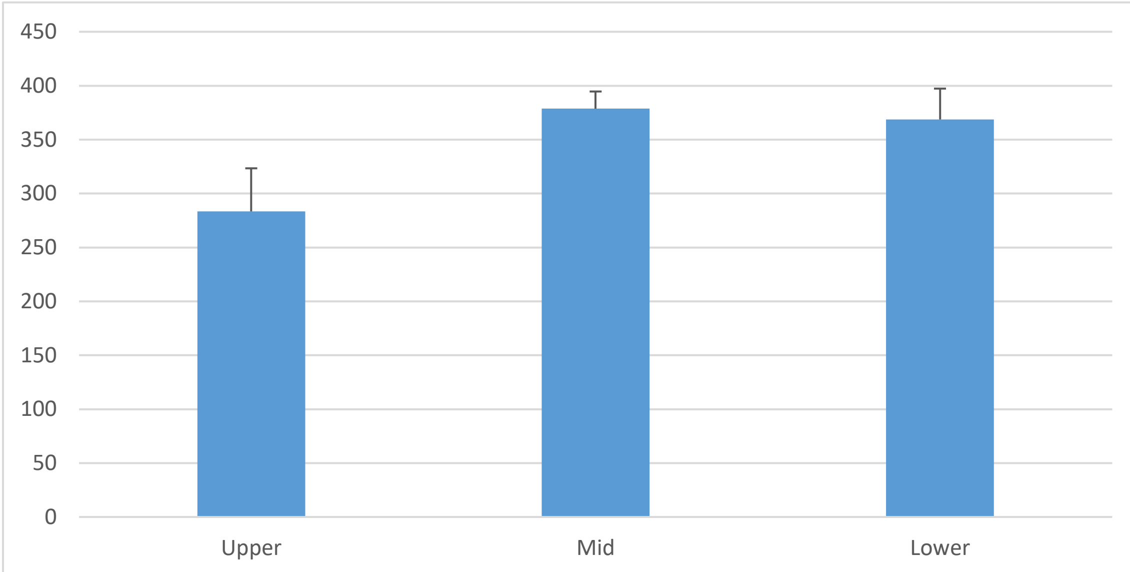

Figure 13. Sulfur (µg/g; means with upper 95% confidence limits).

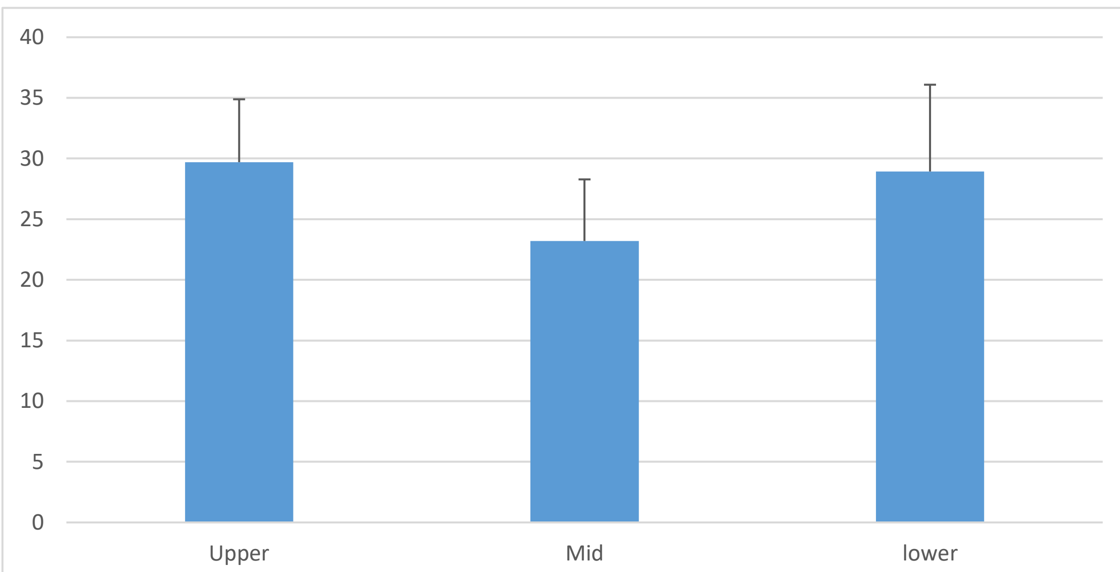

Figure 14. Copper (µg/g; means with upper 95% confidence limits).

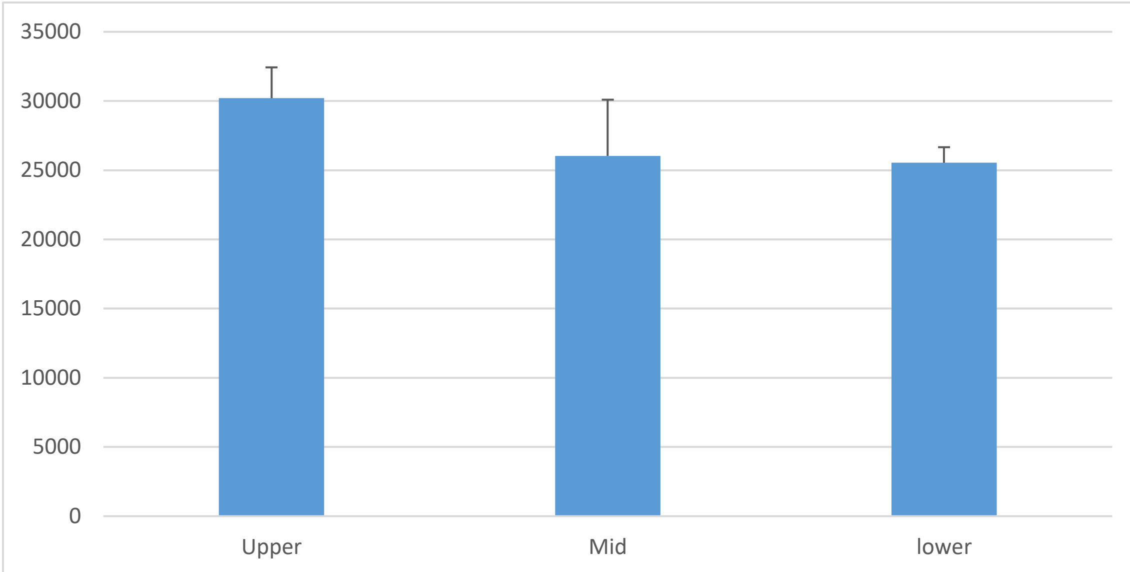

Figure 15. Iron (µg/g; means with upper 95% confidence limits).

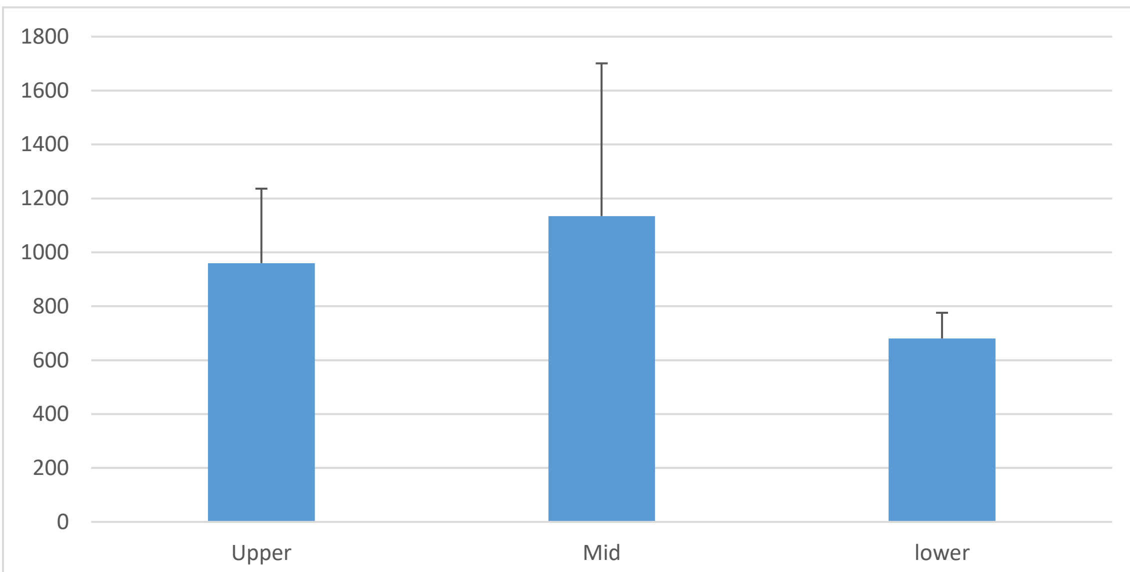

Figure 16. Manganese (µg/g; means with upper 95% confidence limits).

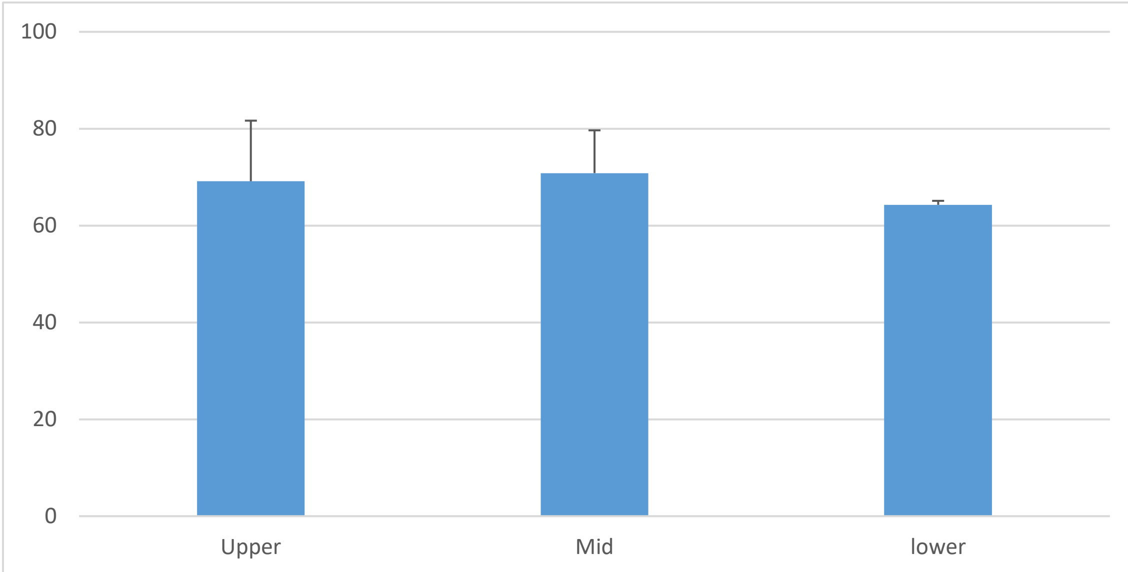

Figure 17. Zinc (µg/g; means with upper 95% confidence limits).

DISCUSSION

Soil quality data are vital to understanding growing patterns of plants (Tilak *et al.* 2005). Plant productivity depends most on a soil's ability to hold nutrients and on the microorganisms that play a role in breaking down biological debris. The most important nutrient for plants is N, essential as a protein constituent that can be further broken down into amino acids, amino sugars, and polypeptides (Allison 1954). In ungulates, N is consumed by grazing on plant materials and a large amount of digested N is returned to the ecosystems through urination and feces (Hobbs 1996). The N concentration in soils at the bison farm was lowest in the upper slope, which is predictable given my second hypothesis based on fundamentals related to seepage. The upslope fields are now used as a rotational grazing area with gates that prevent the bison from venturing out *ad lib* into this area, an excellent response toward rehabilitating soils in the nutrient-deficient fields. The lower and mid-sloped areas are far more frequented by the bison and, due to their smaller and concentrated range within this farm, higher N could represent the constant presence of urine and manure being excreted by the bison. Certainly, the mid-slope area had lowest bulk density and highest SOC, perhaps due to high quantities of manure in the soil. This observation coincides with the first hypothesis, that the bison have the strongest effect on soil quality in the mid-sloped areas.

Metals, in large quantities, can have detrimental effects on soil health and can negatively influence microbial activity (Baath 1989). Although metals in large quantities can be damaging to the soil, metals such as Fe, Zn, Cu, Co, and Ni are essential micronutrients for healthy plant growth (Wuana and Okieimen 2011). P and K are key elements for plant growth and healthy soil, and like C and N, are considered macronutrients. Healthy ranges of P in topsoil are from 50-3000 μg/g (Sims and Pierzynski 2005). The recorded P concentrations throughout all the sample areas of the bison farm range from 914 to 1,073 μg/g, indicating healthy soils. The highest quality soils on the farm, considering C:N ratios, are at the downslope position, again conforming to my second hypothesis. The upper slopes also have the lowest concentrations of the four macronutrients (C, N, P, and K).

Follow-up studies should be done in order to compare results from the tests done in this thesis to future tests. Future studies could examine the influence of the soils on the groundwater or on the stream and pond that are on the property. Water quality and benthic communities in streams and rivers are similarly influenced by soil erosion. Another research topic is the pH of the soils, which was beyond the scope of this thesis.

CONCLUSION

There are significant differences in the C:N ratios, organic C, N, K, and micronutrients in the soils at the Stanley Hill Bison farm. These results indicate that slope position plays an important role on the bison farm. The bison are having the strongest effect on soils in the mid-sloped area and the poorest soil conditions occur on the upslope areas. This thesis' goal was to aid in determining soil attributes, maximizing soil health, and to recommend future farming practices for the Stanley Hill Bison farm. These results can be a baseline for other tests conducted on the farm. Sampling was conducted over a limited timeframe and were taken in autumn when the effects of the bison on the soil could be maximal after a summer of grazing. Future tests should be done in the early weeks of spring to make a comparison to the results found in this thesis. Also, the Db, soil depth (at a constant of 10 cm) and nutrient concentrations could later be used to see if there are differences in amount rather than just differences in nutrient concentration.

As global temperatures continue to change, the earlier springs and later falls could play a crucial role in soil quality on farms in Northwestern Ontario. Soil quality is important to all organisms on earth and continued research into all aspects of soil health, compaction, pH, nutrient analysis or water content is crucial to the planet's future.

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