GRAZING INTENSITY AND CARBON POOLS IN SOILS AND FORAGE PLANTS ON THE THUNDER BAY COMMUNITY PASTURE

by

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ABSTRACT

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Keywords: grazing intensities, carbon, plant communities, loss of ignition, carbon sequestration

This thesis explores carbon (C) storage in the forage plants found on the Thunder Bay Community Pasture (TBCP). Plant tissues, roots and shoots, were collected from the TBCP and analyzed at Lakehead University using a loss on ignition technique. This thesis summarizes the (C) pools, the importance and influence of C on soils and plants species, comparing grazing intensities of cattle on the pasture. C storage in the plant communities subjected to high grazing intensity do not differ from levels found in areas subjected to light and medium grazing intensities. Ultimately, plant species in all three functional groups compared (annuals, grasses and legumes) did not have differences in above-ground (C) stores at the grazing intensities observed in the TBCP.

CONTENTS

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INTRODUCTION

Herbivores can shape grassland ecosystems, with domestic herbivores sometimes doing so and creating issues in sustainable land use (McLeod 1997). Grazing herbivores, for example, can alter the quantity and quality of nutrients being transferred into soil (Bardgett et al. 2003). Ungulates and grasslands have, however co-evolved, and when grazing controls the species composition of grasslands, it can either limit or promote plant richness and diversity, which in turn affects the carrying capacity of the grazers.

Rotational grazing is widely used within the cattle industry in Canada because it can promote and improve the sustainability of native grass-based pasture systems by allowing vegetation to recover after short high intensity grazing (Sanderman et al. 2018). This study will be looking at three grazing intensities and comparing them in terms of the carbon (C) pools found in net belowground production (NBP) and net aboveground production (NAP) created by plant sequestration via photosynthesis. It will do so considering the species composition of the Thunder Bay Community Pasture (TBCP).

The Thunder Bay Community Pasture is located in the agricultural belt southwest of the City of Thunder Bay and is approximately 395.37 hectares over four parcels. The TBCP was developed between the years of 1954 and 1972 when the Federal and Provincial governments acknowledged that the lack of expansion in the livestock industry in the region was due to the limited carrying capacity of the averaged-sized farm (Dilley and Loghrin 1975). The official statement was: “The pasture development will enable farms in the district to increase their beef livestock carrying capacity and upgrade the quality of stock by means of a better breeding program.”

This thesis used plant samples collected by Alyssa Lovatt who was employed at the TBCP over the summer of 2019 with an NSERC Undergraduate Student Research Award. The different forage plants were identified by species compositions in 2 m by 2 m plots (*N* = 46), measuring root and shoot biomass, field composition, and the yield. I was able to correlate three target areas of different grazing intensities by beef cattle (High, Medium and Low) with the C levels in forage plant stems and soil. The hypothesis is that grazing intensity plays a vital role in NBP and NAP and that there will be a greater depletion of C levels in high-intensity grazing areas. This effect can differ and therefore will be compared by functional group, among legumes, grasses, and annuals.

LITERATURE REVIEW

The global C cycle includes four major C pools: Earth's Crust, Terrestrial Ecosystems, Atmospheric Reservoirs and Ocean Reservoirs. This thesis will be focussing on the Terrestrial Ecosystems in the literature review. It includes C stored in vegetation, above- and below-ground organic matter, soils and micro-organisms.

Carbon is an essential element for life on earth, transferred from the environment to living creatures, from plants harvesting the C during photosynthesis and storing it in their roots, stems and leaves. Once vegetation dies, C is released back into soils through respiration and combustion. This process is evidently important for natural ecosystems such as forests, marches and grasslands and is about the creation of natural C sinks and pools (Janowiak et al. 2017). The largest component of organic C found in soil is degraded over millennia and eventually becomes inorganic matter in C pools (Torn et al. 1997).

In terrestrial ecosystems, the highest fraction of C is found below ground (Houghton 2007). Carbon, particularly grassland C, is a necessity within the terrestrial ecosystem. Grassland C helps with water-holding capacity, lowers potential wind and water erosion, and aids in soil fertility (Janowiak et al. 2017). The sequestration of C in forests, grasslands and other natural ecosystems is mitigating the atmospheric CO_2 accumulation by capturing greenhouse gases, this in turn aiding in the fight against climate change (Shao et al. 2015).

Forests behave very different from grasslands. For example, a natural forest setting in Bangladesh was assessed for C stocks and trees had the largest accumulation of C, reaching 59% of the total C in the system (Ullah et al. 2012). The second largest accumulation was in the undergrowth within the forest, herbs, shrubs and grasses weighing in at 38% of the C stock. Finally, the soil and litter were assessed and had only 3% of the C stock. From this study, it is evident that within the C sink systems, trees retain the most amount of C stocks, with vascular plants still playing a vital role in C sequestration.

GRAZING AND HOW IT AFFECTS CARBON POOLS

Herbivorous species often have a top-down control on ecosystems, transforming entire landscapes due to their consumption of plant material. The literature found on grazing species and their effects on C pools is inconsistent and varies depending on geographic range and study conducted. Some studies result in suggestions of herbivore removal to aid the improvement of terrestrial C stocks (*e.g.,* Tanentzap et al. 2012). Slow and non-linear responses of above-ground C stocks in woody vegetation suggest that herbivores have a direct effect on C stocks due to their consumption of plant biomass (Hawkes and Sullivan 2001). However, specific plant species have co-evolved and are more assimilated to high-intensity grazing and have the capability of rapidly recovering from herbivory due to the grazing-associated increases in nitrogen (N) in the soil (Holland et al. 1992).

In a model that suggests an herbivore-optimization curve, above-ground biomass at low to medium grazing intensities/herbivory increases and begins to fall at higher grazing intensities leading to productivity below levels without grazing (Belsky 1987). However, there is a large difference in natural grazing systems versus managed pasture systems (McNaughton 1979). A large problem when dealing with managed pasture systems is the need for fenced herbivores to consume forage even when conditions such as low moisture and low temperatures occur. Unlike the native ungulate species that evolved to migrate and optimize their grazing strategies with seasonal rainfall patterns, livestock species cannot.

BISON

Bison (*Bison bison*) influenced the structure and function of the North American grassland before European settlers (Vinton et al. 1993). Bison grazing strategies were specific and largely influenced by fire regime and local plant communities. Bison selectively consume specific plants and plant parts each season, eventually changing the floral composition, with long-term effects on population dynamics and plant growth capacities (Lauenroth and Burke 2008).

A study of two forb species, *Ambrosia psilostachya* and *Vernonia baldwinii*, undertaken in tallgrass prairie, showed that bison had a direct effect on the reproductive biomass and height of the plants (Fahnestock and Knapp 1994). Although the C levels were not tested on the above-ground biomass, it is assumed that with higher biomass, there would also be a higher amount of C stored in the plant.

CARIBOU

Caribou (*Rangifer tarandus*) can be found circumglobally up to the circumpolar Arctic. In the Arctic, climate change is causing a significant warming that means enhancing CO_2 release from vegetation through decomposition faster than photosynthesis can store C, and turning the Arctic ecosystems from a net C sink into a net C source (Väisänen et al. 2014). The tundra can be especially sensitive to high grazing intensities. In a study over 50 years of controlled pasture for caribou (reindeer), high grazing (HG) and light grazing (LG) had naturally developed different vegetation. Vegetation on the HG of the pasture had developed into a system dominated by graminoids species, with rapid growth and producing high amounts of litter decomposition. The LG section was dominated by dwarf shrubs. Light grazing areas had a 70% stronger C sink than HG areas (Väisänen et al. 2014). This study strengthens the idea that grazing herbivores play a large role on structure and functions of ecosystems and that as climate change effects worsen, the impact of herbivory on C dynamics will only increase.

WHITE-TAILED DEER

Human effects such as increased fragmentation and predator depletion have led to a hyperabundance of many native herbivores; this in turn has led to habitat degradation and the herbivores functioning as major drivers for ecological change. Bressette and Beck (2013) studied the effects of high white-tailed deer (*Odocoileus virginianus*) density on forest regeneration and C sequestration. White-tailed deer diet varies by season: during summer they depend on browse, forbs, grasses and crops when in agriculture regions, while in the winter they rely on the twigs and buds of woody shrubs, trees and tree seedlings (Vangilder et al. 1982). In Bressette and Beck's (2013) study, tree saplings located in a fenced exclosure only had a 9.4% mortality compared to an open site, which had 62.2% mortality in saplings. Carbon sequestration rates were then calculated showing that in saplings this rate was 94% greater in the exclosure site.

CATTLE

Generally, meristems are located close to the base of the plants, meaning leaf tissues can be foraged and most plants will have a rapid recovery after the tissue loss. Janowiak et al. (2017) estimated that in natural short-, mixed- and tall-grass prairies, livestock can deplete above ground C stocks by 0.001-0.50 Tonnes of C per ha per year, matching results in a study by Welker et al. (2004) in central U.S. grasslands. Another study by Lecain et al. (2000) found that C levels in Wyoming grasslands fluctuated in different months of the year with grazing. In late April to late June, CO_2 exchange rates were greater in HG and LG pasture sites than exclosure sites. In many cases the grazed sites showed a significantly larger green vegetation index in the earlier stages of the growing season. After 13 years of grazing, there was no difference in the average CO_2 exchange over the two grazing systems, while the exclosure sites had equal to higher exchange rates in the mid to late season. The livestock grazing had direct effects on the growth and reproduction of the plants.

MATERIALS AND METHODS

Plants were collected by hand clipping in three functional groups (legumes, grasses, and annuals) from the TBCP (Appendix I), and samples were later sorted by grazing intensity site and placed in paper bags. Three 50-m transects were randomly placed in straight, non-overlapping lines at each site. At each 5 m mark, one of ten 2 m^2 square plots were established. Above-ground material was collected from the first corner one-metre square plot and dried and weighed for yield measurements.

The above-ground and below-ground plant samples were placed in a drying oven at 100 °C for 24 hours until they reached a consistent weight over three separate measurements. Following the drying, they rested and air dried for an hour and were then crushed down using an electric coffee grinder, mortar and pestle to be able to fit through a 200-micron sieve. Once crushed, the contents were weighed and placed into a crucible and placed into a muffle furnace at 550 °C for two hours. The contents were weighed after this loss on ignition test, which is an estimate organic C, compared within functional groups across the three sites in a two-way ANOVA (Appendix II). In all cases, a sample size of at least 1 g was used. Due to the lack of biomass collected for some small plant samples, many could not be used for loss of ignition. Most samples were tested for nitrogen (N) (Appendix III) and other macro- and micronutrients (Dalcorso et al. 2014; Appendix IV). Statistical analysis was done using the program SPSS.

RESULTS

There were sufficient samples only of above-ground material to compare loss on ignition (*N* = 31), so only the NAP hypothesis could be tested. For an ANOVA that compared species, there were no differences across sites, controlling for functional group (*F* = 0.5, *p* = 0.93; Appendix II). With individual plants grouped together only by functional group, the same result of ANOVA occurred, no differences across heavy, medium and lightly grazed sites on the TBCP (*F* = 0.5, *p* = 0.85).

DISCUSSION

The importance of considering rotational grazing on the TBCP is in controlled feeding times on the areas that require restoration to optimize yield. This will ultimately optimize profits in the cattle market without supplementing feeding in the summer months. With the knowledge that no functional groups react to differently at this point to heavy, medium and light grazing, the Board of the TBCP can view these results as baseline information to restore areas that are most convenient for restoration.

SAMPLES

In order to receive more accurate results, the project should continue for multiple years, due to changing weather conditions and a changing pasture management regime. Cattle and other ungulate species select for or against certain plants (Lauenroth and Burke 2008), so it is felt that the TBCP study should be carried out for a longer period such as the 13 years of observation by Lecain et al. (2000). In this study, sample sizes across plants were not uniform and ultimately led towards a biased result due to insufficient material to complete loss on ignition analysis. Due to plant communities relying on soil moisture and productivity, I also believe that in order to get a sufficient knowledge of how the pasture is truly responding to grazing intensities soil samples from each site also should be taken.

EQUIPMENT

The equipment used during this thesis worked well but the methods could be improved. Due to the high number of individuals using the same lab setting, different scales were used. The scales were both set to two decimal places accuracy and were tested on the same sample; at times multiple readings for the same sample were only 0.001 g different. However, a singular scale should be used and maintained solely by the individual who is estimating the biomass before and after ignition. Another issue that could be improved is the use of a coffee grinder, which is not sufficient at grinding down all off the plant material. For the future, if sample sizes remained the same, purchase of a higher-power grinder would be beneficial.

CONCLUSION

It was not evident that grazing intensities of the cattle in the TBCP played a crucial role in determining C sequestration by the pasture plant communities. As the literature suggests that there is fluctuation in C pools over a growing season, the research and monitoring should be continued with minor adjustments to the methods and procedures to yield more conclusive results.

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APPENDICES

APPENDIX I

SELECTED PLANT SPECIES

FORBS
Achillea millefolium (Yarrow)
Amelanchier alnifolia (Saskatoon serviceberry)
Cirsium arvense (Creeping thistle)
Cornus canadensis (Creeping dogwood)
Equisetum arvense (Field horsetail)
Fragaria virginiana (Meadow buttercup)
Galium boreale (Northern bedstraw)
Hieracium spp. (Hawkweed)
Leucanthemum vulgare (Oxeye daisy)
Plantago major (Broadleaf plantain)
Potentilla norvegica (Rough cinquefoil)
Prunella vulgaris (Heal-all)
Ranunculus acris (Buttercup)
Rosa blanda (Smooth rose)
Rubus idaeus (Red raspberry)
Solidago spp. (Goldenrod)
Stellaria graminea (Starwort)
Symphoricarpos occidentalis (Western snowberry)
Symphyotrichum puniceum (Aster)
Taraxacum officinale (Common dandelion)
Veronica serpyllifolia (Thyme-leaved speedwell)

GRASSES
Sisyrinchium mucronatum (Slender blue-eye grass)
Carex spp. (Sedges)
Other Grasses

LEGUMES
Trifolium repens (White clover)
Medicago lupulina (Black medick)
Trifolium pratense (Red clover)
Vicia cracca (Bird vetch)

APPENDIX II

ANOVA TESTS

A. ANOVA test between grazing intensity and species and sample size.

Tests of Between-Subjects Effects

Dependent Variable: LOlg

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	.033[a]	14	.002	.451	.929
Intercept	15.839	1	15.839	2987.712	.000
Field	.008	2	.004	.747	.490
FnGrp * Field	.008	6	.001	.251	.952
Field * Set	.013	3	.004	.822	.501
FnGrp * Field * Set	.007	3	.002	.434	.731
Error	.085	16	.005		
Total	24.527	31			
Corrected Total	.118	30			

APPENDIX II (CONTINUED)

B. 2nd ANOVA test between functional group and grazing intensity.

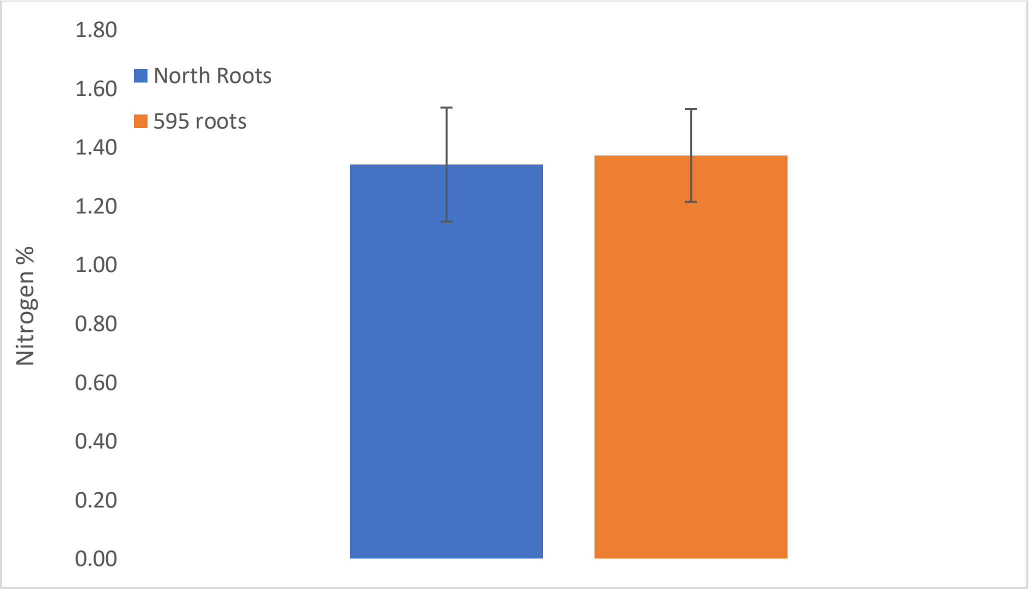
Tests of Between-Subjects Effects

Dependent Variable: LOlg

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	.018[a]	8	.002	.490	.850
Intercept	21.566	1	21.566	4725.348	.000
Field	.008	2	.004	.825	.451
FnGrp * Field	.012	6	.002	.437	.846
Error	.100	22	.005		
Total	24.527	31			
Corrected Total	.118	30			

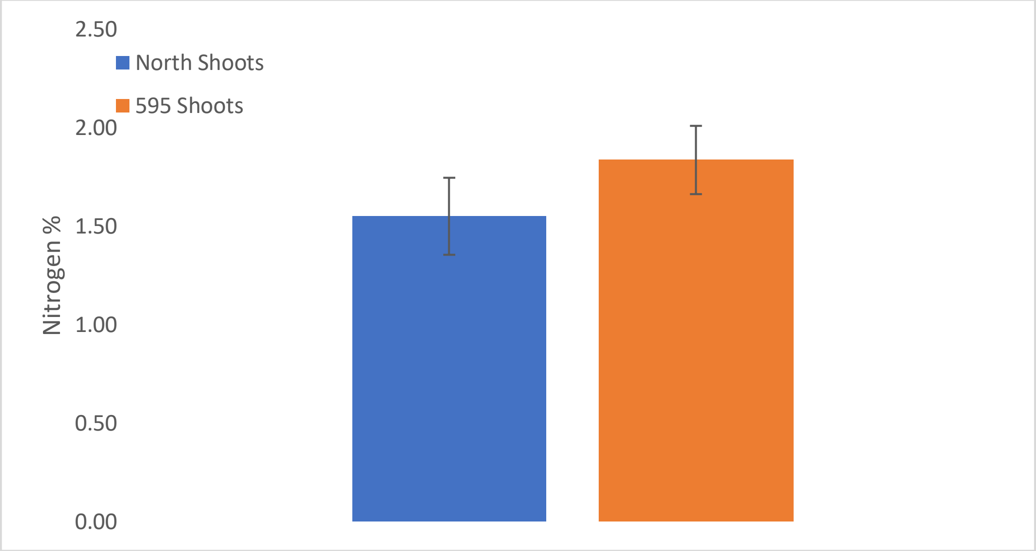
APPENDIX III

MEASURED NITROGEN PERCENTAGES

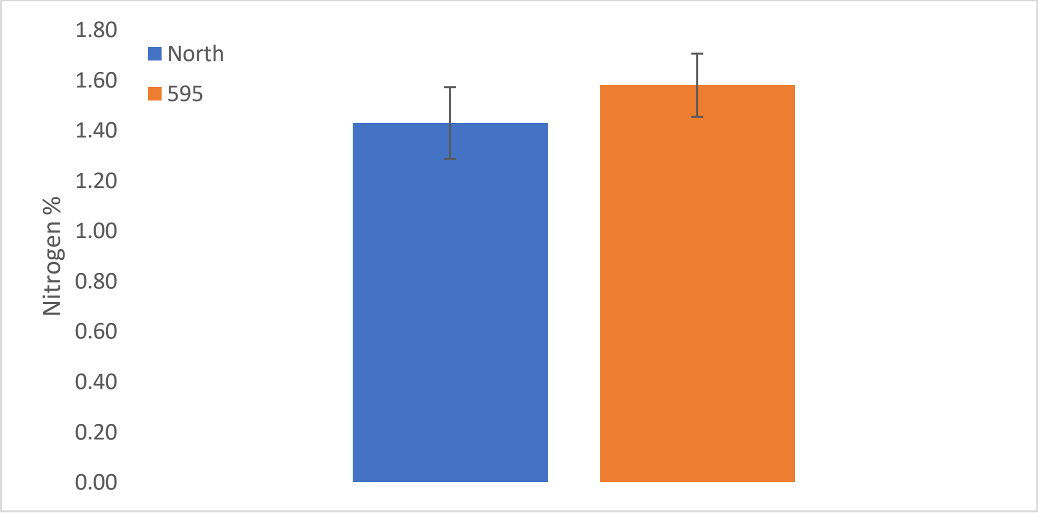


A. Nitrogen Percentages of Roots between grazing intensity locations.

APPENDIX III (CONTINUED)

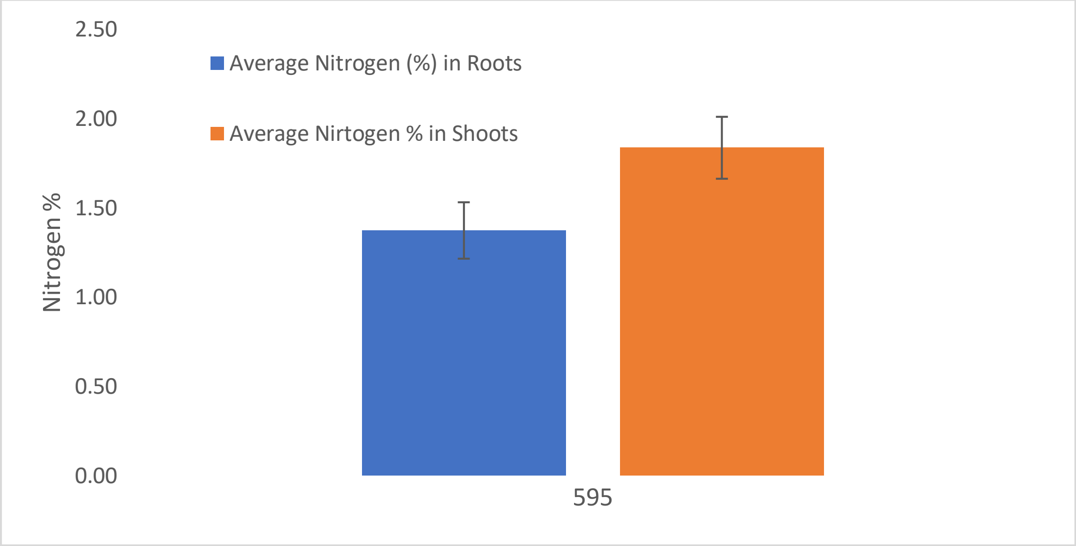


B. Nitrogen Percentages of Shoots between grazing intensity locations.

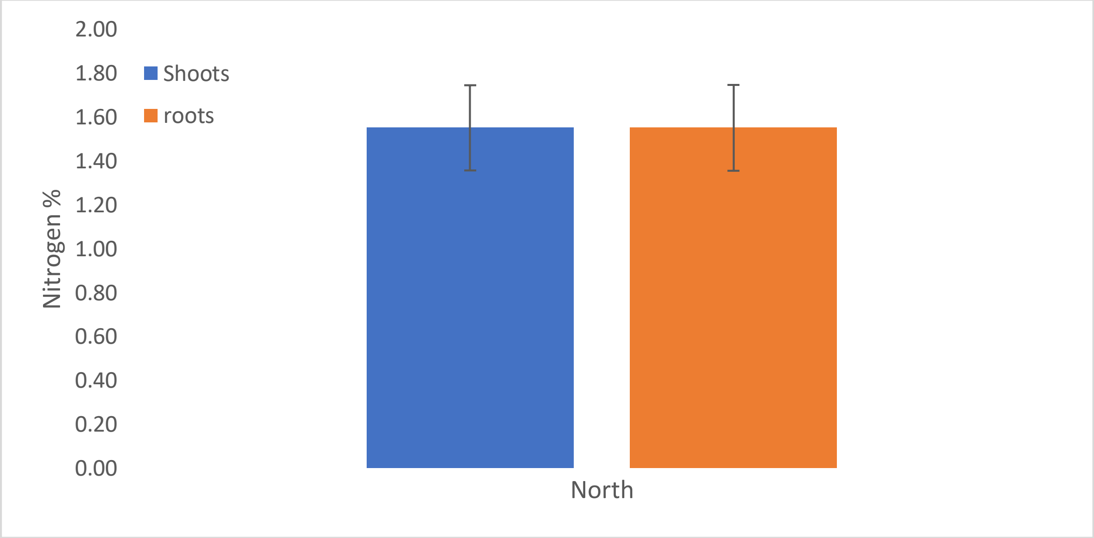


C. Total nitrogen percentages between grazing intensity locations.

APPENDIX III (CONTINUED)

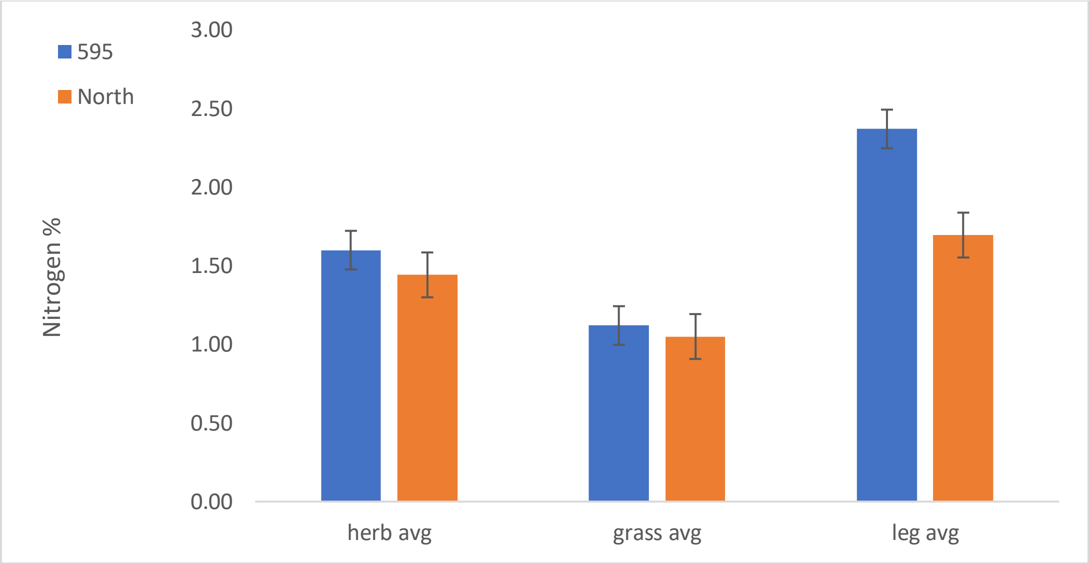


D. Average of Root, Shoots Nitrogen % in 595



E. Average of Root, Shoots Nitrogen % in North

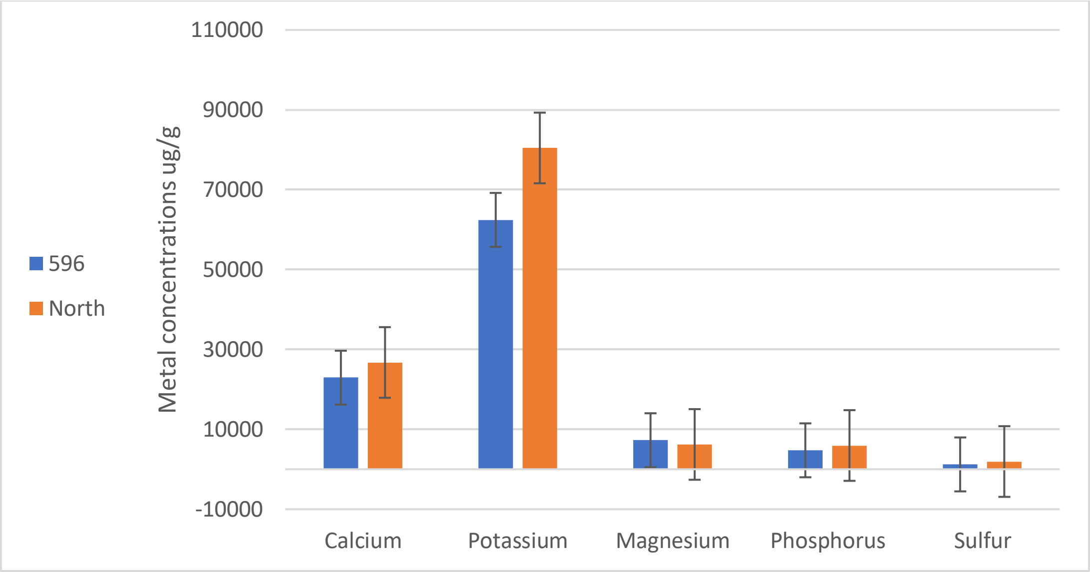
APPENDIX III (CONTINUED)



F. Nitrogen % between functional groups and grazing intensity location.

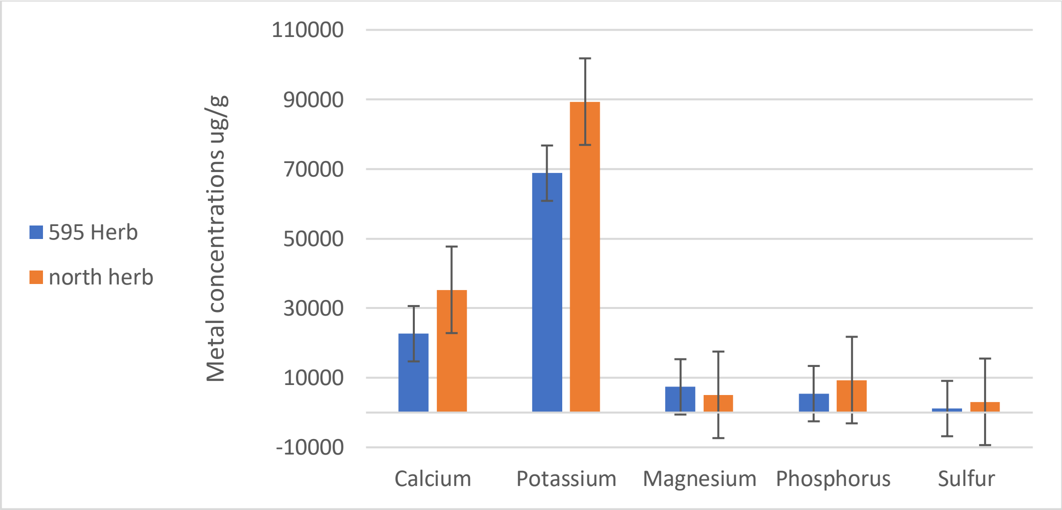
APPENDIX IV

MEASURED METAL CONCENTRATIONS

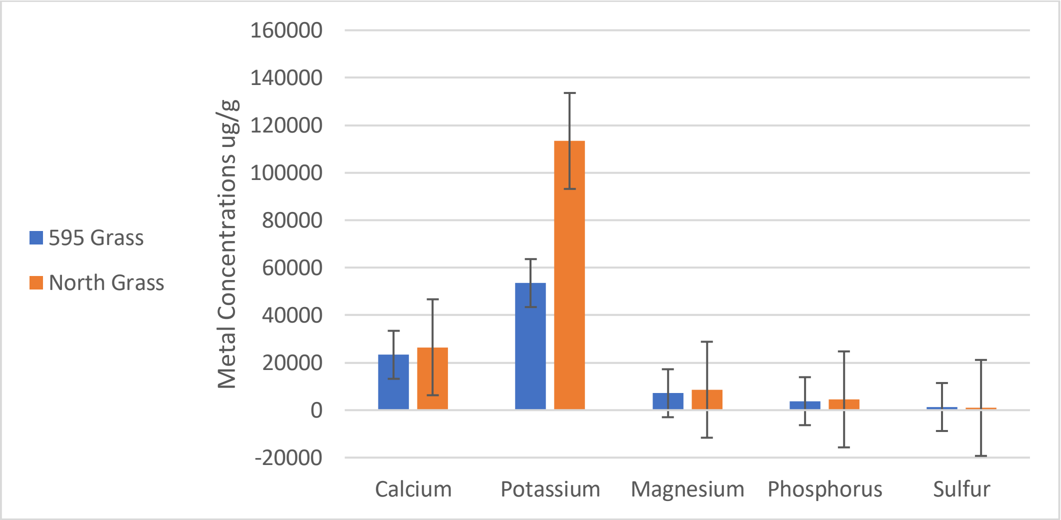


A. Average of metal concentrations between grazing intensity locations ug/g

APPENDIX IV (CONTINUED)



B. Average of metal concentrations between Herbs and grazing intensity locations ug/g



C. Average of metal concentrations between Grasses and grazing intensity locations ug/g