

IN-NII (*BISON BISON L.*) REINTRODUCTION TO
AMSKAPIPIKINI (BLACKFEET) NATION HOMELAND:
RELATIONSHIPS WITH KSAHKO (SOILS)

by

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A thesis submitted in partial fulfillment
of the requirements for the degree

of

Master of Science

in

Land Resources & Environmental Science

MONTANA STATE UNIVERSITY
Bozeman, Montana

May 2022

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DEDICATION

I dedicate this work to my three beautiful children Cassie, Terrance, and Baeley. Always know who you are by staying connected to our Amskapiipikini values and ways to love and care for the lands that support the lives we live. We come from Badger Creek and these lands teach us to be strong and will shape you into the adults that you will become. I love you all so much and it was my dedication to you that I continued to pursue my educational goals so I could provide you with the lives you all deserve. I am honored to be your mother.

ACKNOWLEDGEMENTS

I would like to acknowledge my late mother Catherine (Cassie) Calf Looking who always made sure I knew that in life I must always work hard in life to achieve the goals I set for myself. I would like to thank my father Terry Tatsey for being my rocking and holding me down when life got tough and encouraging me to always work towards the goals, I set for myself. I appreciate my committee members, Tony Hartshorn, Cathy Zabinski and Clayton Marlow, who have supported me throughout my graduate program and throughout my life. You will never know the impact you had on my life and without you three I do not know where I would be in my academic journey. I would like to send my gratitude to the entire LRES Department, for continuing to support me throughout my journey through the program. The MSU Writing Center for helping me Clare, Rose, and Michelle. Ryan and Emma helped me with substrate-induced respiration measurements. I would like to send my appreciation to Alfred P. Sloan Foundation for the Sloan Indigenous Graduate Program, Hopa Mountain Science Fellows Program, Wildlife Conservation Society, Piikani Lodge Health Institute and Liz Carlisle for their financial support. I would like to thank the Blackfeet Nation Buffalo program and the RRJ Cattle Ranch for allowing me to collect samples on the lands which were pivotal to my research project. I want to thank all those many many individuals who helped me dig soil pits in the toughest lands that make up the Amskapiipkani (Blackfeet) lands that broke shovels but never our spirits to get the job done. I would like to honor those who came before me who were the caretaker of the lands that I call home and set the path that I follow today. There are not enough words that can express all that I feel for the help I had to reach such a momentous moment in my life.

AMERICAN INDIAN HERITAGE

Okii (hello) my name is Latrice D. Tatsey and my Indian name is Buffalo Stone Woman. I grew up on my family ranch located in Badger Creek, MT on the Blackfeet Nation. My interest in natural resources and Blackfeet cultural values began at an early age and will continue throughout my lifetime. My upbringing has revolved around ranching, cultural uses of the land, outdoor activities, and respecting Mother Earth.

TABLE OF CONTENTS

1. INTRODUCTION	1
CHAPTER ONE REFERENCES CITED	7
2. HISTORY OF IN-NII AND THE AMSKAPIPIKINI	8
CHAPTER TWO REFERENCES CITED	17
3. IN-NII BISON AND CATTLE	19
In-nii and Cattle History	20
In-nii and Cattle Grazing Effects on Soil Health	31
Effect of Grazing on Plant Soil Feedbacks and Temperature	38
Soil Carbon Sequestration	42
Conclusion	47
CHAPTER THREE REFERENCES CITED	49
4. RESEARCH METHODS	57
Field Sites	57
Experimental Design	61
Soil Samples for Nutrient Analysis	62
Substrate-induced Respiration	63
Field Soil Respiration and Infiltration Rates	65
NRCS “Minimum Dataset” Recommendations	68
Soils of the Blackfeet Nation	70
CHAPTER FOUR REFERENCES CITED	76
5. RESULTS AND DISCUSSION	78
Soil Fertility	78
Substrate Induced Respiration	80
Field Soil Respiration	83
Discussion	87
Soil Nutrients	87
Substrate-induced Respiration	92
Field Soil Respiration	95

TABLE OF CONTENTS CONTINUED

Summary97

CHAPTER FIVE REFERENCES CITED.....101

6. CONCLUSION.....103

CUMULATIVE REFERENCES CITED107

APPENDIX A: Recorded Peak Height CO₂ vs Actual CO₂.....119

LIST OF TABLES

Table	Page
1. Most extensive 10 NRCS soil map units dominating (96%) of the ~10,200-acre area of interest that includes the in-nii and cattle pastures.....	73
2. Median values and p-values for selected soil properties for the in-nii and cattle pastures.....	79
3. Preliminary soil respiration fluxes for fenceline, cattle, or in-nii pasture locations recorded in August 2020 before and after adding 1 inch of water.....	84
4. Comparison of SOC estimates for several ranches based on mapped soil Series	90
5. Temporal trends in soil health indicators over a 20-year period	94
6. Comparison of different substrate-induced respiration rates across studies.....	96

LIST OF FIGURES

Figure	Page
1. Extent of Aboriginal Amskapiipikini Territory and Hunting Range	10
2. Historical distribution of in-nii	11
3. Details of an in-nii harvest site located along Badger Creek (modified from Tatsey 2010)	14
4. Distribution of Grasslands Types in North America. (Figure from Chapman et al., 2015).....	23
5. Boxplots of grass biomass clipped to measure standing crop after one year for each of the treatment types	32
6. Mean soil carbon levels with soil depth under three different, South Dakota grazing regimes	34
7. Postulated effects of alternative grazing management approaches on productivity and biodiversity, soil health, ecosystem services and ranch economics	38
8. Agricultural activities and emission of greenhouse gases from soil and terrestrial/aquatic ecosystems to the atmosphere	40
9. Conceptual model illustrating how abiotic factors might influence PSFs	41
10. Influence of soil landscape position on soil processes that ultimately govern SOC dynamics	44
11. Climate change: Differences between classes of psychological impacts	47
12. View of the Blackfeet Nation in Montana, which borders Glacier National Park to the west and Canada to the north.....	58
13. Map of the in-nii pasture and cattle pasture, along with the water tributaries that flow through these landscapes	59
14. Locations of all the soil samples that were collected for nutrient tests in the in-nii and cattle pastures, which are separated by a fence line	60

LIST OF FIGURES CONTINUED

Figure	Page
15. Numbered locations (1-5) reflect where in-nii and cattle pasture soil samples were taken for soil substrate-induced respiration (SIR) analyses to index soil carbon dynamics.....	64
16. Schematic for the way the SIR samples were taken at each of four fenceline locations indicated in Figure 15	65
17. Getting soil respiration flux readings ($\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$) with the Licor 8100A gas analyzer in the middle of the fence line that separates the in-nii and cattle pastures	67
18. Conceptual figure of C respiration during aerobic soil incubations	68
19. Parent materials underlying some of the soils of the Amskapiipikini Nation	70
20. Mapped soil series across the in-nii and cattle pastures via Web Soil Survey	72
21. Geographic extent of spatially extensive map units associated with cattle and in-nii pastures from this study	75
22. Violin plots showing all cation exchange capacity (cmol^+/kg) values as influenced by treatment of in-nii and cattle.....	79
23. Violin plots of exchangeable magnesium (mg/kg or parts per million [ppm]) as influenced by in-nii and cattle	80
24. Average substrate-induced respiration rates for cattle vs. in-nii-influenced soils receiving either water or an equivalent volume of yeast solution after 4 hours, 24 hours, or 4 days	81
25. Conversions to concentrations expressed as mass of carbon dioxide per unit dry mass of soil through a 3-step process.....	82
26. Ratios of wet-to-dry field soil respiration fluxes measured from the in-nii and cattle pastures	85
27. Soil respiration rates in pastures grazed or ungrazed by cattle and in-nii in Kansas on four different days of the year	86
28. Soil water infiltration rates for the in-nii (I) and cattle (C) pastures	87

LIST OF FIGURES CONTINUED

Figure	Page
29. Soil organic carbon stocks to 1 m as a function of years since management transition at equivalent soil mass of 9,900 Mg/ha.....	91
30. Relationships between the response ratios (RR) of soil microbial community size and RR of soil respiration (SR)	93
31. Changes in soil CO ₂ efflux and soil water content over time	96
32. The current state of quantitative soil health assessments and several problems and pitfalls associated with current approaches	99
33. Model illustrating the return of in-nii and how influences the people and landscape ecosystems.....	104
34. Model illustrating the grazing on the Blackfeet Reservation by in-nii, cattle, wildlife and ranch animals	105

ABSTRACT

In-nii (American Bison) are returning to their Traditional Territories after being nearly wiped out of the Great Plains of North America and Canada. The in-nii are slowly returning to Native American tribes who have the resources to run reintroduction programs like that of the Amskapiipikini (Blackfeet). This in-nii reintroduction presented an opportunity to look at the effects of the return of in-nii to the Amskapiipikini, and what their influences might be on the soils, plants, and water resources of the Blackfeet Nation. This research project was conducted on the Blackfeet Buffalo (In-nii) Ranch and the adjacent RRJ Cattle Ranch, comparing the influence of in-nii and cattle on soil nutrient cycles and soil carbon dynamics. Soil samples were taken from locations on the landscape that were near water sources on lower elevations, mid hillslopes for mid-elevation sites and on hilltops at higher elevations. Soil characteristics included soil organic matter (SOM), nitrate, pH, cation exchange capacity (CEC), and exchangeable calcium, potassium, sodium, and magnesium. Only two (CEC, magnesium) appeared to have been influenced by in-nii and cattle. The remaining soil characteristics were little influenced by grazer type. Substrate-induced respiration was also measured in the lab to see how microbes decomposed SOM (carbohydrates and other molecules) to release energy and CO₂; we found no evidence of differences between in-nii- and cattle-influenced soils. Finally, we measured field respiration rates and water infiltration rates at multiple fence line sites; field soil respiration rates increased when soil had water infiltrated after the dry readings, soils also increased the time to absorb water after the first infiltration tests were run. Our preliminary results suggest that the reintroduction of in-nii to these lands has not yet resulted in measurable differences in soil-related properties of the Blackfeet Nation. Even so, the return of the in-nii for the Amskapiipikini is also about understanding the importance of using cultural science when studying the ecology of a system. Doing this can create an understanding of the traditional ways of knowing while bringing cultural healing and restoring connections between Amskapiipikini, in-nii, and land.

INTRODUCTION

In-nii (American bison; *Bison bison* L.) have been a part of North American ecosystems since time immemorial and after being nearly wiped out in the 1880s, they are slowly returning to the lands where their ancestors set hoof so many years ago. These in-nii herds that migrated all over the North American Great Plains influenced landscapes, ecosystems, and Native American people like the Amskapiipikini (Blackfeet), who depended on these animals for their survival (Tatsey, 2019).

We begin with the history of Amskapiipikini and in-nii, as this conceptualizes the wholeness of science when looking at these two animals. Amskapiipikini science is part of a holistic practice of balancing ourselves within our environment (Bastien, 2004). Amskapiipikini cultural scientific perspectives and Eurocentric scientific perspectives are both necessary in order to come to today's understandings of how in-nii and cattle relate to Amskapiipikini people and to the environment, though "tribal peoples' reality is altered by the interpretation of their experiences through the framework of colonized ideology ...[and tribal] people have internalized [Eurocentric] beliefs and values through this process, and, as a result, interpret their own experiences from an alien and alienating value and belief system" (Bastien, 2004). Rediscovering the relationships and connection of the Amskapiipikini and in-nii is significant in this project because it emphasizes the holistic view I bring as a researcher to my work, and as a rancher of both in-nii and cattle. In the Amskapiipikini world view all things are interconnected to the Amskapiipikini cultural teachings, Amskapiipikini cultural science, and now with incorporating Amskapiipikini cultural science with Eurocentric science this opens new doors for looking at the scientific research processes and practices.

Eurocentric science is one way to study and look at processes of how the world around us functions, and it has created a foundation for one way of understanding the importance of keystone species such as the in-nii. There is much value to this science, and while it has shaped the scientific community through its mostly linear modeling, it is also thought to be limited by the lack of diverse perspectives of its practitioners (Medin and Bang, 2014). This is one reason we need to explore Amskapiipikini cultural science and other Native American cultural science perspectives because those who have lived on these lands for thousands of years ago prior to colonization have a rich knowledge base of the land and ecosystems. Only with such combinations of perspectives can we expect to gain an improved understanding of the world. As my father Terry Tatsey once stated: “There is such interconnectivity of natural systems surrounding earth (Mother Earth) that looking at ecosystems as a whole and not separating them is crucial in restoring and maintaining the natural resources which sustain all who live on Mother Earth” (Tatsey, 2019). A more holistic understanding of the relationship between Amskapiipikini and in-nii can create a bridge between cultural science and Eurocentric science; it can also offer us a richer understanding of our roles as land stewards and conservationists. As Betsy Bastien (2004) has written on the first page of her introduction to “Blackfoot Ways of Knowing”:

As educator and scholar, I believe that the time has come to break the cycle of dependency and to assert the tribal paradigms of Indigenous cultures through affirmative inquiries based on culturally appropriate protocols. Any such inquiry must be designed to explore solutions to contemporary problems from within tribal interpretations. *Ao'tsisstapitakyo'p1* means "to be cognizant and to discern the tribal connections"; it refers to our sacred science and thus to the way to connect with our relations once again experientially through our ways of knowing. These ways of knowing are premised on seeking understanding of the complex levels of kinship relations that constitute a cosmic world of balance and harmony. Indigenous ways of knowing are the tribal processes that align Niitsitapi [lit. "real people," i.e., Indigenous people] with their alliances from which all knowing and knowledge is obtained. This way of knowing is of a different nature than the knowledge

generated using cross-cultural or alien perspectives developed by Eurocentred sciences.

Amskapiipikini organize themselves according to their observation of the natural world and the understanding of their relationship with the environment (Bastien, 2004). The Amskapiipikini are expert cultural scientists, by which I mean that we understand the relationships animals have to the ecosystems they utilize. My father has also stated “Things have changed in our culture, but the core values are still important to us, which we have learned through our traditional teaching; our ceremonies continue to affirm our connection with all of the natural world, and we have stories of our place in the universe and our relationship with all of creator’s creations.”

The knowledge and the forms of teaching and learning are embedded in the ways of the ancestors that we can understand today as epistemologies and pedagogical theories and practices (Bastien, 2004). The ecological aspect of Indigenous knowledge is all about the land (Little Bear, 2009), and this is where the transfer of Amskapiipikini cultural science knowledge is transferred between generations. My father Terry Tatsey was primarily raised by his paternal grandparents, John and Belle Tatsey, as well as his maternal grandparents, Frances and Lillian Bullshoe. As Amskapiipikini elders and knowledge-keepers, these family members shared intergenerational community cultural science, history, values, and indigenous ways of the land through placed-based stories. With the Amskapiipikini cultural science teachings, Terry went on to study in-nii harvest methods on his family ranch in Badger Creek and throughout Amskapiipikini territories. He taught natural resources at Blackfeet Community College from 1993 until 2016. Today, my father is serving on land conservation boards, livestock boards, and continues to work on projects on the Blackfeet Nation.

Mokaksin (wisdom and intelligence) carries the responsibility of living the knowledge and passing it on to the next generation, first and foremost to ensure survival (Bastien, 2004). During my childhood, my father transferred to me the knowledge that my great-grandparents transferred to him. For example, he showed me where drivelines for the in-nii jumps started while riding horse back with him on our family ranch in Badger Creek. I learned from him how to determine if a jump was a morning, afternoon or evening harvest site because the sun played a role in blinding the in-nii as they approached the cliffs. We have ridden by the teepee rings and he has shown me the significance of the rock placement, explaining how our teepees were made and why the door faces the east to greet the sun each morning. On these rides, my father used each location as a land-based learning opportunity, deepening and strengthening my connection to the world around me.

This community practice of Amskapiipikini cultural science has produced vast knowledge about the life habits of in-nii, upon which have based our methods and rituals for harvesting. Hunts occurred using cultural science and traditional ecological knowledge to determine what time of the year to set up camps. Traditional Amskapiipikini land management included the use of prescribed fire so that the in-nii would return to a particular area the following year (Tatsey, 2019). Western research that was conducted on the tallgrass prairies of Kansas has found that in-nii and fire are key to conserving and restoring the biotic factors by reducing the aboveground dead biomass which changes the mosaic throughout the landscape, creating spatial and temporal heterogeneity of plant species (Knapp et al. 1999).

Amskapiipikini place-based teachings and sharing of backgrounds emphasizes the knowledge we have that is important for the relationships we had, and will continue to have, with

in-nii. This knowledge is important not only for our survival but also for the care and management of the land and animals. Interweaving cultural science with Eurocentric science offers not only a unique view of soil and animal health, but it also reaffirms “our ancient ways of knowing...[which] is essential for the generation of knowledge that is healing and unites the people with their alliances, regenerative ways of being, and an aware relationship with the natural world” (Bastien 2004).

In this thesis, I examine the relationship to in-nii throughout the chapters by delving into the importance they have had in the past and might have in the present and future. In Chapter Two I look at that history of in-nii from their historical movement on the land to their cultural importance to the Amskapiipikini. In Chapter Three, I write about in-nii and cattle’s influence on landscapes through their grazing behavior and movement, their potential effects on soil health, plant-soil feedbacks, and soil carbon sequestration. In Chapters Four and Five, I describe how I collected, analyzed, and contextualized soil data from in-nii and cattle pastures.

With this research, I wanted to see if there would be differences or similarities between the in-nii and cattle pastures to understand if their movement on the land influences soil nutrients and properties. Finding correlations or differences in the in-nii and cattle pastures is one way to look at how their movement on the land is important and potentially useful for ranchers or land managers when working with tribal nations where both animals are important staples. In other words, why it’s important to look through Amskapiipikini cultural science and Eurocentric science lens. I expected soils associated with in-nii to have higher soil organic matter, higher soil nutrient contents, and lower soil respiration rates when compared to cattle because these types of findings have been observed in other Western studies. Instead, I found very few differences

between in-nii and cattle grazing effects on soil health properties. For example, I found no significant differences between the in-nii and cattle pastures when it came to soil organic matter. I also used substrate-induced respiration measurements to examine whether the microbial communities in in-nii and cattle pastures differed in how they consumed that soil organic matter. This technique assesses whether the soil organic carbon in each pasture type is respired to differing extents after adding the same amount and concentration of yeast solution (Fierer et al. 2003, Schadel et al. 2020). I used an equivalent amount of water to assess how much of the respired carbon dioxide was due only to the rewetting of soils. As with soil organic matter, I found very few differences in either the magnitude or time course of respired carbon dioxide between cattle and in-nii pastures; about 1-10% of the responses I measured could be attributed to the rewetting of the soils. Finally, I also performed field soil respiration rate and field soil water infiltration rate measurements at multiple fenceline sites. These more preliminary field results, like my earlier results, showed few differences between the in-nii and cattle pastures, mostly due to the great variability I observed, both temporally and spatially. My research explored the relationships of these animals with the landscape and was not intended to argue one might be more superior than the other. Ultimately, my research project focuses on how the return of in-nii might bring healing back to both our people and our places and argues for a broader community foundation for thinking about soil health differences.

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HISTORY OF IN-NII AND THE AMSKAPIPIKINI

Traditionally, in-nii is seen as a gift from *Ihtsipaitapiiyopa* (“source of life”), and it is a part of the ceremonies as well as a staple food for subsistence (Bastien, 2004). Amskapiipikini have sustained values and relationships with in-nii since time immemorial, despite colonial attempts to drive in-nii populations extinct. Today, in-nii are slowly returning to Native American tribal lands including the Amskapiipikini (Blackfeet) Nation after the animals had almost gone extinct due to competition for forage by cattle operations and settlement on the Great Plains. In-nii movement on the landscape makes them unique to the lands which they occupied historically and today. In some ways, the return of in-nii to Amskapiipikini lands may be part of lifting what some have termed “the unbearable heaviness of climate coloniality” (Sultana 2022). <https://doi.org/10.1016/j.polgeo.2022.102638>

Amskapiipikini primarily understand in-nii communities not through abstract population counts, but by identifying larger herds on the landscape, smaller herds, and herds that were made up of more male or female in-nii (Carlson, 2018). Depending on the movement of the herd and lead cow in-nii moved all over in the Amskapiipikini territories throughout Canada and the United States (Tatsey, 2019; Figure 1). In-nii are estimated to have reached a maximum historic population from 30 to 60 million about 150 years ago (Coopedge et al., 1998; Kohl et al., 2013). Today there are roughly 500,000 with around 21,000 in conservation herds (Kohl et al. 2013). Native American Tribes are seeking to reintroduce in-nii to their tribal territories like the Amskapiipikini who own just over 700 (Carlson, 2018). Since the introduction of cattle to the United States in the late 1400’s and early 1500’s their numbers have grown to ~100,000,000, essentially twice that of historical in-nii numbers (NASS, 2021).

The Amskapiipikini understood the in-nii and how they traveled; they knew exactly where the in-nii had their wintering ranges and the corridors in which the in-nii consistently traveled (Figure 2). Seasonal changes influenced the in-nii: they moved “into areas like Glacier National Park during the spring through the summer months, and into areas like Bozeman during the late-fall through winter because the weather was milder” (Whitford, 2010). The southern ranges and corridors were important to Amskapiipikini people in the winter months and for the Crow, Shoshone, and other tribes that used it as common hunting grounds; all these areas were very important to the plains in-nii across the different seasons (Tatsey, 2019).



Figure 1 Extent of Aboriginal Amskapiipikini Territory and Hunting Range (Jackson, 2000 in Zedeño, 2017).

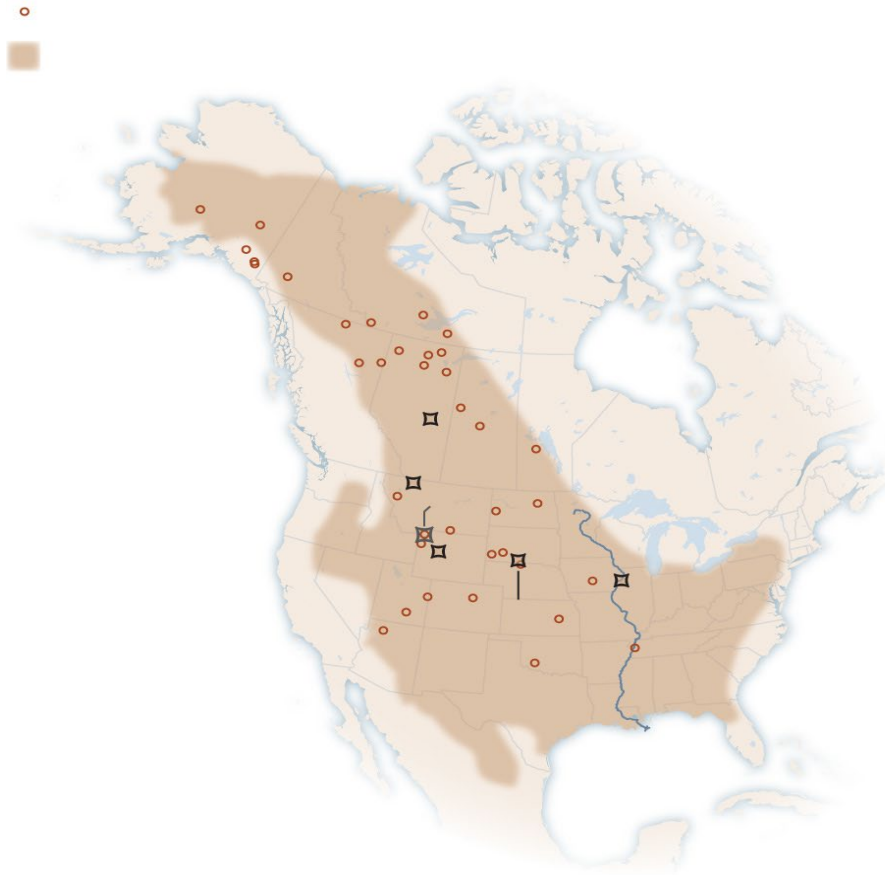


Figure 2. Historical distribution of in-nii. Sources: Kelly Stoner, Wildlife Conservation Society; IUCN. Small open circles are conservation herds in 2019; shading shows historical range; open black boxes reflect herds discussed in a recent National Geographic article (reference here).

The Amskapiipikini people understood that there were larger herds and smaller herds, with some larger herds breaking down every season. Bulls (males) typically stay away from the herds until breeding season. Most in-nii herds were made up of smaller bands of cows (females), newly born calves, yearlings, and two-year-olds; they were related to each other, like a family (Glenbow Museum N.D.). The lead cow of a herd would instinctively know when it was time to move to another area so they could have more selection in their diets and she made the decision when it was time to get a drink of water at the nearest water location (Glenbow Museum

N.D.). For example, in June of 2021 the in-nii manager Ervin Carlson said they were planning on moving the herd from their winter range at Blackfeet Buffalo Ranch on June 15th, but the lead female already started to move the herd a week earlier on their migration trail to and from the summer pastures that are near East Glacier, MT.

It is important for Amskapiipikini to honor the animal before the hunt and harvest because it was a taking of life to sustain life. As part of the “In-nii Calling Ceremony” before every hunt, people would gather in a tipi for the ceremony, and they would ask/pray for a successful hunt that would provide plenty of meat for the coming winter (Glenbow Museum N.D., Zedeño, 2017). The people sang special songs that honored the in-nii and they thanked the in-nii for giving themselves to us and if the ceremony was done correctly, the in-nii would know that the people respected them and would allow themselves to be led to the buffalo jump (pisskan) (Glenbow Museum N.D.).

To procure large quantities of meat, hunters built numerous driveline systems in strategic localities to harvest animals all at once (Zedeño, 2017), which included different harvest methods of in-nii for each season of the year (Tatsey, 2019).

Buffalo Jump or Long Coulee – Fall - Mokoyii (autumn season)

Natural Barriers Primarily – Winter - Sstoyi (cold weather)

Surround- Summer - Niipo (summer)

Sneak-up – Spring - Motoyi (spring)

The main hunt took place in the fall as people were preparing for the long winter; the cows, calves and bulls were harvested during this time as the meat was dense and hides were prime (Tatsey, 2019). These facilities often extended across several square kilometers,

connecting grasslands and water bodies to bluff edges or “jumps” (Bethke et al., 2018). When the Amskapiipikini selected a harvest site, they had to be aware of the seasonal patterns, i.e., location of the Sun, Big Dipper constellation, and other monthly activities; vegetation types that the bison preferred, i.e., fescue, wheatgrass, oat grass etc.; weather patterns, i.e., wind direction because they didn’t want the bison to smell their scent and scatter; and the topography/landforms that they would utilize to hunt/kill the bison (Tatsey, 2019).

There are a dozen or so in-nii jumps documented between Yellowstone and Livingston, indicating the Yellowstone and Lamar Valleys were important for both in-nii and the original human occupants of the region (Gates et al. 2005). Whitford said “the Amskapiipikini used the Madison and Gallatin Rivers areas for their winter camps because this is where they would follow the in-nii; old rock cairns are still visible throughout the state of Montana today” (2010). Figure 3 is an in-nii jump located near Badger Creek, Montana, 28 miles southwest of Browning; the triangles represent rock cairns, the yellow line represents the direction that the Amskapiipikini people would drive the in-nii off the cliffs, and the circles represent the camps of the Amskapiipikini people. Badger Creek water tributary is directly below the jump during the spring, summer and fall months. Many of the in-nii jumps that are on the Amskapiipikini Nation and in the State of Montana have a source of water close by used to clean the animals that were being harvested. Harvest sites of the in-nii on the Amskapiipikini Nation and throughout the North American continent could have played an intricate role in nutrient additions to the land.

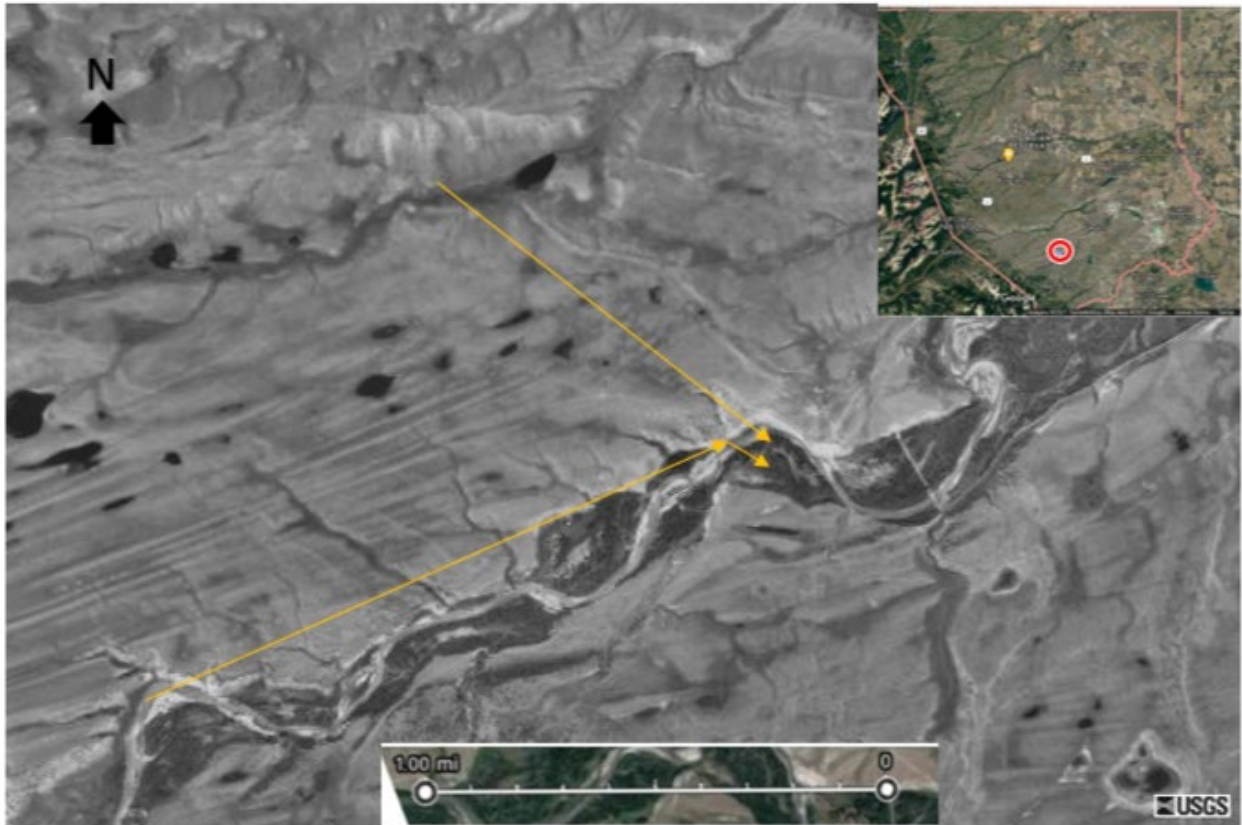


Figure 3. Details of an in-nii harvest site located along Badger Creek (modified from Tatsey 2010). The figure above is of an old in-nii jump used by the Amskapiipikini. The yellow lines represent the directions the in-nii would move. Drivelines used by the Amskapiipikini would have pushed the in-nii towards the jump represented by the arrowheads. These types of harvest sites would have supported many Amskapiipikini camps.

The in-nii in North America are ecologically and paleontologically unique; mitochondrial DNA from the oldest known in-nii fossil found in North America has been aged to between 135 and 195 thousand years before present (Froese et al. 2017). Froese et al. (2017) stated that when in-nii colonized the North American continent they rapidly diversified phenotypically to match their environment. The late Pliocene (5.3 to 2.5 million years ago) forms of in-nii eventually gave rise to the American in-nii (Plains bison; Froese et al. 2017). The plains in-nii ranged throughout much of North America and Canada; historical distribution patterns of plains in-nii are given in Figure 2.

During the Pleistocene and early Holocene, in-nii were much more widely distributed in North America and occupied habitats ranging from semi-desert to boreal forest (Rivals et al. 2007). Although the exact nature of early historic periods of in-nii movement is a matter of conjecture, there is knowledge of contemporary movement patterns as well as archaeological evidence at camping sites and hunting grounds (Gates et al. 2005, Zedeño et al. 2014).

The in-nii populations in the United States were nearly all exterminated in the eastern part of the U.S in the early to mid-1850s, southern in-nii populations were nearly exterminated in the 1860s to 1870s, and the northern and western herds were nearly exterminated in the mid-1870s to 1880s (Zedeño et al., 2014). Settler colonial economies were a significant factor in driving the intensification of bison hunting from the 1870s to the disappearance of the last herds in the mid-1880s (Mamers, 2019). Colonial politicians and policy makers were aware of the impact of bison commodification and population decline on Indigenous communities (Mamers, 2019). In 1880 superintendent Philetus Norris of Yellowstone National Park commented on the presence of about 300 in-nii on the Madison plateau and Madison River (Meagher 1973). When most of the in-nii herds were exterminated, tribes that had histories of feuding with each other were forced to hunt within the northern corridors and ranges to find in-nii, which wasn't very easy (Tatsey, 2019). The emergence of these commercial demands reordered human-in-nii relations: rather than a means of subsistence, in-nii hides and meat became a commoditized good invested with exchange value that reflected the demands of colonial markets (Mamers, 2019). Amskapiipikini held the in-nii in such high regards because this animal was their means for survival; they used the in-nii for food, to construct their lodges from bison hide, and they used their horns for cups, spoons, and fire carriers (Tatsey 2019). William Hornaday suggested a

moral sickness when he wrote, “ it would be an interesting psychological study to determine the exact working of the mind of the man who is capable of deliberately slaying a noble animal in the full knowledge that he can make no earthly use of it, but must leave its magnificent skin, its beautiful head, and several hundred pounds of fine flesh left out to the miserable coyotes and the destroying elements; and if such an act is not deliberate murder, in heaven’s name, what is it?” (Licht, 1997). Granted many in-nii were killed for profits and perhaps a few to eliminate the food source of the Native Americans (Licht, 1997).

The lands that previously held so much diversity have undergone changes with the reduction of in-nii. Not only has the land the in-nii covered drastically changed, but so too have in-ii numbers. Today approximately 500,000 individuals are managed as livestock in North America by private commercial ventures, while conservation herds comprise an additional 20,000 individuals (Kohl et al. 2013). On the Amskapiipikini Nation there are two in-nii populations, one domestic herd and a wild herd of around that make up over 700 animals. The difference in the two herds is the domestic herd is managed like cattle while the wild herd is living with 25,000 acres of pasture and receives little direct care.

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IN-NII BISON AND CATTLE

Imagine being on the landscape over 10,000 years ago and seeing large herds of in-nii influencing soil and vegetative communities all throughout what is now known as the United States. Generations of Amskapiipikani saw just this scene. Before the introduction of cattle, in-nii dominated the landscapes of the Great Plains, influencing vegetation, nutrient cycling, and seed dispersal with their grazing movement throughout the land (Tatsey, 2020). Today, look out on the landscape and large herds of cattle are the predominant forager on the lands, totaling ~45 million beef cows (Klemm and Briske, 2021).

In-nii and cattle influence soil and plant resources through their grazing practices, which helps maintain their health, body weight, and reproductive capacity. Both animals are important to peoples' cultures, lively hoods, ecological functions; and we must find a way to balance out the importance of each of them. They graze to survive, but there is also an ecological value of their grazing behaviors. This chapter will examine how grazing habits influence soil health, plant-soil feedbacks, temperatures, and soil carbon. This review will show how everything is interconnected and how balance is maintained within each ecological process.

Both animals are here to stay on the landscape for agriculture and traditional uses that ranchers and land managers see fit for their operations. These herbivores have long influenced the landscapes from in-nii almost always being on the Great Plains, to the introduction of cattle to the Great Plains. Balancing the utilization of resources through management is nothing new to the Great Plains, from the first land managers, the Native American, who continue to implement traditional practices, to the current ranching of cattle and the development of new management techniques through research from ranchers and universities. The goal is not to see who a better

grazer is, but to look at both in-nii and cattle grazing as tools to maintain soil health, animal health, nutrient cycles, ecological feedback loops, cultural value, and, ultimately, community health.

In-nii and Cattle History

In understanding how soils are influenced by in-nii and cattle, it is important to recognize how each grazer utilizes forages and moves on the landscape. As in-nii are starting to return to their historical lands in much smaller numbers compared to cattle, it is important to document changes in grazing distribution and intensity, as well as historical and modern-day management practices.

With this reintroduction, are soils and vegetation returning to historic states under in-nii grazing? Sherow (2007) wrote that before grasses could evolve, soils needed to be just right for them, and that below-ground processes drive plant community composition. There is a diversity of grasslands in the United States that both the in-nii and cattle have interacted with (Figure 4). Short-grass prairies are made up of short-stature grasses and sod-forming grasses, adapting to an arid climate with little summer precipitation. The United States shortgrass prairie was once approximately 300,000 square miles. Roughly 85 percent of the prairie's vegetative biomass, both living and dead, and 60 percent of the net productivity, occurred beneath the surface (Sims and Singh 1971, Licht, 1997). Mixed-grass prairie has a range of vegetative heights that depend on winter and spring precipitation. The mixed-grass prairie once consisted of 200,000 square miles and has been reduced to less than 30% of that today in the United States (Licht, 1997; Sherow, 2007; Chapman et al., 2015). Tallgrass prairies consist of grasses taller in stature due to greater soil moisture (Licht, 1997; Sherow, 2007; Chapman et al., 2015). The tallgrass prairies in

the United States used to cover 300,000 square miles with less than 4% remaining today. Over 300 species of plants could be found within one square mile of the tallgrass prairie on recently burned areas: 95 percent of the species were perennial with life spans of twenty years or more (Risser, 1981; Licht, 1997).

The Oxford History of the American West (Milner 1994) summarizes the settlement of the Great Plains and the rest of the West: “The full story is not one of the greatest victories and clear success. It is a story of economic boom and financial bust, of the natural resources exploited for distant markets, and of agricultural expansion established with great human cost” (Milner, 1994). The 1862 Homestead Act signed by President Lincoln gave away over 270 million acres to settlers, if they could live on 160 acres for five years and pay a small fee, they could own the land (Ewalt, 2011). In the early 1800s, the first settlers began turning the rich dark soil of the tallgrass prairie into some of the best farmland the world had ever seen (Licht, 1997; Chapman et al. 2015). However, by the 1890s, the tallgrass prairie was essentially gone (Smith, 1992), replaced by plowed fields, shelterbelts, and rock piles; after the settlers conquered almost the entirety of the tallgrass prairie, they again looked West to the lands of treeless horizons and herds of in-nii (Licht, 1997; Chapman et al., 2015). John F. Kennedy said the Homestead Act was “probably the single greatest stimulus to national development ever enacted”, it was also one of the greatest stimuli to the persecution of American Indian Nations, instituting a colonialist displacement of Native tribes, moving them from their homelands to reservations wherein the land was poor and cultural traditions were threatened (Washington , DC: Office of the Federal Register, National Archives and Records Service, General Science Administration, 1963, Ewalt, 2011).

Natural resources management from the wetter eastern United States were often inappropriate for the more arid grasslands of the western United States (Licht, 1997). While cultivating, settlers harvested what they could from the central and eastern plains, and cattle ranchers exploited the arid west grasslands (Licht, 1997; Chapman et al., 2015). The increasing numbers of farms quickly fenced off the open ranges and in other cases ranchers themselves illegally fenced and appropriated the public lands to keep homesteaders out (Hurt, 1994). But homesteading continued, and by the 1890s nomadic cattlemen and their storied cattle drives were history (Licht, 1997).

What replaced them were exploitative, agrarian practices. John Wesley Powell stated that the arid grasses could be easily destroyed by improvident pasturage, and they are then replaced by noxious weeds; he concluded that cattle in the region cannot be enclosed by fences in small fields and that they should be fenced only by townships (thirty-six square miles) or even tens of townships (Licht, 1997). Many Native American tribes who utilized *in-nii* did not generally have access to the lands because of resettlement efforts and millions of *in-nii* were slaughtered and cattle replaced them, changing the way lands are grazed to this day.

Grassland prairie soils were exposed due to the overuse by livestock, and we are still learning what those effects have done to these landscapes (Licht, 1997). Confined cattle within small pastures that were maintained in unnaturally high numbers affected the native vegetation in ways not previously experienced. *In-nii* grazing practices and foraging habits of eating and continuously moving through the landscape allowed grasses time to recover. Contrary to these conditions, cattle being in the pastures for long periods of time threw off the ecological patterns of growth and regrowth. Cattle prefer forage plants (“decreasers”) in the climax community of

tallgrass, midgrass and shortgrass prairie; less-palatable plants not preferred by livestock (“increasers”), as well as unpalatable plants (“invaders”) dominate landscapes (Chapman et al., 2015) when the decreasesers are overgrazed.



Figure 4. Distribution of grasslands types in North America. (Figure from Chapman et al., 2015)

Cattle and in-nii are considered generalist foragers, yet differences in forage selection indicate that cattle graze more often in areas with high plant biomass while in-nii select for intermediate plant biomass in similar environments (Peden et al., 1974; Plumb and Dodd, 1993; Reynolds et al., 1982; Kohl et al., 2013). It is apparent that where grasses and sedges are available in the habitat, they are selectively grazed by in-nii, and where they are sparse, browse

may be substituted, and dietary shifts from grasses to sedges and back again within a habitat type are usually associated with plant phenology (Coopedge et al., 1998). In-nii use of sedges, therefore, may be linked to a simple preference for green succulent forage during periods when warm-season grasses are either dormant or unpalatable (Coopedge et al., 1998); this would be especially important for lactating cows during late winter and early spring (March-April), when in-nii calves are usually born in Oklahoma (Halloran, 1968; Coopedge et al., 1998). In the Henry Mountains of Utah, however, in-nii selected similar forage as cattle but tended to move more, did not overgraze preferred feeding areas, and made greater use of steep slopes (Nelson 1965, Reynolds et al 1982). A similar pattern was found by Kohl et al. (2010) in their study where they quantified differences between bison populations at different locations and spatial scales (American Prairie Reserve, Malta, Montana, USA, and Grasslands National Park, Val Marie, Saskatchewan, Canada, 2010–2011) and bison and cattle at similar locations and spatial scales using behavioral observations, movement analyses, and resource selection functions. They found that cattle selected for riparian areas, lowlands, and areas near water resources, while in-nii selected for higher elevations greater distances from water resources; cattle selected for riparian areas, lowlands, and areas near water resources, while in-nii selected for higher elevations greater distances from water resources.

In the majority of situations, North American in-nii are grazers. Preferences for grasses and sedges, which were the most important foods of the free-roaming bison, fluctuated seasonally and by region (Reynolds et al., 1982). In all seasons in Yellowstone National Park and in northern Canada, sedges comprised the highest proportion of in-nii diets, while grasses were second in importance (Reynolds et al., 1982). Forbs appeared to be important to in-nii only

during summer (Wasser, 1977; Reynolds et al., 1982). Peden (1976) confirmed that in-nii on the short-grass plains in northeastern Colorado consume mainly grasses at all seasons; in spring, sedges were the next most important food source; forbs were important dietary items during fall and winter (Reynolds et al., 1982). Similarly, on semi-desert ranges in southwestern Colorado, grass was the dominant forage utilized by in-nii during the summer and exceeded 27 percent of their diet during all seasons (Reynolds et al., 1982). In-nii in the Colorado National Monument primarily forage on grass in winter and eat both in spring and fall (Wasser, 1977; Reynolds et al., 1982). In other herds located at Wood Buffalo National Park (Soper, 1941) and Elk Island National Park (Holsworth, 1960) in Canada, in-nii were observed feeding on grasses in the summer and sedges in winter (Reynolds et al., 1982). Important winter forage for in-nii included grasses consisting of Idaho fescue, bearded wheatgrass, bluebunch wheatgrass, sandberg's bluegrass, Richardson's needlegrass, and tufted hairgrass, along with shrubs including shrubby cinquefoil, big sagebrush and silver sagebrush (Meagher and Gates et al., 2005). These have a relatively higher nutrient content compared to other plant species in-nii might consume (Meagher and Gates et al., 2005). Geremia along with his research associates (2019) found that in Yellowstone National Park that in-nii can modify the Green Wave based on their grazing behaviors. In-niis' grazing behavior was shown to stimulate plant growth and delay plant maturation, in return the in-nii ate high-quality forage despite falling behind the wave (Geremia et al., 2019). The way that in-nii diet varied based on the season, forage availability, and elevation, shows their relationship with a diversity of landscapes across the continent.

During photosynthesis in these forages, three or four carbon molecules form, creating C₃ and C₄ species with different characteristics that thrive in complementary conditions, providing

in-nii and cattle with food year-round. C₃ plants prefer cool seasons, have lower light and temperature requirements, and require higher moisture; C₄ plants, which prefer warm seasons, have higher light and temperature requirements, and require lower moisture. A study that was conducted at the Samuel H. Ordway, Jr, Memorial Prairie located in north-central South Dakota found that in-nii consumed primarily graminoids, while forbs and browse generally contributed less than 10% of in-nii diets. C₄ grasses accounted for one third of the in-nii diets early in the season and increased to 40% during late July and all of August; in-nii reduced feeding on C₄ grasses after 1 September to 15% by 30 September; C₃ graminoid contributions to in-nii diets were 52-58% from mid-June through mid-August and a large increase in C₃ graminod use by in-nii occurred after 1 September to levels more than 80% (Plumb and Dodd 1993). The study by Plumb and Dodd (1993) found trends in use of C₄ grasses by cattle were less dynamic than those of in-nii, in that cattle use of C₄ grasses didn't vary from late June through early August; however, cattle's use of C₄ grasses declined after early September. Shifts in the amounts of C₃ graminoids eaten by cattle occurred biweekly throughout the summer. Forbs contributed 15% and browse contributed near 10% to cattle diets during June and early July; in late July, use of these plants decreased and was maintained at this level for the remainder of the summer. Plumb and Dodd (1993) state that in-nii select for C₄ grasses and against C₃ graminods during June and August. Ultimately, in-nii and cattle diets vary seasonally, and forage choices come down to nutritional requirements and food selection.

The wildfires that once rejuvenated, maintained, and shaped plant distribution on the prairies have also been repressed for many decades by Western fire suppression practices. Grasslands historically burned in a patchy pattern, in part because of the wallows, trails, and

grazing of bison, and in part because of the soil types and other natural features—but, perhaps, also because they were set that way by Native Americans (Licht, 1997). Colonel Richard Dodge (1899) who traveled the plains from the 1860s to the 1880s noted in the region of present-day Kansas, “the Indians burn portions of the prairie every fall, setting the fires so as to burn as vast an extent of country as possible, and yet preserve unburned sections in the vicinity where they propose to make their fall hunt” (Licht, 1997). The Amskapiipikini would also burn the grasslands so the in-nii would return to the area the following year to eat; this was how the people would select sites to harvest the animals (Tatsey, 2019). Whatever the source, the burns created a mosaic of grassland successional stages throughout the prairie: after the burns, many grasses grew more vigorously, were more nutritious, and flowering increased in many prairie forbs (Risser et al., 1981; Licht, 1997). Through cultural science practices, Amskapiipikini observed the benefits for plant species that contributed to the management of the land. But historical burning is only one practice that influenced in-nii movement and grazing on the landscape.

Management of cattle and in-nii on ranches in ways these ungulates can graze without depleting the land's resources is a difficult task (Tatsey, 2019). The management practices associated with traditional grassland ecosystems have undergone radical changes during the last 50 years: the change from multi-species swards to species-poor plant communities, increased use of inorganic fertilizers, and the shift from hay to silage-making increased stocking rates (Chamberlin et al. 2000). Successful ranchers manage to achieve the best possible profit and the best ecosystem health; they must use basic knowledge of plant physiology and ecology generated by research within an adaptive, goal-oriented management approach to successfully implement

planned grazing management (Teague et al., 2008). Natural rangeland communities are constantly responding to the effects of the most recent disturbance, though in some cases some communities have achieved a steady-state (Teague et al., 2013); the absence of these disturbances in these grassland ecosystems can result in a decline in species diversity and deterioration of the physical appearance of the plants and health of these plant communities (Vogl, 1974; Ria and Parenti, 1978; Pickett and White 1985; Hulbert 1969,1988; Teague et al., 2008).

Management of grazing can enhance soil moisture and seed production; grazing can “condition” the resources to take fuller advantages of episodic events like drought or fire which will create a healthier plant community (Watson et al., 1996; Gerrish 2004; Teague et al., YEAR). There are a few different types of grazing management techniques that enhance animal and plant health. Paddocks that are continuously grazed must have a large enough forage supply for an entire year or grazing season (Teague et al., 2008). Multi-paddock grazing management can regulate the frequency of defoliations of preferred areas in systems where re-growth during a grace period is likely. These techniques afford adequate recovery before re-grazing if grazing periods are short enough (Derner et al., 1994; Teague et al., 2008). An absolute increase in plant growth occurs under intensive grazing systems only if plants are not subject to chronic defoliations and have time and resources to recover following defoliations (Teague et al., 2013). One of the primary yet overlooked reasons for a short grazing period is to allow an adequate opportunity for animals to select a high-quality diet from a mixed sward or landscape with a diversity of topography and vegetation (Derner et al., 1994; Teague et al., 2003).

Rotational grazing management may also be partly implemented through methods other than intensive fencing, including rotating access to water sources (Martin and Ward, 1970; Teague et al., 2013), herding (Bradford, 1998; Teague et al., 2013; Coughenour, 1991; Bather, 2000; Bailey, 2005; Bailey et al., 2008), and manipulating animal behavior (Provenza, 2003; Launchbaugh and Hower, 2005; Teague et al., 2008). Ranch-scale research indicates that plant vigor, ecological condition, and carrying capacity benefit from grazing systems at appropriate stocking rates with only one grazing period during the growing season and the application of full growing-season deferment to each pasture once every 3 to 4 years (Danckwerts, 1984; Tainton et al., 1999; Muller et al., 2007; Teague et al., 2013). Such types of grazing management could help reverse worldwide environmental degradation (Licht, 1997).

Researching the benefits in-nii bring to the landscapes and what their influences will be to ecosystem health (biological, chemical, physical) are important to understand as well as the spiritual connection the in-nii have with the Amskapiipikini. Thus, creating a space to share the knowledge the Amskapiipikini have because of their close connection with the natural world around them could provide greater texture to Western science approaches. This research would reinforce the value of Amskapiipikini cultural science and stories describing the relationship the in-nii have to the land and people, focusing on the balance of people and place and exchanges between them in key beneficial roles.

The interconnectivity of a system can have far-ranging consequences: soil can affect plant health, which can ultimately affect animal health and then the health of people. So, a concern arises: fences are currently limiting the ability of in-nii to steward the land, breaking down that interconnectivity. Most in-nii are in fact enclosed by fences not by their choice but by

management practices of national parks, private ranches, and Tribal Nations to keep them from encountering cattle operations. It is unknown if this has changed their behavior and thereby influenced soil health. These are some of the questions that Native American students at Tribal Colleges and Universities could start to address as they bring their research back to the lands from which they have come. As Hillenbrand et al. (2019) stated, to ensure long-term sustainability and ecological resilience of agroecosystems, agricultural production should be guided by policies that change degrading management practices to low-input regenerative practices that enhance soil and ecosystem function and resilience to improve long-term sustainability and social resilience.

In conclusion, in-nii played an integral role in the Amskapiipikini's lifestyle: the in-nii made it possible for the Amskapiipikini to live in a healthy grassland ecosystem. There were two types of in-nii that lived in the United States: the plains in-nii and wood in-nii which both traveled the lands. With the introduction of land colonization, however, these practices changed. Native American Tribes in the Great Plains that were living on the lands got to see how different management techniques changed that land drastically. The grasslands of the Great Plains and in-nii were slowly being exterminated, replaced by farms and cattle ranches. The management practices that were implemented could have had several costly effects on the land. Because of these effects, it is important to come up with management practices that address the relationship between in-nii, cattle, and soil health to benefit the land and the landowner.

In-nii and Cattle Grazing Effects on Soil Health

Before the introduction of cattle to the Great Plains, in-nii dominated the lands. Their grazing influenced the vegetative communities, soil nutrient exchanges, and nutrient availability (Knapp et al., 1999). As might be expected, grazing tends to reduce grass biomass (Figure 5). It is estimated today that cattle numbers in the United States and Canada are higher than historical bison herds by two times (Kohl et al., 2013). When the shift from in-nii to cattle took place, and settler grazing regimes were implemented, it changed the ecosystem: cattle now had to forage in confined areas, which led to over-grazing (Kohl et al., 2013). Today, cattle ranches are implementing regenerative grazing management techniques that improve soil stabilization and formation, water infiltration, carbon sequestration, and nutrient cycling and availability (Teague et al., 2020).

In-nii move more freely through pastures and do not congregate in areas for long periods of time, compared to cattle. While cattle graze specific plants, in-nii are willing to graze plants that are dominant in a field but are less nutritious, creating diversity in the plant communities (Knapp et al., 1999). The selective grazing for in-nii choosing the abundant grasses increased the photosynthetic rates on average by 53% in grazed tillers whereas it stimulated plants 150% more than in ungrazed plants (Knapp et al., 1999). Thus, greater tissue nitrogen concentrations in the leaves as nitrogen moved from the roots could be causing the movement of carbon reserves from belowground to aboveground tissues (Knapp et al., 1999).

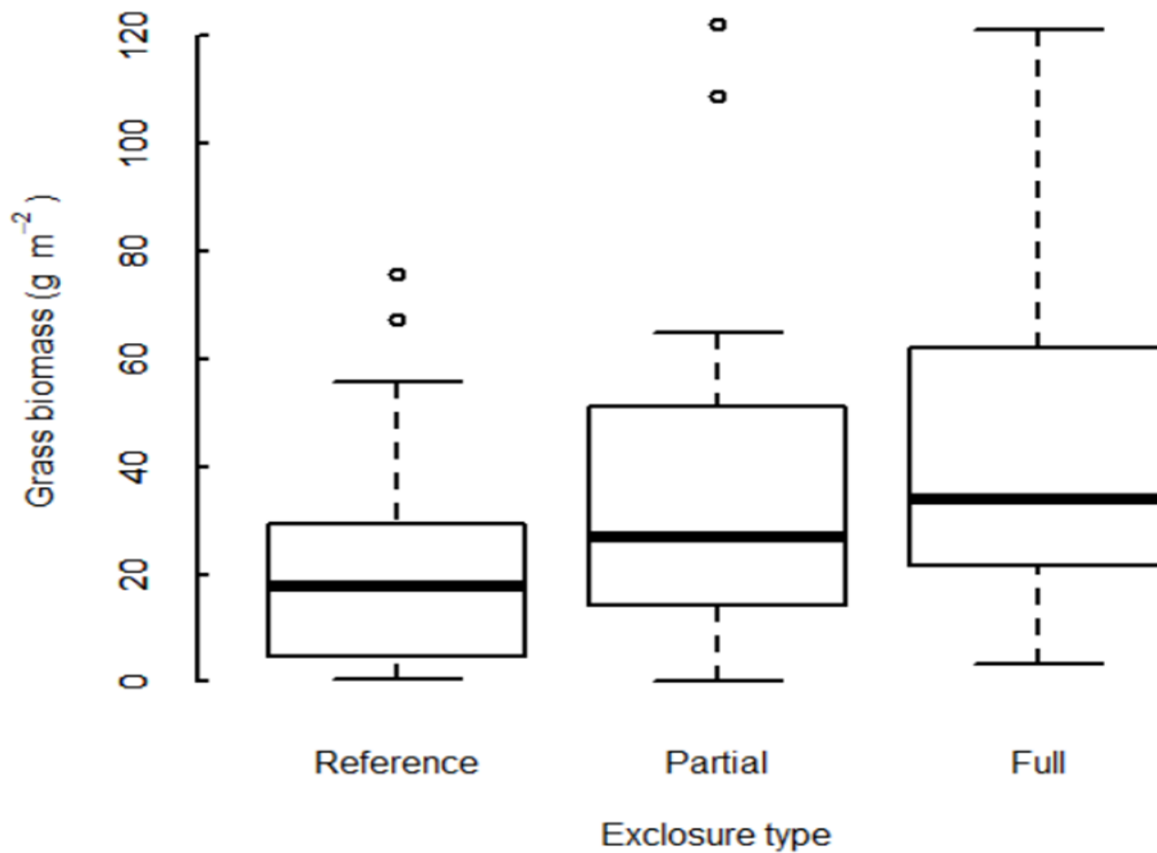


Figure 5. Boxplots of grass biomass clipped to measure standing crop after one year for each of the treatment types ($n = 20$ per type): grazed reference plot; partial enclosure (cattle + bison out); and full enclosure (cattle + bison + lagomorphs out). Significant differences were found among all three plots ($p < 0.05$). The difference between the reference and partial is the large herbivore effect (bison and cattle), and the difference between partial and full is the small herbivore effect (lagomorphs). Total grazing impact is represented by the difference between reference and full. Box plot shows quartiles, median, and 1.5x interquartile range. Circles show outliers beyond 1.5x interquartile range. Source: Ranglack et al., 2015.

The question of grazing management is an essential aspect of wild and domesticated in-
nii and cattle because there are some similarities and differences when it comes to soil and plant
health.

The decomposition of plant material is important for integrating organic matter into the
soil profile. It can take decades for plant matter to be broken down into plant-available nutrients

such as nitrogen. Fire speeds up that process, releasing dead plant material onto the surface of the soil like an instant burst of nutrients, which is an ecological service. Analogous to microbial mineralization of organic matter, pyromineralization of otherwise unavailable forms of nutrients can be an important ecological process (Giardina et al., 2000). Since time immemorial, fire management has been a cultural practice for many Native American tribes in the region. We have used this tool to benefit the land and the in-nii, with the understanding that burned forage could attract in-nii for hunting.

There are many influencing factors that return carbon into the soil, whether through fire, animal movement, grazing densities (Figure 6), or natural plant exudation and decomposition processes. Soil organic carbon is essentially half of soil organic matter (Pribyl, 2010), and, as such, plays an integral role in the health of agricultural systems, which includes grazing. Soils that have high amounts of soil organic matter can hold larger amounts of water benefiting photosynthetic rates in leaves of plants, thus changing the way land is used. The in-nii, and more specifically their hooves, are integral parts of this process as well, by breaking down plant material as well and pushing it into the soil. The benefits of these traditional practices are starting to be researched and better understood by applying western scientific methods. For example, researchers found that in-nii prefer grasses that had been burned (Knapp et al. 1999).

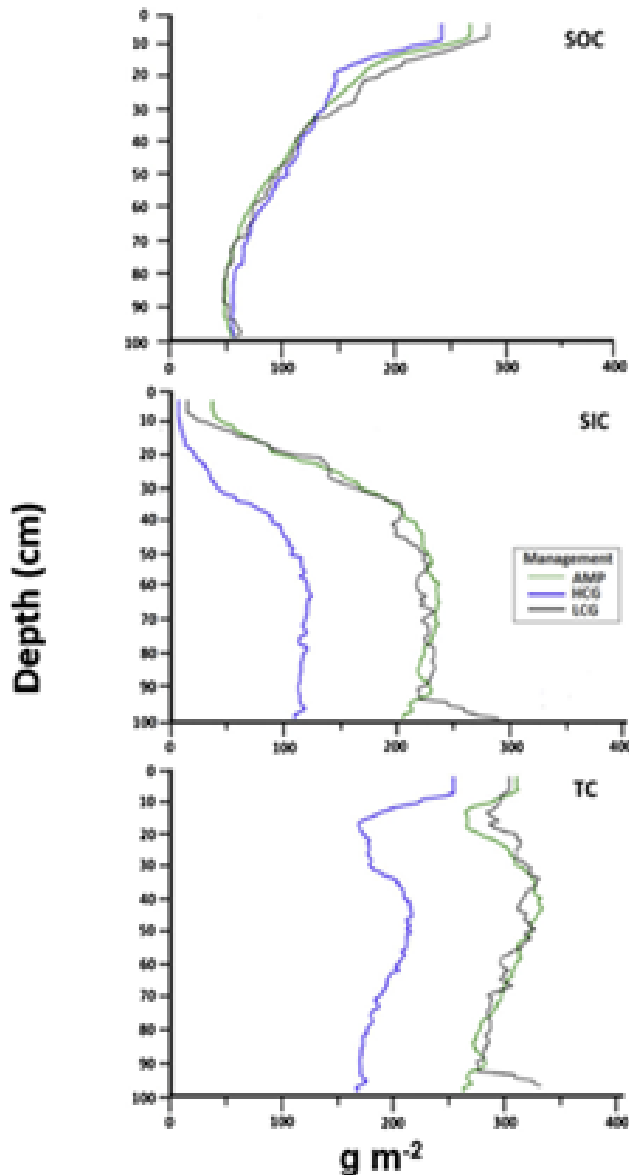


Figure 6. Mean soil carbon levels with soil depth under three different, South Dakota grazing regimes: light, continuously grazed (LCG; 14 animal unit months [AUM] 100 ha^{-1} (12-month basis) with replacement heifers during May to November), heavy, continuously grazed (HCG; 51 AUM 100 ha^{-1} (12-month basis) with cows and calves during May to October), and adaptively (multi-paddock) grazed (AMP; 13.0 AUM 100 ha^{-1}). a) Soil organic carbon (SOC); b) soil inorganic carbon (SIC); and total carbon (TC; Hillenbrand et al. 2019).

Once in-nii move onto the land, their behavior contributes to a wide range of ecological services. When they roll on the ground, they leave behind compressed depressions that serve as

micro-habitats for plant species (Baltes, 2016). Because the water does not infiltrate deeper into the soil, these depressions can retain more moisture, which influences the plant communities and increases biodiversity from the surrounding countryside (Tastad, 2014). On the Konza Prairie, root productivity and root biomass were 30% and 20% lower where in-nii had grazed versus not grazed, but the nitrogen of the new growth in the grazed field increased from 0.6 to 0.9% (1999). Because in-nii urine is nitrogen-rich, grass production is increased and leaves produce higher nitrogen, which makes them more nutritious than grasses growing in patches without urine inputs. This, in turn, encourages in-nii to revisit these grass patches for grazing. (Knapp et al., 1999).

In-nii and cattle grazing behaviors also differ due to their metabolic responses to temperature. The greater cold tolerance of in-nii can be attributed primarily to their greater pelage insulation (Reynolds et al. 1982). An increase in metabolic rate is considered the normal response to cold exposures, although this response may be attenuated by cold acclimatization (Reynolds et al. 1982). For both animals, cold seasons mean more grazing, in order to maintain body weight, temperature, and other body functions. During spring and summer months, cattle will begin to seek thermal relief at 26°C (78.8°F), which is common, while in-nii will seek thermal relief at 36°C (96.8°F), which is uncommon for prolonged periods during the summer months (Allred et al., 2013, Grudzinski et al., 2018). In the summer, the plants are so nutrient-rich that less grazing is required to meet the needs of their bodies.

When cattle are not managed to limit their use of water systems, overuse of any watering area can create ecological damage. It has been documented that in-nii spend less time than cattle by waterways (Kohl et al. 2013). Because cattle do not graze far from water, they often over-use

grazing areas near water. In-nii, however, will graze further away from water sources, contributing to increased soil nutrient input from urine and dung patties. An increase in unregulated cattle access to streams can contribute to a double increase in soil erosion in riparian vegetation areas, compared to forested buffered areas (Grudzinski et al., 2018). This loss of soil reduces the mass of plant roots, which can lead to streambed degradation. Without these root systems, the streambeds destabilize and erode up to 30 times more than that in vegetated riparian areas (Grudzinski et al., 2018). While one study identified no major variations in bare soil coverage or bank degradation between elevated and low severity pasture in riparian area (Grudzinski et al., 2018, Larson et al. 2013), other tests have shown that bare soil coverage rises dramatically due to growing grazing pressure (more than 10% in two years) (Larson et al. 2013).

In-nii and cattle grazing can be managed for seasonal, continuous, or rotational pastures. This decision, made by land managers who have to consider their time and goals, will impact aspects of soil health, including pH, organic material, and element levels including carbon (C)/soil organic matter (SOM), nitrogen (N), phosphorus (P), and sulfur (S) (Doran et al. 1999, Panza 2020). All of these nutrients affect the quality of the soil and are influenced by grazing practices. There has been a loss of 30% to 50% in soil organic carbon in the Midwestern United States from the conversion of natural soils to agriculture systems, but 60% to 70% of carbon can be sequestered back into the soil through new management practices (Lal, 2001; Sanderman et al., 2017). The grazing intensity, which varies between these four management approaches, causes the leaves to reallocate carbohydrates that are stored in the root to help regrowth of new leaves. When over-utilization takes place, the belowground resources that are stored in roots will be depleted, affecting the quality of soils and vegetation (Carlyle, 2019). Ranch operations benefit from implementing

different grazing practices, as seen in a study that was conducted at the 777 Bison Ranch (Hillenbrand et al., 2019). Their use of an adaptive multi-paddock (AMP) system in a shortgrass prairie in the Northern Great Plains found positive results by adjusting their animal number to match forage availability. The animals grazed for shorter periods, which allowed time for plant recovery. This decreased bare ground, and improved their litter cover, herbaceous biomass, plant composition, and water infiltration into the soil (Hillenbrand et al. 2019). Importantly, they found no differences in soil organic carbon between their three different management systems after ~10 years (AMP vs. light or heavy continuous grazing).

Season-long continuous grazing requires less active management, allowing grazers to move freely across the land. They might stay in an area for a longer period to graze, increasing the chances for overuse (Teague, 2020). This type of grazing reduces preferred plants, allowing for less-palatable grass species to increase. The result could be a loss of soil structure, reduced water infiltration, loss of water used for plant availability, increased surface water runoff, soil erosion, and nutrient movement to downslope water bodies (Teague, 2020; Thurow, 1991 as cited in Teague, 2020, Burkart and Stoner, 2002 as cited in Teague, 2020; Babiker et al. 2004 as cited in Teague, 2020; Webber et al. 2010 as cited in Teague, 2020). In Canada they have conducted studies showing in certain cases, soil supplies seem to be improved by pasture, and grazing may be a core aspect of pastureland (Carlyle, 2019).

Comparing results between Hillenbrand's and Teague's research shows that shorter grazing periods are more beneficial for soil health than seasonal-continuous grazing. There is no one-size fix-all situation: it comes down to knowing the land and soils that are particular to an area so the land manager can make more effective decisions.



Figure 7. Postulated effects of alternative grazing management approaches on productivity and biodiversity, soil health, ecosystem services and ranch economics (Frank et al., 1998; Teague et al., 2013; Jakoby et al., 2015; Savory and Butterfield, 2016; Park et al., 2017; Stanley et al., 2018; Dowhower et al., 2019; Pecenka and Lundgren, 2019). (Teague et al. 2020).

Effect of Grazing on Plant Soil Feedbacks and Temperature

During their lives, plants influence the biotic and abiotic features of the soils they grow in, and those influences in turn, affect plant growth, in a process known as plant-soil feedbacks (PSF) (Kulmatiski, 2019). The plants growing will influence the habitat of the plants that will grow the following year. Biotic plant matter feeds organisms, including soil microbes and other soil biota that are part of complex soil food webs. Chemical and physical attributes of the environment and climate affect this transfer of organic matter between living organisms in the soil. All these interactions ultimately impact plant performance, plant community composition, and vegetation dynamics within ecosystems. PSFs vary between ecoregions and between different plant and soil communities (Kardol et al., 2013).

How the intensity and path of PSFs might differ from related and unrelated above- and below-ground drivers is still being studied (Van der Putten et al. 2013). For instance, plant-based shifts of the soil pH may trigger changes in the soil bacterial population, which can contribute to host-specific aggregation of microbial pathogens, thus raising plant-harmful PSFs (Kardol et al. 2013). Positive PSFs may be inhibited, specifically for slow-growing, mycorrhizae-dependent organisms (Suding et al. 2013). Anthropogenic and natural disruptions can also be involved in the formation of PSFs.

As grazers, in-nii and cattle can have a major influence on PSFs and the landscape; plants may respond to above-ground herbivory that could alter resource allocation to roots creating a source of energy for soil food webs (Andriuzzi et al., 2018). It is not yet known how species-specific grazing behaviors impact plant-soil feedbacks, soil nutrient exchanges, greenhouse gas production (Figure 8), and nutrient pools. As discussed above, the composition of plants can differ in areas grazed by cattle, which are generally more selective about their plant choices, and areas grazed by in-nii, who generally graze more uniformly. However, studies do indicate plants in soils of ungrazed and grazed grasslands perform differently (Veen et al., 2013). For example, abiotic factors might change the biomass allocation in response to grazing-induced soil legacy effects. Veen et al. (2013) found that while plant communities are more stable in grazed versus ungrazed sites, plant-soil feedbacks did not differ between grazing treatments.

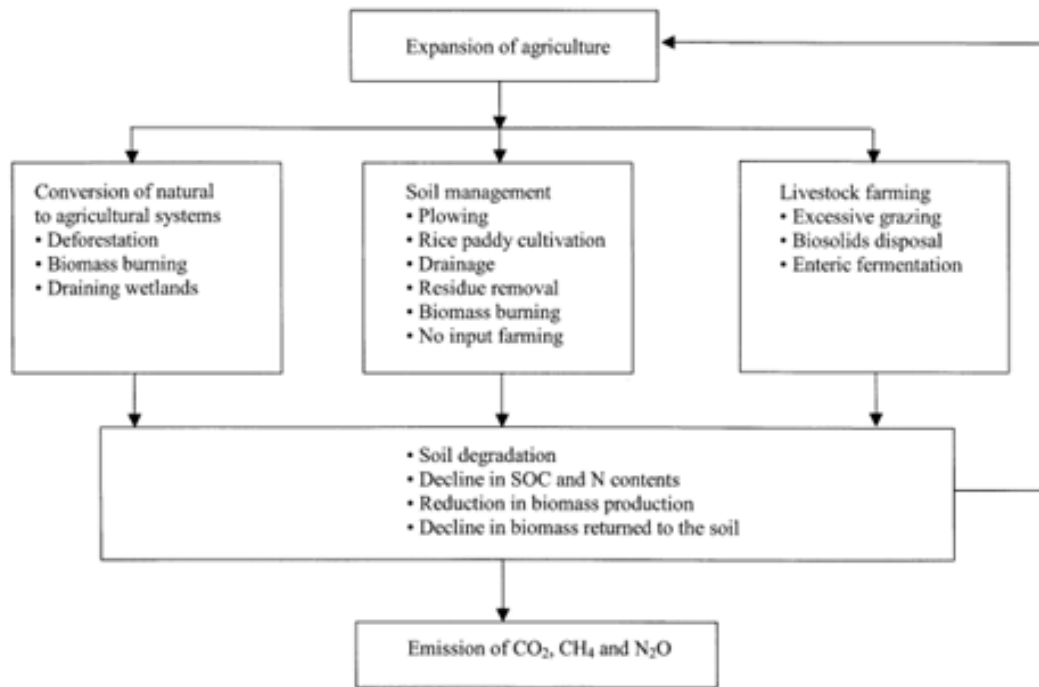


Figure 8. Agricultural activities and emission of greenhouse gases from soil and terrestrial/aquatic ecosystems to the atmosphere. This conceptual model of the expansion of agriculture influencing natural systems and soil functionality (source Lal 2001).

Plant-soil feedback does not operate on an island, though; with climate change, temperature is now affecting this process since greenhouse gases are essential to our Earth's climate (Figure 8). Temperature contributes to environmental factors which are important for sustaining life on Mother Earth. However, as the earth continues to warm and climate change becomes more of an issue, temperature has never been more important to consider. Temperature influences the interconnections of aboveground plant and animal communities, while belowground temperatures influence soil and plant root biological communities. For instance, where in-nii wallow, the soil temperature can be a degree warmer than other areas where wallowing doesn't occur; the soil temperature in the wallows is 4.6°C lower at a 3 cm depth compared to the surface (Panza, 2020).

Plants growing in specific soils with a history of drought appear better able to adjust to temperature increases influencing drought resistance (Kaisermann et al., 2017). Temporal shifts and abiotic conditions can also affect soil biota, which will influence plant communities, ecosystem dynamics, and PSFs (Figure 9; Kardol et al., 2013). Temperature may also influence the behavior of soil organisms and the processing and decomposing rates for nutrients (van der Putten et al., 2013). Ultimately, depending on the environmental factors it can increase litter quality, particularly for fast-growing varieties that require high levels of nutrients (van der Putten et al., 2013). Positive PSF results may decline as organisms respond to hotter soils or experience environmental changes via enhanced nutrient cycling (van der Putten et al., 2013; Kardol et al., 2013; Kaisermann et al., 2017).

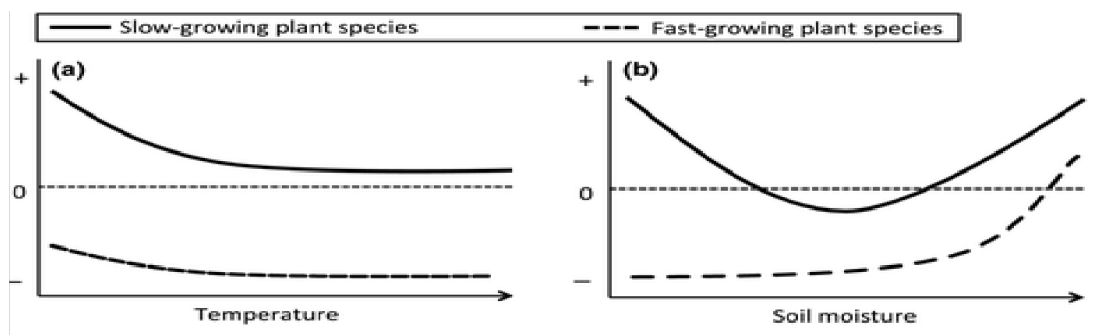


Figure 9. Conceptual model illustrating how abiotic factors might influence PSFs. The x-axis indicates changes from left to right of individual drivers (i.e. rise in the temperature, precipitation), whereas the y- axis indicates how the overall PSFs might change. Plant species whose growth strategies are quick to slow may be anticipated to have opposite reactions when a driver's effect grows. (a) Elevated temperatures in rapid-growing plants could result in more negative PSFs, leading to excessive pathogen strain, whereas slow-growing plants, because of mutualist failure at higher temperatures, often undergo an even more dramatic decline in the strength of positive PSFs. (b) Rising soil moisture can contribute initially to divergent PSFs (slight increase for fast-growing plants, sharp decrease for slow-growing plants) but subsequently gradually shows convergence in positive PSFs for both plant types that could be related to high decomposition rates and high uptake rates of nutrients. Source: Kardol, et al. 2013.

Thus, plant-soil feedbacks and soil temperature have numerous influences on the health of plant communities on a landscape. These interconnections of ecological functions maintain the health of the planet. However, climate change is now not just affecting that larger process but is also changing the ways in which in-nii and cattle graze, while also changing the way communities approach the use of their resources.

Soil Carbon Sequestration

The diversity and abundance of in-nii and cattle forage ultimately depends on a plant's ability to take carbon dioxide (CO₂) out of the atmosphere and convert it to a food source through photosynthesis. This process converts solar energy into chemical energy. Soil carbon sequestration is a mechanism by which atmospheric CO₂ is absorbed and photosynthesized and then deposited as litter or exudates into soil (Ontl, & Schulte, 2012). Carbohydrates, the main food source plants derive from this interaction, accumulate primarily in the leaves of plants and help structure cell walls. Observational experiments have demonstrated that plants developing at elevated CO₂ concentrations greater than atmospheric concentrations (currently ~420 parts per million) have a comparatively higher carbon-fixing rate, which can produce more carbohydrates and thereby potentially support more herbivory (De Stefano, Jacobson, 2018). In-nii and cattle have the capacity to access this energy by breaking down plant cellulose, and, in turn, their grazing behaviors influence the ability of plant communities to uptake carbon through the photosynthetic process (Teague et al., 2020).

Teague and associates (2020) showed that properly managed agricultural systems limit overgrazing, which ensures that enough aboveground photosynthetic machinery is available to

integrate carbon into the soil, which generally is thought to improve soil health. By increasing soil carbon, this style of management can provide an ecological service for grasslands. Plant cover and litter cover maintain soil functioning and the soil-building process, which can reduce soil exposure and bare ground to minimize erosion (Hillenbrand et al. 2019).

Throughout the United States, increased demand for agricultural production beginning during the nineteenth-century Industrial Revolution transformed a significant area of natural prairie environments into intensively cultivated farms. This agricultural intensification contributed to a decline in soil organic carbon (SOC), which may have resulted in 50 to 100 gigatons (Gt) of carbon emissions to the atmosphere (Yang et al., 2019). For context, terrestrial portions of Earth are thought to emit approximately 136 Gt of carbon to the atmosphere annually (Yang et al., 2019). Declines in SOC could have then led to a decrease in plant root biomass, accelerating soil degradation. Such losses of carbon reserves impact a soil's ability to host healthy plant communities and grazing animals. Today, atmospheric CO₂ and temperatures are rising, which, through increased soil exposure, can weaken plants' ability to photosynthesize, respire and facilitate nutrient cycling (Naylor et al., 2020).

All of these factors discussed in this chapter influence carbon gains and carbon losses (Stanley et al., 2018; Figure 9). The ability of the soil to sequester carbon can also be affected by local restrictions on environmental processes at the level of a wetlands or crop area. Landscape position can change many processes, including soil degradation, sediment accumulation, and other soil factors that can vary at a small scale. Slope, for instance, by redistributing soil moisture, can influence soil aerobic status and micronutrient availability, which may have implications for soil carbon gains through plant photosynthesis. In summary, the healthy plant

communities that in-nii and cattle depend on, in turn depend on a soil's ability to sequester carbon because SOC represents a plant life-support system, beginning with water-holding capacity.

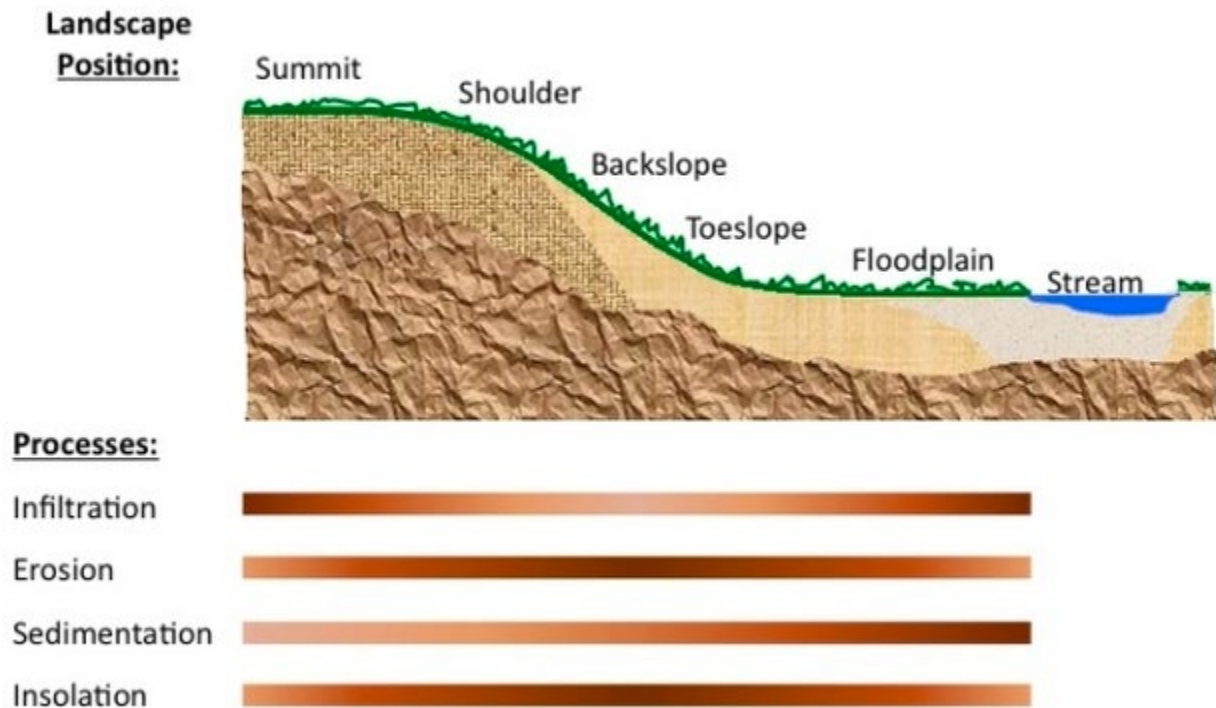


Figure 10: Influence of soil landscape position on soil processes that ultimately govern SOC dynamics (Stanley et al. 2018). Darker hues represent relatively larger values. Insolation (quantity of sunshine received) also depends on aspect.

Recent work by a number of researchers implies framing of soils as a sink for atmospheric CO₂ might serve as a distraction to reducing fossil C and land use change-related emissions. For example, Dyke (2022) has noted “that while motivated by concerns of climate justice and equity, net zero [carbon framing] has become co-opted to facilitate a ‘burn now-pay later’ approach that threatens to overwhelm younger people and future generations with vast economic and technological debts.” This framing most recently has been in terms of “natural

climate solutions" (NCS; Fargione et al. 2018, Bossio et al. 2020): "solutions" such as reforestation, biochar-crop residue, cover crops, agroforestry, and avoided forest, grassland, and peatland conversions could help mitigate rising atmospheric CO₂ levels. The cumulative magnitude of investments in such "carbon stabilization" or "climate mitigation" approaches might be on the order of ~5 billion metric tons of carbon dioxide equivalent per year (Bossio et al. 2020), which is approximately 10% of annual anthropogenic emissions. Importantly, these authors noted this "level of mitigation... [accounts] only for biophysical constraints, if there were no economic, social, institutional or other barriers to implementation." No matter the cumulative magnitude of these approaches, these investments should not detract from efforts to reduce fossil fuel emissions. This of course does not mean discovery of soil-linked ways to soak up atmospheric CO₂ at rates that are unambiguous and consequential is unimportant. Because our atmosphere's concentration of carbon dioxide reflects the balance of both anthropogenic and 'background' inputs and removals, every little bit of additional soil carbon helps. But Anderson et al. (2018) first admitted "Some of us have contributed to among the most optimistic assessments of the potential of NCS, whereas others have been more pessimistic. But one thing on which we agree, and which technical literature generally acknowledges, is that the benefits of NCS do not decrease the imperative for mitigation from the energy and industrial sectors." Later these same authors note "In every analysis to date, getting the required cuts [in fossil carbon emissions] from energy and industry still entails a major increase in the level of ambition and the rate of progress." In other words, there is an emerging consensus that even while cutting fossil carbon emissions will be difficult, we must accelerate these reductions.

Framed more bluntly, Janzen et al. (2022) recently wrote "overly optimistic projections for [NCS-related] soil C gains may dilute the urgency of other strategies, notably of reducing fossil C emissions." In my opinion, no wild (and unforeseen) NCS successes will make it any easier to do the heavy lifting any truly regenerative or sustainable land management practice must catalyze: reducing our fossil fuel emissions. We cannot afford thinking 'it's ok to burn now because we are exploring soil carbon sequestration approaches.' Simply put, this thinking creates too great an economic, psychological (see Doherty and Clayton 2011), and technological debt for current and future humans.

These are only some of the reasons why the Blackfoot Tribe developed a Blackfoot Climate Change Adaptation Plan in 2018 (<https://blackfeetclimatechange.com/>). In fact, the opening letter to that 2018 plan begins "The Blackfoot (Amskapiipikini) have long believed that we are the caretakers of the land and resources where we have resided for many thousands of years. To this day, we use this land for spiritual and cultural purposes.... Our connection to the land and its resources is the base from which we draw on for our cultural and spiritual needs.... We must hold on to these spiritual ties to the land and pass them on to our youth who are destined to become our future leaders and caretakers of the land." It is worth noting that many authors have studied the psychosocial and indirect impacts of "changing and contested views of climate change" (Figure 11). This thesis, in effect, serves as part of the 'observe and learn' ("monitoring action effectiveness") element associated with the Climate Change Adaptation Cycle in that 2018 Plan; additionally relevant to this thesis, this plan included two explicit goals: "promote soil health" (page 50) and "establish monitoring systems for adapting to changes in the environment" (page 53).

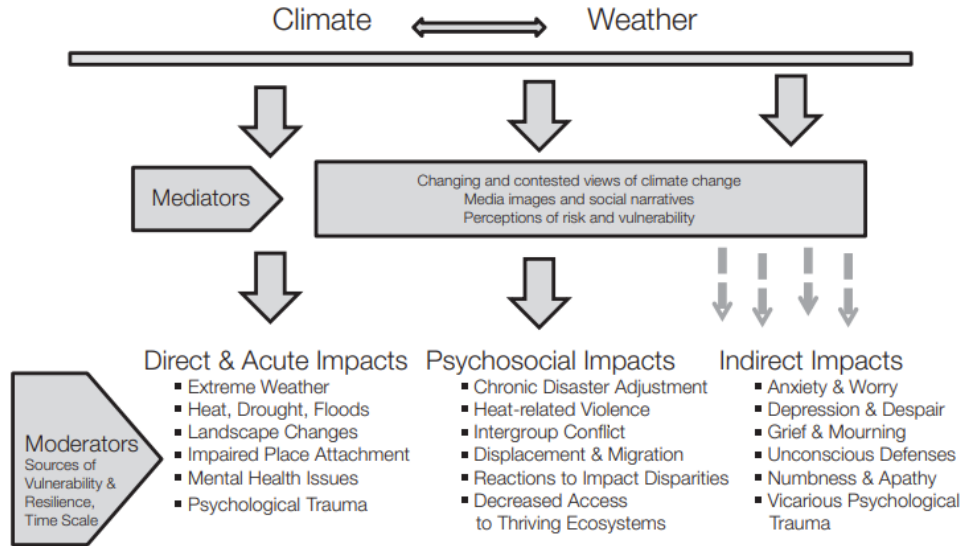


Figure 11. Climate change: Differences between classes of psychological impacts (source).

Conclusion

In-nii and cattle grazing habits influence and are influenced by soil health, plant-soil feedbacks, temperatures, and soil carbon sequestration dynamics. Looking through a holistic lens allows us to see the interconnections between all of these ecological relationships. Grazing of large ungulates like in-nii and cattle has been evolving on earth since time immemorial. These large animals have influenced the development of soils and nutrient cycles; this co-evolution has contributed to how grassland soils have evolved to hold large amounts of carbon in semi-arid grasslands (Retallack, 2013; Hillenbrand et al., 2019). In-nii and cattle are on the landscapes to stay because they both have important values they bring to people and their cultures, be they from a land- or economics-based perspectives.

Grazing by large ungulates can have both positive and negative effects on soil health. Teague et al. (2013) wrote that grazing in agro-ecosystems can, somewhat counterintuitively, increase soil stability and soil function, improving ecosystem services. The opposing view is

overgrazing by large ungulates can have devastating effects to the environment like significant soil deterioration, soil erosion, and biodiversity loss (Grudzinski et al., 2016). Current research has found that grazing can reverse environmental damage to the ecosystems that is caused by human mismanagement and neglect when management techniques are applied (Teague et al., 2020). In-nii are returning to many landscapes where their ancestors historically roamed and grazed, and cattle have been introduced to many of these landscapes. It is important to see how the land is responding when it comes to soil health. In other words, “when the bison (in-nii) return, will their habitat rebound?” (Johns, 2021).

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RESEARCH METHODS

Field Sites

The in-nii study site is a 10,000-acre pasture grazed by a herd of 360 in-nii (bison) on the Blackfeet Buffalo Ranch on the Blackfeet Reservation, Montana, USA (N48°30'36.55, W112°36'40.41). I sampled soils from this in-nii site in the summers of 2018 and 2019. The cattle site includes 3,000 acres that is privately owned and grazed and 4,000 leased acres with an estimated 600 cattle on the RRJ Ranch on the Blackfeet Reservation, Montana, USA (N48°28'21.75, W112°37'9.32). I sampled soils from this cattle site in the summers of 2018 and 2019 (Figures 12, 13, 14).

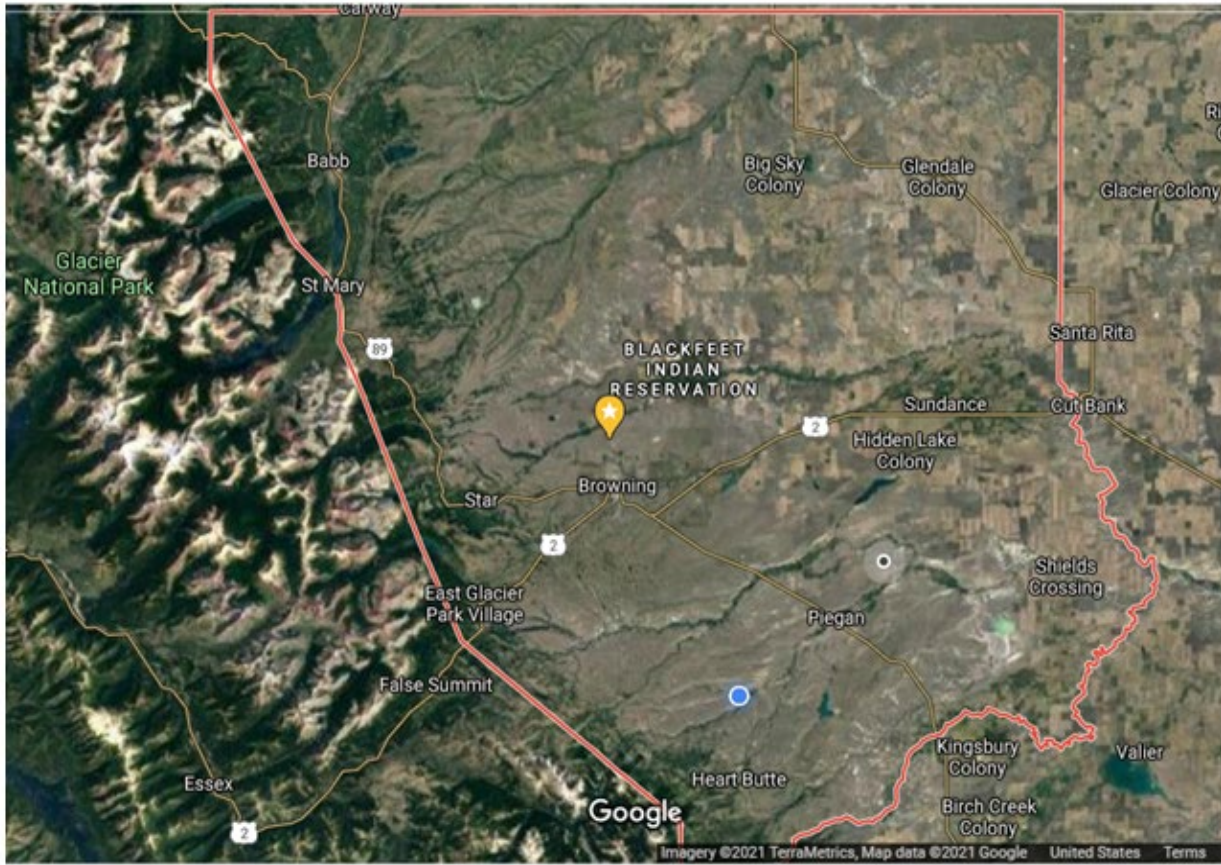


Figure 12. View of the Blackfoot Nation in Montana, which borders Glacier National Park to the west and Canada to the north. The grey dot shows where the in-nii and cattle ranches are located.

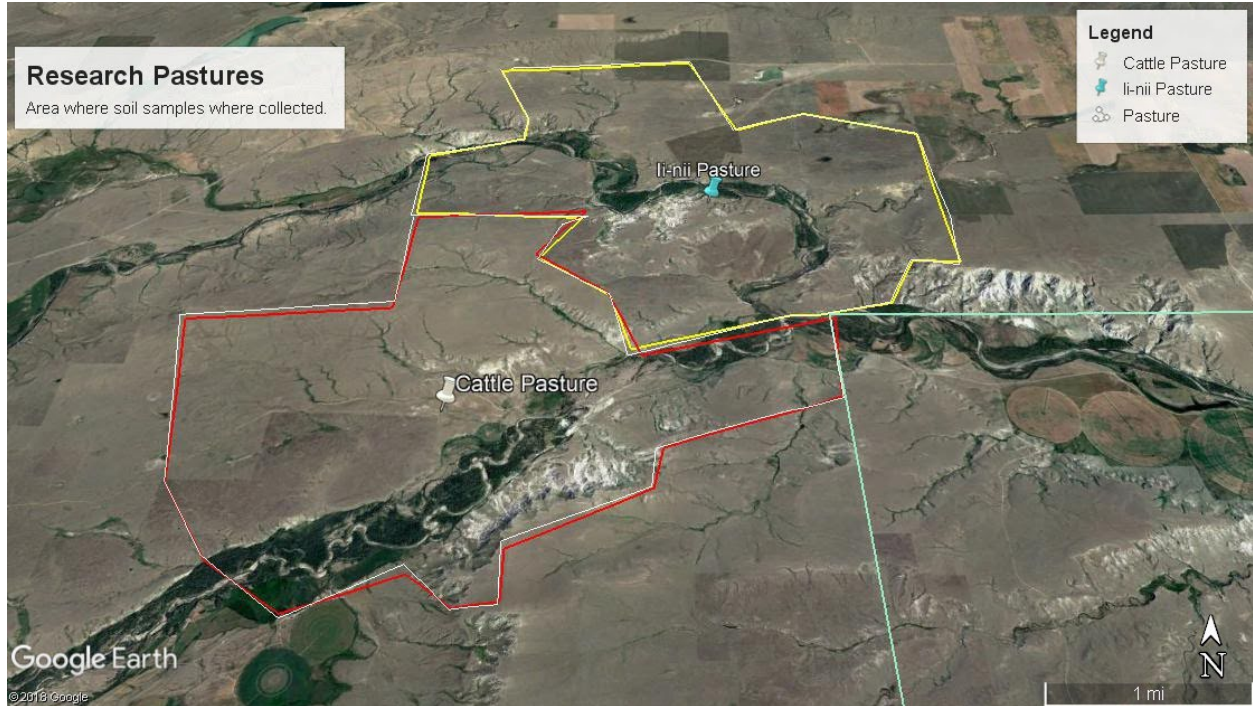


Figure 13. Map of the in-nii pasture (yellow border) and cattle pasture (red border), along with the water tributaries that flow through these landscapes. Two Medicine River flows through the in-nii pasture and Badger Creek through the cattle pasture, then meets where the green line meets the in-nii and cattle pastures.

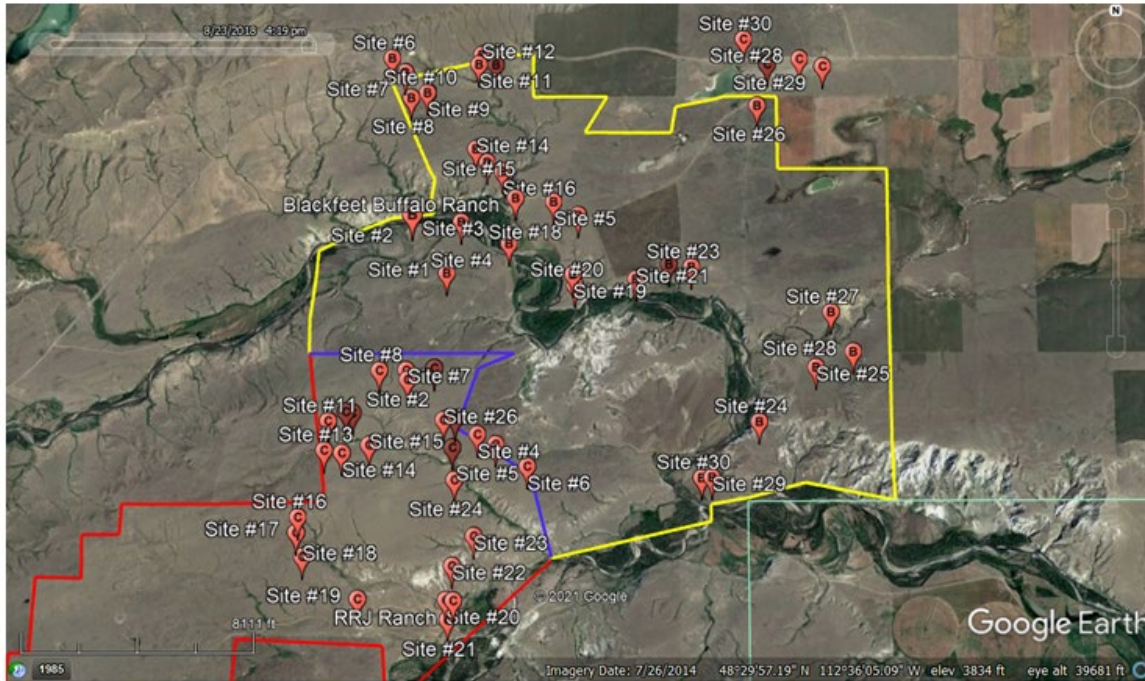


Figure 14. Locations of all the soil samples that were collected for nutrient tests in the in-nii (yellow-bordered) and cattle (red-bordered) pastures, which are separated by a fence line (blue).

The in-nii pasture is a mixture of foothills, plains, and badlands; Two Medicine River meanders through the lands. The cattle pasture is also composed of foothills, plains, and badlands; Badger Creek makes its way through the landscape; both the Two Medicine River and Badger Creek connect where the in-nii and cattle pastures border each other (Figure 14). Both the in-nii and cattle pastures are typically grazed from October 15th to June 15th under seasonal continuous grazing, then the in-nii and cattle are moved to their summer pastures from June 16th to October 14th. These sites experience long, cold winters, with lows averaging -6.2°C (43°F) for December, January and February, and highs in winter averaging 4.3°C (40°F); these sites receive about 453 mm (18 inches) of yearly rainfall precipitation (en-climate-data.org, 2021). In-nii and cattle consumed a mixture of perennial grasses along with supplemental hay and salts during extreme winters to allow animals to maintain their energy levels, as most in-nii and cattle

females are pregnant and will calve before being moved. Due to the size of the Blackfeet Buffalo Ranch and RRJ Ranch all soil samples collected during this study were from the in-nii and cattle pastures that were near each other (Figure 13). Observation of the land use by the in-nii and cattle was a key source for identifying sample sites since the animals were off to their summer pastures due to samples being collected in August 2018. Figure 14 shows the layout of in-nii and cattle grazing pastures and sampling areas.

Experimental Design

The in-nii and cattle ranches border one another and have similar grazing practices of seasonal continuous grazing. In-nii were first reintroduced to the Blackfeet Nation in the early 1990's after the animals were historically removed. In 1999, an additional young herd was introduced to the 10,000-acre Blackfeet Buffalo Ranch; today this in-nii herd is about 400 animals with the additional herd of in-nii at another ranch. Cattle have been on the RRJ ranch land (today 3000 acres deeded and 4000 acres leased) for nearly 125 years; today that cattle herd is about 600 animals. Sites in the in-nii and cattle pastures were selected to bracket a range of grazing intensities: low-elevation sites near the bottoms of Two Medicine River and Badger Creek were likely to have had the highest use by both in-nii and cattle, whereas intermediate-elevations like coulees were likely to have had the lowest use by in-nii, and the high-elevation sites on tops of ridges (furthest from water sources) were likely to have had the lowest use by in-nii.

Soil Samples for Nutrient Analysis

I collected 30 soil samples between August 16 and August 23, 2018 from each of the in-nii and cattle pastures to test for differences in chemical properties. Sampling was stratified, with four from low-elevation, high-intensity sites; nine from high-elevation sites; and the remaining 17 from intermediate-elevation sites. Soil samples were collected by digging small pits that were approximately 1 foot x 1 foot wide to a depth of 1 foot. The samples were first taken from the bottom 6-12-inch depth interval and then from the 0-6-inch depth interval to reduce soil mixing from the two depths. Soil samples were then dried and sieved (2 mm), placed in bags and sent to WARD Laboratories, Inc. in Kearney, Nebraska (wardlab.com) to be tested for 12 agronomically important properties ("Soil analysis S-101"): soil pH, soluble salts (1:1 soil:water; as electrical conductivity [EC; mmho/cm is mathematically the same as dS/m]), organic matter (as loss-on-ignition [LOI {2.25 hours at 360°C}]; %), 1 molar (*M*) potassium chloride (KCl)-extractable nitrate (as ppm N), Mehlich 3-extractable phosphorus (ppm P) and sulfate (ppm), 1 *M* ammonium acetate (NH₄Oac-extractable) base cations (K [ppm], Ca [ppm], Mg [ppm], Na [ppm]) sum of cations for cation exchange capacity (CEC [milliequivalents/100 g is mathematically the same as cmol₊/kg]) and base cation saturation (%). SOM values were converted to SOC assuming SOC was 0.5 of SOM (Pribyl, 2010). Data was analyzed in RStudio (2021.09.1+372 "Ghost Orchid" Release, 2021-11-08) to determine whether there were any statistically significant differences in these properties between the in-nii and cattle pastures using analysis of variance; we interpreted p values as recommended by Muff et al. 2022: p-values <0.01 were interpreted as showing strong evidence whereas p-values >0.05 were interpreted as showing weak to no evidence.

Substrate-induced Respiration

To support our substrate-induced respiration (SIR) experiment, I also collected four cattle-influenced soil samples from each of four locations on August 16th, 2020, each eleven feet from the center of the wire fence separating the in-nii and cattle pastures (Figure 15). Four in-nii-influenced soil samples were collected from the same four locations (marked 1, 2, 4, 5 in Figure 14) in addition to four additional samples from near an in-nii water source near the confluence of the Badger and Two Medicine Rivers. Samples were collected in a circular, teepee fashion (Figure 16). SIR analyses were performed at the Montana State University Soils Teaching Laboratory; all samples were run in triplicate. In the lab, soils were air-dried, ground using a mortar and pestle, before 5 grams was placed in 50-milliliter (mL) centrifuge tubes retrofitted with 20-mm-diameter gray butyl septa (Wheaton 20-0025).

A subset of samples were oven-dried to constant weight to be able to express results on an oven-dry soil basis. SIR samples were broken into four categories: blank (empty tube), no treatment (just soil), soil amended with 1.5 ml water, and soil with an equivalent volume of a yeast solution (1.5 ml of 12 g autolyzed yeast in 1 L, Difco Laboratories, Detroit, MI; Fierer et al. 2003). Headspace measurements of carbon dioxide were obtained from each soil sample at 0, 4, 24, and 96 hours (4 days). Headspace sampling was done by piercing the septa with a needle attached to a 5-ml syringe, slowly mixing the headspace, withdrawing a 5-ml gas sample, and then injecting that gas sample into a sample port. Gas samples were conveyed through a Licor 820 infrared gas analyzer (Lincoln, NE) using a 100% nitrogen (UN1066) carrier gas stream set to 0.5L/min. Peak concentrations of CO₂ were recorded and then converted to headspace concentrations using a calibration curve with three known standards (500, 1000, and 10,000

ppmV) and the resulting equation $y=76.4x$, where y was the CO_2 concentration and x was the peak CO_2 reading ($R^2=0.9999$).



Figure 15. Numbered locations (1-5) reflect where in-nii and cattle pasture soil samples were taken for soil substrate-induced respiration (SIR) analyses to index soil carbon dynamics. The “I” simply indicates the In-nii Ranch and the “C” simply indicates the RRJ Ranch.

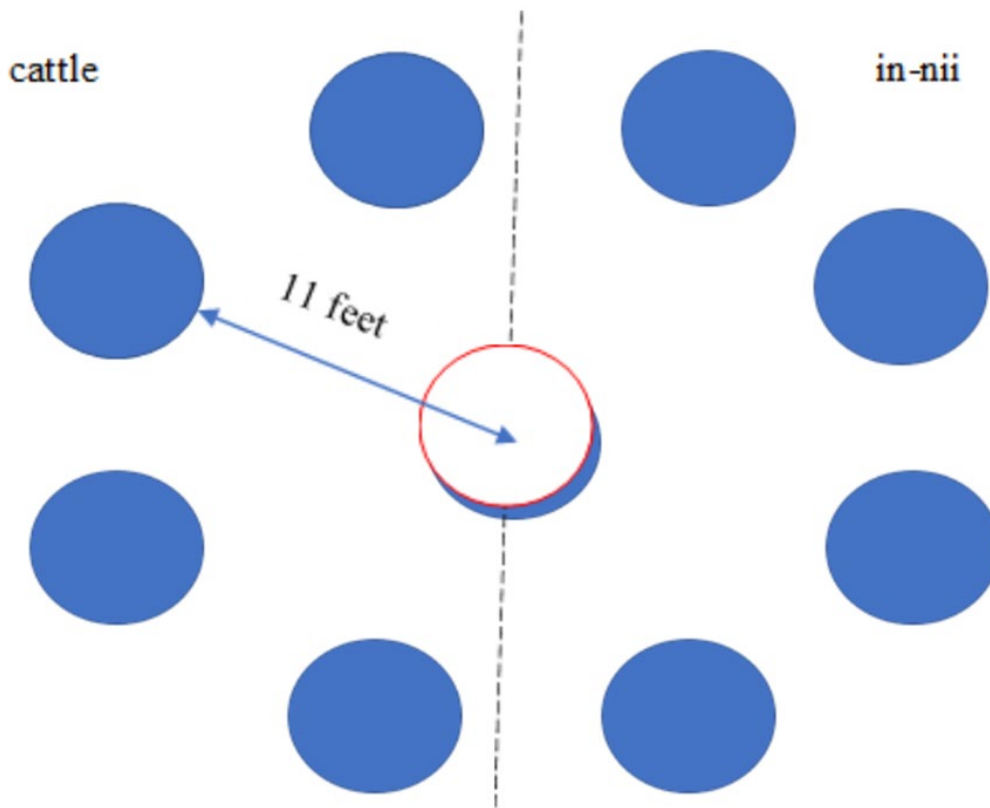


Figure 16. Schematic for the way the SIR samples were taken at each of four fenceline locations indicated in Figure 15, representing an Amskapiipikini tiipii ring. The center circle represents the middle of the lodge and this is where the fence (dashed line) separated the in-nii and cattle pasture.

Field Soil Respiration and Infiltration Rates

The infield soil respiration and infiltration measurements from the in-nii and cattle pastures were obtained in August 2019 to understand how quickly, and to what extent, these soils responded to the addition of 1 inch of water. Measurements were obtained using a battery-powered Licor 8100A infrared gas analyzer (Lincoln, NE) with an 8-inch (20-cm)-diameter survey chamber (part 8100-103) over a 1-minute interval, not including a 15-second "dead band"; only linear- or exponential-fits with CVs <2% were used in analyses. Because these

measurements were obtained after installing an 8-inch-diameter, 4-inch tall PVC ring (available as D3034 Sdr35 sewer PVC pipe with ring gasket) 1 inch into the soil, we used this same ring to perform soil water infiltration rate measurements. In brief, we first installed each ring using a folding, serrated saw and subsequently collected a 'dry' soil respiration measurement (typically 10 minutes following soil disturbance). Respiration fluxes are reported with units of micromoles carbon dioxide per square meter per second ($\mu\text{mol CO}_2/\text{m}^2/\text{s}$ or $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$). We placed the gasketed survey chamber on the ring (Figure 18). Following the 'dry' flux reading, we then lined the rings with plastic sheets before adding 1 inch of water; we started timing upon yanking on the plastic sheet to obtain an infiltration rate (Basche and DeLonge, 2019 [crop contexts], Xu et al., 2018 [range contexts]; seconds for 1 inch of water to infiltrate). After all water had infiltrated (the delay was typically 4 minutes), we obtained a 'wet' soil respiration measurement.

Approximately 4 minutes after the 'wet' flux reading, we obtained a second infiltration rate for that ring. Because many infield measurements were opportunistic because they were often collected as demonstrations while training Regenerative Grazing interns, and so not all 'dry' and 'wet' pairs of measurements were obtained, we aggregated all 'dry' and 'wet' flux measurements, calculated median rates, and then ratioed these to clarify the responsiveness of in-nii- and cattle-influenced soils to a water addition.



Figure 17. Getting soil respiration flux readings ($\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$) with the Licor 8100A gas analyzer in the middle of the fence line that separates the in-nii (left side) and cattle (right side) pastures. A portion of the circular ring design (Figure 16) is partially visible on the left.

Our laboratory and field analyses of the in-nii and cattle soils were run to get an understanding of how carbon (C) is stored and released throughout the pastures. Globally, soils store more carbon than all plants and our atmosphere combined (Post et al. 1982). Perhaps even more significantly, annual respiration of that soil carbon back to the atmosphere is estimated to total XXX, about 6-7 times the combined total of all anthropogenic carbon emissions (all trains, planes, and automobiles; Raich and Schlesinger 1992, IPCC AR6 WG3 xxx). Schädel et al. (2020) wrote that the magnitude of C lost to the atmosphere via microbial decomposition is a function of the amount of C that is stored in soils, the quality of that organic matter, and physical, chemical, and biological factors that comprise the environment for decomposition. Our

SIR incubations were intended to help estimate the decomposability of SOM by measuring carbon dioxide released as C is mineralized from soils under controlled conditions using a common protocol (Figure 18; Schädel et al. 2020).

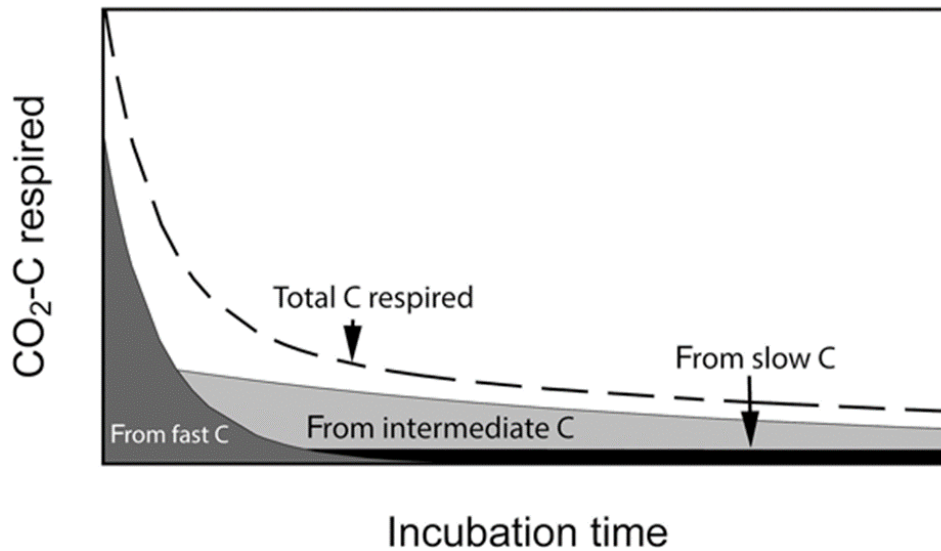


Figure 18. Conceptual figure of C respiration during aerobic soil incubations. Total $\text{CO}_2\text{-C}$ flux is composed of contributions from different C pools which changes over time. Fast-cycling C dominates total $\text{CO}_2\text{-C}$ flux at the beginning of the incubation and is later replaced by slower-cycling C pools (Schadel et al., 2020).

NRCS “Minimum Dataset” Recommendations

SIR has been recommended as a part of a "minimum dataset" for soil health demonstration trials by the USDA NRCS (2019; Technical Note 450; accessible via <https://soilhealthnexus.org/getting-to-the-science-of-soil-health-usda-releases-standard-indicators-and-laboratory-procedures-to-assess-soil-health/>) (Stott, 2019). Numbers have been added to the following section for clarity.

Laboratory soil health assessments must include the following set of indicators according to methods in Technical Note 450-03: 1. soil organic carbon (ppm), 2.

aggregate stability (%), 3. bioavailable nitrogen (mg/g dry weight), 4. respiration (mg CO₂/g dry weight) and 5. active carbon (ppm). A comprehensive chemical soil test 6. pH, 7. EC, 8. organic matter, 9. nitrate-N, 10. phosphorus, 11. potassium, 12. calcium, 13. magnesium, 14. sulfur, 15. iron, 16. manganese, 17. copper, 18. zinc, and 19. boron based on state-approved procedure is required.

Later in the same document, there is this note: “Measurements of 20. bulk density and 21. infiltration are also required.” Source =

https://www.nrcs.usda.gov/wps/PA_NRCSCConsumption/download?cid=nrcseprd1420229&ext=pdf Of these 21 elements, my work focused on 2/3 of these indicators: #1, #3-14, and #21.

Results from incubation studies can inform global models about C pool sizes and rates of SOM processing (mostly derived from incubations) and sensitivities of process rates with respect to changes in abiotic factors such as soil temperature, moisture, pH, etc. Incubation durations may vary from less than 1 d to up to many years (Schädel et al., 2020, O’Dea et al. 2015). My incubations were intended to get an understanding of the C dynamics under relatively well-controlled laboratory conditions: no roots or root exudates, no diel or seasonal temperature swings, no rainstorm-induced shifts in soil moisture. Just soil microbes, in a centrifuge tube, metabolizing SOM into carbon dioxide, which we can measure very precisely with an infrared gas analyzer. Because we limited the incubations to the first four days, our interests were mostly focused on what this conceptual model calls “fast carbon.”

While some researchers have adopted a traditional model of three pools of SOC related to turnover times (fast, intermediate, slow), more recently, models (e.g., Cotrufo and Lavelle 2022) suggest we should instead think of mineral associated organic matter (MAOM; slower turnover times, long residence times) or particulate organic matter (POM; faster turnover times, short residence times). Because our understanding of what happens to SOM over time and space

is still improving, we interpret our results with caution. It is worth remembering not one molecule of the maybe millions of molecules that make up SOM lasts forever in the soil. In other words, not one molecule can resist being metabolized or mineralized to carbon dioxide. Or as Powlson and Jenkinson (1981) has noted “no fraction of the organic matter in plants and animals can withstand decomposition to carbon dioxide and water. If this were not so, any completely resistant fraction would by now cover the surface of the earth.” We do not really understand how soil C is processed but we do understand that no form of soil C lasts forever.

Soils of the Blackfeet Nation

In Western science, soils are thought of as being the function of five state factors: climate, organisms, relief, parent material, and time (Cl, O, R, P, T; Jenny 1941). Haight et al. (1969) mapped both soils and included a cross-section (Ninaistako [Chief Mountain; A]-Cutbank [B]) of the parent materials underlying the Blackfeet Nation (Figure 19).

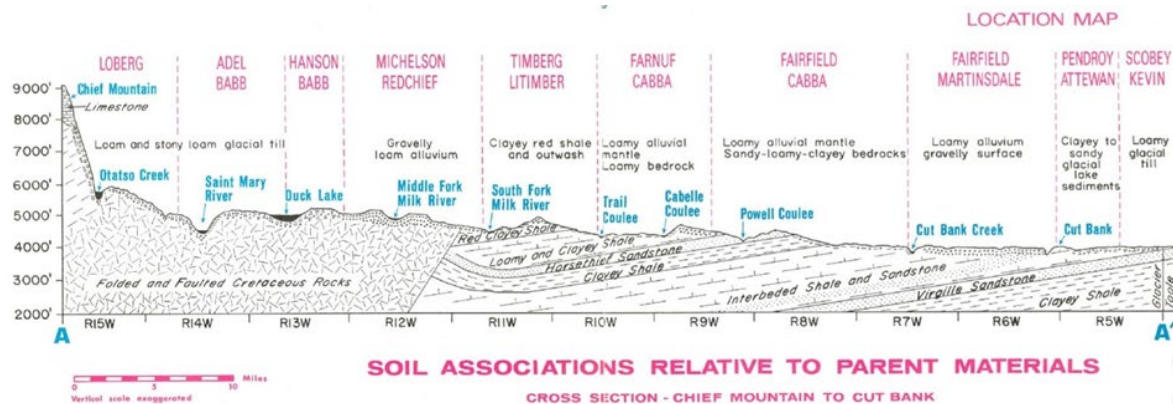


Figure 19. Parent materials underlying some of the soils of the Amskapiipikini Nation. The Fairfield Cabba soil series overlies interbedded shales and sandstones, which stratigraphically underlie the Horsethief Sandstone and overlie the Virgelle Sandstone (both approximately late Cretaceous or from 66-100 million years ago). Detail from Haight et al. 1969.

In addition, we summarize more recent information from the NRCS SSURGO database accessed via SoilWeb or WebSoilSurvey. We first defined an area of interest including the in-nii and cattle pastures (Figure 20).

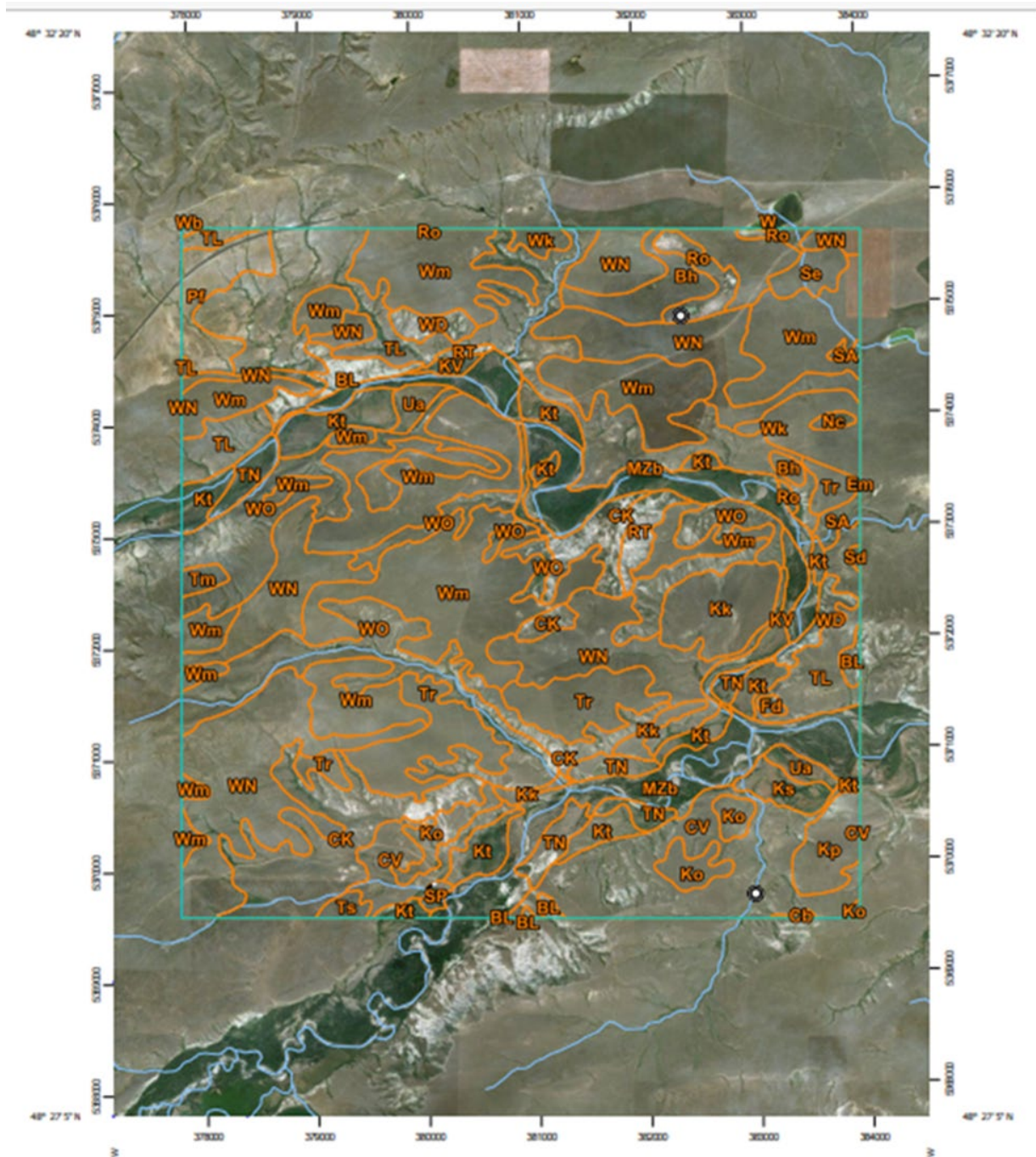


Figure 20. Mapped soil series across the in-nii and cattle pastures via Web Soil Survey.

Table 1. Most extensive 10 NRCS soil map units dominating (96%) of the ~10,200-acre area of interest that includes the in-nii and cattle pastures. The average % soil organic matter for these map units is also presented.

Order	Soil map unit (abbreviation)	Area fraction	%SOM
1	Williams (Wm, WN)	0.42	3.50
2	Crago-Kiev (CV, Kk, Kp)	0.12	3.13
3	Cabba-Badlands-Rock outcrop	0.10	1.38
4	Fairfield (TL)	0.09	3.00
5	Mixed alluvial land (MZb)	0.08	1.25
6	Korchea-Kiwanis (Kt, KV, Ks)	0.05	1.92
7	Turner (Tr, Ts)	0.05	3.00
8	Pendroy (Pf)	0.021	0.75
9	Beaverton (Bh)	0.020	2.00
10	Tinsley (TN)	0.016	1.35
	Total	0.96	

Ten mapped soil map units made up nearly 96% of this area (~10,200 acres) of interest bracketing the cattle and in-nii pastures. Of these map units, the dominant series (42%) was the Williams series (“Wm” or “WN” in Figure 20), technically a fine-loamy, mixed, super active, frigid Typic Argiustoll of the order Mollisol. The Williams series dominates vast portions of North Dakota, covering a total of 4.5 million acres; a typical Williams profile has a shallow A horizon (0-3 inches) and a well-developed calcic subsurface horizon (Bk; 3-15 inches; Figure 21). Calcic horizons show an accumulation of calcium carbonate, which effervesces violently in the presence of acids such as 10% hydrochloric acid. These soils typically have pHs of 7-8 and SOM levels of ~1-5% in the uppermost 2 horizons. The next most-dominant soil map units were the Crago-Kiev (12%), Cabba-badlands-rock outcrop (10%), Fairfield (9%), and mixed alluvial land (8%); these soils vary considerably in their properties. The Fairfield, for example, while also a Typic Argiustoll, has lower SOM (1-3%), and is only mapped across 180,000 acres. The Crago, by contrast, is technically a loamy-skeletal, carbonatic, frigid Aridic Calcustept, of the

order Inceptisol; its typical pH and SOM values are 7.7-8.5 and 2-5%, respectively. The Kiev is technically a fine-loamy, mixed, superactive, frigid Typic Calciustoll, also of the Mollisol order; no lab data are reported for this series as it has only been mapped across 84,000 acres. The Cabba is technically a loamy, mixed, superactive, calcareous, frigid, shallow Typic Ustorthent, of the least-well-developed order Entisol. Though it is poorly developed, the Cabba series is areally extensive, having been mapped across 2.2 million acres of the Northern Great Plains. Consistent with its grouping with both the badlands and rock outcrop map units, the Cabba is a rocky soil with a very high pH (8.0-8.7) and intermediate SOM (0.5-3.5%). No lab data are available for the mixed alluvial land map unit, but it would not be uncommon to find SOM values >10% in these low-lying areas.

The NRCS's Web Soil Survey tool suggests a SOM rating (%) for almost all map units (excepting catch-all map units like badlands or rock outcrops). These averages are presented in Table 1. Because the actual soil pedons characterized to support these types of NRCS georeferenced data are not located on the Blackfeet Nation, the applicability of these map data is limited for broader Blackfeet purposes or my specific study area. Far more detailed and recent (1990s-2000s) soils characterization information exists specifically for the Blackfeet Nation (J. Kimmelshue, pers. comm.): “[We] are VERY well versed in every square foot of [the] reservation from a soils perspective. Our soils team spent many months up there.” This characterization effort included “many backhoe pits, many crews, over many years, with many photos” and was led by the consulting firm CH2M Hill, now Jacobs. Unfortunately, this Blackfeet Nation-specific soils information is not publicly available as it was used to support the Blackfeet Water Compact, approved by Blackfeet tribal members in a historic vote in April 2017

(<https://blackfeetnation.com/watercompact/>). Efforts since 2016 to obtain a georeferenced inventory of soil samples collected and archived have been unsuccessful.

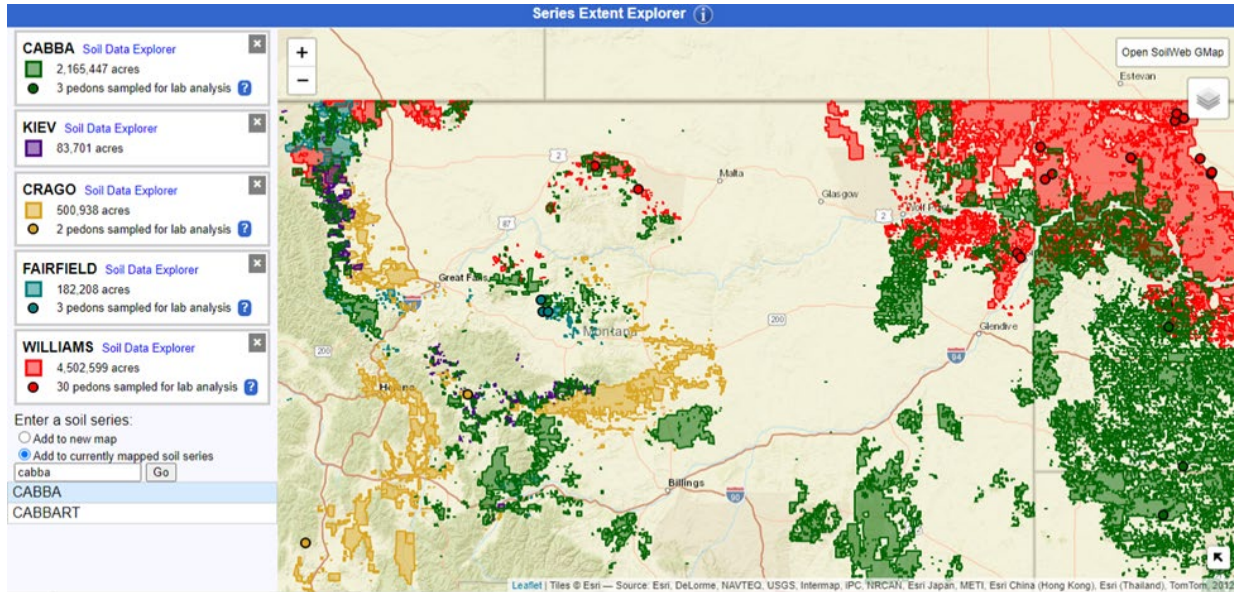


Figure 21. Geographic extent of spatially extensive map units associated with cattle and in-nii pastures from this study. Note most of the area mapped as these soils occur in North Dakota, not the Blackfeet Nation. In addition, none of the 38 pedons used to characterize these 5 mapped series was collected from the Blackfeet Nation. It is entirely possible that the mapped soil properties associated with these dominant series differ for the Blackfeet Nation in general and my study area specifically.

(<https://casoilresource.lawr.ucdavis.edu/see/#williams,fairfield,crago,kiev,cabba>)

CHAPTER FOUR REFERENCES CITED

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RESULTS AND DISCUSSION

Soil Fertility

We expected to find statistically significant differences in levels of soil organic matter (SOM); nitrate; exchangeable calcium (Ca), magnesium (Mg), potassium (K), and sodium (Na); pH; and cation exchange capacity (CEC) between cattle and in-nii pastures; however, this was not the case for all these soil properties. While there were statistically significant differences between cattle and in-nii pastures for CEC and Mg (Figure 22 and 23, respectively; F values: 5.4 and 11.6, respectively; p-values <0.05; see Table 2), we found no statistically significant differences for SOM, nitrate, Ca, K, Na, and pH (p-value >0.05; see Appendix 1 for these figures). We used landscape elevation (high, medium, low) to index potential differences in grazing intensities (see Section 4.1) since we expected the highest cattle and in-nii grazing intensities at the lowest elevations near Two Medicine River and Badger Creek. Based on opportunistic observations, we also expected to find the lowest cattle grazing intensities at the highest elevations and the lowest in-nii grazing intensities at the medium elevations. In our analysis of variance for this suite of nutrients, our expected grazing intensities were not a significant factor. For CEC and Mg, however, landscape elevation appeared to have mixed influence; it was not a significant factor for CEC but was a significant factor for Mg (F values: 2.8 and 4.8, respectively; p-values 0.07 and 0.01, respectively; see Appendix 1). On the Konza Prairie in Kansas, for example, in-nii nitrogen-rich urine may have increased grass production making the grass more nutritious than grasses growing in patches without urine inputs (Knapp et al., 1999).

Table 2 Median values (\pm interquartile range [IQR]) and p-values for selected soil properties for the in-nii and cattle pastures.

Soil property (units)	Innii	Cattle	P value (* <0.05)
Soil organic matter (%)	3.9 \pm 0.9	3.7 \pm 1.3	0.34
pH (unitless)	7.8 \pm 0.5	7.4 \pm 0.7	0.19
Cation exchange capacity (cmol ₊ /kg)	24.5 \pm 10.1	20.0 \pm 6.7	0.04*
Calcium (mg/kg)	3644 \pm 2089	2836 \pm 1392	0.16
Magnesium (mg/kg)	502 \pm 212	419 \pm 176	0.001*
Potassium (mg/kg)	340 \pm 239	390 \pm 88	0.16
Sodium (mg/kg)	12 \pm 10	10 \pm 2	0.47
Nitrate-N (mg/kg)	1.3 \pm 2.0	1.5 \pm 0.9	0.77

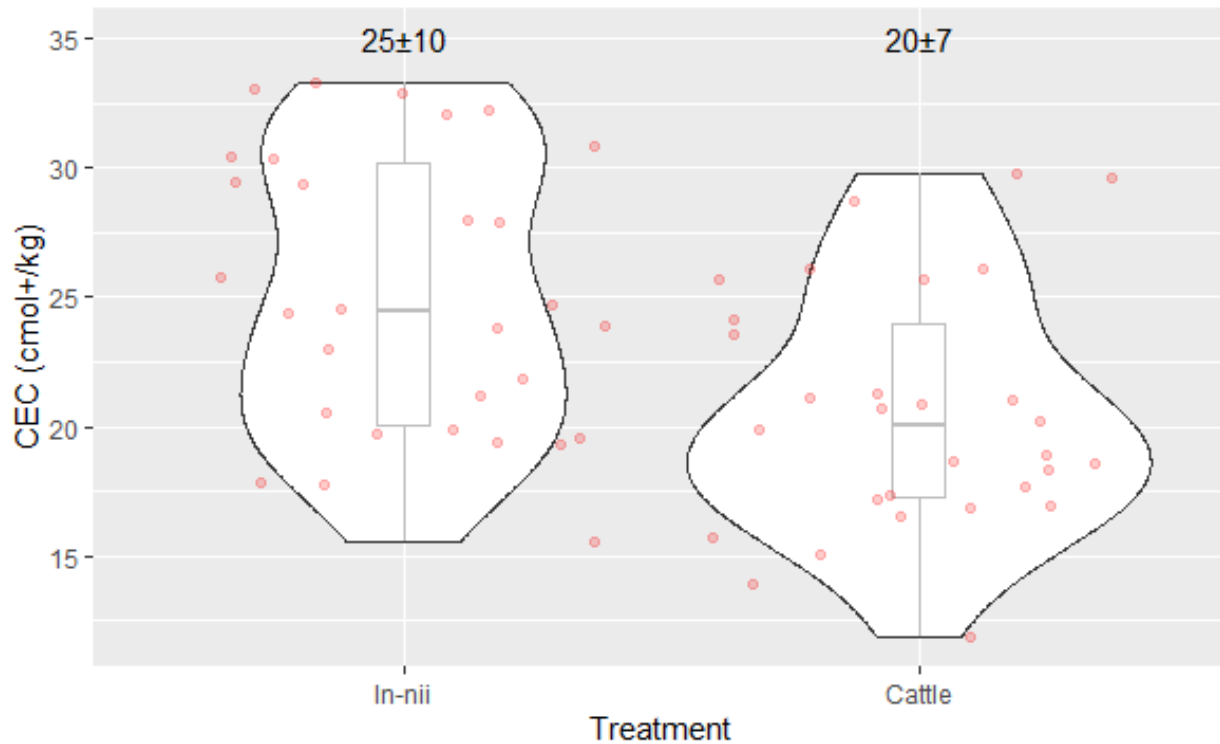


Figure 22. Violin plots showing all cation exchange capacity (cmol₊/kg) values as influenced by treatment of in-nii and cattle. Shapes are governed by the distributions of jittered or offset datapoints; inset within the violin plots are box plots where the central horizontal line indicates the median, the upper portion of box is the 75th percentile, the lower portion of the box is the 25th percentile, and the vertical “whiskers” extend to 1.5x the inter-quartile range (IQR; labels at top are median \pm IQR).

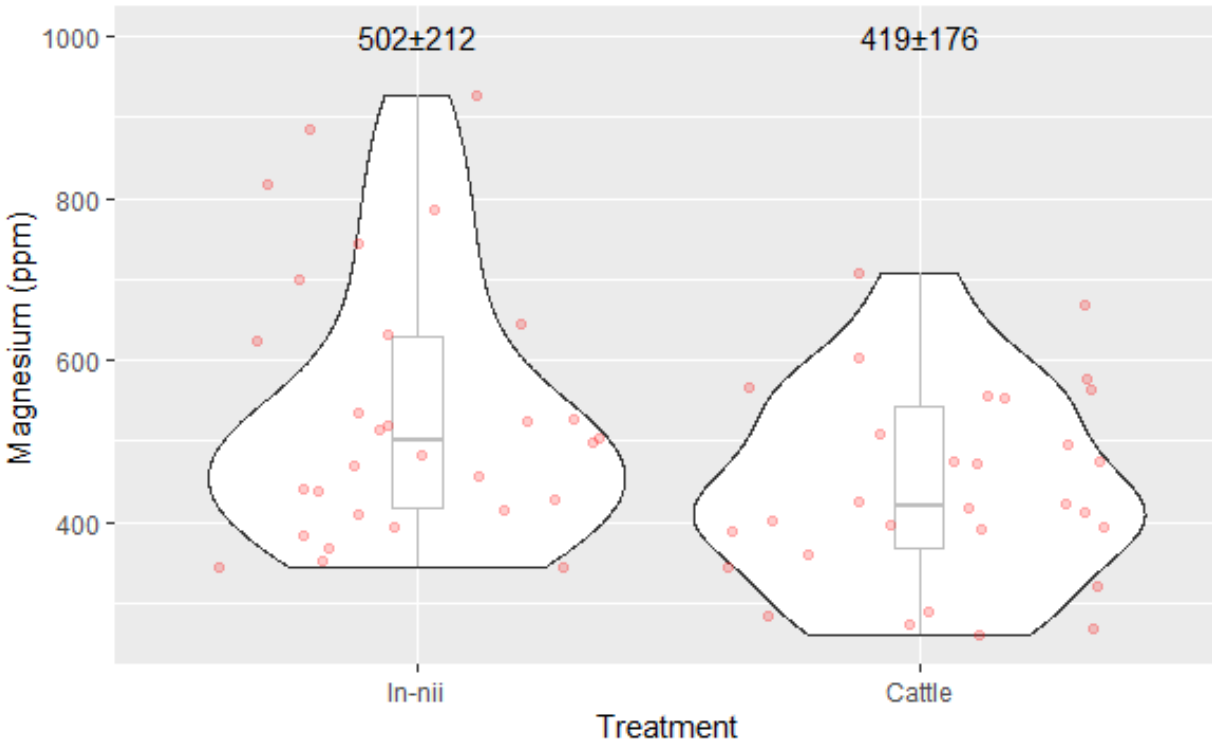


Figure 23. Violin plots of exchangeable magnesium (mg/kg or parts per million [ppm]) as influenced by in-nii and cattle. Other graphical elements as in Figure 17.

Substrate Induced Respiration

Our substrate-induced respiration (SIR) analyses were meant to minimize the effects of diel or seasonal influences; rainstorms or droughts or antecedent soil moisture; root exudates; or grazing-associated herbivory- or compaction-related influences. Our SIR results showed large differences over the four-day (96 hours; 96H) incubation and large differences between the water and the yeast additions, but essentially no differences between the cattle and in-nii soils. In fact, both sets of soils showed very little or no response to the addition of the yeast solution until after 24H of incubation. Furthermore, carbon dioxide levels generally decreased from 24 to 96H of incubation. And while in-nii SIR at 24H (~36,000 ppm) were slightly greater than cattle SIR at the same measurement period (~30,000 ppm), each of these averages had very large error bars.

The SIR measurements showed minor differences between the in-nii and cattle pastures after controlling for amendment or incubation time (Figure 24), though the largest differences occurred between water- and yeast-amended soils. Temporal differences (after 4, 24, or 96 hours) were intermediate. Statistically speaking, we found little evidence of difference between the in-nii- and cattle-influenced soils ($p=xxxx$), though we found strong evidence of difference between water and yeast additions ($p=yyyy$).

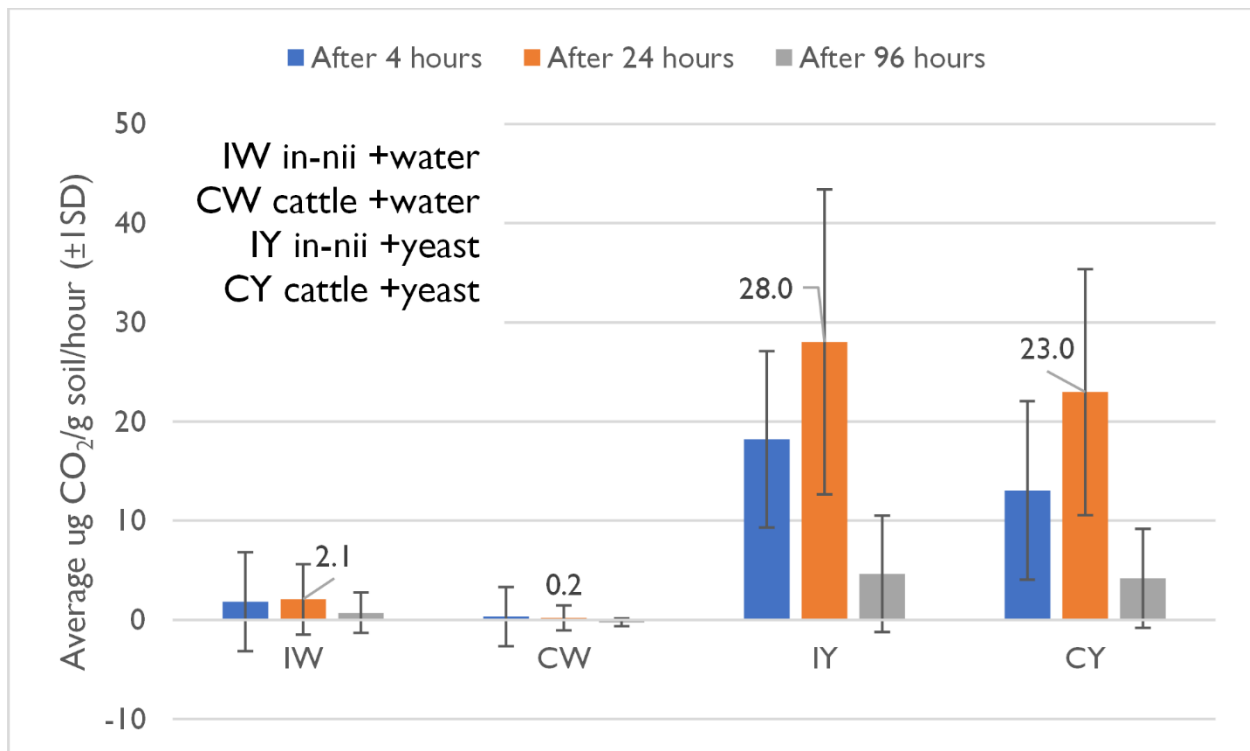


Figure 24. Average (± 1 SD) substrate-induced respiration (SIR) rates ($\mu\text{g CO}_2/\text{g soil/h}$) for cattle- (C) vs. in-nii (I)-influenced soils receiving either water (W) or an equivalent volume of yeast solution (Y) after 4 hours (left blue column), 24 hours (middle orange column [average values are highlighted]), or 4 days (right gray columns).

These concentrations expressed in parts per million by volume (ppmV; e.g., $\mu\text{L L}^{-1}$) can be converted to concentrations expressed as mass of carbon dioxide per unit dry mass of soil through a 3-step process (see Haviland 2022). Briefly:

1. the standard temperature-sensitive conversion for ppmV CO₂ (volume:volume) to mg CO₂ m⁻³ (mass:volume) is 1.7959 for CO₂ at 25°C (44/24.5; Kuo 2014:8),

2. the m³ to L conversion is 0.001, and

3. the per volume (L)⁻¹ to per mass (g soil)⁻¹ conversion requires the quotient of the centrifuge tube volume (0.05L) to oven dry weight-equivalent mass of soil used (~4.5 g; 0.0058).

The resulting concentration units are in mg CO₂ (g soil)⁻¹ and these can be converted into rate units by subtracting time 0 measurements (~7000 ppmV=0.14 mg CO₂ g⁻¹) and dividing by the elapsed number of hours. For the 24-hour +yeast measurements for in-nni pasture samples, for example, a value of 35,000 ppmV (Figure 26) converts to a rate of 24 µg CO₂ g⁻¹ h⁻¹.

$$\begin{aligned}
 & 35,000 \text{ ppmV} \cdot \frac{44 \text{ mg CO}_2}{24.5 \text{ m}^3} \cdot \frac{1 \text{ m}^3}{1000 \text{ L}} \cdot \frac{0.05 \text{ L}}{4.5 \text{ g soil}} = \frac{0.7 \text{ mg CO}_2}{\text{g soil}} \\
 & \left[\frac{0.70 \text{ mg CO}_2}{\text{g soil}} \right]_{t=24h} - \left[\frac{0.14 \text{ mg CO}_2}{\text{g soil}} \right]_{t=0h} = \frac{0.024 \text{ mg CO}_2}{\text{g soil} \cdot h} = \frac{24 \text{ } \mu\text{g CO}_2}{\text{g soil} \cdot h}
 \end{aligned}$$

Figure 25. Conversions to concentrations expressed as mass of carbon dioxide per unit dry mass of soil through a 3-step process

We acknowledge no single conversion could allow for direct comparisons with other studies, as other SIR studies report results across a broad range of unit systems, including volumes of carbon dioxide per mass of soil per hour (µL CO₂ g⁻¹ h⁻¹; Szili-Kovacs and Elhottova 2007)) to masses of CO₂-C equivalent per mass of soil per hour (µg CO₂-C g⁻¹ h⁻¹) to masses of CO₂-C equivalent per mass of SOC per hour (µg CO₂-C [g SOC]⁻¹ h⁻¹). Many studies also report rates using time units other than hour (e.g., days, weeks).

The yeast-induced results for both sets of the in-nii and cattle soil samples showed large jumps between the 0, 4h, and 24h sets. After 96h, even yeast-induced rates began to decline toward water-induced rates. We noticed a trend with in-nii averages being slightly greater (~20%) than corresponding cattle averages. For the water-induced readings for the in-nii soil samples, all values were about 10X smaller than corresponding yeast-induced results after the initial 0 and 4h readings. More specifically, water explained between 7-16% of the +yeast rates for in-nii. By contrast, water only explained ~1% of the +yeast rates for cattle.

Field Soil Respiration

Soil respiration was also measured in the field to get an understanding of how the soils release carbon in their natural environments (Table 3, Figure 26). Soils release carbon continuously in the field since roots never stop respiring and are constantly producing root exudates and these are then consumed by microorganisms. These soil respiration rates are sensitive to diel and seasonal temperature swings; drought-, rainstorm-, or snowmelt-induced shifts in soil moisture; as well as by the types of grazers (in-nii and cattle).

Table 3. Preliminary soil respiration fluxes ($\mu\text{mol CO}_2\text{m}^{-2} \text{s}^{-1}$) for fenceline, cattle, or in-nii pasture locations recorded in August 2020 before ('dry') and after ('wet') adding 1 inch of water. Due to mismatched fluxes ('wet' and 'dry' fluxes were only obtained from 3 of 15 pasture-site combinations), we aggregated across the five sites within a pasture location type, calculated median fluxes ('wet' or 'dry'), and then ratioed these wet-to-dry median fluxes (unitless). "—" indicates no data collected.

Pasture	Wet					Median	IQR
	Site 1	Site 2	Site 3	Site 4	Site 5		
Fenceline	138	—	22	—	11	22	63.5
In-nii	—	—	14	22	—	18	4.0
Cattle	29	—	—	40	—	35	5.5

Pasture	Dry					Median	IQR
	Site 1	Site 2	Site 3	Site 4	Site 5		
Fenceline	5	1.7	2.1	—	3.3	2.7	1.7
In-nii	6	—	—	—	—	6.0	—
Cattle	—	—	3	—	—	3.0	—

Pasture	Wet/Dry					Median
	Site 1	Site 2	Site 3	Site 4	Site 5	
Fenceline	28	—	10	—	3	8.1
In-nii	—	—	—	—	—	3.0
Cattle	—	—	—	—	—	11.5

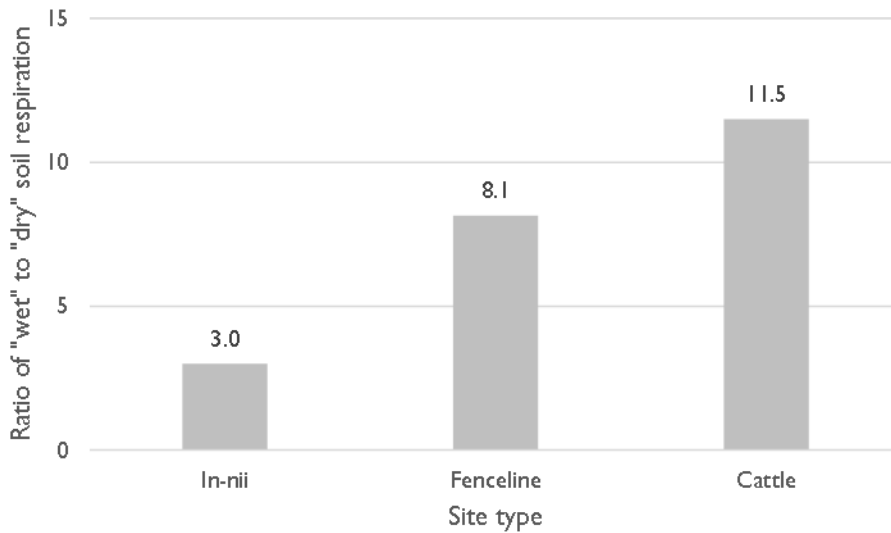


Figure 26. Ratios of wet-to-dry field soil respiration fluxes measured from the in-nii and cattle pastures (and fenceline in between these). When water is added to the soils for both in-nii- and cattle-influenced soils, soil respiration rates strongly increase as microorganisms metabolize substrates that make up soil organic matter.

The median field respiration rates under ‘dry’ conditions ranged between 6.0 for in-nii and 3.0 for cattle. The in-nii values are 2x that of the cattle, which could have been due to the plant communities that make up the in-nii pasture that have larger amounts of root biomass that are also respiring or the microorganisms have a higher population density in the in-nii pasture.

We can compare our results with those from Kansas, where tallgrass prairie soils were grazed by in-nii (bison) and cattle (Figure 27; Bremer et al. 1998). When comparing similar days (Days 243 vs 244), they reported little difference between cattle- or in-nii-grazed soils, though in-nii-grazed rates were slightly higher. Earlier in the season (Days 210 and 222), in-nii-grazed rates were lower than cattle-grazed rates, though this comparison is confounded by measurements separated by 12 days. Ungrazed soils, however, under each management system, generally showed soil respiration rates about 30% greater than paired grazed soils.

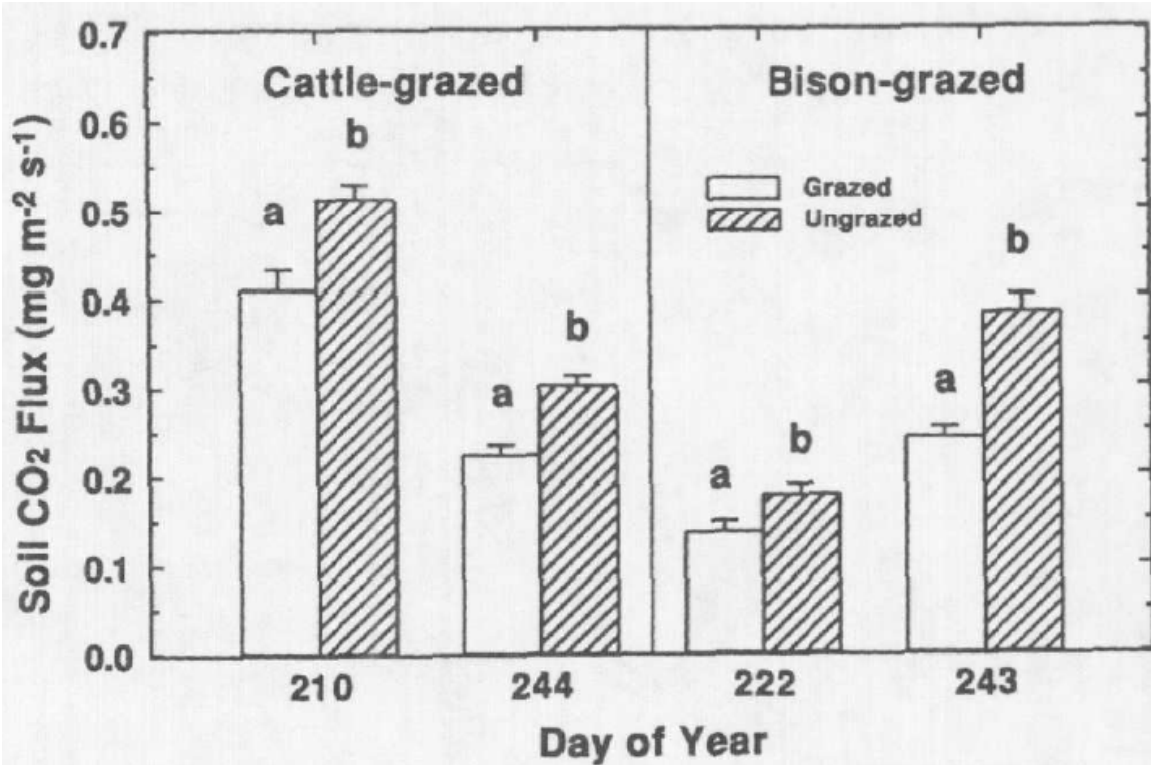


Figure 27. Soil respiration rates in pastures grazed (hollow bars) or ungrazed (diagonal lines) by cattle and in-nii (bison) in Kansas on four different days of the year ($n=20$; Bremer et al. 1998). The two cattle-grazed pairs represent separate sites; the two in-nii-grazed pairs represent the same site. Indications of statistical significance (different lowercase letters) are limited to within-day comparison between grazed and ungrazed pastures, not between days or between cattle and in-nii. For comparison purposes with my study, a flux of $0.44 \text{ mg CO}_2/\text{m}^2/\text{s}$ would be equivalent to a flux of $10 \text{ umol CO}_2/\text{m}^2/\text{s}$ (multiply Bremer et al. y axis values by ~ 23); my study only obtained such relatively high rates following addition of water in the field (see Table 6).

Infiltration rates were spatially variable (sites 1-5) and varied between the first and second inch of water applied (Figure 28). No clear differences in infiltration rates between the in-nii and cattle pastures were apparent. For example, average ($\pm 1\text{SD}$; CV) infiltration rates for applied water ranged from a minimum of 17 ± 13 seconds (CV 0.76) for the first inch on cattle pastures to a maximum of 85 ± 53 seconds (0.62) for the 2nd inch on in-nii pastures. In-nii pasture soil infiltration rates (first inch) averaged 31 ± 24 seconds (0.62) and cattle pasture rates (2nd inch) averaged 69 ± 46 seconds (0.66).

Water is limited due to the very arid climate because of where the in-nii and cattle pastures are located, so infiltration rates were done to gain an understanding of how the soil absorbs precipitation. The watering holding capacity plays a significant role in the soil's nutrient availability, plants, and for the health of the in-nii and cattle.

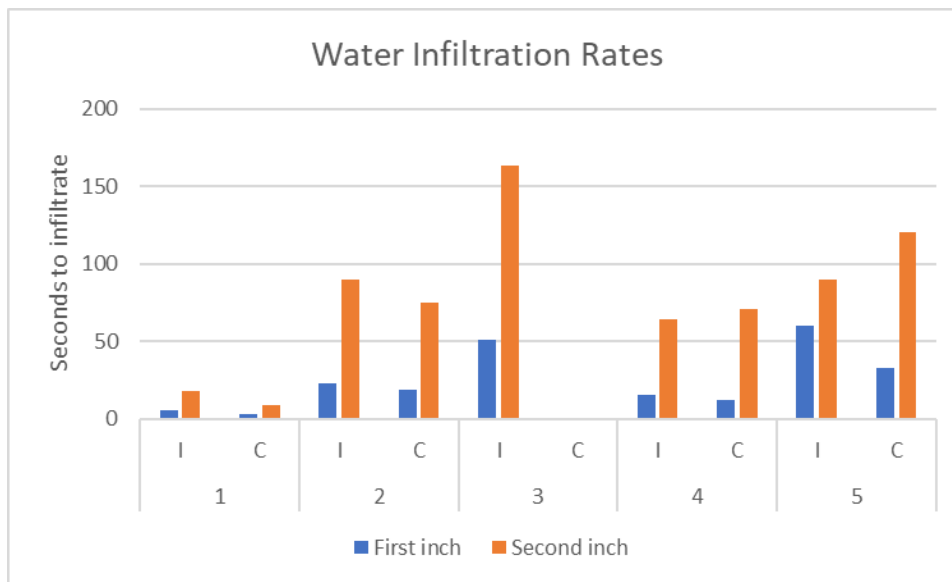


Figure 28. Soil water infiltration rates for the in-nii (I) and cattle (C) pastures showing large variability between sites (1-5) and between the first and second inch of water applied. Variability between the in-nii and cattle pastures was not as pronounced.

Discussion

Soil Nutrients

Soil is a complex mixture of minerals and organic matter, each of which has inherent properties which combine in the context of time, climate, topography, and biota to determine emergent soil properties, and the relationships between SOM and soil functions are complex, with various interactions and feedbacks at multiple levels (Cotrufo and Lavellee, 2021). Out of

24 vegetation and soil variables we measured, we found that 2 were significantly different between in-nii-grazed sites and cattle-grazed sites within the time frame of our study.

McMillan et al. (2019) also compared in-nii and cattle in a study based in Phillips County, Montana, trying to document the changes they were seeing aboveground within the plant communities to see if in-nii are modifiers of plant communities. In this study, within 10 years the historical plant community still wasn't at the level they thought it should be but they found that in-nii helped increase species richness and compositional heterogeneity (McMillan et al. 2019). This work implies it could take longer than 10 years to detect measurable changes within the plant communities that then, perhaps even with a greater lag time, affect soil health.

Hillenbrand et al. (2019) studied the effects of different grazing management practices on soil and vegetation at the 777 Bison Ranch in South Dakota. They reported soil organic carbon estimates to 1 m depth ($\sim 10 \text{ kg SOC m}^{-2} \cdot \text{m}$) as well as depth profiles for SOC (Figure 6). From the depth profiles, we estimated their adaptively managed paddock (AMP) system resulted in $\sim 6.1 \text{ kg SOC m}^{-2} \cdot 0.3 \text{ m}$, whereas the light continuously grazed (LCG) system yielded slightly, though not statistically significantly, more ($\sim 6.5 \text{ kg SOC m}^{-2} \cdot 0.3 \text{ m}$) and the heavy continuously grazed (HCG) system yielded slightly less ($\sim 5.5 \text{ kg SOC m}^{-2} \cdot 0.3 \text{ m}$). Using only my average SOM values (3.9 and 3.7% for in-nii- and cattle-influenced, respectively; Table 5) and assuming SOC is half of the SOM and that there were 0 rocks in the uppermost foot of your profiles and using the average Williams bulk density (1.4 Mg m^{-3} ; Soil Data Explorer [<https://casoilresource.lawr.ucdavis.edu/see/>]), in-nii- and cattle-influenced soils contained 8.2 and 7.8 $\text{kg SOC m}^{-2} \cdot 0.3 \text{ m}$, respectively.

That these 777 Ranch (South Dakota) estimates are approximately 3/4 of our Blackfeet Nation estimates could be due to mathematical, climate, soil and/or management factors: (i) we assumed SOC was half of SOM, consistent with Pribyl (2010), but the actual SOC:SOM ratio could differ from 0.5; (ii) the average elevation of 777 Bison Ranch appears to be ~3300 feet whereas the Johnson Ranch is at an elevation of ~3800 feet; though the 777 Bison Ranch is wetter than the Johnson Ranch (mean annual precipitation: 500 vs. 380 mm) it is also warmer (7 vs 4°C) and has a longer frost-free season (95 vs 72 days) so evapotranspiration could lower effective precipitation; (iii) the dominant soil series at the 777 Bison Ranch have been reported as the Blackpipe, Emigrant, Kyle, and Norrest (Hillenbrand et al. 2019), which correspond to the soil orders Mollisols, Mollisols, Vertisols, and Alfisols, respectively; the RRJ Ranch is dominated by the Williams, Crago, Kiev, and Cabba series, which correspond to Mollisols, Inceptisols, Mollisols, and Entisols, respectively. Hillenbrand et al. (2019) reported the fraction of their LCG, AMP, and HCG treatments represented by their four dominant series; if the fraction of lower-SOC, non-Mollisol orders (e.g., Entisols) were greater than the fraction of higher-SOC, Mollisol orders, this could explain the lower SOC estimate for the 777 Bison Ranch; and finally, (iv) the 777 Bison Ranch has only been managed holistically for ~40 years; prior to this time “Much of the land had been continuously grazed with cattle and was in poor condition at the time of purchase. Some was previously farmed and planted with crested wheat and smooth brome and some pastures were chiseled to enhance water infiltration and stimulate a seed bank response of blue grama and buffalo grass” (Chico State n.d.). Though the RRJ and Blackfeet Buffalo Ranches are also likely to reflect prior management legacies, it could be that the slightly lower SOC stocks of the 777 Bison Ranch still reflect such management legacies.

Table 4 implies that the reported 777 Bison Ranch SOC values for AMP ($\sim 10 \text{ kg SOC m}^{-3}$) appear to be slightly greater than the corresponding SSURGO-derived estimates of SOC stocks by series, with average estimates for the four series ranging from 7-9 kg SOC m^{-3} . Our RRJ and Blackfeet Buffalo Ranch-derived estimates to a shallower 30-cm depth suggest a greater boost, perhaps attributable to management. Our estimates were $\sim 8 \text{ kg SOC m}^{-2} \cdot 0.3 \text{ m}$, whereas the corresponding SSURGO-derived estimates to the same depth interval ranged from 2-5 $\text{kg SOC m}^{-2} \cdot 0.3 \text{ m}$.

Table 4. Comparison of SOC estimates for several ranches based on mapped soil series. Values in parentheses represent the range of values to a specified depth interval for that soil series.

777 Bison Ranch series (% of land grazed)	Estimated kg SOC/m ² *0.3m (SoilWeb)¥	Estimated kg SOC/m ³ [Hillenbrand et al. 2019 values]	RRJ and Blackfeet Buffalo Ranch series (% of land)	Estimated kg SOC/m ² *0.3m (SoilWeb)¥
Blackpipe (11)	5 (3-6)	9 (6-12) [~ 13]	Williams (42)	3 (2-4)
Emigrant (20)	4 (2-6)	8 (5-11) [~ 10]	Crago (~ 6)	2 (0-4)
Kyle (17)	2 (1-4)	7 (5-10) [~ 10]	Kiev (~ 6)	5 (3-7)
Norrest (42)	3 (2-4)	7 (4-11) [~ 11]	Cabba (~ 5)	2 (1-3)

¥ Accessed at <https://casoilresource.lawr.ucdavis.edu/gmap/>

Rowntree et al. (2020) hypothesized “changes in soil C could ... be the greatest opportunity for reducing beef’s carbon footprint” since “livestock-induced soil C changes can have large impacts on the GHG [greenhouse gas] balance of these production systems.” They performed a life-cycle assessment of the effects of multispecies (cattle, chickens, ducks, geese, guinea fowl, goats, pigs, rabbits, sheep, turkeys) pasture rotational (MSPR) management on various soil indicators, including SOC, for the White Oak Pastures (WOP) cropland-restoration

effort in Clay County, Georgia (Figure 29). This ~1200-ha operation is dominated by Faceville, Marlboro, and Greenville fine sandy loams (all Udults [wet Ultisols] in US Soil Taxonomy) and, on average, receives >1300 mm (51 inches) of annual precipitation.

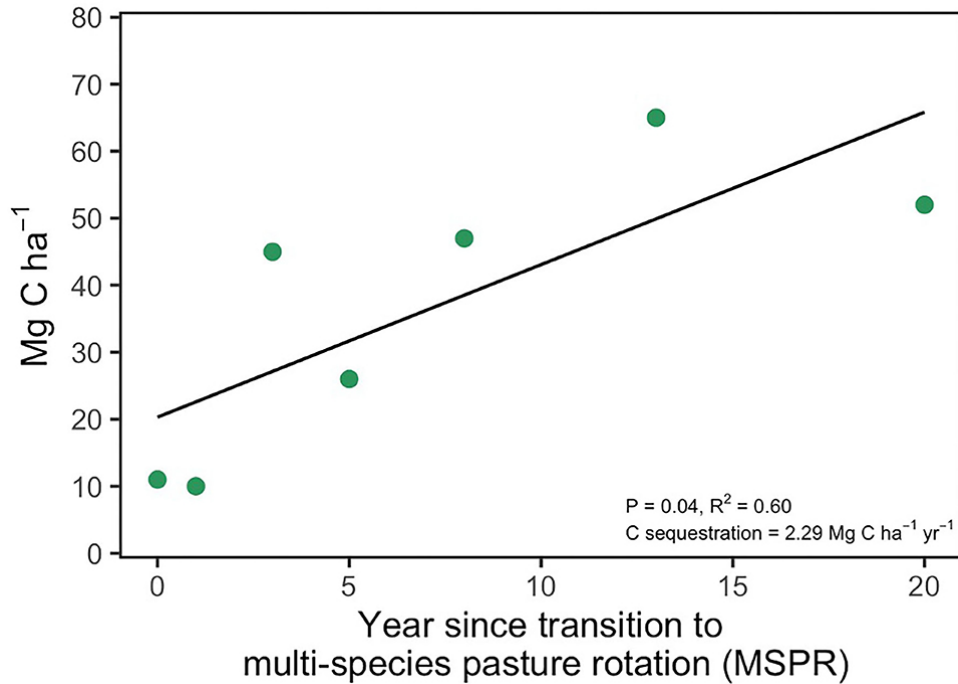


Figure 29. Soil organic carbon stocks to 1 m as a function of years since management transition at equivalent soil mass of 9,900 Mg/ha (Rowntree et al. 2020). Points represent least-squared means adjusted for soil clay content generated from 4 in-field replicate soil samples.

MSPR beef produced in this system, incorporating soil C gains, would be a net sink of $-4.4 \text{ kg CO}_2\text{-e (kg carcass weight [CW])}^{-1}$, which is far less than the typical carbon footprint of beef (e.g., $+19\text{-}26 \text{ kg CO}_2\text{-e (kg CW)}^{-1}$; Reynolds 2022 or WOP's own estimate of $+33 \text{ kg CO}_2\text{-e (kg CW)}^{-1}$ [Rowntree et al. 2020]). Since the WOP produces about 270,000 kg of beef annually (about half of their total CW across all species), this yields an annual operation-wide C sink of approximately -1.2 million kg or -1200 metric tons of CO₂-e (Rowntree et al., 2020). For

context, the average vehicle in the US produces about 5 metric tons of CO₂ annually (EPA 2018), so this WOP sink is equivalent to zeroing the emissions from ~240 vehicles annually.

In this case, their reported units in Mg SOC per hectare can be converted to kg SOC m⁻² by multiplying by a factor of 0.1 (as the product of 1000 kg/Mg and 1 ha/10,000 m²). In other words, initially SOC levels were ~1 kg SOC m⁻² (~10 Mg SOC ha⁻¹), but then they appeared to peak at ~6.5 kg SOC m⁻² (~65 Mg SOC ha⁻¹) after 13 years of MSPR (Figure 29). These values are nearly half those reported to the same depth interval of 1 m by the 777 Bison Ranch (11-13 kg SOC m⁻²), perhaps because of the much warmer temperatures, lower clay content (5-20%), and/or shorter duration of management.

Substrate-induced Respiration

In our controlled laboratory experiment comparing the in-nii and cattle soil, the yeast-induced results for both the in-nii and cattle soils showed large jumps between the 4h and the 24 sets (Figure 25). The in-nii +yeast averages were slightly greater (~20%; 28 vs 23 ug CO₂/g/h) than corresponding cattle averages, while water-induced readings for the in-nii and cattle soils, all values were about 7X smaller than corresponding yeast-induced results after the initial 0 and 4h readings. While there could be several factors that could contribute to these results, ultimately it comes down to whether there is significance between in-nii and cattle and we did not detect a very pronounced difference. Interestingly, the presence of yeast in solution (a decomposable form of carbon) specifically promoted a substantially greater production of carbon dioxide than the addition of an equivalent volume of water. This, in effect, is why we supply a respirable substrate to the soil microbes under controlled conditions. It becomes especially important in soils where microbes might be carbon-limited. Specifically, +yeast samples generated about 12-

14X greater carbon dioxide after 24 h than the corresponding +water samples. We observed a decline in respiration rates after 24 hours, with +yeast rates dropping about 5-6X by the 96-h reading. This should be expected given the size of the yeast addition (~15 mg C) and peak respiration rates we measured (~30 ug CO₂/g soil/hour; Figure 24), as these values would suggest that the yeast addition represented a minimum of 500 hours of substrate.

Zhao et al. (2017) found that grazing intensity appeared to have little influence on the relationship of microbial community size and SR (Figure 30).

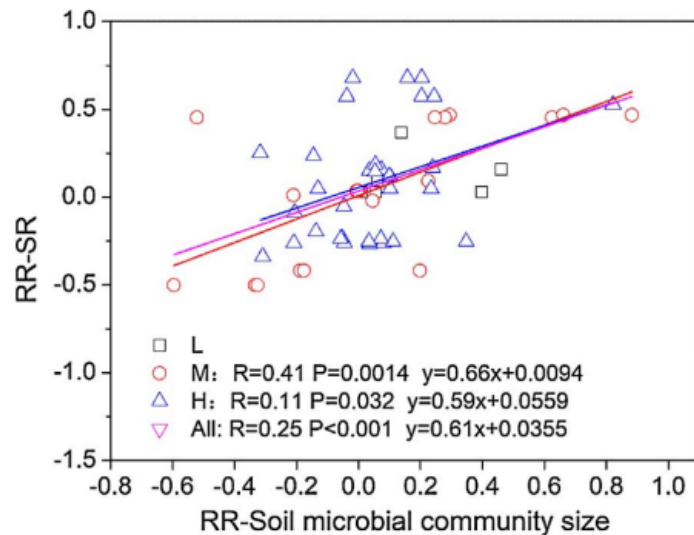


Figure 30. Relationships between the response ratios (RR) of soil microbial community size and RR of soil respiration (SR); L: Light grazing intensity; M: Moderate grazing intensity; H: heavy grazing intensity. (Zhao et al., 2017).

In their meta-analysis, response ratios (RR) of total microbial community size were positively related with SR for all grazing intensities, but in some cases the fraction of the variance explained was extremely low ($R^2=0.012$; heavy grazing).

Table 5. Temporal trends in soil health indicators over a 20-year period (Rowntree et al. 2020). ACE soil protein refers to autoclaved citrate-extractable protein and indexes the labile portion of the soil organic nitrogen pool, most of which is unavailable to plants.

	Year							Equation	p-value	R ²
	0	1	3	5	8	13	20			
Water-stable aggregation (%)	–	0*	11	7	47	47	53	$y = 2.9 + 2.9x$	0.02	0.76
Microbial respiration (mg CO ₂ day ⁻¹)	–	0*	0.56	0.54	0.94	1.16	1.16	$y = 0.07 + 0.01x$	0.03	0.75
Active C (ppm)	–	80	325	380	522	884	844	$y = 167 + 41x$	< 0.01	0.85
Water holding capacity (g water g soil ⁻¹)	–	0.19	0.20	0.15	0.15	0.28	0.21	–	0.44	–
ACE soil protein (mg g ⁻¹)	–	0*	5	3	15	22	23	$y = 0.2 + 1.3x$	< 0.01	0.86
Soil organic matter (%)	–	1.1	2.0	2.8	2.6	3.5	5.2	$y = 1.1 + 0.22x$	< 0.01	0.93

*Indicates Negative least-squared means were adjusted to 0.

Table 5 shows the long-term relationship between grazing and six soil health indicators which is important in understanding how soils change over the years. In this Georgia study, they found that multispecies pasture rotation management increased water-stable aggregates, microbial respiration, active carbon, bioavailable soil protein, and soil organic matter (Rowntree et al. 2020). Their work implied such a management approach could be one way to offset cattle-related greenhouse gas emissions. It's not about whose numbers are better but about how to improve our understanding of how different grazing management systems might improve the land, using grazers as a tool. Their work suggests it could take decades to see the results of their grazing management system reflected in soil health indicators, and their Georgia study site averages 51 inches of annual rainfall. In my much drier study site (25 inches), it could take even longer to see the effects of an improved grazing management system and this does not account for differences in evapotranspiration.

Field Soil Respiration

A study was performed in California at Santa Rosa Mountain to look at the effects of rewetting soils that are in arid and semi-arid climates (Chatterjee and Jenerette 2011; Figure 31). They found a pattern that seemed to be similar to the field soil respiration rates because as the soil was wet the CO₂ flux would increase and then decrease as time went on. If we were able to rewet the soil multiple times like Figure 31, I think we would have seen this similar pattern with our field sites.

Chatterjee and Jenerette found literature from Davidson and Janssens (2006) that variation in organic matter quality, long-term climate, and microbial community are important components influencing temperature moisture effects on CO₂, and that deciphering their relative control mechanisms is challenging (2011).

In their findings and results suggest that precipitation induced pulses are an important component of arid soil C dynamics, soil temperature strongly influences the pulse magnitude, and microenvironment and wetting history alter the temperature sensitivity of the pulse response (Chatterjee and Jenerette, 2011). This is important to know because as the earth continues to warm, we can gain an understanding of how the soil will interact with the environment they encompass.

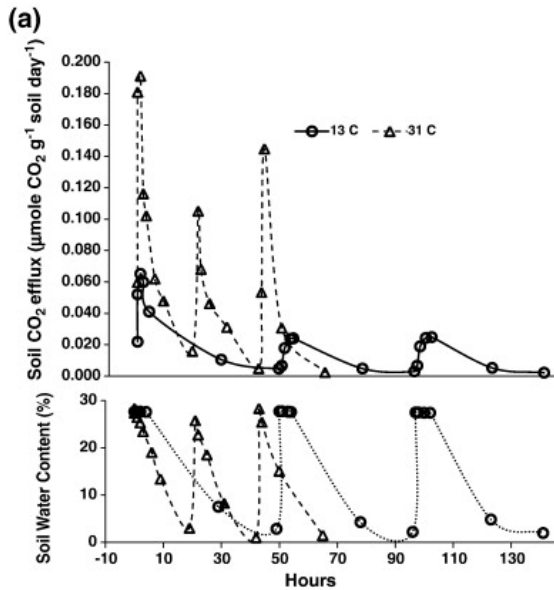


Figure 31. (a) Changes in soil CO₂ efflux ($\mu\text{mol CO}_2 \text{ g}^{-1} \text{ soil day}^{-1}$) and soil water content over time (hours) at 13 and 31 °C incubation temperatures at three drying rewetting events. (Chatterjee and Jenerette, 2011)

Table 6. Comparison of different substrate-induced respiration rates across studies.

prototype for substrate-induced respiration table	ug CO2/g/h			Notes
	Cattl e	In-nii	Ungrazed	
This study	0.2	2.1	--	After 24 h
This study	-0.2	0.7	--	After 96 h
Rowntree et al. 2020 (Georgia)	1.2	--	--	After 3 y of multispecies pasture rotation
Rowntree et al. 2020 (Georgia)	2.4	--	--	After 20 y of MSPR
West 1999 (Kansas)		2.5	2.2	Incubation 1
West 1999 (Kansas)		1.1	1.2	Incubation 2

Some caveats are in order. Measurements were only collected over a 10-day period in August 2020; additional measurements during other portions of the year could help clarify seasonal differences and annual trends. While our fence line approach was intended to quantify differences between in-nii and cattle, this approach presumed comparable grazing intensities

across the fence. Nevertheless, as our remotely sensed and remotely sense-able suite of grazing intensity indices expand (e.g., Primi et al. 2016), the usefulness of such fence line approaches for separating management "signals" from background soil-landscape "noise" should increase. Site 1's wet in-nii flux of 138 $\mu\text{mol CO}_2/\text{m}^2/\text{s}$ was anomalously high; excluding this flux does not change the overall pattern shown in the graph, with in-nii wet/dry flux ratios (3) about half the fence line ratio of 6.1 (vs 8.1 with anomalous value) and about 1/4th the cattle ratio. This reflects the general robustness of medians to anomalously low or high values.

Summary

It is important to know the history of the land to understand how changes in ecological cycles influence the health of the soil, land, and animals. Soil chemistry, biology, and physical properties are all invaluable to the overall function of soil, as they drive the soil's ability to hold water, sustain plant life and assist in resisting disturbance (Doran, 1999; Parr et al., 1992). For indigenous scientists who look at the world through lenses of cultural science and western science ideologies, the dual perspective creates a deeper connection to research we conduct. My research project investigates how reintroduction of in-nii and current cattle herds influence soil nutrients and substrate induced respiration (SIR) on the Amskapiipikini Nation.

In-nii and Cattle play an important role in how they utilize the lands resources. Grazing can have positive benefits to the grassland ecosystems through management of cattle and free-ranging in-nii. Gaining a better understanding of the effects these animals have on the resources is vital information as when policies are being created and improving the health of the lands become key to having successful operations for the Amskapiipikini as a whole.

Researching how to correctly care for and manage these animals is key to improving the health of the plants, along with the water and soils they utilize. Having a baseline study is important to connect the past to the future, to see if in 10 to 20 years the soils are starting to change and how learning from studies can be informative to ranch operators. By looking at how in-nii utilize the land, these techniques can be applied to cattle operations on the Amskapiipikini Nation. This will provide benefits to the ranchers and improve their land's resources and their animals' health.

Building on recent work, even improved animal management will still require improved soil health indicators (Wade et al. in review; Figure 32) for quantifying those impacts. As in-nii return to the Amskapiipikini, perhaps improved soil health indicators could be expanded to include measures of community well-being (Paul et al. in review). If the World Health Organization defines health as “a state of physical, mental and social well-being and not merely the absence of disease or infirmity” (2022) perhaps our definition of soil health could be expanded to include an element of social well-being for those humans engaged in promoting and those affected by soil health.

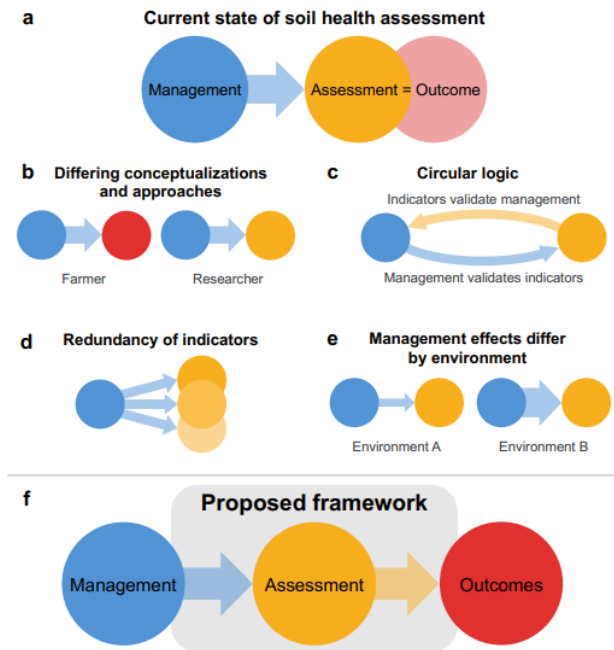


Figure 32. (a) The current state of quantitative soil health assessments and (b-e) several problems and pitfalls associated with current approaches. These include (b) differing approaches to soil health by key stakeholder groups, (c) a circular logic that is ubiquitous among the soil health literature, (d) current difficulties in addressing the redundancy of soil health indicators, and (e) the differing management effects across environments, while (f) outlines the scope of the currently proposed framework (Wade et al., in review).

Pikani Lodge Health Institute works with cattle ranchers to implement regenerative grazing practices through the lens that mimics traditional in-nii movements on the lands, where an area is uniformly grazed and then rested. My research on soil nutrients and SIR is being incorporated into a current PLHI project using the lens of cultural science and western science methodologies. The RRJ Cattle Ranch is currently looking at how in-nii grazing mimicry and regenerative grazing could improve the health of their lands and their animals. This helps to create the bigger picture of how to utilize cultural science and traditional teaching of the

management of in-nii herds and make them applicable to today's cattle ranch operations to have healthier animals and lands for future generations.

In the culture of the Amskapiipikini we do not own these lands, we only care for them and manage them for future generations. As my dad has taught me lessons that he learned from his grandfather, that we must leave the lands in better condition than we found them, so this is the mission I have while promoting the teachings of cultural science and its application to western science research. While many Native Students conform their research to the western ways of doing so, many more should pave the way to utilize our cultural and indigenous knowledge base to create a more diversified science and advance all who live on Mother Earth.

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CONCLUSION

In-nii and cattle grazing systems in the Amskapiipikini Nation do not appear to have different impacts on soil health, using a suite of measurements including soil nutrients and substrate-induced respiration (SIR). For example, of 11 soil properties, we only found two (cation exchange capacity and exchangeable magnesium) that showed statistically significant differences between soils collected from in-nii- or cattle-grazed pastures. Our SIR results showed strong evidence that the soil microbial communities responded relatively quickly (4-24 hours) to the experimental addition of yeast to the incubation microcosms, and the water component of that substrate only accounted for ~20% of that microbial activity. But we found no differences in our SIR results between the two soils though average in-nii-influenced CO₂ concentrations were ~20% higher than cattle-influenced concentrations for the 24- and 96-h measurement periods.

Further research over larger sampling areas on the Amskapiipikini Nation, over different seasons, and exploring interactions with cultural practices such as prescribed burning is likely to assist in extracting the environmental or management factors that play potentially disproportionate roles in shifting such soil health measures. Beyond these specific soil health measures, the broader cultural impact of the reintroduction of in-nii should be explored in tandem with additional measures related to soil water and nutrient cycles, community health, and community resilience. Future research could then provide a better understanding of the potential roles in-nii and cattle grazing might play in the near future of the Amskapiipikini. Figure 33 highlights Amskapiipikini worldviews when looking at the return of the in-nii and its impact on cultural healing. Of course, in-nii also influence ecological functions that relate to the health of

the soil, and this could then serve as the foundation for a reciprocal relationship between the land and animals.

This research has confirmed that soil processes take time might take decades.

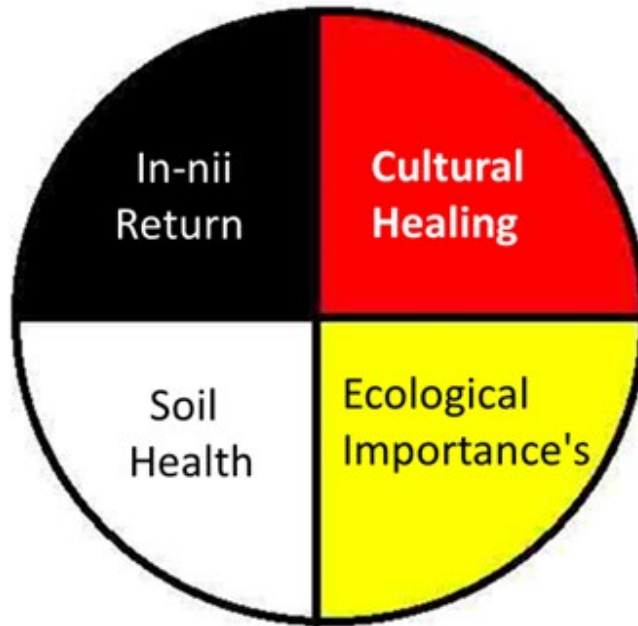


Figure 33. Model illustrating the return of in-nii and how influences the people and landscape ecosystems.

With the relative absence of research looking at the impacts of in-nii and cattle grazing on community health including soil health, there is a need for a better understanding of the interactions between specific grazing practices and objective measures of soil health (Figure 34).

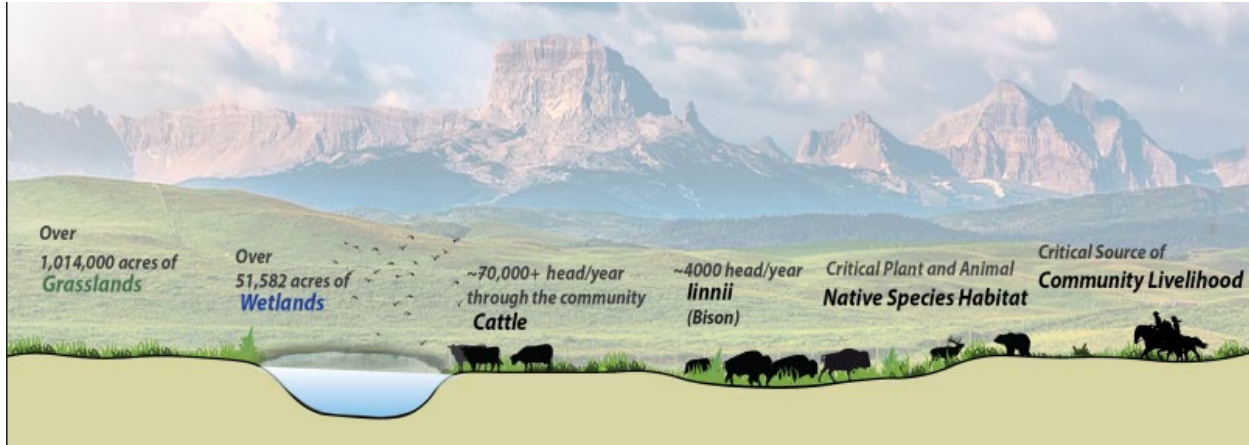


Figure 34. Model illustrating the grazing on the Blackfeet Reservation by in-nii, cattle, wildlife and ranch animals. (Piikuni Lodge Health Institute, 2020)

For example, while other studies from Australia to South Dakota have attempted to clarify whether "holistic planned grazing" or "rotational grazing" (higher-intensity and shorter-duration grazing versus more conventional lower-intensity but longer-duration) yields measurable differences in soil health indices, no studies to our knowledge have explored to what extent or how in-nii might be incorporated into a suite of regenerative practices aimed at boosting community resilience in the face of intersecting threats such as climate change, agricultural and transportation infrastructural challenges, and shifting socioeconomic conditions. Our results from this study should demonstrate to ranchers and livestock operators that grazing by in-nii and cattle, as indexed here, appears to yield few differences in soil health indicators. This absence of evidence should not be interpreted as evidence of absence (of a management effect). Western science cannot always measure what's important. As such, these findings should become the starting point for further research into an understudied topic. The subtle soil nutrient differences for soils grazed by in-nii and cattle should not be interpreted as trying to make one grazing system appear better than the other; instead, these findings should begin to frame our

understanding of the potential impacts these large ungulates might have when grazing landscapes, they are shaped by—but also, in turn, shape. Finally, my results highlight the opportunities for additional research where the only thing that separates two agricultural systems is a barbwire fence. Of course, for many of us Amskapiipikini, the even greater barrier between Western science and Cultural science approaches to exploring these types of elements of community health remains a pressing and critical challenge.

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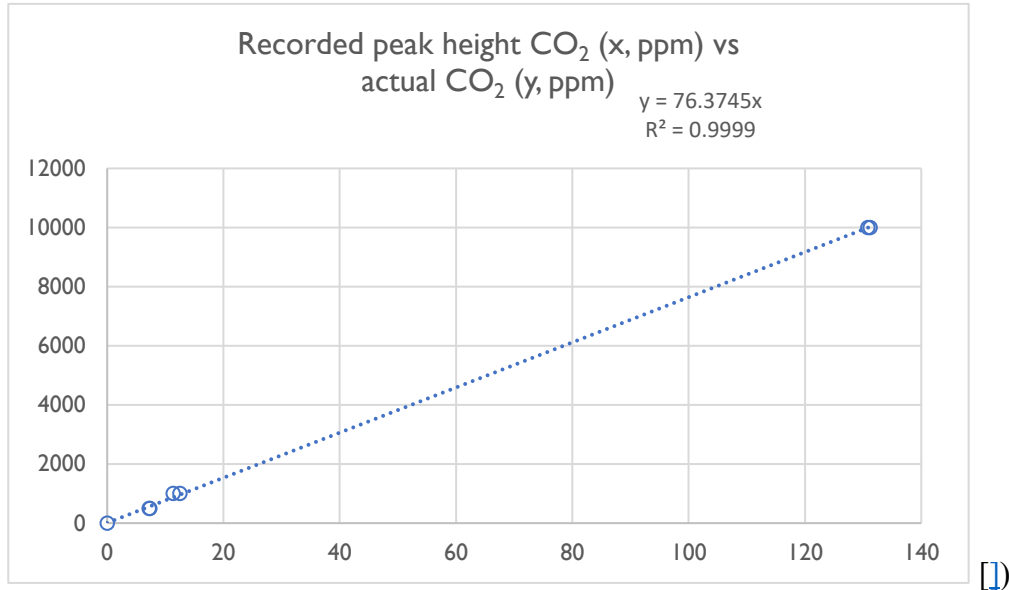
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APPENDIX A

RECORDED PEAK HEIGHT CO2 VS ACTUAL CO2



The reason this graph is here is that with all science we want to understand if our observations are ‘normal’ or not. In my science, we also want anyone to be able to get the same results we did if they “re-ran” an experiment. So we compare observations and we provide details about how we got from Number X to Number Y. Here this is showing how we went from peak CO₂ on the gas analyzer (Number X; starting number) to real CO₂ concentration (Number Y, where we ended up and what we used in our graphs and tables and math). We got this relationship by injecting known (expensive) calibration gases. This graph shows an extremely strong relationship between unknown peak CO₂ levels we measured with known CO₂ concentrations from the calibration gases.