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Effect of Bison Fecal Deposition on Vegetation Heterogeneity of Palouse Prairie

Abstract

Restoration of soil nutrient content by herbivore defecation is a fundamental process in grassland ecology as it facilitates the process of vegetation regrowth. One such nutrient, nitrogen, is key to vegetation growth in the palouse prairie of northwest Montana, where it is a scarce and limiting factor in the soil. Previous studies have suggested that American bison (*Bison bison*) fecal matter returns nitrogen to the soil, aiding in vegetation heterogeneity in both size of vegetation and species diversity. My hypothesis was that addition of bison fecal matter to plots of prairie would show a significant increase in soil nitrate content, vegetation biomass, and height of the vegetation. I established plots with and without fecal matter addition on two sites with distinct plant communities and herbivore feeding habits on the National Bison Range in Moiese, MT. One site (Tri2) has been restricted to bison grazing for several years while the other is frequented by herds of bison throughout each year (BR). Each plot received addition of water while only the experimental sites received 50 cubic oz. of bison feces. Plant height, plant biomass by clipping, soil nitrate concentrations, and radiometer measurements were conducted every two weeks during the month of July. Statistical results illustrated a significant increase in change in plant height, change in biomass measured by radiometer within 30.5 cm of the plot, and a nearly significant increase in change in biomass over the trial period. It seems that the fecal matter does increase plant biomass, but in a very localized range. Soil nitrate concentrations did not illustrate any significant results, which may have been influenced by the low number of sampling periods and the rapid intake of nitrate by the vegetation. A significant, positive correlation was found between change in nitrate concentrations and change in biomass measured by radiometer. The significance of these results is that bison fecal deposits do seem to increase vegetation biomass and size, creating a heterogeneity in plant size. Furthermore, previous studies have noted that areas near recent fecal droppings are not grazed by ungulates immediately, allowing this vegetation to reach increased reproductive capabilities, possibly allowing for an increase in grassland species heterogeneity as well.

Introduction

Excess metabolic wastes from ruminants have fertilized world grasslands for millions of years. These wastes often contain valuable nutrients, such as nitrogen forms like nitrate, nitrite, and ammonium, as well as phosphorus. While these wastes have been used as fertilizer in agricultural fields, they have been natural fertilizers in grassland ecosystems for much longer, renewing the grass species which the ruminants feed on. One ruminant in particular, the American bison (*Bison bison*), has been roaming the grasslands of the Palouse prairie for thousands of years. Previous studies have illustrated that fecal deposition has increased the standing crop and nitrogen content in grass shoots (Bazely and Jefferies, 1985; Hakamata, 1986). This process has been fundamental in restoring nutrients to the soil, allowing vegetation regrowth and continuing the cycle of herbivore-plant interactions on the grassland.

Chemical and mechanical processes in the bison digestive tracts transform plant matter into feces to be consumed by aerobic and anaerobic bacteria and fungi. These nitrifying decomposers change the fecal concentrations of nitrogen from ammonium (NH_4) to nitrite (NO_{2-}) and finally to nitrate (NO_{3-}), which is readily usable and assimilated by plants, stimulating their regrowth. Thus, bison feces returns nitrogen to the soil in a form that becomes more readily available to plants (Floate, 1981). This cycle, known as the nitrogen cycle, keeps supplies of nitrogen available to plants through the soil, allowing plants to restore nutrients lost by grazing and continue to provide for grazers.

The Palouse prairie of the intermontane northwestern Montana is characterized by its nitrogen-poor soils. With nitrogen as the limiting reagent in plant growth, it can logically be expected that an addition of nitrogen to the soil would stimulate plant growth and biomass (Risser and Parton, 1982). While there has not been a chemical analysis of the nitrogen content of *Bison bison* feces, the closely physiologically related livestock cattle have been shown to produce up to 7 mg of nitrogen per gram of manure (Hach, 2001). Bison fecal deposition, which is relatively the same size if not larger than that of cattle, is likely to return an even larger quantity of nitrogen to the soil. Furthermore, previous studies have suggested that addition of bison fecal matter increases vegetation heterogeneity (Schoenecker and Singer, 2003). The closer the vegetation is to the feces the more it will grow, which is typically positively correlated with reproductive capabilities. Fecal deposition sites, from a vegetative perspective, are unevenly spaced - which, in combination with uneven seed dispersal and vegetation consumption by herbivores, leads to heterogeneity . Thus, vegetation heterogeneity increases in both the varieties of plant sizes and species (Augustine and Frank, 2001; Shiyomi et al., 2000).This vegetation heterogeneity thesis is supported by the plant communities located on the National Bison Range. As illustrated in a previous study, a paddock of the Range in which the bison herds are allowed to graze has a greater plant diversity than a section in which the bison are restricted from grazing (Velez Reyes, 2008). For my study, I am interested in whether these two sites would respond to fecal deposition differently, since one site has been accustomed to this treatment while the other has not.

Based on previous supporting research, I hypothesize that the addition of bison fecal matter to natural Palouse prairie will stimulate plant growth in terms of biomass, plant height, and soil nitrogen content. To test this hypothesis, I will establish plots of Palouse prairie on the National Bison Range near Moiese, MT, on some of which I will deposit bison fecal matter and others I will leave as controls. My hypothesis is that the plots containing the bison fecal depositions will increase amounts of plant biomass and soil nitrogen. Furthermore, I hypothesize that plant communities which the bison have been continually grazing on will increase plant growth more than plant communities which the bison have been restricted from grazing on. I believe that this difference will come from the different plant communities in each site, which have been established by the effects of grazing or lack thereof.

Methods

I established 40 circular plots of approximately 153.86 square inches with a radius of 7 feet. Twenty of these plots were located in a site known as Triangle 2, which is located on the National Bison Range but is kept separate from the bison herds. This site contains both native and invasive grassland species, but it is primarily dominated by western wheatgrass (*Pascopyrum smithii*), tumbleweed mustard (*Sisymbrium altissimum*), crested wheatgrass (*Agropyron cristatum*), snowberry (*Symphoricarpos accidentalis*), spotted knapweed (*Centaurea stoebe*), pepperweed (*Lepidium spp.*) *Dianthus* species, and prickly lettuce (*Lactuca serriola*). On this site, the 20 plots were laid out in two transects, containing 10 plots each, that were approximately 50 yards apart. Both of these transects were laid out along areas that contained the aforementioned species, but primarily focused on the presence of *Pascopyrum smithii*, which I intended to use to measure relative change in plant height. The other site, which I named simply "Bison Range," was approximately a half-mile from Triangle 2. The primary difference between the two sites was that the "Bison Range" site was located within a paddock in which the bison had been allowed to graze in previous years. This has changed many of the characteristics of the site, especially in plant diversity and amount of dead plant material. This site contained a much greater variety of plant species than Triangle 2, including soft brome (*Bromus hordaceus*), crested wheatgrass (*Agropyron cristatum*), western wheatgrass (*Pascopyrum smithii*), arrowleaf balsamroot (*Balsamorhiza sagittata*), tumbleweed mustard (*Sisymbrium altissimum*), sulphur cinqefoil (*Potentilla* recta), Canadian thistle (*Cirsium arvense*), *Dianthus* species, St. John's Wort (*Hypericum perforatum*), yarrow (*Achillea millefolium*), *Pseudorogneria spicata*, lupine (*Lupinus spp.*), cheatgrass (*Bromus tectorum*), and a variety of Aster species. Two transects of 10 plots each were established approximately 30 yards apart and stretching along the slope of a slight hill with a north-facing aspect.

Before arrival at the site, I determined that the control and experimental plots would be placed alternatively so that each treatment would be represented equally in different parts of each site. Soil samples were taken at five plots of each treatment at each site. The soil samples were obtained by clearing the ground of organic material and digging between 10-20 cm into the topsoil to remove a few grams of soil. This soil was placed into sealed plastic bags until soil extraction into a potassium-chloride solution. The full soil extraction method was similar to that used in Belovsky laboratory protocol (Belovsky, 2000 Methods; Page et. al., 1982; Adamsen et al., 1985). Five of both the control and experimental plots at each site had five soil samples removed at distances of 6 inches, 18 inches, 30 inches, 54 inches, and 84 inches along a radius from the deposition. Soil samples were taken before the deposition, shortly after the deposition, two weeks afterward, and four weeks afterwards.

Plant height measurements were also taken at each plot weekly throughout the trial period from late June to early August. At both sites, I measured the average plant height of the plot by measuring ten individuals that were of prominent species in the plot.

Radiometry, which measures the reflection of light by vegetation, was also used at all plots to measure plant biomass, in accordance with the laboratory protocol of Belovsky. Radiometer readings were continued weekly throughout the trial period. Each plots was also clipped prior to fecal deposition and again at the end of the trial period to measure biomass.

Fresh (i.e. retaining some moisture) bison fecal matter was collected from a herd in a nearby paddock on the Bison Range. The feces were mixed together and apportioned out in equal amounts to ensure that there would be no difference in the quality of fecal deposition (Post et al., 2001). The experimental plots received approximately 50 ounces of fecal matter, which was measured by packing it into a measuring cup. To guarantee that there was nutrient transfer from the feces to the soil, 0.665 liters of water were poured over entirety of both control and experimental plots, which represented the average 0.26 cubic inches of rain in an average rainstorm in June for nearby Charlo, MT (www.weather.com). The control plots remained free of fecal deposition, though all other treatment remained equal. The experimental plots received approximately 50 ounces of *Bison bison* feces. Repeated measures ANOVA tests and General Linear Model (GLM) tests were conducted for statistical analysis on the radiometer, nitrate, and clipped vegetation biomass data.

Results

The results of the repeated measures ANOVA test illustrated a statistically significant response in the radiometer measurements within 30.5 cm (1 ft.) of the fecal deposition ($p=0.0302$). There was no statistically significant response for any further distance from the deposition, up to a distance of 2.13 m (7 ft.) at the edge of the plot. Repeated measures ANOVA tests indicated that there were no statistically significant responses to the treatment for soil nitrate and clipped vegetation biomass at any distance. There was a statistically significant relationship between change in plant height and treatment ($p=0.00011$). All statistical results of repeated measures ANOVA tests are illustrated in Table 1.

A GLM test showed a near statistically significant relationship between change in soil nitrate (DELTAN) and change in the amount of vegetation biomass clipped (CLIPDELTA) ($p=0.1043$). Other statistically significant results illustrated the difference between the two sites in radiometer measurements, biomass measured by clipping, and soil nitrate concentrations across all distances. Linear regression illustrated a statistically significant positive correlation between nitrate change and radiometer measurements (see Table 1).

Discussion

In accordance with previous research, my experimental results indicated that *Bison bison* fecal matter affects plant biomass in a localized region around the deposition (Bazely and Jefferies, 1985; Hakamata, 1986). While other tests may have showed a trend in this direction, the high variance of the clipped vegetation biomass data may have inhibited any significant relationship (see Figures below). These findings agree with previous research conducted on the effects of cattle feces on vegetational heterogeneity, which concluded that plant size and biomass increased in areas affected by fecal deposition (Augustine and Frank, 2001; Shiyomi et al. 2000). Fecal deposition thus increases vegetational heterogeneity in both plant sizes, e.g. which sections of a grassland will have larger individuals because of their proximity to bison feces. It can also increases species diversity by randomly distributing fecal depositions that may interfere with unaltered soil resource competition among grassland species, allowing grassland species with a weaker fitness to outcompete more fit species if the weaker species happens to be within a close proximity of the fecal matter.

These findings agree with my statistically significant results that illustrated that plant height increased in the presence of bison fecal deposition to a nearly 60 mm average among all species compared to nearly 32 mm average in control plots. However, as all plant height data was collected in close proximity to the fecal deposition, the change in plant height along a radius out from the deposition cannot be analyzed. In combination with increased biomass, as measured by radiometer, it appears that the addition of bison fecal deposition increased the size and productivity of nearby vegetation. The increased size of the vegetation is typically positively correlated with an increased reproductive output, which may increase species heterogeneity as well (Augustine and Frank, 2001; Shiyomi et al., 2000). Furthermore, bison and cattle refrain from consuming vegetation near recently created fecal deposits, thus allowing these plants to continue their growth longer than the grazed vegetation surrounding them. However, these patches of higher vegetation are preferentially fed upon once the presence fecal matter is no longer a barrier to grazing. Not only does this increase size heterogeneity of the grassland community, but this also aids in seed dispersal, as these larger plants will become more reproductively successful and can spread their seeds via consumption by the grazing individual.

While bison fecal depositions have been shown to significantly increase plant biomass, the beneficial effect of the fecal matter is limited. Statistically significant radiometer measurements illustrated that plant biomass only increased within a distance of 30.5 cm (1ft.), referred to here as Distance A, within the deposition. In addition, this finding was not supported by the clipped vegetation data at the Triangle 2 site, but this may have again been due to the high variance within the clipped biomass data. At the Bison Range site, there was a statistically significant relationship between the treatment and the amount of biomass measured by clipped vegetation within Distance A .

Results from soil nitrate concentration tests proved inconclusive, with no significant relationship between treatment or distance from the deposition with nitrate levels. However,bison fecal matter may still be returning nitrogen to the soil. As previous research has suggested, bison feces returns the nitrogen to a form that is more readily available by the vegetation and grazing increases plant nitrate assimilation (Floate, 1981; Frank et Evans, 1997). As noted observationally, grasshoppers were present at both sites and each site showed some sign of vegetation destruction through grasshopper grazing. Plant regrowth, from previous grasshopper grazing, may have increased nitrate uptake from the soil, utilizing the readily available nitrogen from nearby bison fecal deposits as continuously as it was released from the fecal matter. Three brief nitrate sampling sessions may not have been thorough enough to capture the constant, continuous uptake of increased nitrate in the soil. However, the increased biomass in both radiometer measurements and plant height testify to the beneficial effects of proximity to bison fecal deposits (Risser and Parton, 1982). Furthermore, a linear regression between change in biomass, measured via radiometer, and change in nitrate demonstrated a statistically significant positive correlation. Unfortunately, restraints in time and funding did not allow for testing of others nutrients such as ammonia or phosphate, which could also be stimulating vegetation growth.

As hypothesized, the effects of the fecal deposition varied between the Bison Range and Triangle 2 sites. Change in sites affected the plant biomass within Distance A, with a significant relationship at the Bison Range site but not at the Triangle 2 site. This may have been caused by the plant species present at the Bison Range site compared to Triangle 2. The reason behind the very distinct plant communities at the Bison Range site, the Triangle 2 site, and a nearby Triangle 1 site is not understood, and I recommend it as a future research study. From a speculation standpoint, I would estimate that the community differences would be due to a mixture of bison grazing, bison fecal deposition, and human-induced effects. A mixture of historical and observational analysis may be beneficial in determining the cause of these differences.

Figures and Tables

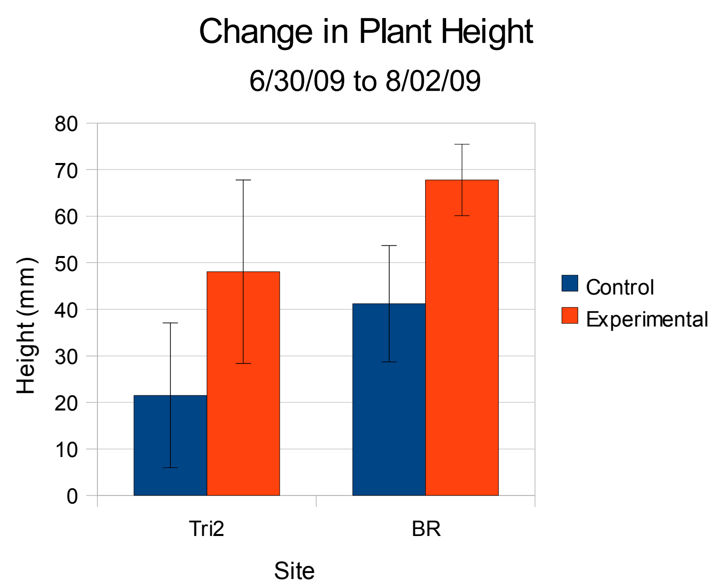

Figure 1: This figure illustrates the statistically significant increase in plant height in plots with treatment, labeled as experimental, compared to those without, labeled as control ($p = 0.000011$). Change in plant height reflects an increase in biomass caused by the addition of bison fecal matter.

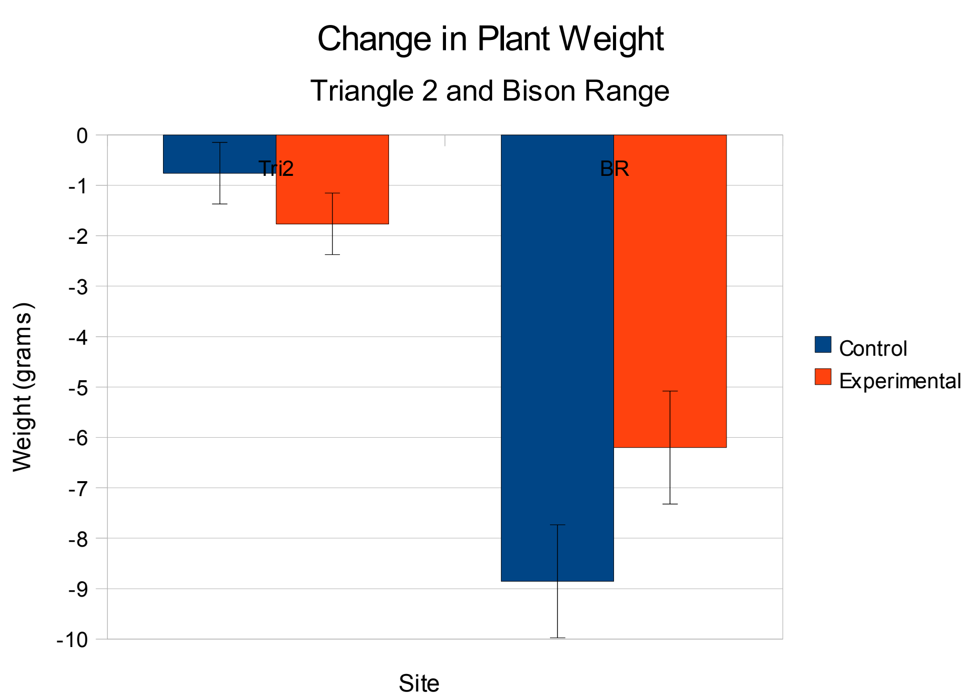

Figure 2: This figure illustrates the nearly statistically significant increase in plant weight in plots with treatment, labeled as experimental, compared to those without, labeled as control ($p = 0.1043$). While all change was negative, due to vegetation withering from lack of moisture as the summer progressed, in the Bison Range side the weight decreased less, possibly caused by the experimental treatment.

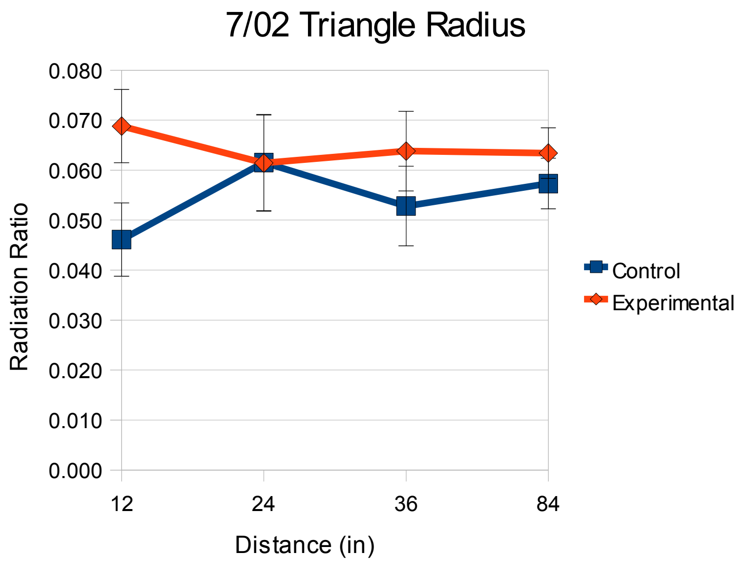

Figure 3: This figure illustrates the change in radiometer measurements in progression from the fecal deposition, from 12 to 84 inches, at the Triangle 2 site on 7/02. The radiometer measurement is the ratio of the radiation that is reflected from the vegetation, which is a measure of biomass. These readings were taken briefly after the application of bison fecal matter.

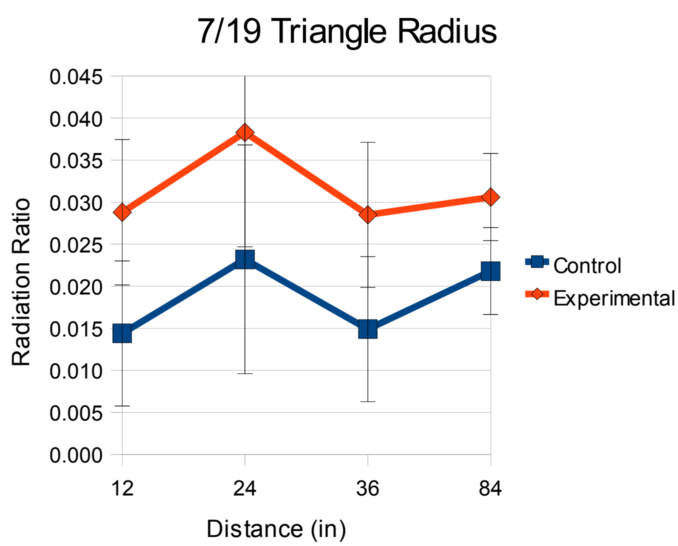

Figure 4: This figure illustrates the change in radiometer measurements in progression

from the fecal deposition, from 12 to 84 inches, at the Triangle 2 site on 7/19. The radiometer measurement is the ratio of the radiation that is reflected from the vegetation, which is a measure of biomass. These readings were taken nearly two weeks after the application of bison fecal matter. There was no statistically significant change in radiation ratio between these distances.

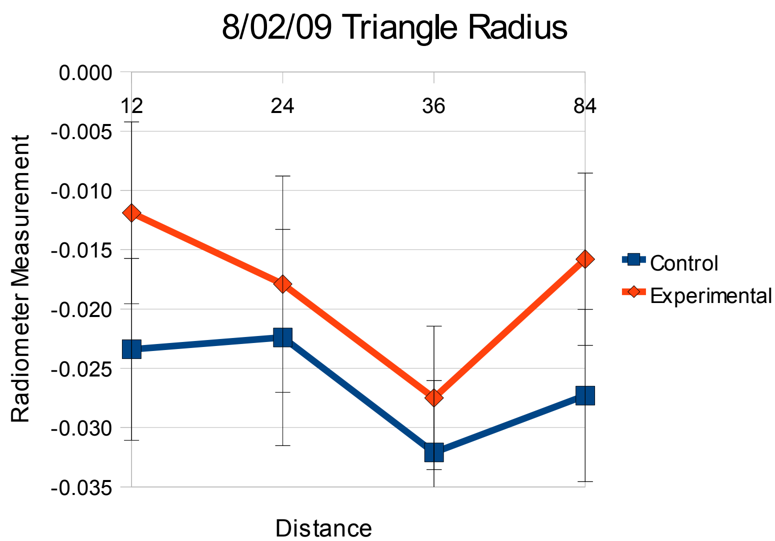

Figure 5: This figure illustrates the change in radiometer measurements in progression from the fecal deposition, from 12 to 84 inches, at the Triangle 2 site on 8/02. The radiometer measurement is the ratio of the radiation that is reflected from the vegetation, which is a measure of biomass. These readings were taken four weeks after the application of bison fecal matter. There was no statistically significant change in radiation ratio between these distances.

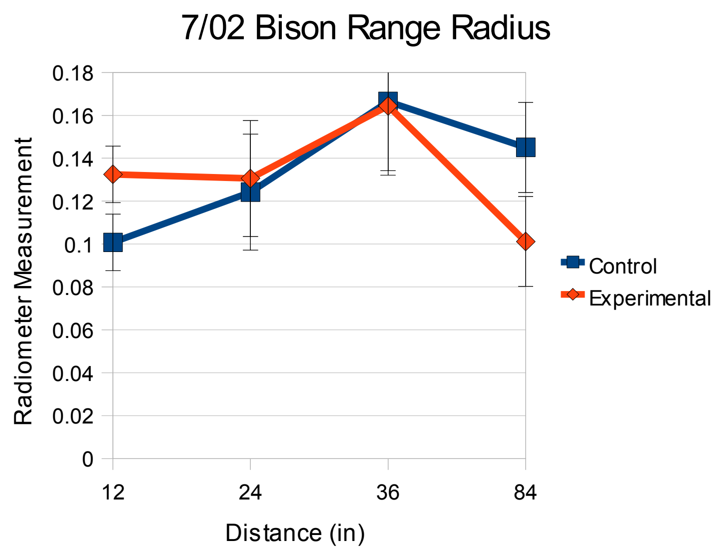

Figure 6: This figure illustrates the change in radiometer measurements in progression from the fecal deposition, from 12 to 84 inches, at the Bison Range site on 7/02. The radiometer measurement is the ratio of the radiation that is reflected from the vegetation, which is a measure of biomass. These readings were taken briefly after the application of bison fecal matter. There was no statistically significant change in radiation ratio between these distances.

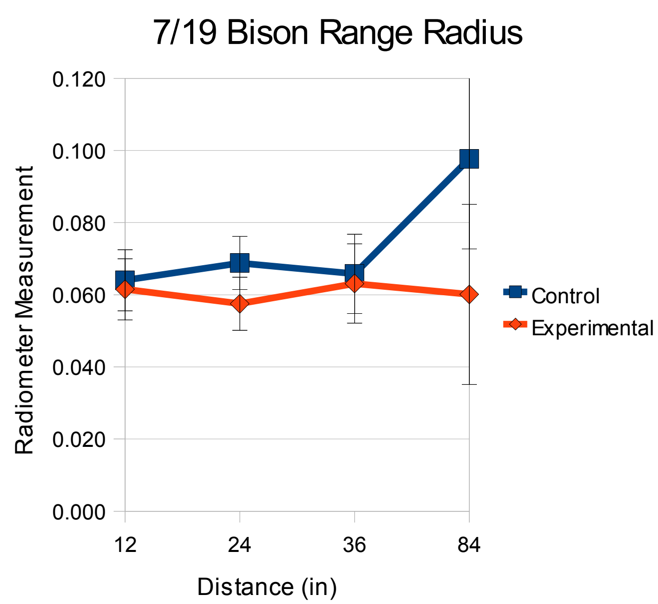

Figure 7: This figure illustrates the change in radiometer measurements in progression from the fecal deposition, from 12 to 84 inches, at the Bison Range site on 7/19. The radiometer measurement is the ratio of the radiation that is reflected from the vegetation, which is a measure of biomass. These readings were taken two weeks after the

application of bison fecal matter. There was no statistically significant change in radiation ratio between these distances.

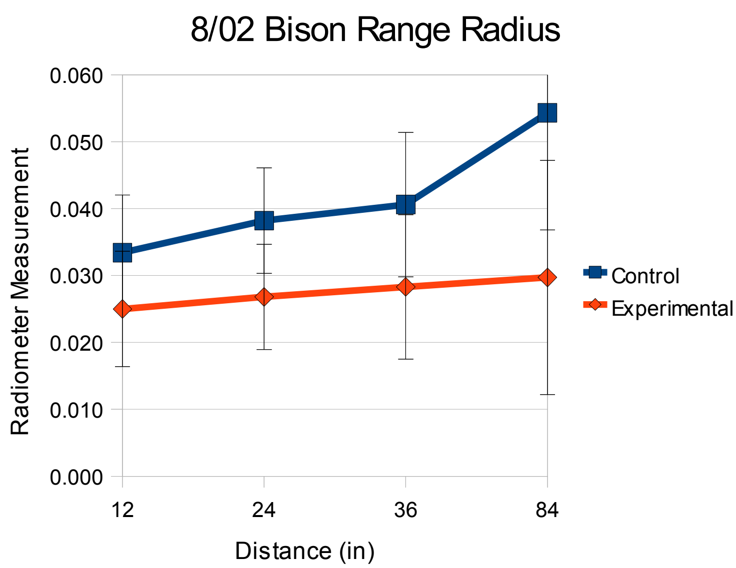

Figure 8: This figure illustrates the change in radiometer measurements in progression from the fecal deposition, from 12 to 84 inches, at the Bison Range site on 8/02. The radiometer measurement is the ratio of the radiation that is reflected from the vegetation, which is a measure of biomass. These readings were taken four weeks after the application of bison fecal matter. There was no statistically significant change in radiation ratio between these distances.

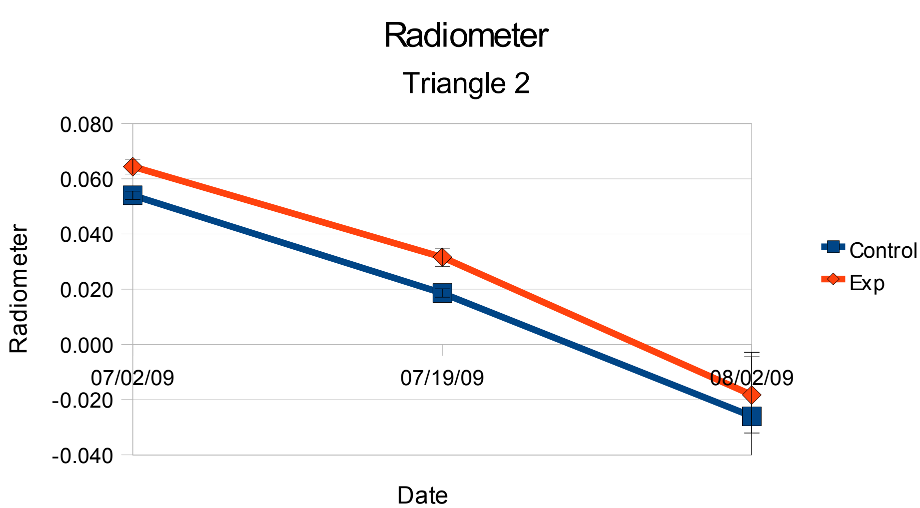

Figure 9: This figure illustrates the change in radiometer measurements from 7/01/09 to 8/02/09 in plots at Triangle 2 with treatment (Exp) and without treatment (Control). There was no statistically significant relationship between treatment in radiometer

measurements over these three dates, most likely due to the high variance of the readings at 8/02/09.

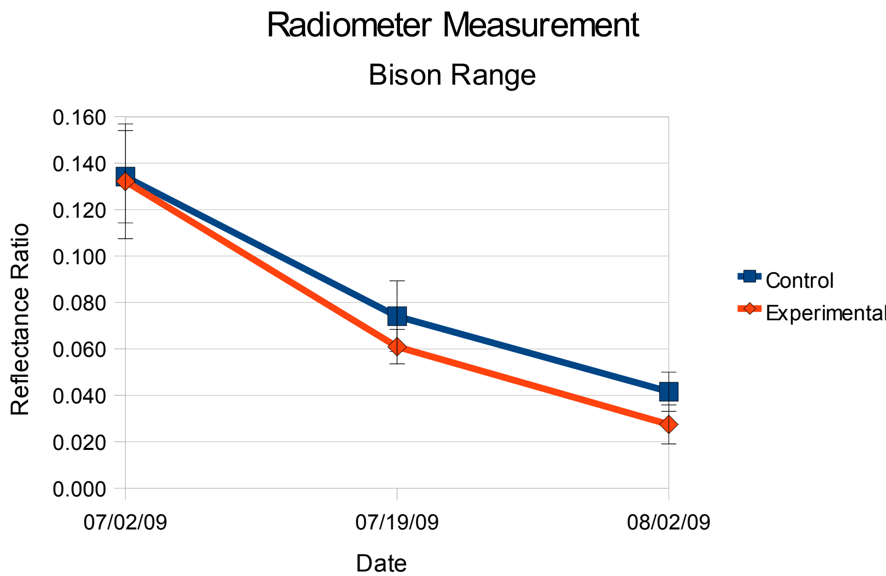

Figure 10: This figure illustrates the change in radiometer measurements from 7/01/09 to 8/02/09 in plots at the Bison Range site with treatment (Experimental) and without treatment (Control). There was no statistically significant relationship between treatment in radiometer measurements over these three dates, most likely due to the high variance of the readings.

Table 1: This table illustrates all relevant statistical tests run, the site(s) incorporated into the test, the type of statistical test used, the F-ratio, and the p-value. Significant, or near significant, p-values are highlighted in yellow.

Relationship	Site	Test	F-ratio	P-value
Plant Height by Treatment	Both	ANOVA	19.759378	0.000011
Clipped Biomass by Treatment	Both	GLM	2.733472	0.104291
Radiometer at A Treatment	Both	ANOVA	5.095540	0.030150
Nitrate by Treatment	Both	ANOVA	0.395000	0.532000
Nitrate by Treatment	BR	ANOVA	0.923000	0.345000
Nitrate by Distance	BR	ANOVA	0.766000	0.560000
Nitrate by Distance	Tri2	ANOVA	0.474000	0.754000
Nitrate by Radiometer 1 to 2	BR	Regress.	1.635000	0.214000
Nitrate by Radiometer 1 to 2	Tri2	Regress.	0.703000	0.410000
Nitrate by Radiometer 1 to 3	Both	Regress.	11.948000	0.014000

Literature Cited

Adamsen, F.J., Bigelow, D.S., and G.R. Scott. 1985. *Com. Soil Sci. Plant Anal.* 16:883-898.

Augustine, D.J., and D.A. Frank. 2001. Effects of migratory grazers on spatial heterogeneity of soil nitrogen properties in a grassland ecosystem. *Ecology*: 82:11:3149-3162.

Belovsky, G.E. and J.B. Slade. 2000. Insect herbivory accelerates nutrient cycling and increases plant production. *Proceedings of the National Academy of Sciences of the United States of America* 97:26:14412-14417.

Cid M.S. and M.A. Brizuela. 1998. Heterogeneity in tall fescue pastures created and sustained by cattle grazing. *Journal of Range Management* 51:644-649.

D.R. Bazely and R.L. Jefferies. 1981. Goose feces: a source of nitrogen for plant growth in a grazed salt marsh. *Journal of Applied Ecology* 22:693–703.

Floate, M.J.S. 1979. Effects of grazing by large herbivores on nitrogen cycling in agricultural ecosystems. *Ecological Bulletins*.

Frank D.A. and R.D. Evans. 1997. Effects of native grazers on N cycling in Yellowstone National Park. *Ecology* 78:7:2238-2248.

Hach Company. 2001. Soil and irrigation water interpretation manual. U.S.A.

Hakamata, T., 1986. Studies on evaluation of heifer excreta contribution on grazing pasture fertility. *Rep. Hokkaido Pref. Agric. Exp. Stat.* **55**, pp. 1–88.

Page, A.L., Miller, R.H. and D.R. Keeney. 1982. *Methods of Soil Analysis* (Am. Soc. Agron. Soil Sci. Soc. Am., Madison, WI), Part 2.

Post, D.M., Armbrust, T.S., Horne, E.A., and J.R. Goheen. 2001. Sexual segregation results in differences in content and quality of Bison (Bos bison) diets. Journal of Mammology 82:2:407-413.

Shiyomi, M., Takahashi, S., and H. Kirita. 2000. Roles of plant biomass and vegetational heterogeneity, and energy-matter cycling in grassland sustainability. *Ecological Modeling* 132:2:135-149.

Singer, F.J. and Kathryn A. Schoenecker. 2003. Do ungulates accelerate or decelerate nutrient cycling? *Forest Ecology and Management* 181:2:189-204

Velez Reyes, V. 2008. Grasshopper diversity among three sites with differing herbivory regimes on the National Bison Range. UNDERC West Student Papers.