PRAIRIE DOG (*CYNOMYS LUDOVICIANUS)* CONTRIBUTIONS TO SOIL CHANGE ON GRAZED MIXED-GRASS PRAIRIE

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The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

MASTER OF SCIENCE

SUPERVISORY COMMITTEE:

Kevin Sedivec
Co-Chair
Mark Liebig
Co-Chair
Edward (Shawn) DeKeyser

Frank Casey

Jack Norland
Approved by Department Chair:

04/12/2012 Kevin Sedivec
Date Signature

ABSTRACT

Vegetation and soils were evaluated on a black-tailed prairie dog (*Cynomys ludovicianus*) colony and adjacent non-disturbed mixed-grass prairie in central South Dakota. The study's objectives were 1) determine differences in plant species diversity and richness, and selected soil quality parameters between prairie dog colonies and adjacent non-disturbed sites, and 2) evaluate impacts of prairie dogs on water infiltration rates. Three soil series were evaluated representing three ecological sites (Opal, Cabba, and Wayden). Plant species richness was higher on the Control on Opal soils, while being lower on the Control on Cabba soils. Lower soil pH and higher nitrate concentrations were found on the prairie dog town for Opal and Cabba soils near the soil surface, close to the prairie dog mounds. These findings show prairie dog impacts on soil parameters can vary across different soil types, which can affect the diversity and richness of vegetative communities within prairie dog colonies.

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CHAPTER 1. INTRODUCTION AND LITERATURE REVIEW

Introduction

Black-tailed prairie dogs (*Cynomys ludovicianus*) historically occupied 40 million ha of short and mixed-grass prairie in the Great Plains (Hoogland 1995), from northern Mexico to Southern Canada and from the Rocky Mountain foothills east to the tall grass prairies (Nelson 1919). However, over the past century the prairie dog population has decreased to a point where they occur on about two percent of their original range, and in the Northern Great Plains this covers approximately 2,378 km^2 (Sidle et al. 2001). Reasons for this decline are attributed to loss of habitat, eradication programs, and disease such as the plague (Cully and Williams 2001).

Black-tailed prairie dogs can have a major impact on ecosystems. The impact prairie dogs have on an ecosystem can also affect how other wildlife species utilize prairie dog towns. Coppock et al. (1983a) observed higher nitrogen and *in vitro* dry matter digestibility on prairie dog towns as opposed to adjacent no-colonized areas. These increases in nutrition quality attracted wild ungulates to actively select prairie dog towns for grazing (Coppock et al. 1983b). Agnew et al. (1986) found bird and small mammal densities higher on prairie dog towns than the associated no prairie dog town areas.

One major impact prairie dogs have on an ecosystem is they alter the vegetative communities. Prairie dogs will continuously fell the vegetation located within their town as a defensive measure (King 1955) as well as a food source. Since prairie dogs preferentially select graminoids as a food source (Hanson and Gold 1977), there tends to be a shift in the vegetative community from graminoids to forbs (Coppock et al. 1983a). Along with this shift in the vegetative community there is an increase in plant species diversity and richness in the community of younger prairie dog towns; however, as the dog town ages the plant species diversity and richness decline to pre-colonized levels (Archer et al. 1987). The amount of litter and bare ground present on the prairie dog town also follow this trend. As a prairie dog town ages the amount of litter present decreases and amount of bare ground increases. This increase in bare ground can influence the amount of water runoff and amount of water infiltrating into the soil.

Prairie dogs also impact the ecosystem from their burrowing activities. These impacts can have an effect on both the vegetation and soil properties. They can influence vegetation through their clipping of belowground roots and stems. Impacts in the soil include increasing soil pH and phosphorus, while decreasing soil nitrogen (Carlson and White 1987, Carlson and White 1988).

Literature Review

Black-tailed prairie dogs (*Cynomys ludovicianus*) are one of five prairie dog species that inhabit the North American continent. They are burrowing rodents that live in large colonies, or towns, that can extend for many hectares (ha). Originally the black-tailed prairie dog inhabited areas ranging from the tall grass prairies west to the foothills of the Rocky Mountains, and from Mexico north into southern Canada (Hall 1981, Agnew et al. 1986). Black-tailed prairie dogs are most common in the short grass and mixed grass prairies of these regions and are not typically seen at elevations above 1830 meters (Hoogland 1995).

Prairie dogs tend to select locations for burrows based on topographical features (slope and aspect) and soil texture. Prairie dog colonies are typically located on slopes less than 7% and areas where the soils are deep, well developed, and the threat of flooding is minimal (Dahlsted et al. 1981). They select relatively flat areas to detect predators easier than areas with greater slope (King 1955). However, as the colony expands, they will utilize areas with greater slope even though it is not optimal habitat (Koford 1958). The aspect, or the direction the hole faces, is also preferentially selected by prairie dogs, especially at the northern latitudes (Koford 1958). Prairie dogs tend to select areas that face south; both as a food source, since the vegetation receives more sunlight and for warmth, since prairie dogs are active throughout the year. Soil texture also plays a role in the areas prairie dogs select. The soils must be capable of supporting the burrows, so they cannot be prone to collapse or flooding (Osborn 1942; Koford 1958). Reading and Matchett (1997) found that clay-loam and loam soils were soil textures preferred by prairie dogs.

The black-tailed prairie dog is the most numerous and widespread of the five species (Hall 1981, Hoogland 1995). Historically, prairie dog populations were estimated to be as high as five billion (Seton 1929, Costello 1970) occupying 40 to 100 million ha in North America (Nelson 1919, Miller et al. 1994); however, these numbers are continuously debated (Vermeire et al. 2004). Vermeire et al. (2004) argued that 40 million ha is the high end of their range due to anthropogenic influences, which helped to expand prairie dogs eastward into the tall grass prairie.

Currently, black-tailed prairie dogs are estimated to cover approximately 2,378 km^2 in the Northern Great Plains, which is about 2% of their former range (Sidle et al. 2001). Primary causes for the decline in black-tailed prairie dog populations are attributed to habitat loss, eradication programs, and disease such as plague (Cully and Williams 2001).

With the reduced population, habitat fragmentation is a concern. With these fragmented populations, problems may arise from diseases, population immigration, and reduced genetic exchange (Wilcox and Murphy 1985).

Prairie dog towns create habitat utilized by different animal species such as mammals, reptiles and birds. Kotlier et al. (1999) consider prairie dogs a keystone species, due to the fact that they have a profound effect on other species and the biological diversity in their ecosystem. Some species utilize prairie dog towns their whole lives, while others live on prairie dog towns but are not dependent on them for survival. Prairie dogs are prey to some species, while others utilize the burrows as shelter (Kotlier et al. 1999).

Vegetation

Black-tailed prairie dogs have a major impact on vegetation. These impacts come from the clipping of aboveground and belowground structures of the vegetation. Prairie dogs will clip the aboveground vegetation as a means of defense, so they tend to keep the vegetation short (King 1955). The vegetation is also used as a food source. Accordingly, prairie dogs constantly graze vegetation throughout the year (Winter et al. 2002).

Black-tailed prairie dogs prefer to consume graminoids over forbs (Hanson and Gold 1977), however they will consume forbs (Fagerstone et al. 1981) especially later in the season when graminoids are not as nutritious (Uresk 1984). Uresk (1984) found black-tailed prairie dogs diet consists of up to 87% graminoids, 12% forbs, and 1% shrubs, arthropods and seeds. Sixty five percent of the diet was four plant species or genera: sand dropseed (*Sporobolus cryptandrus*), sedge (*Carex* spp.), blue grama (*Bouteloua gracili*) and wheatgrasses (*Pascopyrum* spp.) (Ursek, 1984). The most dominant forb species found in black-tailed prairie dog diets was scarlet globemallow (*Sphaeralcea coccinea*)

(Fagerstone et al. 1981, Uresk 1984). Even though prairie dogs utilize vegetation as a food source, most of the vegetation felled within a colony is for defense and to aid in communication (King 1955).

There are grazing induced differences in vegetative composition between prairie dog towns compared to areas outside prairie dog towns. These differences were also influenced by the age of the colonies (Coppock et al. 1983a). Coppock et al. (1983a) found younger colonies had the least vegetative biomass, while the older colonies had biomass similar to areas not affected by prairie dogs.

As a prairie dog colony ages and the time that the town has been under continuous heavy grazing pressure increases, the amount of bare ground increases and amount of litter decreases (Archer et al. 1987). This increase in bare ground is due to prairie dogs continuously felling the vegetation material. Having an increase in bare ground can help facilitate seedling germination, which can create a flush of annual forbs. An increase in bare ground can also promote runoff, which in turn can increase soil erosion. With this increase in runoff there could be less water infiltrating into the soil. There also may be an increase in the evaporation rates on these sites (Archer et al. 1987). These changes could lead to lower water availability rates in these areas.

Plant species composition on rangeland is influenced by prairie dogs. Archer et al. (1987) found plant species diversity and richness was greatest on the younger colonies and as the colonies aged the diversity and richness declined. The increased diversity can be attributed to a dominance of graminoids off colony. As prairie dogs colonize an area, graminoids decline; however, forbs increase at a faster rate. As a colony ages the graminoids decrease and towns become dominated by forbs, thereby reducing species diversity and richness. Graminoids comprised greater than 85% of the total biomass of the plant community on areas not impacted by prairie dogs (Coppock et al. 1983a). However, in older prairie dog colonies, biomass quantity was similar to the non-colonized area, but forbs and shrubs comprised 95% of the total biomass. There is a shift in the vegetation height from mid-height grasses in non-colonized areas, to short-grass and forbs species on the prairie dog town (Winter et al. 2002). As grasses are grazed and the number of grass species decline, the plant community shifts toward grasses adapted to herbivory. These adaptations include grasses that are short in stature, possess sharp tipped awns, and have a growth characteristic of sprawling.

Changes that occur in the vegetation, from graminoid dominated systems to forb dominated systems, also occur in the soil seed bank (Fahnestock et al. 2003). Along with increases in forb species, there is a tendency for relatively poor forage quality species. These species replace highly palatable species in the seed bank, which could indicate if prairie dogs were removed from the system the towns may not rapidly go back to the original ecosystem prior to prairie dog colonization.

Buckhouse and Colthrop (1976) found grazing may conserve soil moisture due to the removal of transpiring leaf tissue. This would lead to increased water potentials, which would allow the remaining tissue of grazed plants to have a higher growth rate in areas where grazing does not occur (Wolf and Perry 1982). Archer and Detling (1986) found no differences in water potential on and off of prairie dog towns. This was true even though the root biomass was less on the prairie dog colony, soil temperatures were greater on the town, and ungulate grazers may have increased the bulk density on the prairie dog colony, potentially reducing water infiltration rates. Such similarities may have been due to lower amounts of live standing biomass on the prairie dog colony, which reduced the amount of water lost to transpiration. This reduction in transpiration may have promoted soil water retention.

Exotic plant species are those plants not present prior to European settlement. These species have invaded areas over time and have the ability to spread and invade an area. Fahnestock et al. (2003) found prairie dog towns harbored more exotic species such as field bindweed (*Convolvulus arvensis*), Russian thistle (*Salsola iberica*), and prickly lettuce (*Lactuca serriola*). The increase in the number of exotic species is likely due to the increase in bare ground, which can facilitate germination of these invasive plant species. However, even though there was an increase in the number of exotic species, they also found exotics were not dominant on the prairie dog towns (Fahnestock et al. 2003).

Under heavy continuous grazing pressure, changes occur in the plant population. One change is a tendency of the plant community to shift from a tall and mid-grass plant community to a more short-grass community. Another change is from being tall and erect in lightly grazed areas to being short and more prostrate in these more heavily grazed areas (Gregor and Sansome 1926, Kemp 1937, Hickley 1961). These shorter and more prostrate forms have a tendency to produce more tillers as a response to grazing. The differences between the shorter more prostrate plant populations and the taller more erect populations can be the result of plastic responses to grazing; where if the grazing was to be removed then the shorter prostrate plants will once again start growing taller and more erect (Quinn and Miller 1967). However, sometimes these differences can be genetic differences after many growing seasons, with the shorter more prostrate plants remaining. After two growing seasons in a greenhouse western wheatgrass (*Pascopyrum smithii*) from a prairie dog town maintained the short prostrate growth form and more tillers due to the heavy grazing compared to the grass phenotypes collected off of the prairie dog town remaining taller and more erect, with fewer tillers (Detling and Painter, 1983). This finding suggests the two populations of western wheatgrass were distinct.

A good proportion of the net primary production is found belowground in grassland systems (Sims and Singh 1978). Since the belowground rooting system is usually the means in which plants acquire nutrients, any disruption in the soil profile will influence aboveground plant dynamics. With the burrowing activities of the prairie dog, as well as any clipping of belowground plant materials, there is an impact in nutrient flow to aboveground biomass. This limited flow further restricts the amount of aboveground production (Sims and Singh 1978).

Prairie dogs can also influence the forage quality and plant nutrient content of vegetation. In ungrazed rangeland the shoot nitrogen content usually decreases as plants age and mature (Kamstra 1973, Kilcher 1981). Plant percent digestible dry matter follows a similar trend as plants age and mature (Burzlaff 1971). When grazing is introduced, both shoot nitrogen content and percent digestible dry matter can increase (Jameson 1964, Kamstra et al. 1968). The same pattern holds true in prairie dog towns (Coppock et al. 1983), where plants tended to be more digestible and have increased shoot-nitrogen concentrations than areas off town. The intense grazing of prairie dogs maintains plants with younger leaves resulting in lower carbon: nitrogen ratio of aboveground biomass. Prairie dog herbivory does not alter the neutral detergent fiber or acid detergent fiber when compared to areas that are not colonized by prairie dogs (Johnson-Nistler et al. 2004). Furthermore, prairie dog activity did not reduce hemicellulose, cellulose, or lignin fractions within plant communities compared to plant communities not grazed by prairie dogs (Johnson-Nistler et al. 2004).

Some animal species favor the habitat created on prairie dog towns due to the increased plant digestibility and nitrogen availability found in the vegetation. Ungulates such as bison (*Bison bison*), elk (*Cervus canadensis*), and pronghorn (*Antilocapra americana*) preferentially graze on prairie dog towns (Coppock et al. 1983b, Wydeven and Dahlgren 1985, Krueger 1986). Coppock et al. (1983b) observed bison spend approximately 40% of their time on prairie dog towns, with the immature grass parts of the town most utilized for grazing.

Soils

A key component of rangelands is soils. Soils not only provide a physical medium for vegetation, they also provide water and nutrients for plants to grow. Likewise, vegetation plays an important role in soil development. Vegetation cover promotes water infiltration (Brady and Weil 2008) and decreases runoff and soil erosion (Holechek et al. 2004). With the grazing habits of black-tailed prairie dogs, there may be less vegetation to intercept precipitation, which could lead to increased runoff.

The process of mineralization makes nutrients available for use by plants (Schaetzl and Anderson 2007). Nitrogen mineralization rates were found to be higher on areas affected by prairie dogs compared to areas without prairie dogs (Holland and Detling 1990, Fahnestock and Detling 2002). Higher nitrogen mineralization rates may have been the result of both increased inputs of nitrogen and increased nitrogen availability (Fahnestock and Detling 2002), with increased inputs from urine and fecal material and greater nitrogen availability resulting from the growth of plants with a low C:N ratio in aboveground biomass (Fahnestock and Detling 2002).

Prairie dogs can also affect rangeland due to their burrowing activities. When prairie dogs make burrows and keep them intact, they are constantly mixing the soil. Soil mixing occurs as prairie dogs excavate soil from lower horizons and deposit it on the surface and as a result of soil falling into the burrows from the burrow opening. Soils from deeper depths usually have different properties than soil found at the surface. Carlson and White (1988) found soil colors on the mound were lighter than soils away from the mound. This change in color was due to the lighter colored soil from deeper in the soil profile being brought to the surface and mixed with darker surface soils. They also found soil texture was more variable on mound soils due to the placing of below ground soils.

Inversion of soil horizons by prairie dogs may also influence soil pH. Soil pH at the surface close to the burrow has been found to be higher than areas not on the mound (Carlson and White 1987, Carlson and White 1988). Higher pH was a result of the soil parent material, which was calcareous and naturally high in pH, brought to the surface and deposited, then mixed with non-calcareous surface soils. As the distance increased from the mound, pH gradually decreased as the effect of the soil mixing dissipated. As the age of the prairie dog burrow increased, a decrease in soil pH occured due to the leaching of carbonates from the mixed soil and acidification from nitrification and mineralization (Carlson and White 1988).

Prairie dogs can also affect soil nitrogen and phosphorus as a result of their burrowing activities. Nitrogen was found to be less on the surface of the soils near prairie dog mounds; however, nitrogen content was similar throughout the soil profile (Carlson and White 1987). Soil phosphorus levels were higher on the mound compared to adjacent off-mound soils, and decreased with increasing distance from the hole (Carlson and White 1988). Increased soil phosphorus on prairie dog mounds was attributed to the accumulation of fecal material and bones. These materials are rich in phosphorus and are usually deposited near the mound surface or in the burrow, where they can be brought to the soil surface over time.

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CHAPTER 2. EFFECT OF PRAIRIE DOG (*CYNOMYS LUDOVICIANUS*) COLONIZATION ON THE PHYSICAL AND CHEMICAL PROPERTIES OF SELECTED SOILS IN THE NORTHERN GREAT PLAINS

Abstract

Vegetation and soils were evaluated for three soil series on a black-tailed prairie dog (*Cynomys ludovicianus*) colony and adjacent non-disturbed mixed-grass prairie in north central South Dakota. The objectives of this study were to evaluate 1) attributes of plant species diversity and richness, and 2) selected soil quality parameters between prairie dog colonies and non-prairie dog disturbed sites. Three soil series evaluated were a deep clayey (Opal), shallow loamy (Cabba), and shallow clayey (Wayden) ecological sites. Vegetation was clipped by species to evaluate species richness and diversity in 2010 and 2011. Soils on the prairie dog town were collected in depth increments of 0-10, 10-20, 20-30, 30-60, and 60-100 cm increments at distances of 30, 60, and 120 cm from the center of prairie dog burrows and compared to soils on adjacent non-disturbed sites in 2010. Plant species richness was higher on the control in 2010 on the Opal soil series, while richness was higher on the prairie dog town on the Cabba soil series. Species diversity was higher on the control on the Opal soil series in both 2010 and 2011 and the Wayden soil series in 2010. On the Opal soil series, pH was higher on the control near the soil surface at 30 and 60 cm from the hole center, while on the Cabba soil series pH was higher on the control in the middle depths at 30, 60, and 120 cm from the hole center. Soil nitrate levels were higher on the prairie dog town on the Opal and Wayden soil series near the soil surface at 30 and 60 cm from the hole center, while on the Cabba soil series soil nitrate was higher on the prairie dog town at the 120 cm distance from the hole center. Total nitrogen was

higher on the prairie dog town on the Cabba soil series deeper in the soil profile 30 and 60 cm from the hole center. Findings from this study suggest prairie dog affects on soil properties will differ based on inherent soil attributes within ecological sites.

Introduction

Black-tailed prairie dogs (*Cynomys ludovicianus*) historically occupied 40 million ha of short and mixed-grass prairie in the Great Plains (Hoogland 1995), from northern Mexico to Southern Canada and from the Rocky Mountain foothills east to the tall grass prairies (Nelson 1919). However, over the past century the prairie dog population has decreased to a point where they occur on about two percent of their original range, and in the Northern Great Plains this covers approximately 2,378 km^2 (Sidle et al. 2001). Reasons for this decline are attributed to loss of habitat, eradication programs, and disease such as the plague (Cully and Williams 2001).

Black-tailed prairie dogs can have a major impact on ecosystems. The impact prairie dogs have on an ecosystem can also affect how other wildlife species utilize prairie dog towns. Coppock et al. (1983a) observed higher nitrogen and *in vitro* dry matter digestibility on prairie dog towns as opposed to adjacent no-colonized areas. These increases in nutrition quality attracted wild ungulates to actively select prairie dog towns for grazing (Coppock et al. 1983b). Agnew et al. (1986) found bird and small mammal densities higher on prairie dog towns than the associated no prairie dog town areas.

One major impact prairie dogs have on an ecosystem is they alter the vegetative communities. Prairie dogs will continuously fell the vegetation located within their town as a defensive measure (King 1955) as well as a food source. Since prairie dogs preferentially select graminoids as a food source (Hanson and Gold 1977), there tends to be a shift in the vegetative community from graminoids to forbs (Coppock et al. 1983a). Along with this shift in the vegetative community there is an increase in plant species diversity and richness in the community of younger prairie dog towns; however, as the dog town ages the plant species diversity and richness decline to pre-colonized levels (Archer et al. 1987). The amount of litter and bare ground present on the prairie dog town also follow this trend. As a prairie dog town ages the amount of litter present decreases and amount of bare ground increases. This increase in bare ground can influence the amount of water runoff and amount of water infiltrating into the soil.

Prairie dogs also impact the ecosystem from their burrowing activities. These impacts can have an effect on both the vegetation and soil properties. They can influence vegetation through their clipping of belowground roots and stems. Impacts in the soil include increasing soil pH and phosphorus, while decreasing soil nitrogen (Carlson and White 1987, Carlson and White 1988).

There is an abundance of information on the impacts prairie dogs have on the vegetation community; however, there is a lack of information on the impacts of the associated soils, especially at different depths. The objectives of this study were determine 1) differences in plant species diversity and richness and 2) selected soil quality parameters between prairie dog colonies and non-prairie dog disturbed sites.

Study Area

Location and Land Use

The study was conducted 16 km southeast of McLaughlin, South Dakota on the Standing Rock Indian Reservation in Corson County. The study area is approximately

1400 hectares of both private land and leased tribal land. The ranch has been under current management since the early 1940's. Historically, there were approximately 300 head of cattle and 100 head of horses that grazed the land. However, cattle have been absent since 2009 with ranch currently grazed by approximately 90 head of horses. The prairie dog population on this land occupied two small towns comprising six to eight hectares in the early 1950's. The prairie dog population gradually increased on both of the towns starting in 1985. Currently, prairie dogs occupy over 800 hectares of the ranch.

Climate

The study area is characterized by a continental semi-arid climate, with hot summers and cold winters (Heil 1995). The 30-year mean annual precipitation for McLaughlin, SD is 455 mm, with 83% of the precipitation occurring from April through October (ACIS, 2012). The peak precipitation months are May through August, with 58% of the annual precipitation occurring during this period. The mean annual temperature is 6.5°C.

Temperatures were similar to the 30-year mean in 2010, with the exception of February and December which was slightly lower than average (Table 2.1; ACIS, 2012). Greater precipitation was received at the study site in 2010 compared to the 30-year average. The winter months of January and December, as well as September, were wetter than normal and October and November drier than normal (Table 2.2).

Table 2.1. Mean monthly[1] temperature (°C) for McLaughlin, South Dakota for 2010 and the 30-year mean (ACIS 2012).

Month	Mean Temperature	30 Year Mean Monthly Temperature
January	-12.0	-10.1
February	-12.8	-7.0
March	0.6	-1.4
April	9.1	6.5
May	11.2	13.1
June	18.8	18.5
July	21.9	22.2
August	22.3	21.2
September	13.5	15.1
October	9.4	7.7
November	-2.1	-0.9
December	-11.1	-8.1
Average	**5.7**	**6.4**

[1] The mean monthly temperature determined using mean daily temperatures.

Table 2.2. Monthly precipitation (mm) for McLaughlin, South Dakota for 2010 and the 30-year mean (ACIS 2012).

Month	Monthly Mean	30 Year Mean
January	21.3	11.8
February	7.4	13
March	11.7	26
April	76.5	41.6
May	93.0	72.3
June	52.8	81.1
July	63.5	55.9
August	43.9	54.5
September	78.7	34.6
October	5.3	36.6
November	8.6	13.1
December	30.5	14.1
Total	**493.2**	**454.6**

Vegetation

Three soil series (Opal, Cabba, and Wayden) were selected for this study, each supporting a different plant community. The Opal soil series was classified as a clayey ecological site with a current plant community of western wheatgrass (*Pascopyrum* *smithii*), blue grama (*Bouteloua gracilis*), sedges (*Carex* Spp.), fringed sagewort (*Artemisia frigida*), and prostrate knotweed (*Polygonum aviculare*) on both the prairie dog town (PDT) and Control sites (off the prairie dog town). The clayey ecological site had a historic climax plant community (HCPC) of green needlegrass (Nassella *viridula*) and western wheatgrass. Under heavy, continuous season-long grazing the green needlegrass decrease and blue grama and buffalograss (*Buchloe dactyloides*) increase (USDA-NRCS 2012d).

The Cabba soil series was classified as a shallow loamy ecological site with a current plant community of western wheatgrass, prairie junegrass (*Koeleria macrantha*), blue grama, sedges, fringed sagewort, and dandelion (*Taraxacum officinale*) on the Control site. On the PDT, the plant community comprised of western wheatgrass, blue grama, green needlegrass, sedges, fringed sagewort, deervetch (*Lotus unifoliolatus*), and sweetclover (*Melilotus spp.*). The HCPC for the shallow loamy ecological site was western wheatgrass, needlegrass, and plains muhly (*Muhlenbergia cuspidata*) (USDA-NRCS 2012f).

The Wayden soil series was classified as a shallow clayey ecological site with a current plant community of western wheatgrass, prairie junegrass, blue grama, needle and thread (*Hesperostipa comata*), green needlegrass, Kentucky bluegrass (*Poa pratensis*), yellow coneflower (*Ratibida columnifera*), deervetch, curlycup gumweed (*Grindelia squarrosa*), silverleaf scurfpea (*Pediomelum argophylla*), and Indian breadroot (*Pediomelum esculenta*) on the Control site. The dominant species were western wheatgrass, blue grama, deervetch, wooly plantain (*Plantago patagonica*), fetid marigold (*Dyssodia papposa*), and woodsorrel (*Oxalis corniculata*) on the PDT. The HCPC for the shallow clayey ecological site was western wheatgrass and warm season mid grasses (USDA-NRCS 2012e).

Soils

Opal soils are classified as fine, smectitic, mesic Leptic Haplusterts (USDA-NRCS 2012h). This soil series is found primarily in central South Dakota, mostly west of the Missouri River. Opal soils are moderately deep, fine clays found on gently sloping terrains with a 0-25% slope formed from clayey residuum derived from shale parent material. This soil series is well-drained with medium to very high runoff, depending on the slope, and very slow permeability; however, after periods of drought, permeability may be rapid due to large cracks in the soil. Opal soils are found on the backslope, with the down slope shape linear and the across slope shape convex to linear (USDA-NRCS 2012b).

The typical pedon for this soil series contains the following horizons: A, Bss1, Bss2, Bkss, Cyz1, Cyz2, Cr1, and Cr2 (USDA-NRCS 2012h). The A horizon is five cm thick and grayish brown clay, with moderate medium and fine granular structure. There are many fine and medium sized roots found in this horizon. The Bss1 horizon is about 20 cm thick and grayish brown clay. The structure of this horizon is moderate medium and coarse subangular blocky. There are many fine and medium roots associated with this horizon. A characteristic of this horizon is the presence of nonintersecting slickensides, with cracks 1.25 cm wide. There are 1% pebbles present and a slight effervescence, indicating carbonates present. The Bss2 horizon is 15 cm thick and grayish brown clay. There is weak coarse prismatic structure that is parting to moderate medium and coarse subangular blocky structure. Fine and medium roots are common, but there are less than the above horizons. There are many prominent intersecting slickensides with cracks 2.5

cm wide and a strong effervescence. The Bkss horizon is 25 cm thick and light brownish gray color. The structure is weak coarse prismatic structure parting to moderate medium and coarse subangular blocky structure. There are few fine sized roots. Many prominent intersecting slickensides are present with cracks in the soil 1.25 to 2.5 cm thick. There are many fine and medium accumulations of carbonate and the soil has strong effervescence (USDA-NRCS 2012h).

The Cyz1 and Cyz2 horizons are 12 cm thick and light brownish gray, with many fine yellowish brown mottles present. There are many fine and medium nests of gypsum and other salts. The Cr1 and Cr2 horizons are 63 cm thick and light brownish gray and dark gray soft shale present. There are fine prominent strong brown mottles present. These horizons also have many yellowish brown iron stains in cracks and seams. The Cr1 horizon has many fine nests of gypsum and other salts, while the Cr2 horizon only has few fine nests of salts (USDA-NRCS 2012h).

Opal soils are used both as cropland and rangeland (USDA-NRCS 2012h). The dominant range species for this soil series are western wheatgrass, green needlegrass, blue grama, sideoats grama (*Bouteloua curtipendula*), and sedges. The land capability class for this soil series is 3e, meaning it is suitable for cropping and the dominant limitations are wind and water erosion (USDA-NRCS 2012b). Other soils associated with the Opal soils are the Bullcreek, Chantier, Dupree, Hurley, Labu, Lakoma, Promise, and Sansarc soils (USDA-NRCS 2012h).

Cabba soils are classified as loamy, mixed, superactive, calcareous, frigid, shallow Typic Ustorthents (USDA-NRCS 2012g). This soil series is found in western North Dakota, central and eastern Montana, and northwestern South Dakota. These are shallow loams found on terrains with a slope of 3-60%, and is derived from loamy residuum derived from sedimentary rock parent material. The Cabba soil is well-drained, moderately permeable with a slow to fast runoff depending on the slope. These soils are found on backslopes and shoulders of hills. The downslope shape is convex and the across slope shape is convex and linear (USDA-NRCS 2012a).

The typical Cabba series pedon consists of the following horizons: A, Bk1, Bk2, and Cr (USDA-NRCS 2012g). The A horizon is 7.5 cm thick and grayish brown loam. The structure is moderate fine granular. There are many very fine and fine roots in this horizon. The horizon is slightly effervescent and slightly alkaline. The Bk1 horizon is 13 cm thick and light brownish gray loam. It has weak fine and medium subangular blocky structure. There are many very fine and fine roots, with many very fine pores present. This horizon is strongly effervescent and slightly alkaline. The Bk2 horizon is 18 cm thick and pale brown clay loam. Very fine and fine roots are common as well as very fine pores. There is strong effervescence in this horizon and it is moderately alkaline. The Cr horizon is 114 cm thick and pale brown. There are a few very fine and fine roots, mainly in the upper part and in vertical cracks. This horizon is strongly effervescent and moderately alkaline (USDA-NRCS 2012g).

Cabba soils are mainly found in rangeland (USDA-NRCS 2012g). The dominant species for this soil series are little bluestem (*Schizachyrium scoparium*), western wheatgrass, needle and thread, prairie sandreed (*Calamovilfa longifolia*), bluebunch wheatgrass (*Pseudoroegneria spicata*), green needlegrass, plains muhly, forbs and shrubs. The land capability class for this soil is 7e, meaning this soil is not ideal for cropland but suitable as rangeland (USDA-NRCS 2012a). A limitation on this soil is water erosion (USDA-NRCS 2012g).

Wayden soils are classified as clayey, smectitic, calcareous, frigid, shallow Typic Ustorthents (USDA-NRCS 2012i). They are found in eastern and northern Montana, western North Dakota, north central Wyoming, and northwestern South Dakota. This soil series is found on sites with 6-40% slope and formed from parent material that is clayey residuum weathered from shale. This soil series is well-drained with slow permeability and slow to rapid runoff, depending on slope. These soils are found on shoulder, backslopes, and summits of hills. The down slope shape is convex and the across slope shape is either linear or convex (USDA-NRCS 2012c).

The typical pedon of the Wayden soil series contains the following horizons: A, Bk, By, and Cr (USDA-NRCS 2012i). The A horizon is 7.5 cm thick and light gray silty clay. The structure is strong, very fine granular. There are many fine and very fine roots. This horizon is slightly effervescent and moderately alkaline. The Bk horizon is 10 cm thick and light gray silty clay. It is a moderate coarse and medium subangular blocky structure parting to a moderate fine subangular blocky. Fine and very fine roots are common with fine pores. This horizon is slightly alkaline with strong effervescence. The By horizon is 20 cm thick and light gray silty clay. The structure is weak coarse, subangular blocky parting to moderate fine subangular blocky. There are fine and very fine roots common in this horizon as well as many gypsum crystals present. This horizon has slight effervescence and moderately alkaline. The Ct horizon is 114 cm thick and olive silty clay shale with yellowish brown moist stains on plates. It is extremely hard and very fine and slakes in water. It has a slight effervescence and moderately alkaline (USDA-NRCS 2012i).

The Wayden soil series is mainly used as rangeland however some areas with gentle slopes can support small grain crops (USDA-NRCS 2012i). The predominant species found on rangeland sites include: western wheatgrass, little bluestem, needle and thread, forbs and shrubs. The land capability class for this soil is 7e, meaning it is not well suited for cropland and the greatest limitation is wind erosion (USDA-NRCS 2012c). Soils associated with the Wayden series include: Amor, Belfield, Bradenburg, Cabba, Flasher, Moreau, Morton, Regeant, Rhodes, Ringling, Sen and Vebar (USDA-NRCS 2012i).

Methods

Three soil series were evaluated for the effects of black-tailed prairie dog colonies on soil physical and chemical properties. These soils were studied on the prairie dog towns (PDT) and off the prairie dog town (Control).

Vegetation Sampling

Vegetation was collected for each of the soil series in late July 2010 and 2011. Two 1/8 m^2 quadrats were sampled at four locations on both the Control and PDT for each soil series. On the PDT samples were collected 1 m from the center of the hole at two locations at opposite points from the center. Samples were randomly selected on the Control sites and collected in non-disturbed areas. The Control sites were adjacent to the PDT sites in the same soil series. Each quadrat was clipped by species and placed into individual labeled bags. Samples were oven dried at 55°C for 72 hours and then weighed.

Soil Sampling

Soil samples were collected at five locations on each of the soil series on the Control sites and four locations on the PDT sites. The five locations on the Control were randomly selected on the same soil series as the corresponding PDT sites. The four locations on the PDT were randomly selected within each soil series and corresponded with the center of mound hole created by prairie dogs.

Soil samples were collected from each soil series in July 2010. Samples were collected at the five locations of the Control to a 100 cm depth. The sampling depths on the PDT sites differed depending on the distance from the center of a mound hole. Samples were collected 30 and 60 cm from the hole center at a depth of 100 cm, while samples were collected to only a 30 cm depth 120 cm from the hole center. The depth increments for near-surface samples were 0 to 10, 10 to 20, and 20 to 30 cm, while 30 to 60 and 60 to 100 cm depth increments were collected 30 and 60 cm from the hole center. Soil cores were collected using a 3.5-cm (i.d.) Giddings hydraulic probe (Giddings Machine Co., Windsor, Colorado). Eight soil cores were collected from each of the 0 to 10, 10 to 20 and 20 to 30 cm depth increments and four soil cores at the 30 to 60 and 60 to 100 cm depth increments. Samples were saved in a double-lined plastic bag and placed in storage at 5°C until processed.

Whole samples were air dried in a greenhouse for a minimum of three days and mechanically ground to pass a 2 mm sieve. Identifiable plant material (>2.0 mm) was removed prior to grinding. Laboratory analyses conducted on the soil samples included electrical conductivity (EC), pH, extractable NO_3-N, extractable NH_4-N, available P, total N, organic and inorganic C, cation exchange capacity, and exchangeable cations: K, Na, Ca, and Mg. Electrical conductivity and pH were estimated from a 1:1 soil-water mixture (Watson and Brown 1998, Whitney 1998). Soil NO_3-N and NH_4-N were determined from 1:10 soil-KCl (2 *M*) extracts using cadmium reduction followed by a modified Griess-Ilosvay method and indophenol blue reaction (Mulvaney 1996). Plant-available soil P was estimated by bicarbonate extraction (Olson et al. 1954). Total soil C and N was determined by dry combustion on soil ground to pass a 0.106 mm sieve (Nelson and Sommers 1996). Using the same fine-ground soil, inorganic C was measured on soils with a pH ≥ 7.2 by quantifying the amount of CO_2 produced using a volumetric calcimeter after application of dilute HCl stabilized with $FeCl_2$ (Loeppert and Suarez 1996). Soil organic carbon (SOC) was calculated as the difference between total C and inorganic C. Exchangeable cations (Ca^{+2}, Mg^{+2}, K^{+}, and Na^{+}) were estimated by atomic absorption spectrometry with the sum taken to reflect cation exchange capacity (Sumner and Miller 1996). Where applicable, data were expressed volumetrically by depth using field measured soil bulk density (Blake and Hartge 1986).

Statistical Analysis

Species richness and Shannon diversity was calculated using PC ORD 5.10 (McCune and Mefford 2006). Microsoft Excel was used to calculate differences between samples collected on the PDT to those collected off the PDT using a two sampled t test. A $P \leq 0.05$ was considered significant.

Treatment and depth effects for soil properties bulk density, soil pH, nitrate, ammonium, phosphorus, cation exchange capacity, potassium, sodium, calcium, magnesium, electrical conductivity, total nitrogen, carbon to nitrogen ratio, and soil organic carbon were analyzed using a nested design with the depths being the nested effect. The PROC MIXED procedure (Version 9.2 of the SAS System for Windows, Copyright © 2002-2008 SAS Institute Inc.) was used for the statistical analysis. Means were compared using the LSMEANS procedure with the overall P-value adjusted by using the Tukey procedure. All of the data were transformed using a square root transformation to normalize the data and a $P \leq 0.05$ was considered significant.

Results

Vegetation

Plant species richness was higher ($P=0.04$) on the Control site (7) than PDT (4) on the Opal soil series in 2010 (Table 2.3). However, there were no difference ($P>0.05$) in plant species richness between the PDT and Control in 2011 (Table 2.3). Plant species diversity was higher ($P \leq 0.01$) on the Control site (1.306) than PDT (0.64) in 2010 (Table 2.3). Plant species diversity was also higher ($P=0.04$) on the Control (1.899) than PDT (1.384) in 2011.

There were no differences ($P>0.05$) found between the PDT and Control for plant species richness in 2011 or plant species diversity in 2010 and 2011 on the Cabba soil series (Table 2.3). Plant species richness was higher ($P \leq 0.01$) on the PDT (11) compared to the Control (7) in 2010.

There were no differences ($P>0.05$) found in plant species richness in 2010 and 2011, or plant species diversity on the Wayden soil series in 2011. Plant species diversity was higher ($P=0.03$) on the Control (1.790) than on PDT (1.164) in 2010 (Table 2.3).

Table 2.3. Species richness and diversity (Shannon) on the prairie dog town (PDT) and Control sites for the Opal, Cabba, and Wayden soil series near McLaughlin, SD, 2010 and 2011.

		Opal[1]		**Cabba**[1]		**Wayden**[1]	
Year	Treatment	Richness	Diversity	Richness	Diversity	Richness	Diversity
2010	Control	7^{a}	1.306^{a}	7^{a}	1.592	10	1.790^{a}
	PDT	4^{b}	0.638^{b}	11^{b}	1.565	7	1.164^{b}
2011	Control	12	1.899^{a}	14	2.023	19	2.321
	PDT	9	1.384^{b}	11	1.753	17	2.056

[1] Values within years with a different letter (a,b) differ at P≤ 0.05.

Soil Physical Properties

Soil bulk density was higher on the Control than the PDT at the 0-10 cm depth 30 cm (P≤0.01) and 60 cm (P≤0.01) away from the mound hole center on the Opal soil series (Figure 2.1). Soil bulk density was higher (P=0.04) on the Control than the PDT at the 20-30 cm depth 120 cm from the hole center on the Cabba soil series (Figure 2.2). There were no differences (P>0.05) in bulk density between Control and PDT for the Wayden soil series (Figure 2.3).

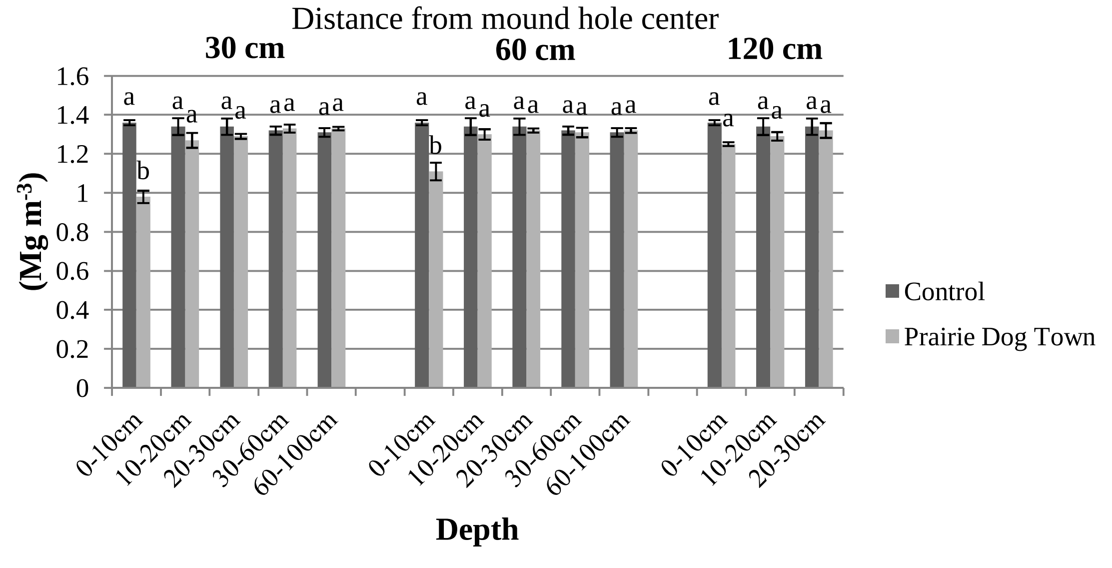

Figure 2.1. Soil bulk density (Mg m^{-3}; ± SE) by depth for each treatment for the Opal soil series at 30, 60, and 120 cm from the mound hole center near McLaughlin, SD, July 2010. Values within distance with the same letter (a,b) are not significantly different (P>0.05).

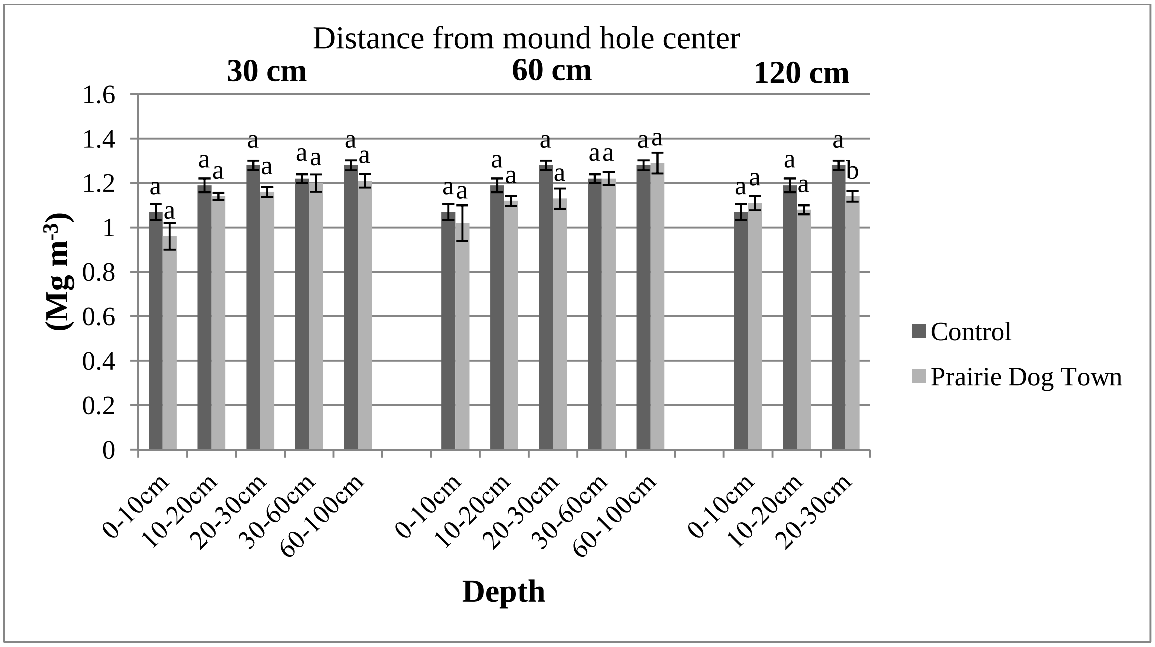

Figure 2.2. Soil bulk density (Mg m^{-3}; ± SE) by depth for each treatment for the Cabba soil series at 30, 60, and 120 cm from the mound hole center near McLaughlin, SD, July 2010. Values within distance with the same letter (a,b) are not significantly different (P>0.05).

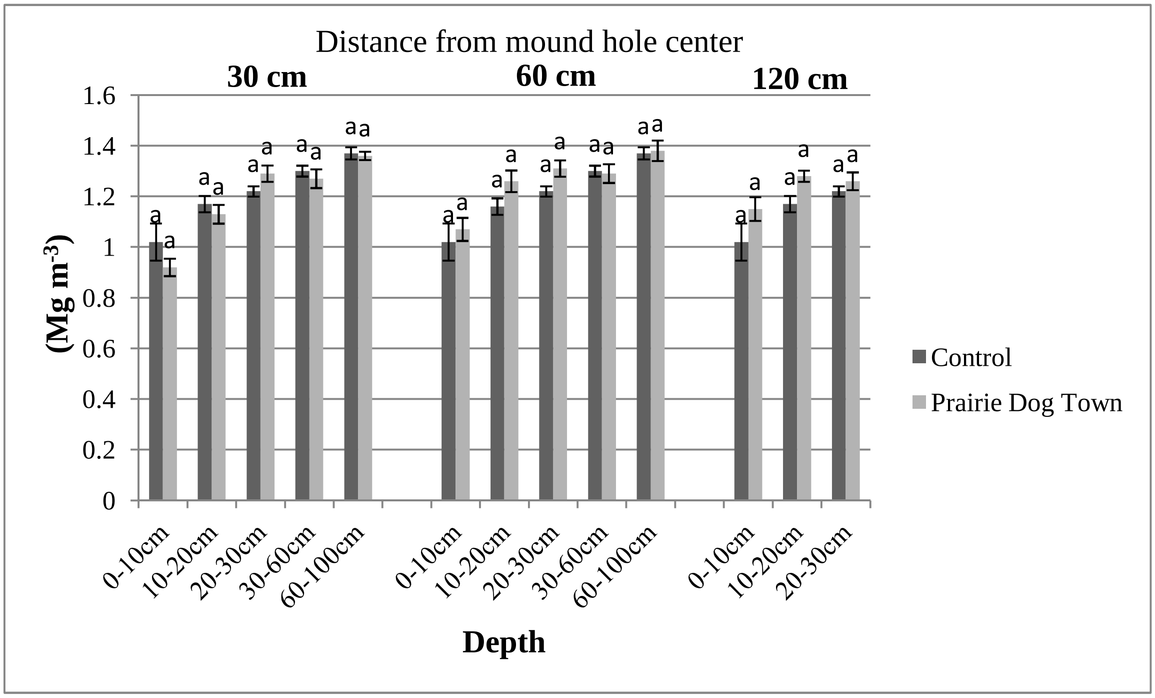

Figure 2.3. Soil bulk density (Mg m^{-3}; ± SE) by depth for each treatment for the Wayden soil series at 30, 60, and 120 cm from the mound hole center near McLaughlin, SD, July 2010. Values within distance with the same letter (a,b) are not significantly different (P>0.05).

Soil Chemical Properties

Opal Soil Series

Soil pH was higher on the Control at the 0-10 cm depth, 30 cm ($P \leq 0.01$) and 60 cm ($P \leq 0.01$) from the mound hole center; at the 10-20 cm depth, 30 cm ($P=0.01$) from the center of the mound hole; at the 30-60 cm depth, 60 cm ($P=0.01$) distance from the mound hole center; and at the 60-100 cm depth, 30 cm ($P \leq 0.01$) and 60 cm ($P \leq 0.01$) from the mound hole center compared to the PDT (Figure 2.4). Electrical conductivity was higher ($P=0.04$) on the Control site compared to PDT at the 10-20 cm depth, 120 cm from the hole center (Figure 2.5). Soil NO_3-N was higher on the PDT at the 0-10 cm depth, 30 cm ($P \leq 0.01$) and 60 cm ($P=0.01$) away from the mound hole center; and at the 10-20 cm depth, 30 cm ($P=0.02$) away from the mound hole (Figure 2.6). Soil NH_4-N was higher on the PDT than the Control at the 0-10 cm depth, 30 cm ($P \leq 0.01$) and 60 cm ($P \leq 0.01$) away from the mound hole center (Figure 2.7). Available phosphorus was higher on the PDT than the Control at the 0-10 cm depth, 30 cm ($P \leq 0.01$) and 60 cm ($P=0.04$) away from the mound hole center (Figure 2.8). There were no differences ($P>0.05$) in total nitrogen (Figure 2.9) and C:N ratio for all depths and at all distances away from the mound hole center (Figure 2.10).

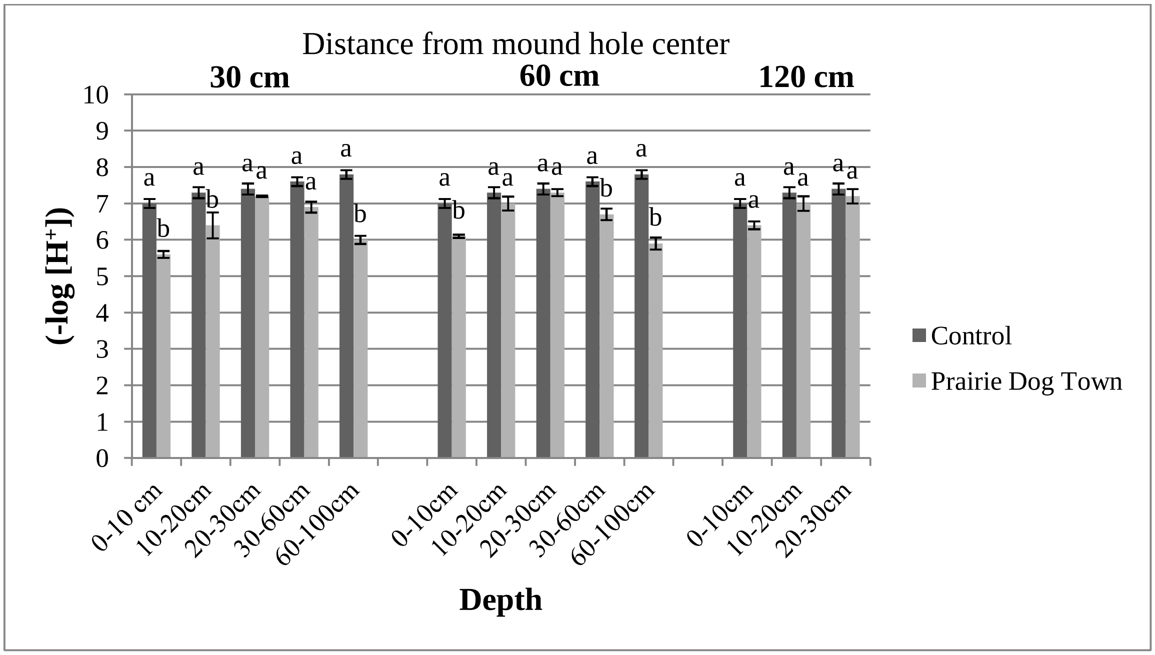

Figure 2.4. Soil pH (-log [H^+]; ± SE) by depth for each treatment for the Opal soil series at 30, 60, and 120 cm from the mound hole center near McLaughlin, SD, July 2010. Values within distance with the same letter (a,b) are not significantly different (P>0.05).

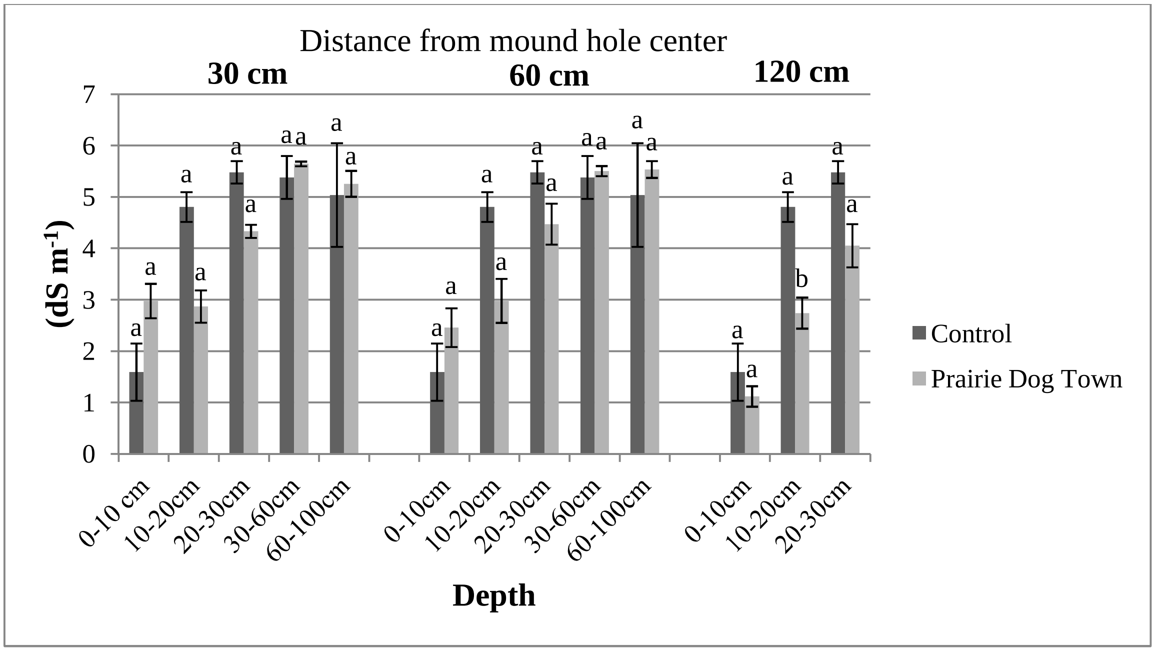

Figure 2.5. Electrical conductivity (dS m^{-1} ± SE) by depth for each treatment for the Opal soil series at 30, 60, and 120 cm from the mound hole center near McLaughlin, SD, July 2010. Values within distance with the same letter (a,b) are not significantly different (P>0.05).

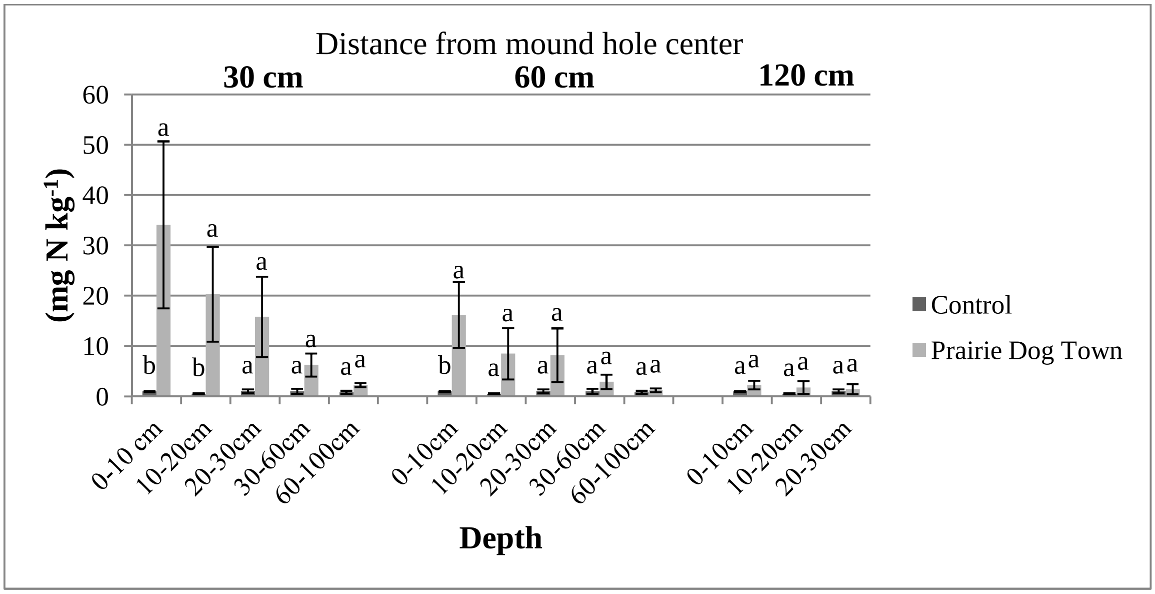

Figure 2.6. Soil NO_3-N (mg N kg^{-1}± SE) concentration by depth for each treatment for the Opal soil series at 30, 60, and 120 cm from the mound hole center near McLaughlin, SD, July 2010. Values within distance with the same letter (a,b) are not significantly different (P>0.05).

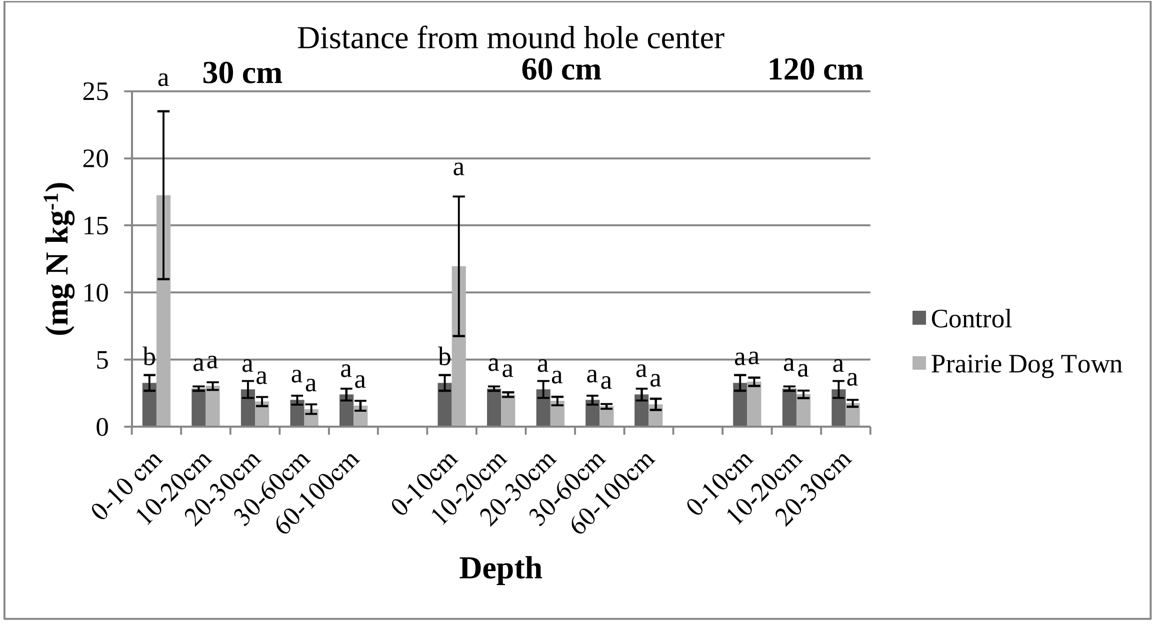

Figure 2.7. Soil NH_4-N (mg N kg^{-1}± SE) concentration by depth for each treatment for the Opal soil series at 30, 60, and 120 cm from the mound hole center near McLaughlin, SD, July 2010. Values within distance with the same letter (a,b) are not significantly different (P>0.05).

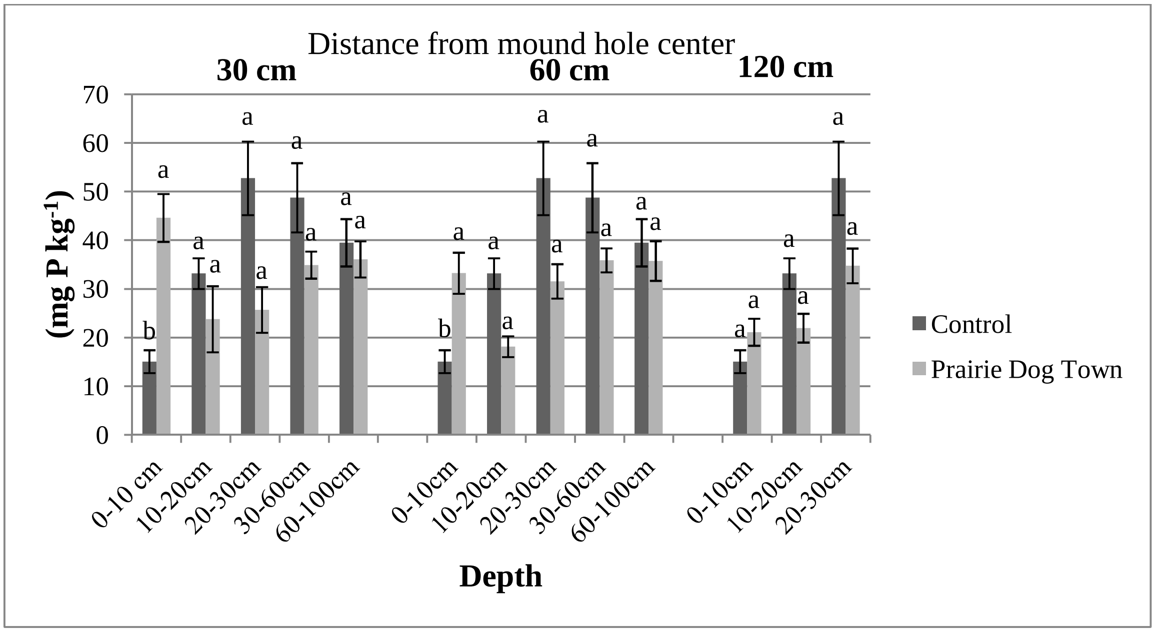

Figure 2.8. Available P (mg P kg^{-1}± SE) concentration by depth for each treatment for the Opal soil series at 30, 60, and 120 cm from the mound hole center near McLaughlin, SD, July 2010. Values within distance with the same letter (a,b) are not significantly different (P>0.05).

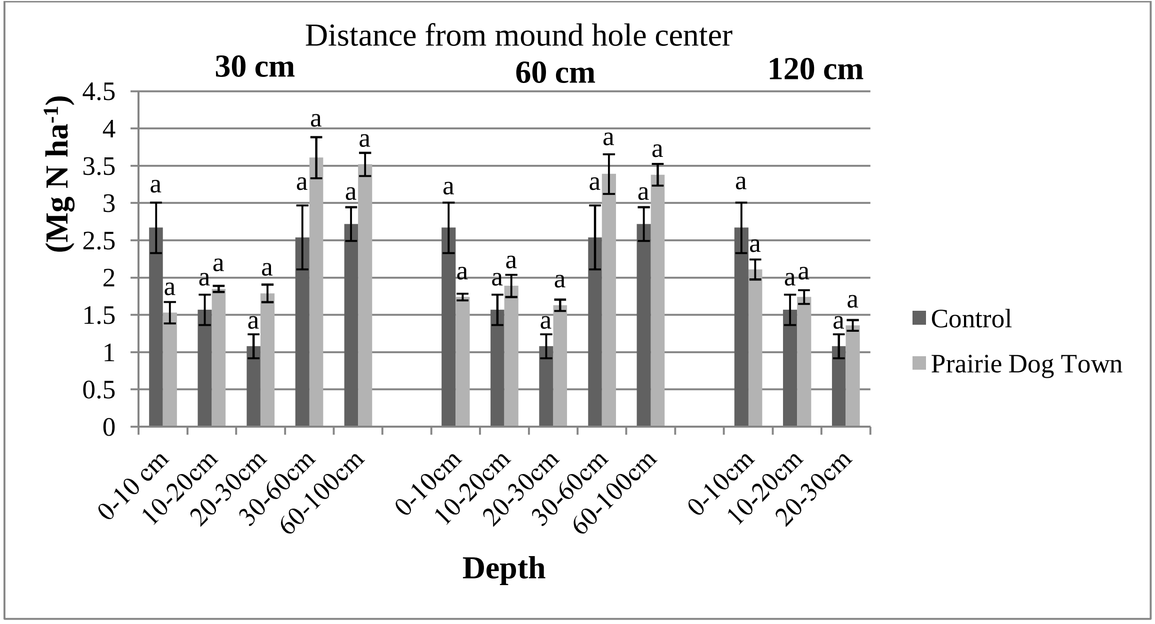

Figure 2.9. Total nitrogen (Mg N ha^{-1}; ± SE) concentration by depths for each treatment for the Opal soil series at 30, 60, and 120 cm from the mound hole center near McLaughlin, SD, July 2010. Values within distance with the same letter (a,b) are not significantly different (P>0.05).

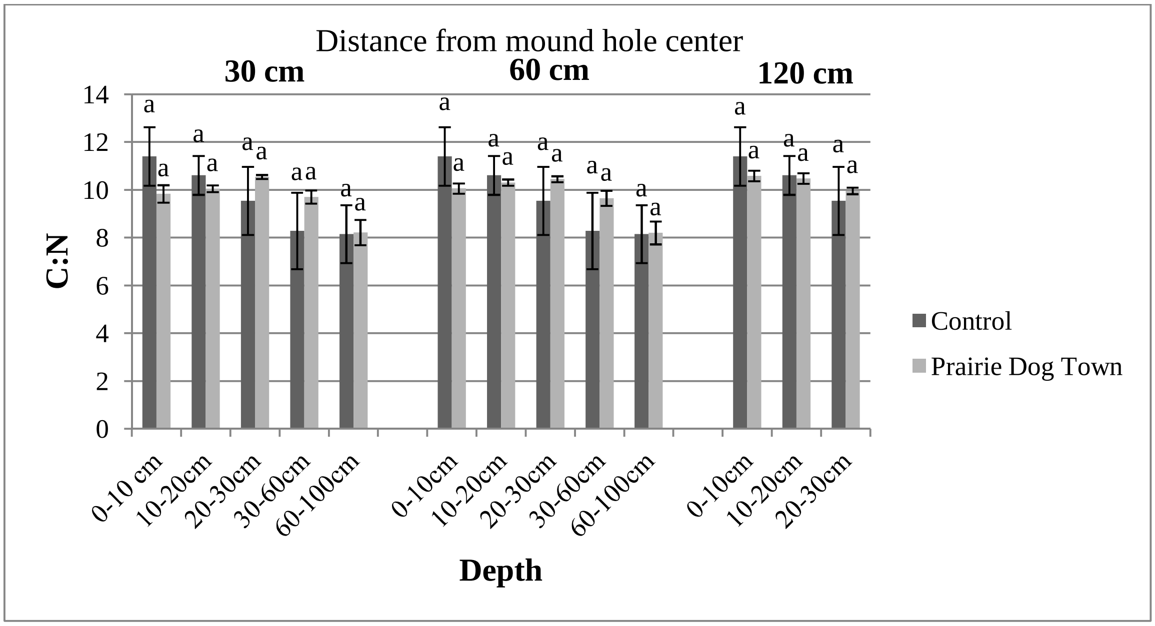

Figure 2.10. Carbon to nitrogen (C:N) ratio (± SE) by depth for each treatment for the Opal soil series at 30, 60, and 120 cm from the mound hole center near McLaughlin, SD, July 2010. Values within distance with the same letter (a,b) are not significantly different (P>0.05).

Cation exchange capacity (CEC) was higher on the Control site at the 10-20 cm depth, 60 cm (P≤0.01) from the mound hole center; at the 20-30 cm depths, 30 cm (P≤0.01), 60 cm (P≤0.01), and 120 cm (P≤0.01) away from the mound hole center; and at the 60-100 cm depth, 60 cm (P=0.04) away from the mound hole center (Figure 2.11). No differences (P>0.05) occurred in the exchangeable potassium (Figure 2.12) at all depths and distances from the mound hole center. Exchangeable sodium was higher (P<0.05) on the Control site for all depths at each distance from the mound hole center (Figure 2.13). Exchangeable calcium was higher (P= 0.04) on the PDT 30 cm from the mound hole center at the 0-10 cm depth compared to the Control (Figure 2.14). However, at the 10-20 cm depth, 30 cm (P=0.02), 60 cm (P=0.01), and 120 cm (P=0.02) away from the hole center, exchangeable calcium was higher on the Control compared to the PDT (Figure

2.14). The same was true at the 20-30 depth, 30 cm (P≤0.01), 60 cm (P≤0.01), and 120 cm (P≤0.01) distance from the hole center and at the 60-100 cm depth at 30 cm (P=0.01) and 60 cm (P=0.02) from the mound hole (Figure 2.14). There were no differences (P>0.05) in exchangeable magnesium for any depth or distance from the hole center (Figure 2.15).

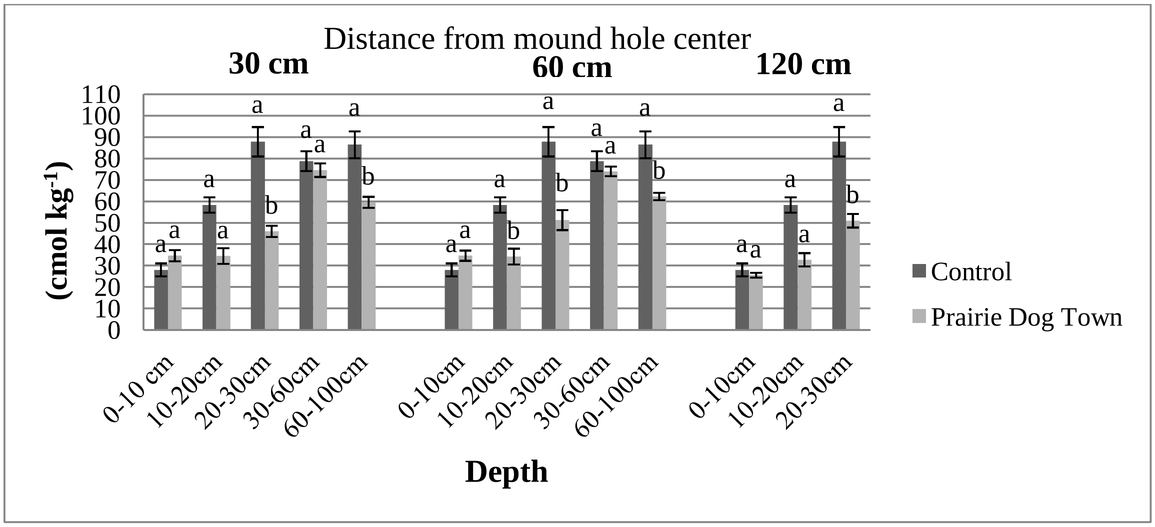

Figure 2.11. Cation exchange capacity (cmol kg^{-1}; ± SE) by depth for each treatment for the Opal soil series at 30, 60, and 120 cm from the mound hole center near McLaughlin, SD, July 2010. Values within distance with the same letter (a,b) are not significantly different (P>0.05).

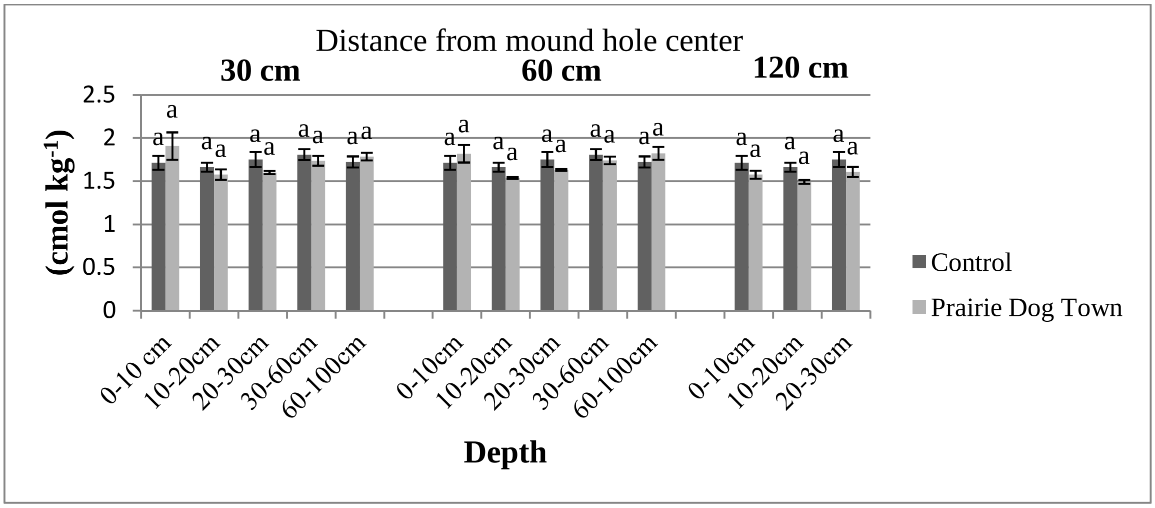

Figure 2.12. Exchangeable potassium (cmol kg^{-1}; ± SE) concentration by depth for each treatment for the Opal soil series at 30, 60, and 120 cm from the mound hole center near McLaughlin, SD, July 2010. Values within distance with the same letter (a,b) are not significantly different (P>0.05).

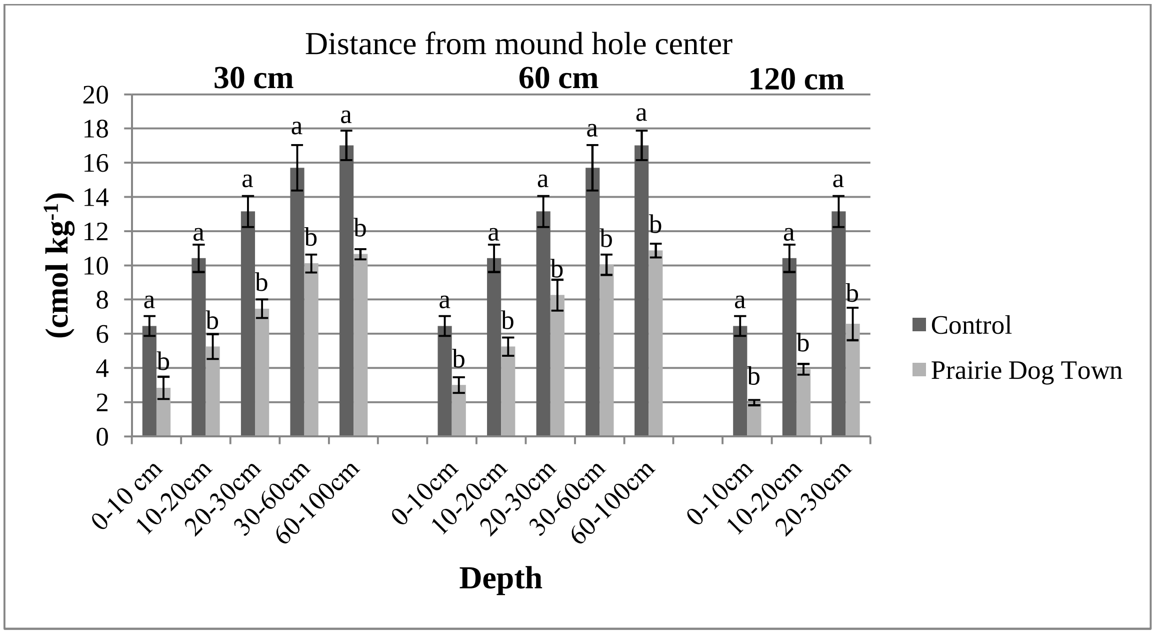

Figure 2.13. Exchangeable sodium (cmol kg^{-1}; ± SE) concentration by depth for each treatment for the Opal soil series at 30, 60, and 120 cm from the mound hole center near McLaughlin, SD, July 2010. Values within distance with the same letter (a,b) are not significantly different (P>0.05).

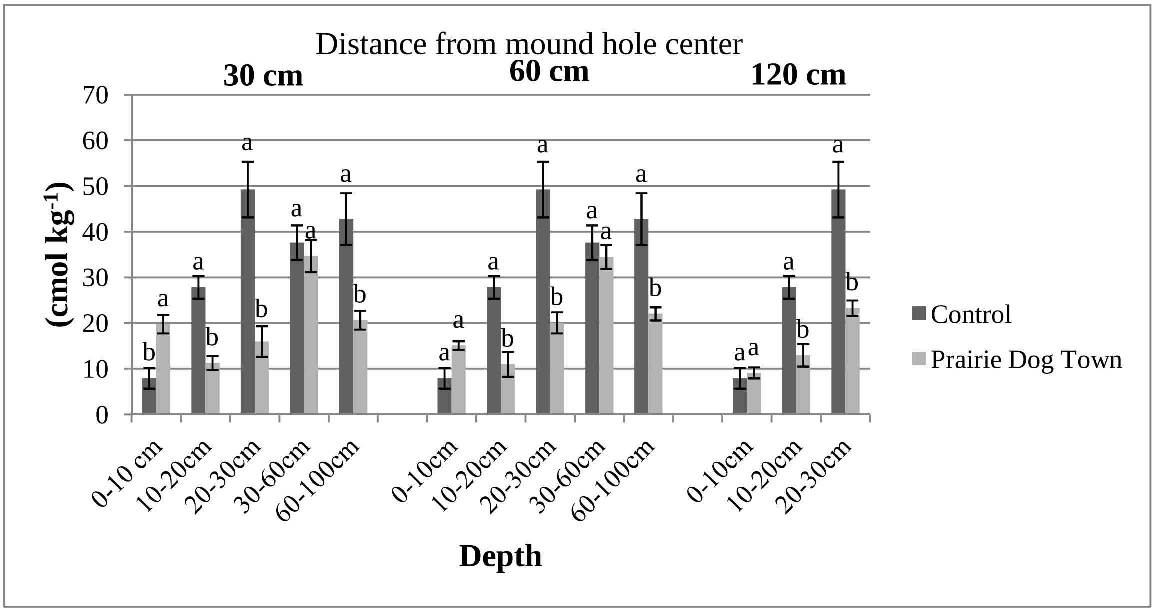

Figure 2.14. Exchangeable calcium (cmol kg^{-1}; ± SE) concentration by depth for each treatment for the Opal soil series at 30, 60, and 120 cm from the mound hole center near McLaughlin, SD, July 2010. Values within distance with the same letter (a,b) are not significantly different (P>0.05).

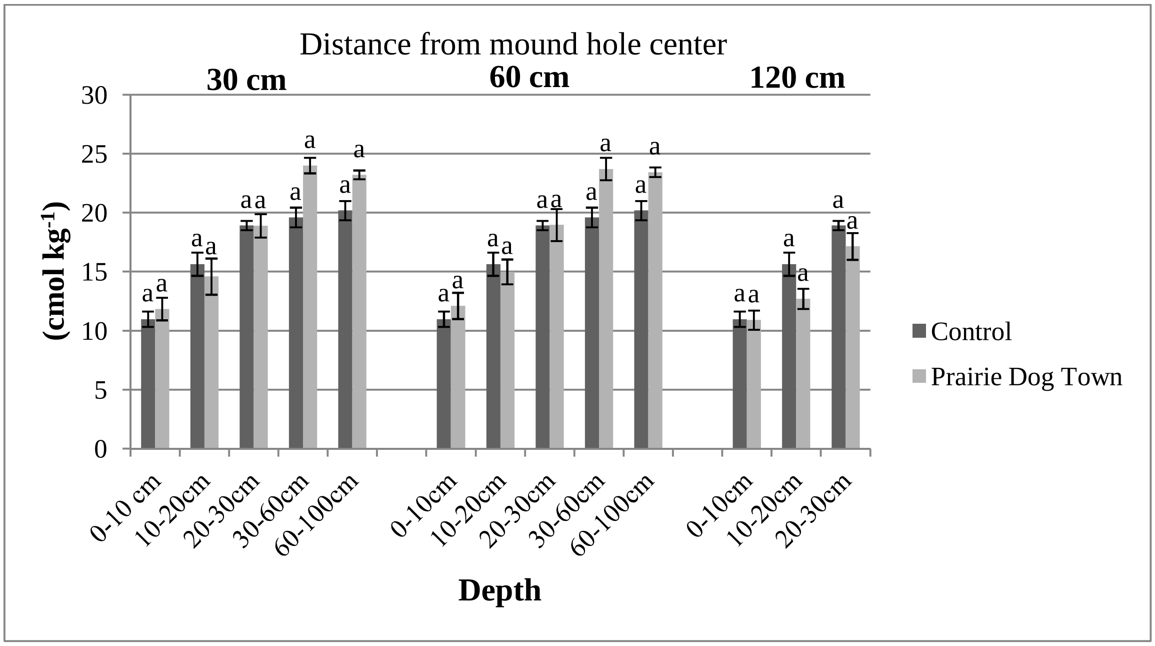

Figure 2.15. Exchangeable magnesium (cmol kg^{-1}; ± SE) concentration by depths for each treatment for the Opal soil series at 30, 60, and 120 cm from the mound hole center near McLaughlin, SD, July 2010. Values within distance with the same letter (a,b) are not significantly different (P>0.05).

Cabba Soil Series

Soil pH was higher on the Control than the PDT at the 10-20 cm depth, 30 cm (P≤0.01), 60 cm (P≤0.01), and 120 cm (P≤0.01); and at the 20-30 cm depths, 30 cm (P≤0.01), 60 cm (P≤0.01), and 120 cm (P≤0.01) distances from the mound hole center on the Cabba soil series (Figure 2.16). There were no differences (P>0.05) in electrical conductivity between the PDT and Control for all depths and distances (Figure 2.17) for the Cabba soil series. Soil NO_3-N was higher on the PDT at the 0-10 cm depth for all distances from the mound hole center (30 cm P=0.01, 60 cm P=0.02, 120 cm P=0.02; Figure 2.18). There were no differences (P>0.05) in soil NH_4-N between the PDT and Control at all depths and distances (Figure 2.19). Available P was higher (P=0.01) on the PDT at the 0-10 cm depth, 30 cm from the mound hole center (Figure 2.20).

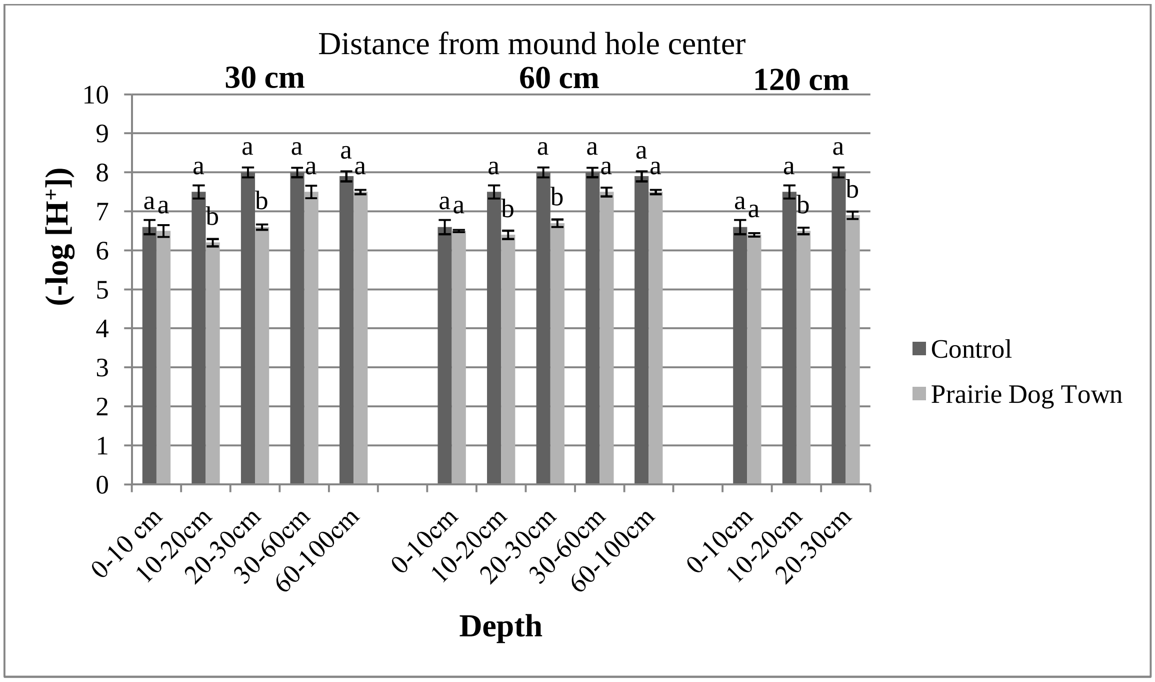

Figure 2.16. Soil pH (-log [H$^+$]; ± SE) by depth for each treatment for the Cabba soil series at 30, 60, and 120 cm from the mound hole center near McLaughlin, SD, July 2010. Values within distance with the same letter (a,b) are not significantly different (P>0.05).

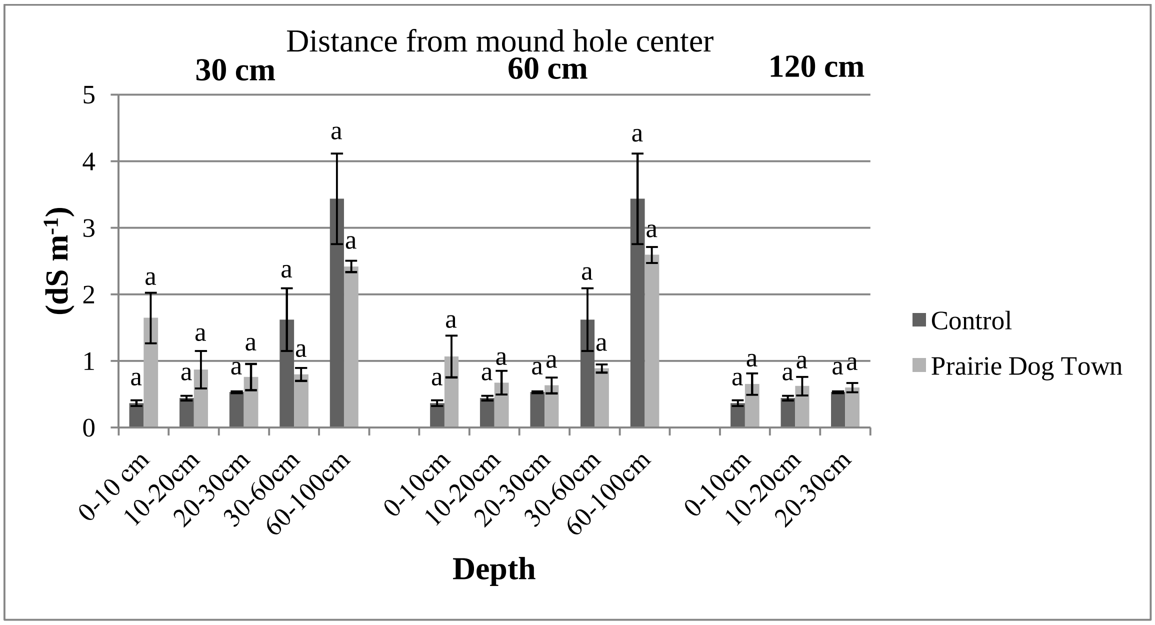

Figure 2.17. Electrical conductivity (dS m^{-1} ± SE) by depth for each treatment for the Cabba soil series at 30, 60, and 120 cm from the mound hole center near McLaughlin, SD, July 2010. Values within distance with the same letter (a,b) are not significantly different (P>0.05).

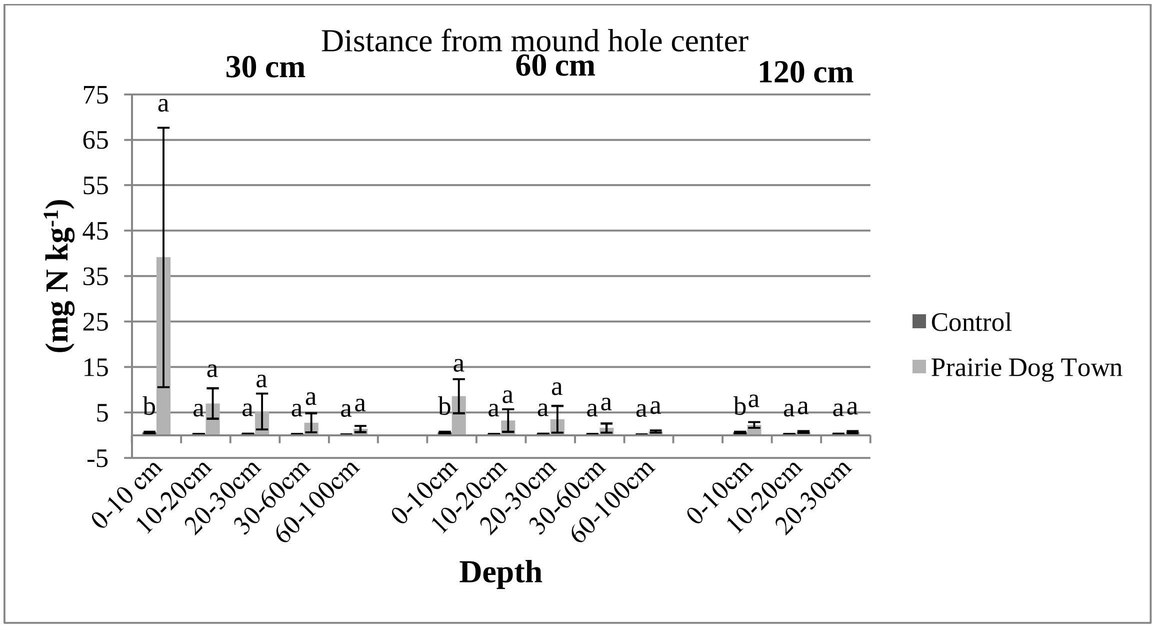

Figure 2.18. Soil NO_3-N (mg N kg^{-1}± SE) concentration by depth for each treatment for the Cabba soil series at 30, 60, and 120 cm from the mound hole center near McLaughlin, SD, July 2010. Values within distance with the same letter (a,b) are not significantly different (P>0.05).

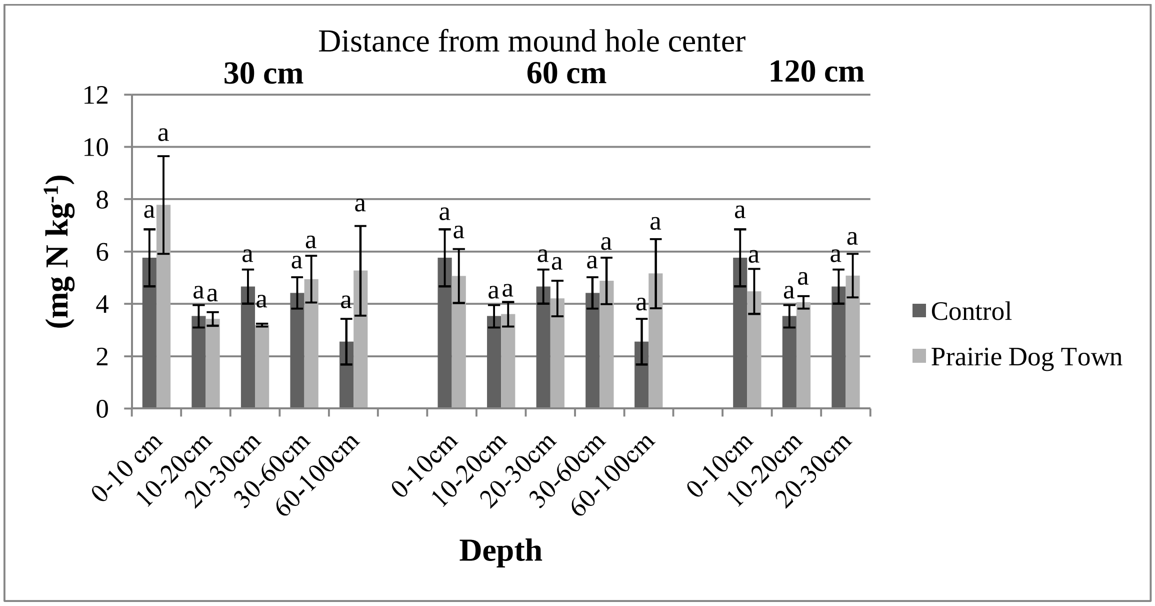

Figure 2.19. Soil NH_4-N (mg N kg^{-1}± SE) concentration by depth for each treatment for the Cabba soil series at 30, 60, and 120 cm from the mound hole center near McLaughlin, SD, July 2010. Values within distance with the same letter (a,b) are not significantly different (P>0.05).

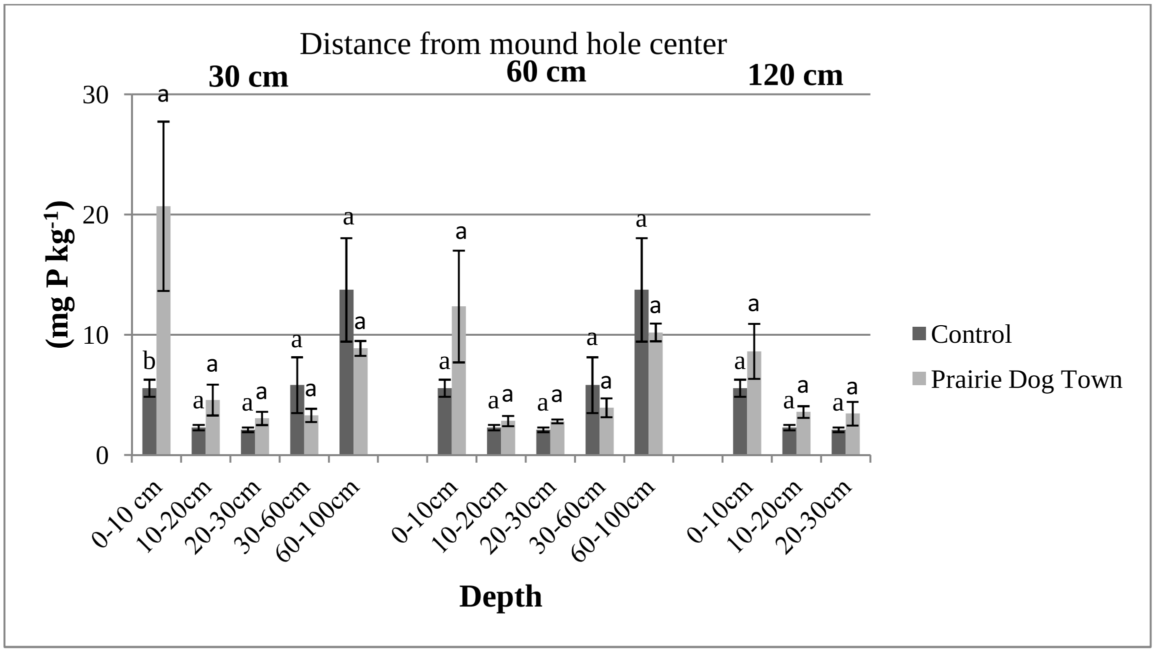

Figure 2.20. Available P (mg P kg^{-1} ± SE) concentration by depth for each treatment for the Cabba soil series at 30, 60, and 120 cm from the mound hole center near McLaughlin, SD, July 2010. Values within distance with the same letter (a,b) are not significantly different (P>0.05).

Total nitrogen was higher on the PDT at the 30-60 cm depth, 30 cm (P=0.02) and 60 cm (P≤0.01) from the mound hole center, and at the 60-100 cm depth, 60 cm (P=0.01) from the mound hole center (Figure 2.21). The C:N ratio was higher on the Control at the 30-60 cm depth, 30 cm (P=0.01) and 60 cm (P≤0.01) from the mound hole center, and at the 60-100 cm depth, 30 cm (P=0.04) and 60 cm (P≤0.01) from mound hole center (Figure 2.22).

No differences (P>0.05) occurred between the PDT and Control for CEC (Figure 2.23), and exchangeable potassium (Figure 2.24), sodium (Figure 2.25), calcium (Figure 2.26), and magnesium (Figure 2.27) for all depths and at all of the distances from the mound hole center.

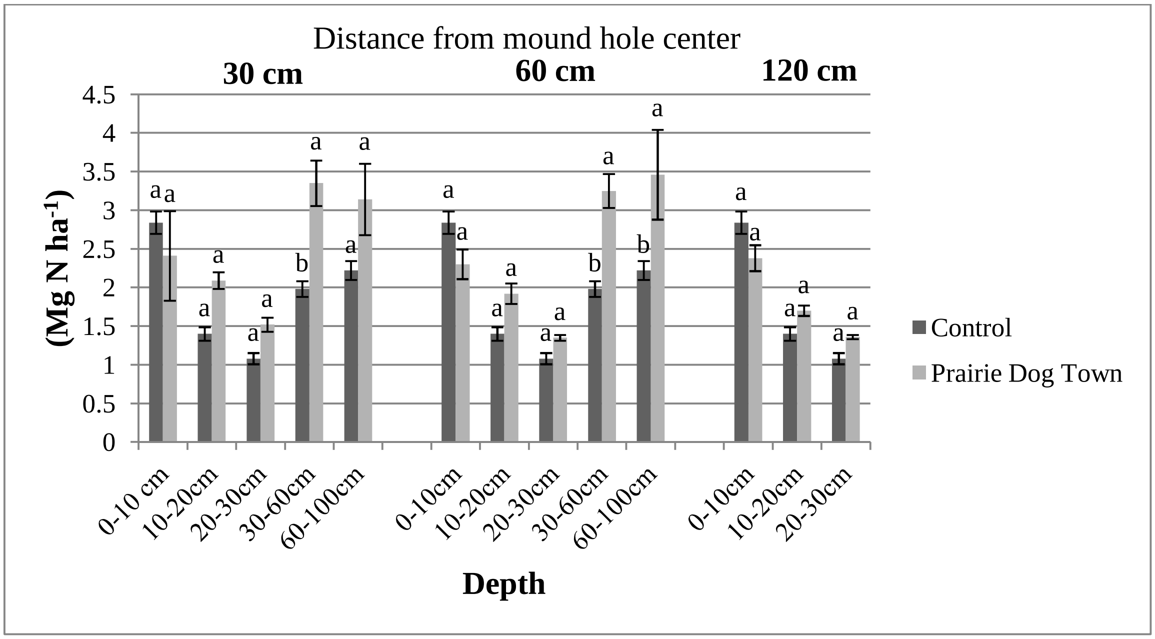

Figure 2.21. Total nitrogen (Mg N ha^{-1}; ± SE) concentration by depths for each treatment for the Cabba soil series at 30, 60, and 120 cm from the mound hole center near McLaughlin, SD, July 2010. Values within distance with the same letter (a,b) are not significantly different (P>0.05).

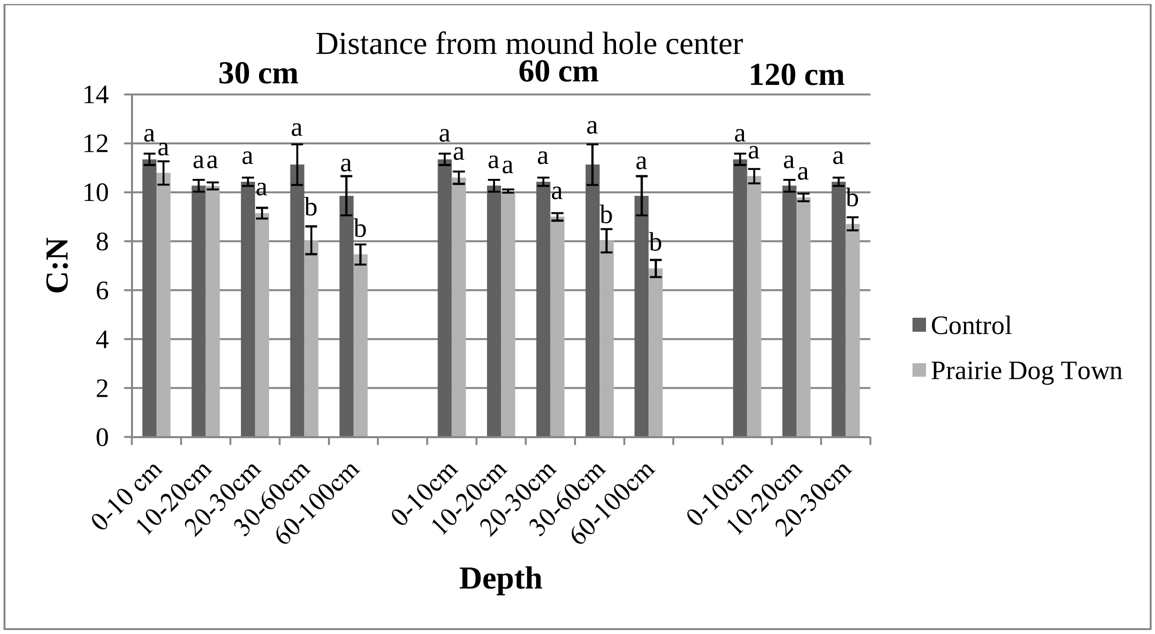

Figure 2.22. Carbon to nitrogen (C:N) ratio (± SE) by depth for each treatment for the Cabba soil series at 30, 60, and 120 cm from the mound hole center near McLaughlin, SD, July 2010. Values within distance with the same letter (a,b) are not significantly different (P>0.05).

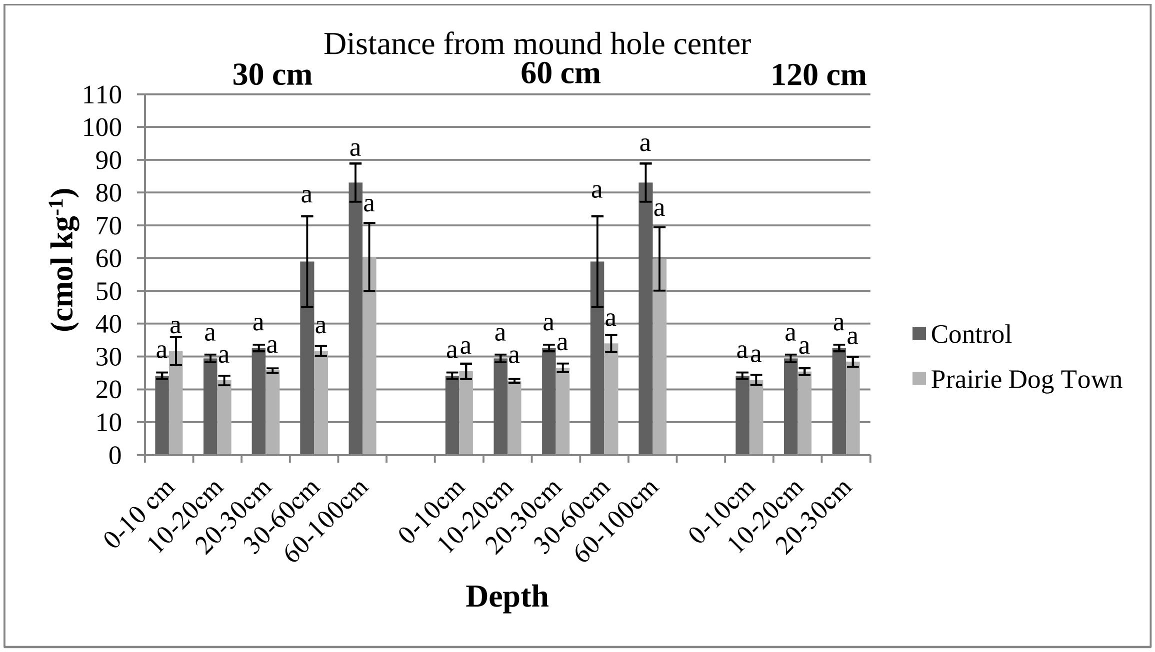

Figure 2.23. Cation exchange capacity (cmol kg^{-1}; ± SE) by depth for each treatment for the Cabba soil series at 30, 60, and 120 cm from the mound hole center near McLaughlin, SD, July 2010. Values within distance with the same letter (a,b) are not significantly different (P>0.05).

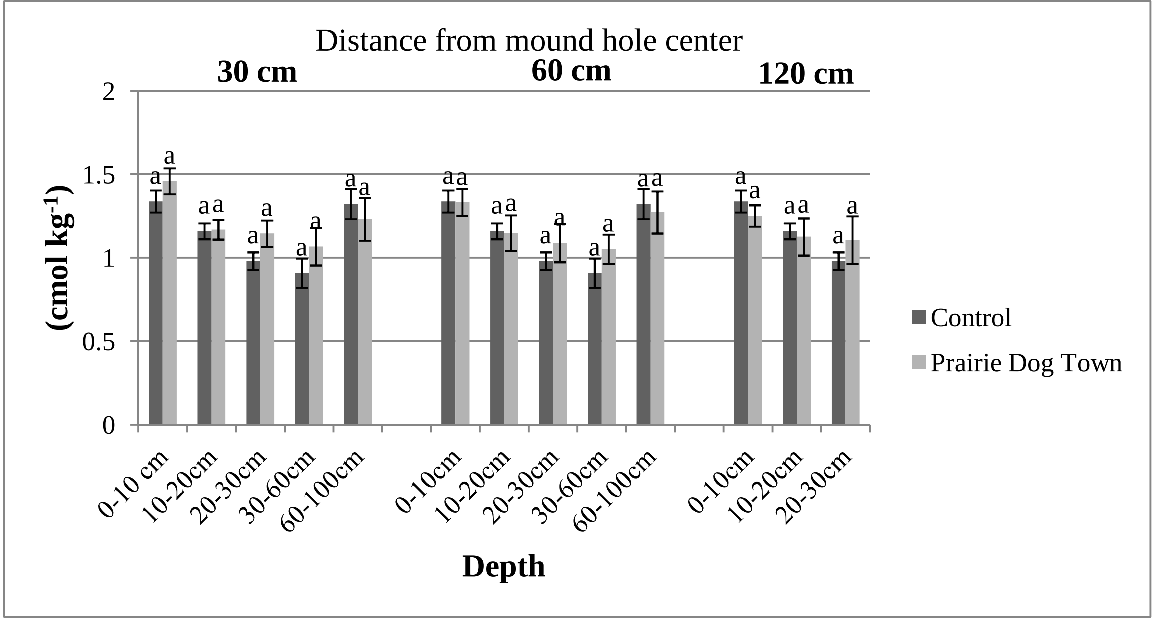

Figure 2.24. Exchangeable potassium (cmol kg^{-1}; ± SE) concentration by depth for each treatment for the Cabba soil series at 30, 60, and 120 cm from the mound hole center near McLaughlin, SD, July 2010. Values within distance with the same letter (a,b) are not significantly different (P>0.05).

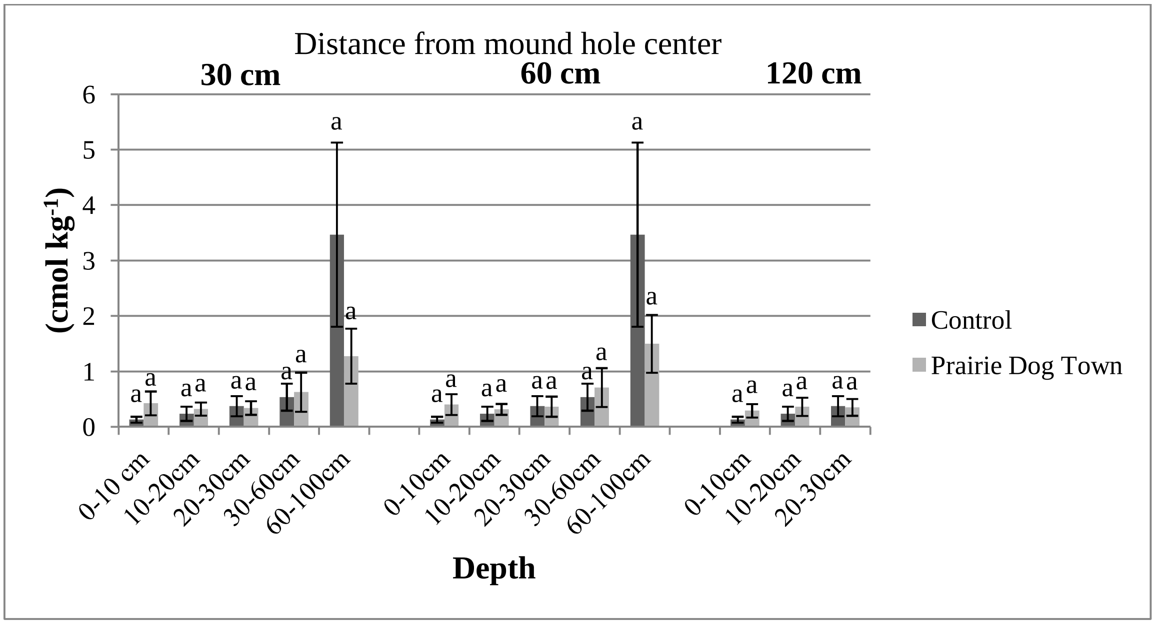

Figure 2.25. Exchangeable sodium (cmol kg^{-1}; ± SE) concentration by depth for each treatment for the Cabba soil series at 30, 60, and 120 cm from the mound hole center near McLaughlin, SD, July 2010. Values within distance with the same letter (a,b) are not significantly different (P>0.05).

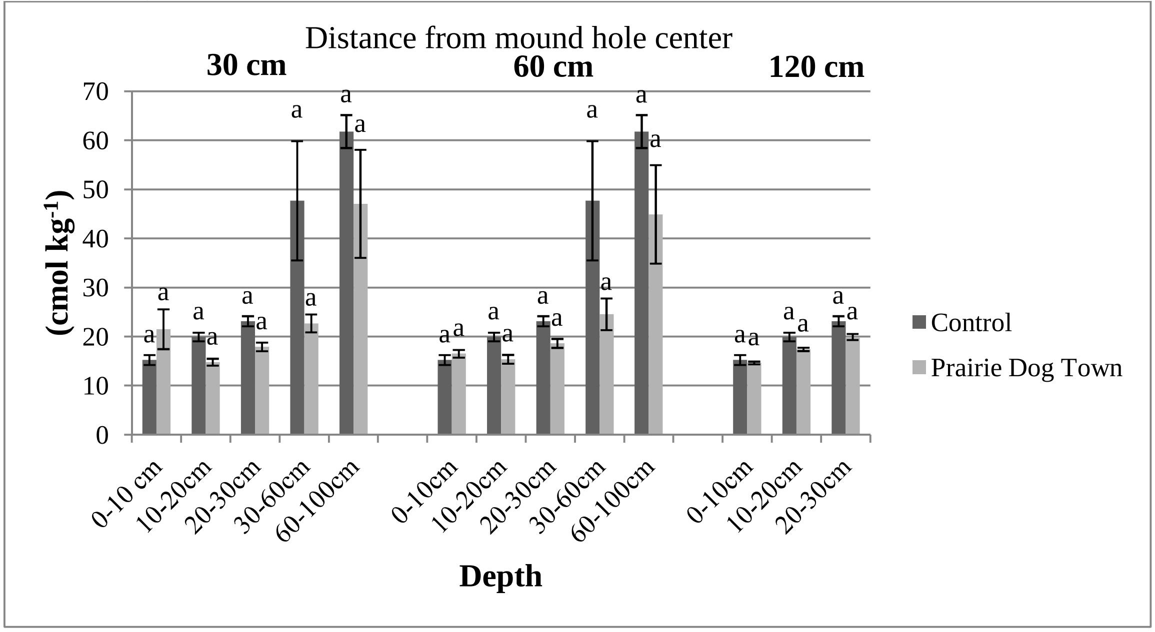

Figure 2.26. Exchangeable calcium (cmol kg^{-1}; ± SE) concentration by depth for each treatment for the Cabba soil series at 30, 60, and 120 cm from the mound hole center near McLaughlin, SD, July 2010. Values within distance with the same letter (a,b) are not significantly different (P>0.05).

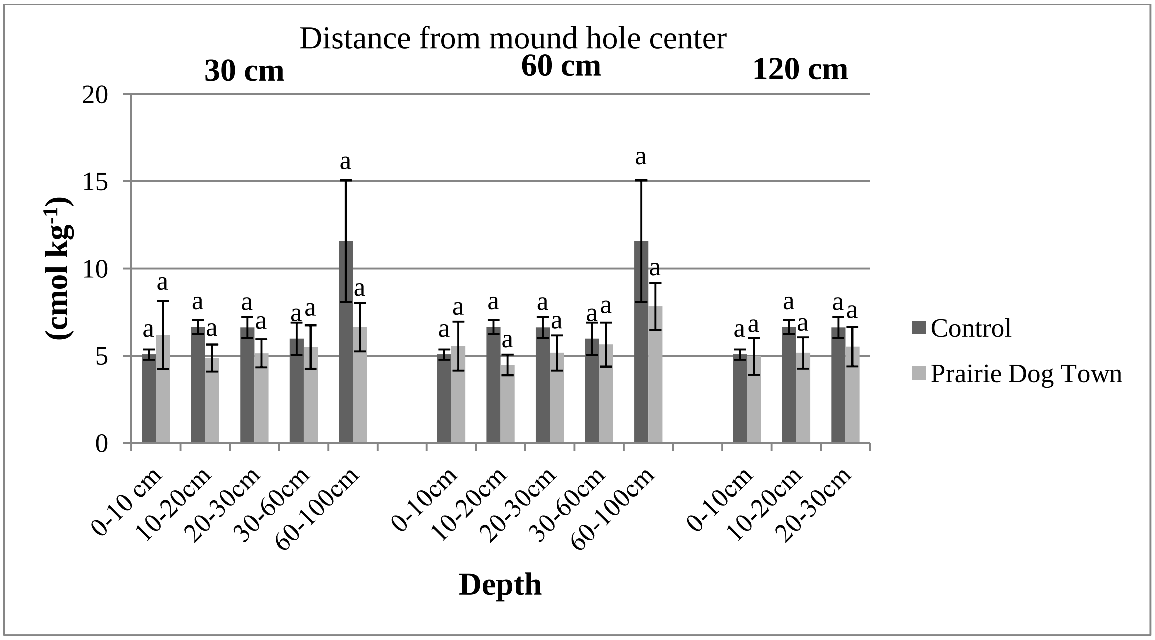

Figure 2.27. Exchangeable magnesium (cmol kg^{-1}; ± SE) concentration by depths for each treatment for the Cabba soil series at 30, 60, and 120 cm from the mound hole center near McLaughlin, SD, July 2010. Values within distance with the same letter (a,b) are not significantly different (P>0.05).

Wayden Soil Series

Soil pH was higher on the Control site compared to the PDT at the 20-30 cm depth, 30 cm from the mound hole center (P=0.01; Figure 2.28). There were no differences (P>0.05) in electrical conductivity for all depths at all distances at the Wayden site (Figure 2.29). Soil NO_3-N content was higher on the PDT at the 0-10 cm depth, 30 cm (P≤0.01) and 60 cm (P=0.04) distance from the mound hole; and 10-20 cm depth, 30 cm (P=0.03) from the mound hole center (Figure 2.30). Soil NH_4-N was higher on the PDT at the 0-10 cm (P≤0.01), 10-20 cm (P=0.03), and 60-100 cm (P=0.02) depths, 30 cm from the mound hole center (Figure 2.31). Soil NH_4-N was higher on the PDT at the 60-100 cm depth, 60 cm (P=0.03) from the mound hole; and at the 10-20 cm depth, 120 cm (P=0.04) away from mound hole. Available P was higher (P=0.01) on the PDT 30 cm away from the mound hole center at the 0-10 cm depth compared to the Control site (Figure 2.32).

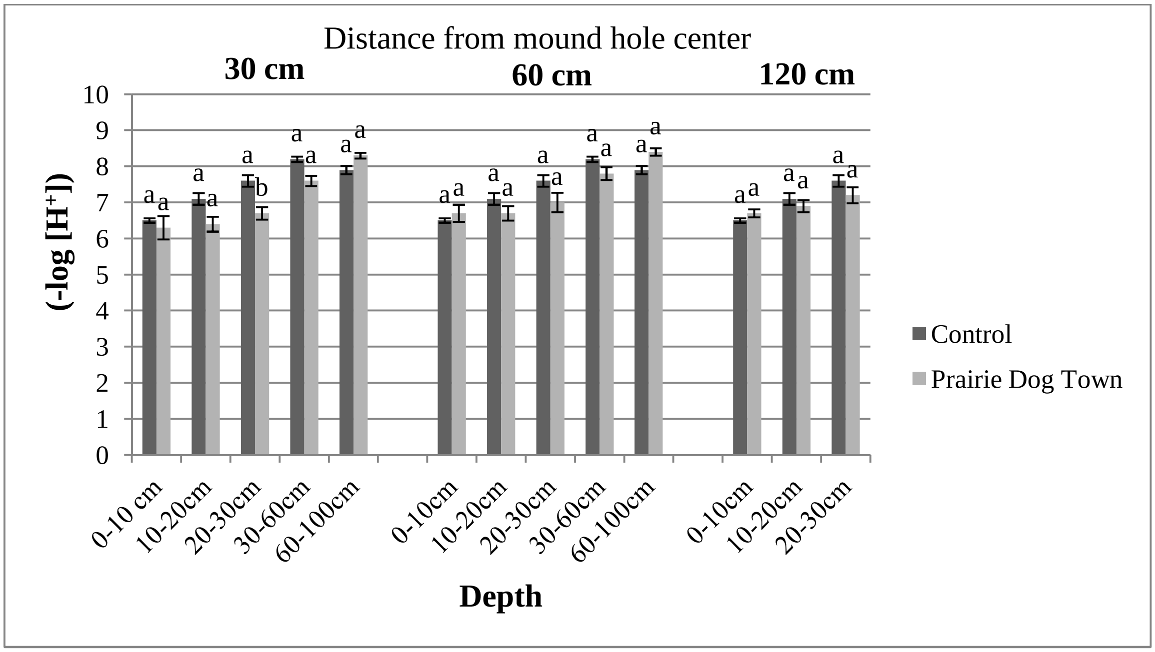

Figure 2.28. Soil pH ([H$^+$]; ± SE) by depth for each treatment for the Wayden soil series at 30, 60, and 120 cm from the mound hole center near McLaughlin, SD, July 2010. Values within distance with the same letter (a,b) are not significantly different (P>0.05).

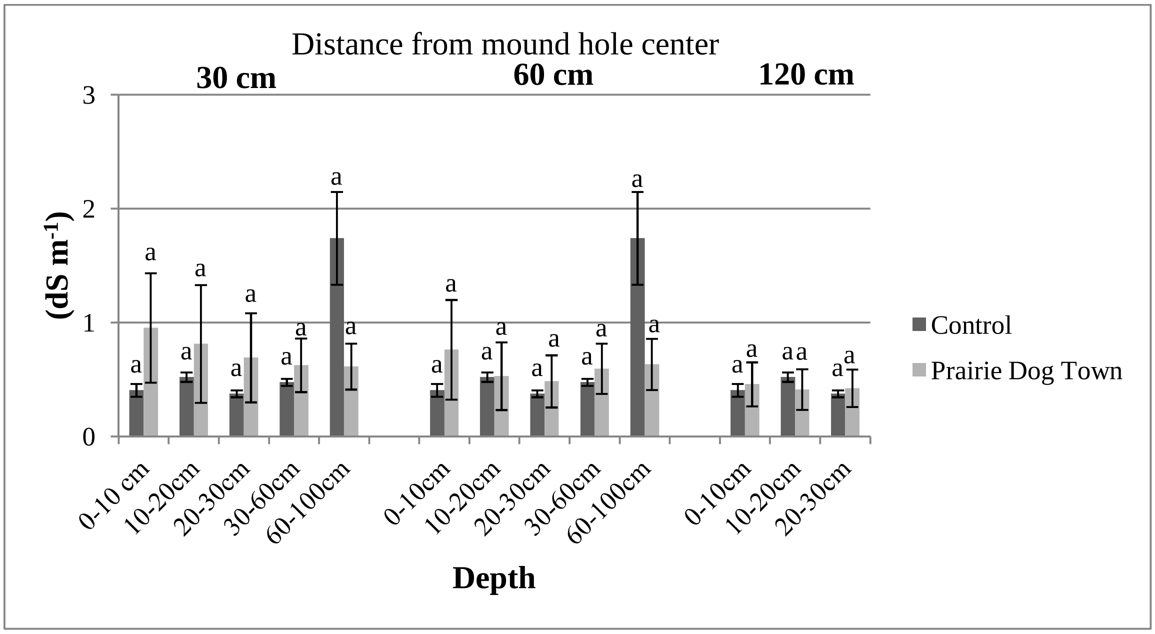

Figure 2.29. Electrical conductivity (dS m^{-1} ± SE) by depth for each treatment for the Wayden soil series at 30, 60, and 120 cm from the mound hole center near McLaughlin, SD, July 2010. Values within distance with the same letter (a,b) are not significantly different (P>0.05).

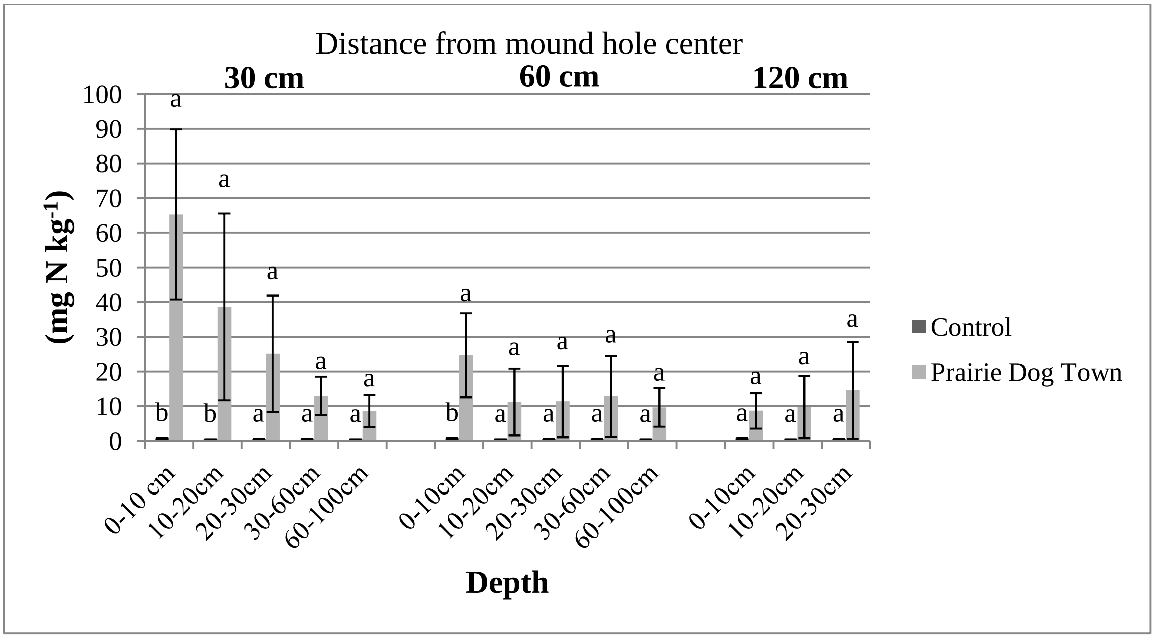

Figure 2.30. Soil NO_3-N (mg N kg^{-1}± SE) concentration by depth for each treatment for the Wayden soil series at 30, 60, and 120 cm from the mound hole center near McLaughlin, SD, July 2010. Values within distance with the same letter (a,b) are not significantly different (P>0.05).

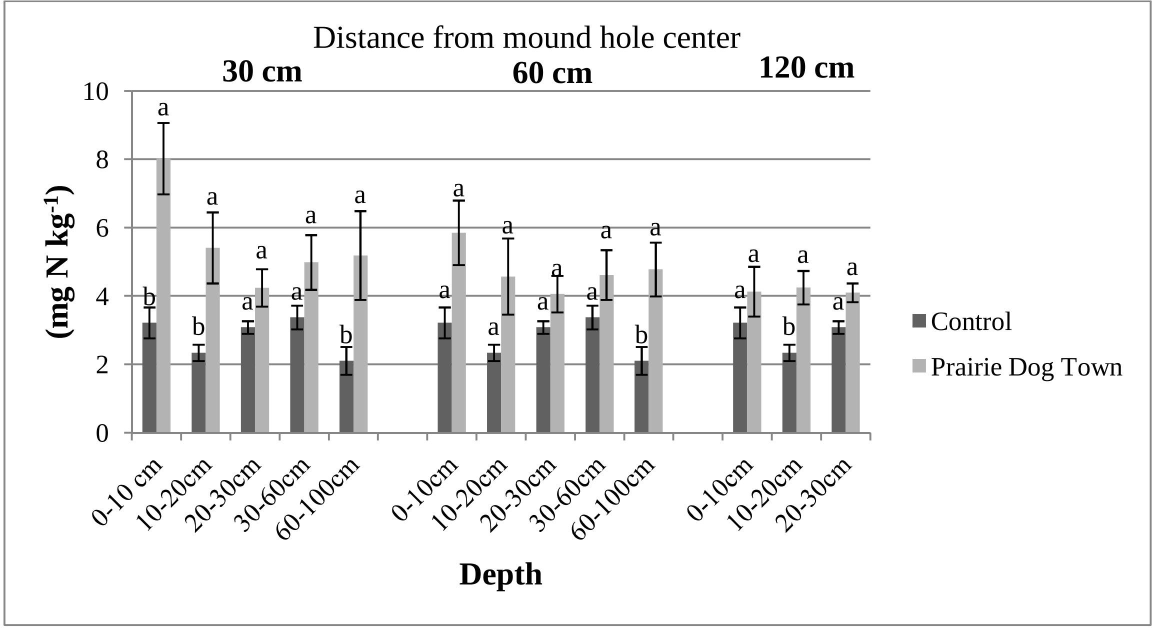

Figure 2.31. Soil NH_4-N (mg N kg^{-1}± SE) concentration by depth for each treatment for the Wayden soil series at 30, 60, and 120 cm from the mound hole center near McLaughlin, SD, July 2010. Values within distance with the same letter (a,b) are not significantly different (P>0.05).

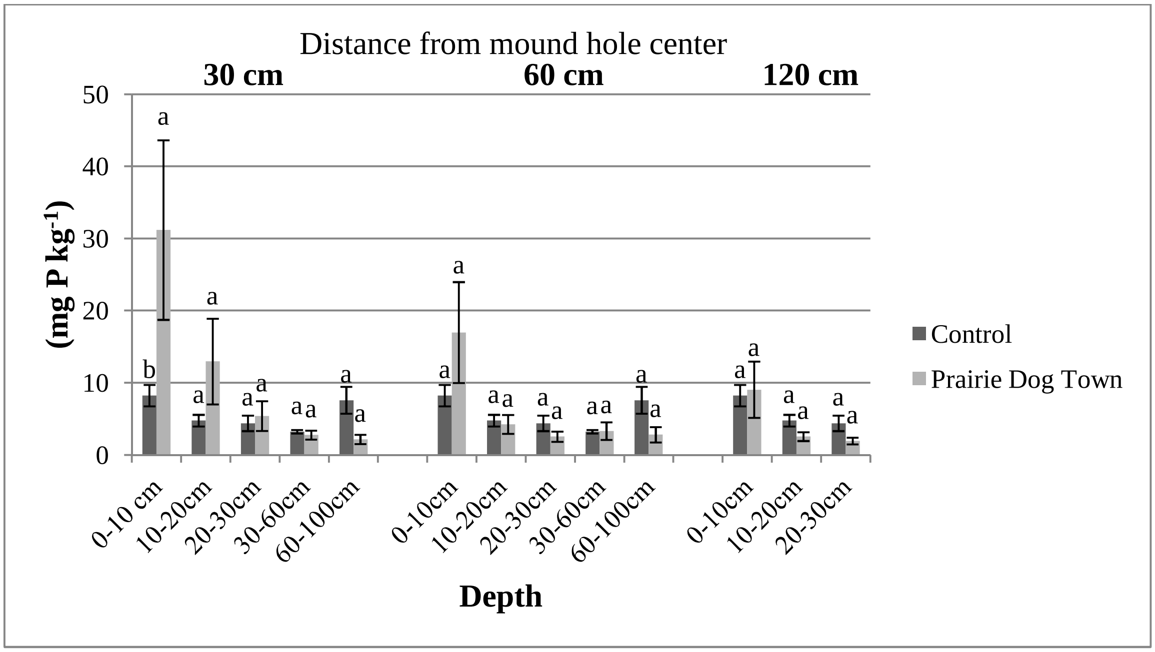

Figure 2.32. Available P (mg P kg^{-1}± SE) concentration by depth for each treatment for the Wayden soil series at 30, 60, and 120 cm from the mound hole center near McLaughlin, SD, July 2010. Values within distance with the same letter (a,b) are not significantly different (P>0.05).

Total nitrogen was higher on the PDT than the control at the 10-20 cm depth, 30 cm (P=0.01) from the mound hole center and at the 60-100 cm depth, 60 cm (P≤0.01) away from the mound hole (Figure 2.33). The C:N ratio was higher on the Control site compared to the PDT at the 30-60 cm depth, 30 cm (P=0.03) away from the mound hole center, and at the 20-30 cm depth, 120 cm (P=0.04) away from the mound hole (Figure 2.34). There were no differences (P>0.05) between on the PDT and Control sites for exchangeable potassium (Figure 2.36), sodium (Figure 2.37), and magnesium (Figure 2.39) on the Wayden soil series. Cation exchange capacity was higher on the Control compared to PDT at the 10-20 cm (P≤0.01) and 20-30 cm (P≤0.01) depths, 120 cm away from the mound hole center (Figure 2.35). Exchangeable calcium was higher on the Control at the 0-10 cm (P=0.03), 10-20 cm (P=0.03), and 20-30 cm (P≤0.01) depths, 120 cm from the mound hole center compared to PDT (Figure 2.38).

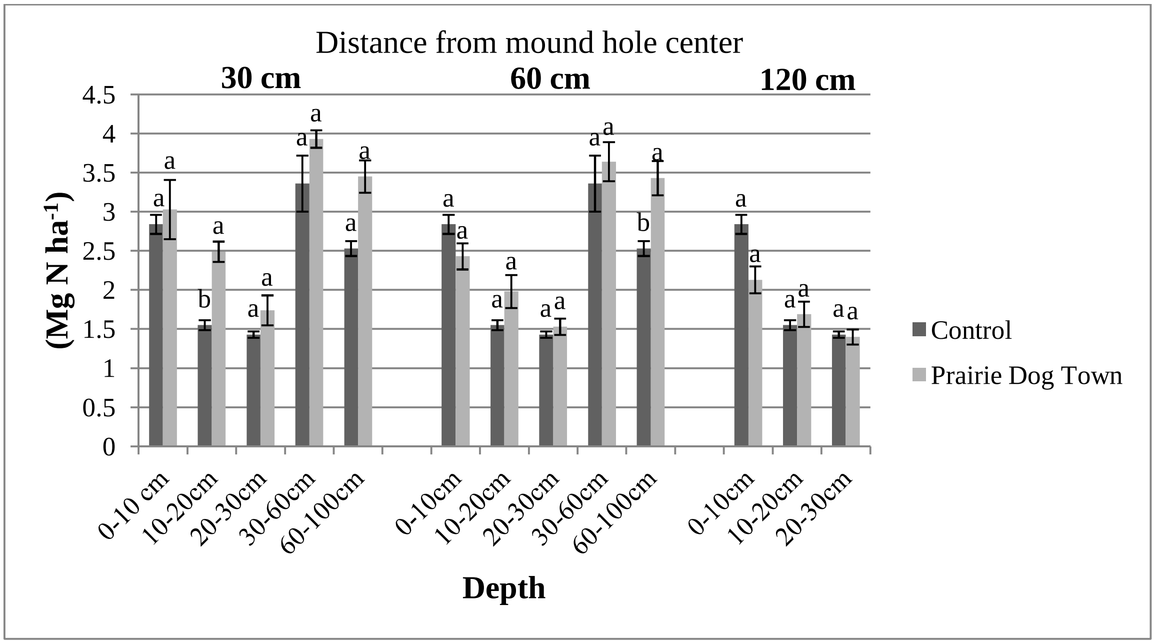

Figure 2.33. Total nitrogen (Mg N ha^{-1}; ± SE) concentration by depths for each treatment for the Wayden soil series at 30, 60, and 120 cm from the mound hole center near McLaughlin, SD, July 2010. Values within distance with the same letter (a,b) are not significantly different (P>0.05).

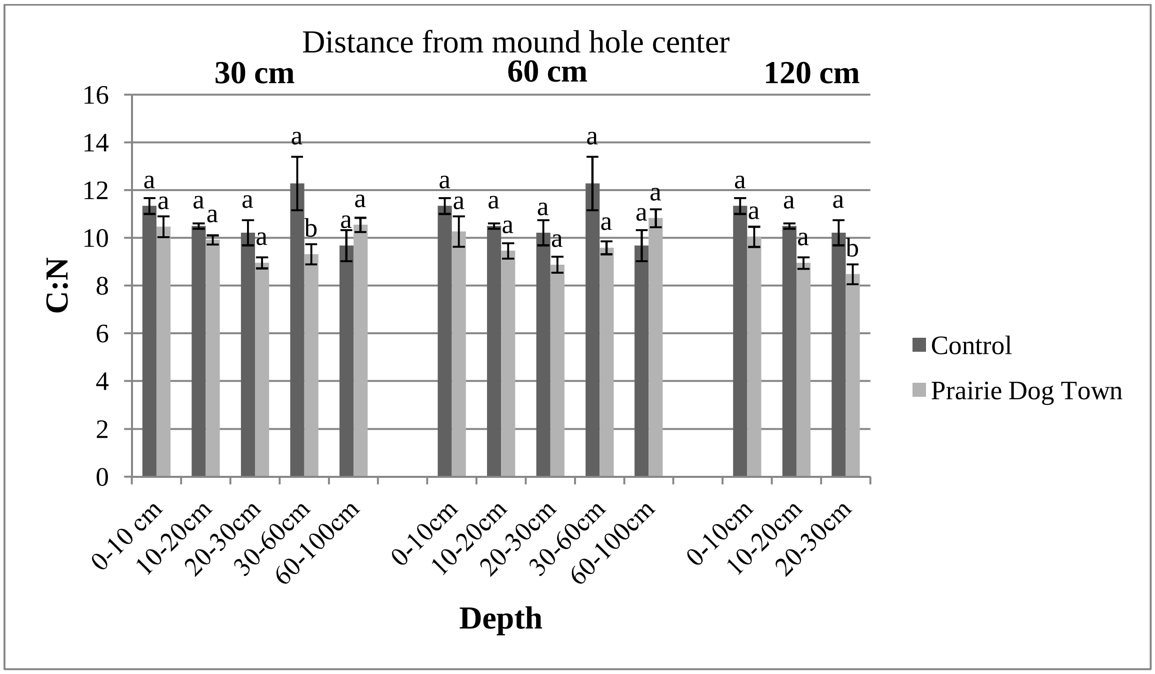

Figure 2.34. Carbon to nitrogen (C:N) ratio (± SE) by depth for each treatment for the Wayden soil series at 30, 60, and 120 cm from the mound hole center near McLaughlin, SD, July 2010. Values within distance with the same letter (a,b) are not significantly different (P>0.05).

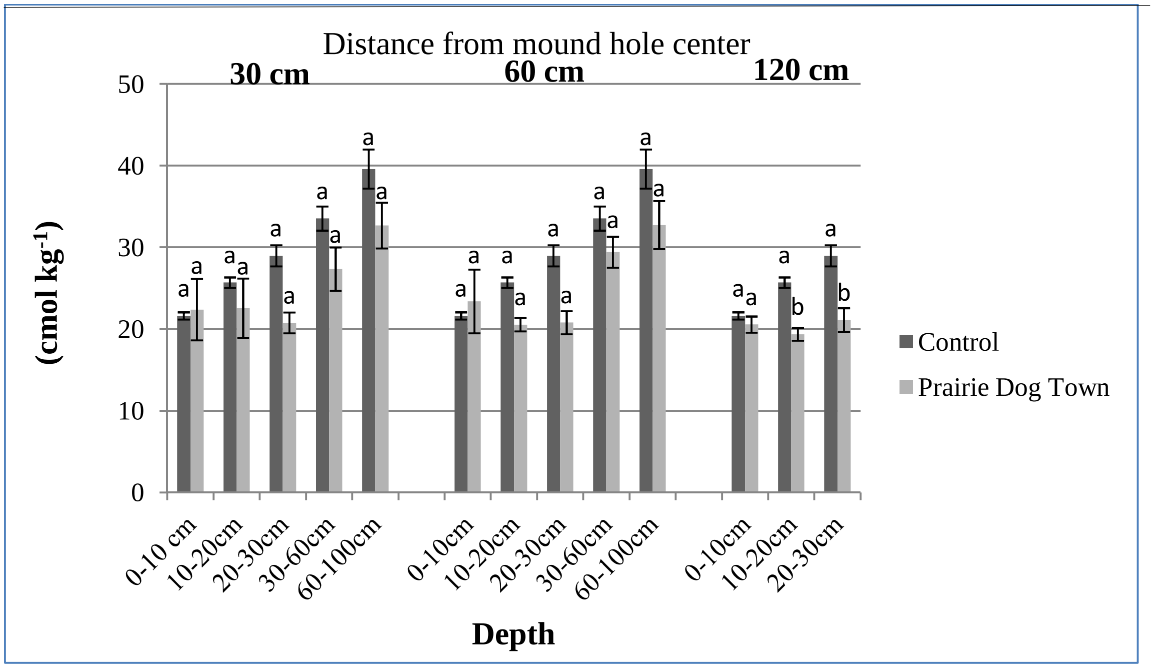

Figure 2.35. Cation exchange capacity (cmol kg^{-1}; ± SE) by depth for each treatment for the Wayden soil series at 30, 60, and 120 cm from the mound hole center near McLaughlin, SD, July 2010. Values within distance with the same letter (a,b) are not significantly different (P>0.05).

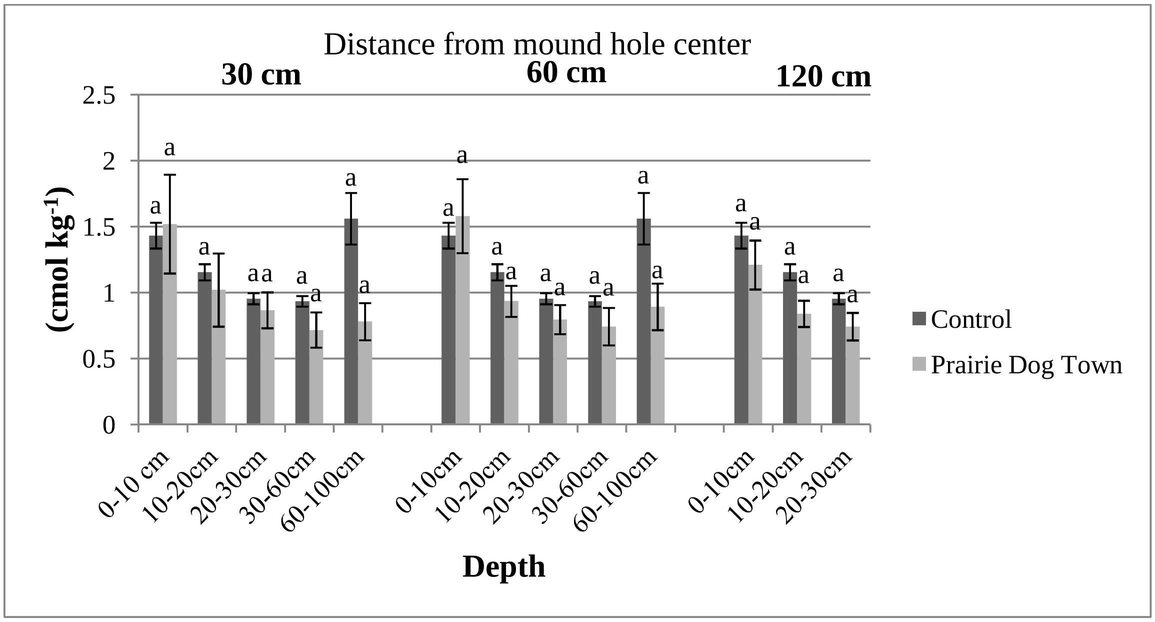

Figure 2.36. Exchangeable potassium (cmol kg^{-1}; ± SE) concentration by depth for each treatment for the Wayden soil series at 30, 60, and 120 cm from the mound hole center near McLaughlin, SD, July 2010. Values within distance with the same letter (a,b) are not significantly different (P>0.05).

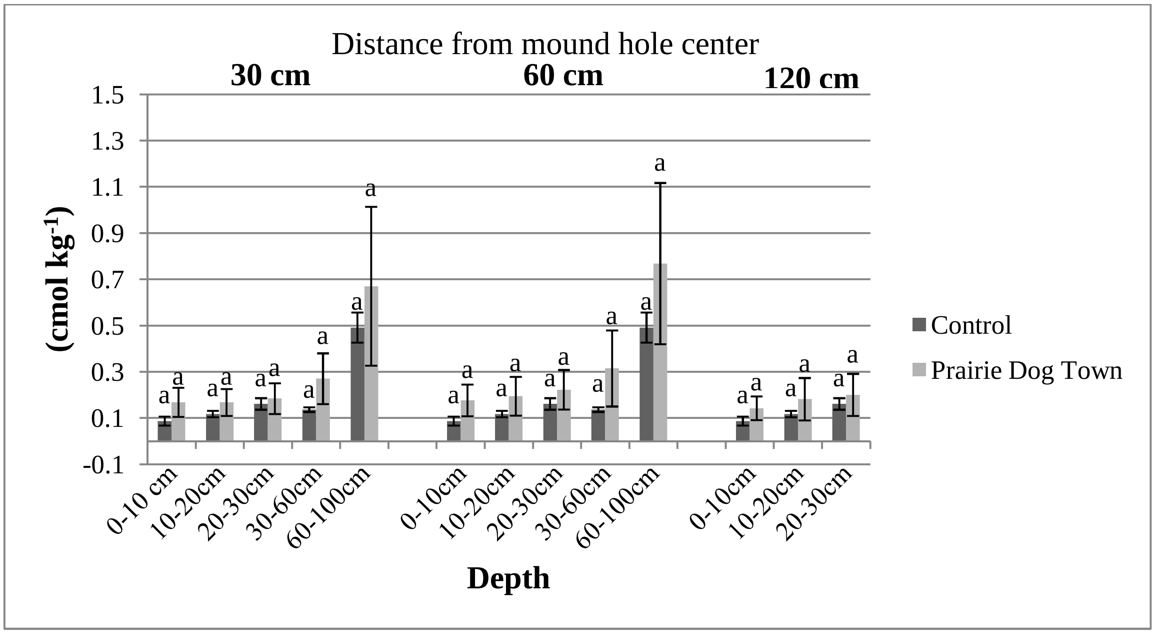

Figure 2.37. Exchangeable sodium (cmol kg^{-1}; ± SE) concentration by depth for each treatment for the Wayden soil series at 30, 60, and 120 cm from the mound hole center near McLaughlin, SD, July 2010. Values within distance with the same letter (a,b) are not significantly different (P>0.05).

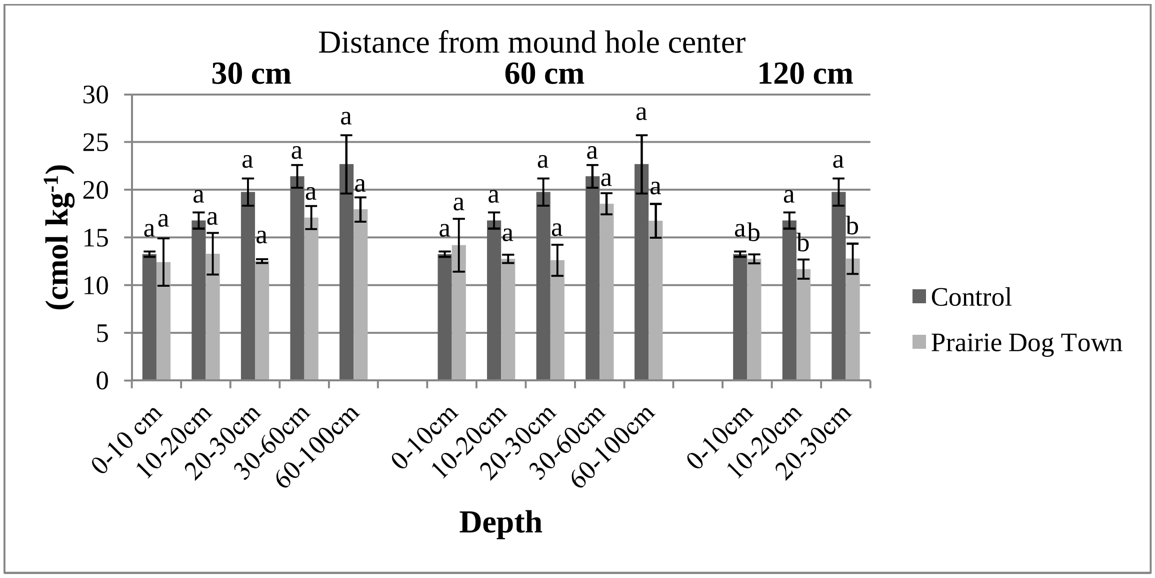

Figure 2.38. Exchangeable calcium (cmol kg^{-1}; ± SE) concentration by depth for each treatment for the Wayden soil series at 30, 60, and 120 cm from the mound hole center near McLaughlin, SD, July 2010. Values within distance with the same letter (a,b) are not significantly different (P>0.05).

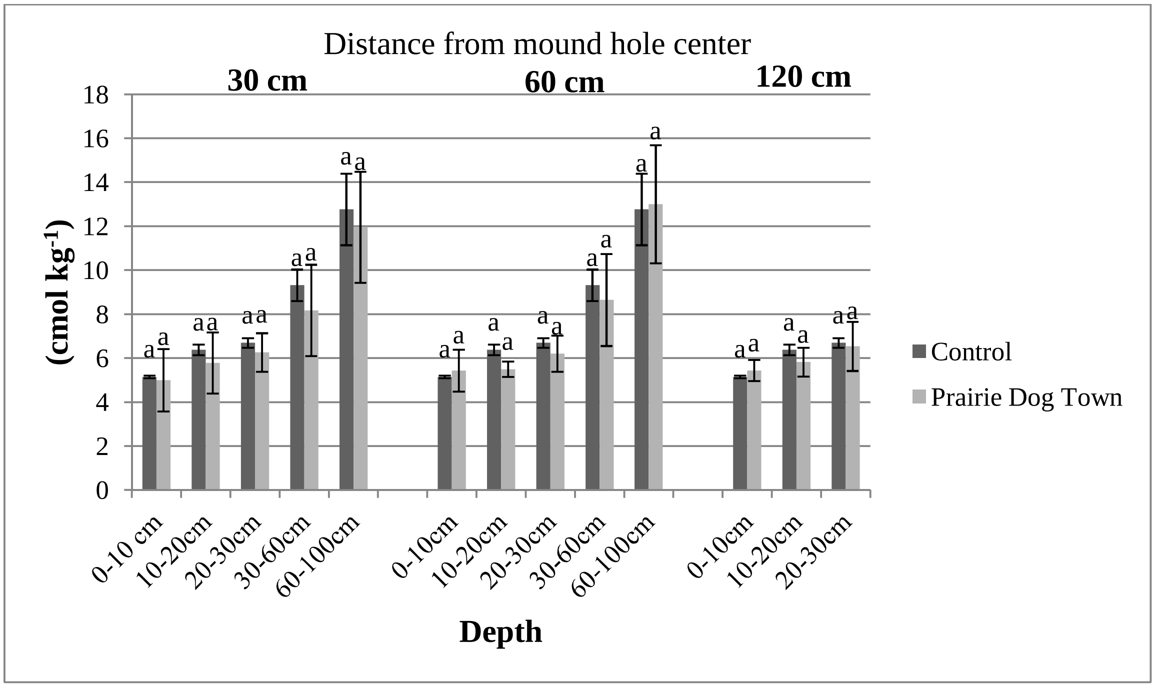

Figure 2.39. Exchangeable magnesium (cmol kg^{-1}; ± SE) concentration by depths for each treatment for the Wayden soil series at 30, 60, and 120 cm from the mound hole center near McLaughlin, SD, July 2010. Values within distance with the same letter (a,b) are not significantly different (P>0.05).

<u>Soil Organic Carbon</u>

There were no differences (P>0.05) in soil organic carbon (SOC) on the Opal soil series between the Control and PDT (Table 2.4). Soil organic carbon was higher (P=0.04) on the Control site (32.1 Mg C ha^{-1}) compared to the PDT (25.7 Mg C ha^{-1}) at the 0-10 cm depth, 120 cm away from the mound hole center on the Cabba soil series. This was similar to the Wayden site, where the SOC was higher (P≤0.01) on the Control site (32.3 Mg C ha^{-1}) than the PDT (21.2 Mg C ha^{-1}) near the surface, 120 cm away from mound hole.

Table 2.4. Soil organic carbon (Mg C ha^{-1}; ± SE) by depth for each treatment for the Opal, Cabba, and Wayden soil series at the 30, 60 and 120 cm distances from the mound hole center near McLaughlin, SD, for 2010.

	Opal					
	30 cm		60 cm		120 cm	
Depth (cm)	Control	PDT	Control	PDT	Control	PDT
0-10	31.7 ± 7.5	15.2 ± 1.8	31.7 ± 7.5	17.7 ± 0.8	31.7 ± 7.5	22.6 ± 1.9
10-20	17.1 ± 3.0	18.7 ± 0.5	17.1 ± 3.0	19.5 ± 1.8	17.1 ± 3.0	18.4 ± 1.2
20-30	11.0 ± 2.7	18.9 ± 1.2	11.0 ± 2.7	17.1 ± 0.9	11.0 ± 2.7	13.6 ± 0.8
30-60	23.5 ± 7.8	35.3 ± 3.5	23.5 ± 7.8	32.9 ± 3.3		
60-100	22.7 ± 4.4	29.1 ± 2.1	22.7 ± 4.4	27.8 ± 2.1		

	Cabba					
	30 cm		60 cm		120 cm	
Depth (cm)	Control	PDT	Control	PD	Control[1]	PDT
0-10	32.1 ± 1.4	26.9 ± 7.3	32.1 ± 1.4	24.8 ± 2.0	32.1 ± 1.4^{a}	25.7 ± 2.3^{b}
10-20	14.4 ± 0.9	21.5 ± 1.2	14.4 ± 0.9	19.3 ± 1.4	14.4 ± 0.9	16.6 ± 0.7
20-30	11.3 ± 0.8	13.9 ± 1.2	11.3 ± 0.8	12.2 ± 0.4	11.3 ± 0.8	11.8 ± 0.4
30-60	21.8 ± 1.2	26.8 ± 2.4	21.8 ± 1.2	25.7 ± 1.9		
60-100	21.6 ± 1.4	23.4 ± 3.4	21.6 ± 1.4	23.4 ± 3.8		

	Wayden					
	30 cm		60 cm		120 cm	
Depth (cm)	Control	PDT	Control	PDT	Control[1]	PDT
0-10	32.3 ± 1.6	32.1 ± 5.2	32.3 ± 1.6	24.7 ± 2.4	32.3 ± 1.6^{a}	21.2 ± 1.8^{b}
10-20	16.3 ± 0.7	24.8 ± 1.2	16.3 ± 0.7	19.1 ± 2.6	16.3 ± 0.7	15.1 ± 1.5
20-30	14.7 ± 1.0	15.7 ± 1.9	14.7 ± 1.0	13.6 ± 1.0	14.7 ± 1.0	11.8 ± 0.8
30-60	42.3 ± 8.3	36.4 ± 0.7	42.3 ± 8.3	34.6 ± 1.9		
60-100	24.3 ± 1.3	36.4 ± 2.6	24.3 ± 1.3	37.2 ± 3.0		

[1] Compared values between Control and PDT within same depth and distance from mound hole with a different letter (a,b) differ at $P \leq 0.05$.

Discussion

Plant species diversity was lower on the PDT associated with the Opal soil series in 2010 and 2011, and Wayden soil series in 2010. Other studies found plant species diversity higher on PDTs, especially younger towns due to an increase of annual forb species (Coppock et al 1983a; Archer et al. 1987). Plant species richness was different between the PDT and Control on the Opal and Cabba soil series in 2010; there were no differences in species richness between sites for any soil series in 2011. Archer et al. (1987) found PDTs had higher species richness than areas off PDTs.

Although we found no differences in soil bulk density on the Cabba and Wayden soil series, bulk density was lower on the PDT at the 0-10 cm depth extending to 60 cm from the mound hole center on the Opal soil series. In a study done in the Sonoran and Chihuahuan Deserts, Kerley et al. (2004) found bulk density to be lower on pocket gopher mound soils compared to non-mound soils on the Chihuahuan Desert. Similar to our study, Kerley et al. (2004) observed site differences, and found no differences in soil bulk density between pocket gopher mound soils and non-mound soils on the Sonoran desert. Our findings and those reported by Kerley et al. (2004) suggests soil type and soil depth are important parameters to consider when addressing the impact of burrowing animals on soil bulk density.

Nitrate levels were higher on the PDT at all three soil series, especially close to the prairie dog burrow and at the surface depths. These increases in nitrate levels could be the result of deposits of prairie dog urine and fecal material. This increase in soil nitrate levels would explain increased nitrogen cycling on prairie dog towns as reported by Polley and Detling (1988). Ammonium levels were higher on the PDT associated with both the Opal and Wayden soil series. These increases were again found close to the prairie dog burrow and near the soil surface.

Soil pH was lower on the PDT than the control in both the Opal and Cabba soil series of our study. This occurred in the depths closer to the soil surface and at distances closer to the prairie dog burrows. These findings contradict those reported by Carlson and White (1987, 1988) from a study in southwestern South Dakota, where soil pH was found to be higher on prairie dog mound than adjacent non-mound soils. They observed a trend of decreasing soil pH with increasing distance from the mound. We did not find differences in soil pH associated with the Wayden soil series, indicating prairie dogs impact soil pH differently among soil types. Carlson and White (1988) found pH decreased with mound age as basic materials were leached from surface soil, coupled with smaller amounts of substratum being deposited on the soil surface and more soil deposited on the surface coming from the mound as prairie dog tunnels were relocated. The decrease in the soil pH could also be linked to increased acidification on the PDTs due to nitrification. Urea and fecal materials from prairie dogs provide ammonium which is subject to nitrification. During this process hydrogen ions are released into the soil solution. In an efficient ecosystem, vegetation will take up the nitrate and the excess hydrogen will bind with hydroxyl ions to form water. On the PDT close to the burrow, vegetation is less abundant than areas off the PDT. Accordingly, less vegetation growth under conditions of high available nitrogen will result in less uptake of soil nitrate thereby contributing to increased soil acidification over time.

Total nitrogen was higher on the PDT at the Cabba site than on the Control at deeper depths, both 30 and 60 cm from the center of the hole. However, total nitrogen was not different close to the surface between PDT and Control. However, Carlson and White (1987) observed total nitrogen levels were lower on the prairie dog mound than the adjacent non-mound soil at the shallow depths, but similar to our findings, found no differences in total nitrogen between the mound soil and adjacent non-mound soil.

The increase in nitrogen on the Cabba and Wayden soil series at the closer distances to the mound hole center influenced the C:N at those same distances. Since there were greater nitrogen and lower organic carbon concentrations on the PDT, the ratio of carbon to nitrogen was lower. The lower carbon to nitrogen levels found on the PDT were associated with the Cabba and Wayden soil series at 120 cm from the hole center. Holland and Detling (1990) theorized that a lower carbon to nitrogen ratio found on the PDT was due to the vegetation not allocating as much carbon to the root system as a response to the intensive grazing from prairie dogs.

Carlson and White (1987, 1988) reported total phosphorus was highest on the prairie dog mound soils and decreased with distance from the mound. This was consistent with our findings, where all three soil series had higher phosphorus contents on the soil surface in the PDT 30 cm from the mound hole center, while the Opal soil series greater phosphorus extended 60 cm from the hole center. Carlson and White (1988) theorized elevated phosphorus levels were due to the presence of prairie dog fecal and skeletal residues being deposited on mound soils.

Electrical conductivity was not different between Control and PDT sites for all three soil series. A similar outcome was found by Kerley et al. (2004) with pocket gophers in the Sonoran Desert. However, in the Chihuahuan Desert one of their sites did have a difference in electrical conductivity between the pocket gopher mound and non-mound soil. They hypothesized the increased electrical conductivity on the mound was due to the properties of the soil, with the site in the Chihuahuan Desert having a shallow layer of calcium carbonate that increased the pH and electrical conductivity of the site.

The Opal soil series had a higher CEC on the Control site than on the PDT, suggesting a possible difference in inherent soil attributes between sites. The Wayden soil series only had a difference in CEC at the 10-30 cm depth, 120 cm from mound hole center, and the Cabba soil series had no differences in CEC. The CEC was derived in an additive manner from the exchangeable cations in the soil (e.g. potassium, sodium, calcium, and magnesium). On the Opal soil series, exchangeable potassium and magnesium were not different between the control site and the PDT. Exchangeable sodium was lower on the PDT at all depths and distances from the hole center. Exchangeable calcium was lower on the PDT at the same depths where CEC was different, on both the Opal and the Wayden soil series.

Kerley et al. (2004) compared the levels of exchangeable potassium, calcium, and magnesium on pocket gopher mounds to non-mound soils in the Sonoran and Chihuahuan Deserts and found only differences in potassium levels at one of their Chihuahuan desert sites (mound soil greater than non-mound soil). The remaining cations were not different between pocket gopher mounds and non-mound sites. In our study, prairie dogs either did not impact cation levels, similar to Kerley et al, (2004), or possibly lowered specific cations compared to the Control sites. Additionally, differences in CEC and exchangeable cations between PDT and Control sites could be the result of slight differences in soil type as expressed by the presence of smectitic clays, which serve as exchange sites for cations

(Brady and Weil 2008). Kerley et al. (2004) found coarser textured soils provided less cation exchanged compared to clay soils.

Summary and Conclusion

Objectives of this study were to evaluate differences in vegetation species diversity and richness and determine differences in selected soil quality parameters between prairie dog colonies and adjacent non-disturbed sites. In 2010, species richness was lower on the PDT for the Opal soil series and higher on the PDT on the Cabba soil series. Diversity was higher off the PDT on the Opal soil series in both 2010 and 2011 and on the Wayden soil series in 2010.

It appears soil type was a driver in some differences observed between treatments. The clayey soils (Opal and Wayden) tended to have a lower CEC on the PDT, which was influenced primarily by exchangeable calcium. On the shallow soils (Cabba and Wayden) total nitrogen was higher on the PDT, which in turn influenced the carbon to nitrogen ratio which was higher on the control. Soil pH was lower on the PDT in the deep clayey soil (Opal) on the surface (0-10 cm) and at the deep depth (60-100 cm), and in the shallow loamy soil (Cabba) in the middle depths (10-30 cm). Ammonium was higher on the PDT in the deep clayey soil (Opal) in the surface soils. Nitrate and phosphorus were higher on the PDT in all three soil series near the soil surface.

Differences in soil properties affect vegetation diversity and growth and can create patches where the PDT mounds possessed different plant communities than observed under adjacent non-disturbed sites. The soils on the PDT were more acidic than the soils on adjacent sites not impacted by prairie dogs, especially at the soil surface. This acidification is due to increased ammonium nitrogen being deposited on the soil from prairie dog urination and fecal material. This increased nitrogen is converted to nitrate through the nitrification process. While this process is occurring there are increased hydrogen ions released into soil solution. This increase in hydrogen concentration is reflected in the lower pH. There also is increased phosphorous at the soil surface close to the mound center due to prairie dog fecal materials and skeletal remains. Results from this study suggest rangeland restoration strategies should account for patches of high nutrient, acidic soils caused by previous prairie dog activities.

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CHAPTER 3. EFFECTS OF PRAIRIE DOG (*CYNOMYS LUDOVICIANUS*) COLONIZATION ON THE WATER INFILTRATION RATES OF SELECTED SOILS IN THE NORTHERN GREAT PLAINS

Abstract

Vegetation and soils were evaluated for three soil series on a black-tailed prairie dog (*Cynomys ludovicianus*) colony and adjacent non-disturbed mixed-grass prairie in north central South Dakota in 2011. Objectives of this study were to evaluate differences in soil infiltration rates between prairie dog colonies and adjacent non-prairie dog infested sites. The three soil series evaluated existed on deep clayey (Opal), shallow loamy (Cabba), and shallow clayey (Wayden) ecological sites. Water infiltration, gravitmetric water content and penetration resistance were measured on a control site and in two locations on each prairie dog colony (near burrow and off burrow). Water infiltration rates were measured using single ring infiltrometers and soil penetration resistance was measured using a dynamic cone penetrometer. On the Cabba and Wayden soil series water infiltration rates were higher on the near burrow sites compared to the off burrow and Control sites. Penetration resistance, a measure of soil compaction, was lowest on the near burrow sites on all soil series. The findings of this study show that black-tailed prairie dogs affect water infiltration rates on shallow soils.

Introduction

Black-tailed prairie dogs (*Cynomys ludovicianus*) historically occupied 40 million ha of short and mixed-grass prairie in the Great Plains (Hoogland 1995), from northern Mexico to Southern Canada and from the Rocky Mountain foothills east to the tall grass prairies (Nelson 1919). However, over the past century the prairie dog population has decreased to a point where they occur on about two percent of their original range, and in the Northern Great Plains this covers approximately 2,378 km^2 (Sidle et al. 2001). Reasons for this decline are attributed to loss of habitat, eradication programs, and disease such as the plague (Cully and Williams 2001).

Black-tailed prairie dogs can have a major impact on ecosystems. The impact prairie dogs have on an ecosystem can also affect how other wildlife species utilize prairie dog towns. Coppock et al. (1983a) observed higher nitrogen and *in vitro* dry matter digestibility on prairie dog towns as opposed to adjacent no-colonized areas. These increases in nutrition quality attracted wild ungulates to actively select prairie dog towns for grazing (Coppock et al. 1983b). Agnew et al. (1986) found bird and small mammal densities higher on prairie dog towns than the associated no prairie dog town areas.

One major impact prairie dogs have on an ecosystem is they alter the vegetative communities. Prairie dogs will continuously fell the vegetation located within their town as a defensive measure (King 1955) as well as a food source. Since prairie dogs preferentially select graminoids as a food source (Hanson and Gold 1977), there tends to be a shift in the vegetative community from graminoids to forbs (Coppock et al. 1983a). Along with this shift in the vegetative community there is an increase in plant species diversity and richness in the community of younger prairie dog towns; however, as the dog town ages the plant species diversity and richness decline to pre-colonized levels (Archer et al. 1987). The amount of litter and bare ground present on the prairie dog town also follow this trend. As a prairie dog town ages the amount of litter present decreases and amount of bare ground increases. This increase in bare ground can influence the amount of runoff and water infiltrating into the soil.

We sought to evaluate effects of black-tailed prairie dogs on soils within a mixed-grass prairie of the Northern Great Plains. In this study we quantified differences in water infiltration rates between prairie dog colonies and adjacent non-prairie dog infested sites on these soil series.

Study Area

Location and Land Use

The study was conducted 16 km southeast of McLaughlin, South Dakota on the Standing Rock Indian Reservation in Corson County. The study area is approximately 1400 hectares of both private land and leased tribal land. The ranch has been under current management since the early 1940’s. Historically, there were approximately 300 head of cattle and 100 head of horses that grazed the land. However, cattle have been absent since 2009 with ranch currently grazed by approximately 90 head of horses. The prairie dog population on this land occupied two small towns comprising six to eight hectares in the early 1950’s. The prairie dog population gradually increased on both of the towns starting in 1985. Currently, prairie dogs occupy over 800 hectares of the ranch.

Climate

The study area is characterized by a continental semi-arid climate, with hot summers and cold winters (Heil 1995). The 30-year mean annual precipitation for McLaughlin, SD is 455 mm, with 83% of the precipitation occurring from April through October (ACIS, 2012). The peak precipitation months are May through August, with 58%

of the annual precipitation occurring during this period. The mean annual temperature is 6.5°C.

Temperatures were similar to the 30-year mean in 2011, with the exception of February and December which was slightly lower than average (Table 3.1; ACIS, 2012). There was an increase in precipitation compared to the 30-year mean in 2011. The winter months of January and December, as well as September, were wetter than normal and October and November drier than normal (Table 3.2).

Table 3.1. Mean monthly[1] temperature (°C) for McLaughlin, South Dakota for 2011 and the 30-year mean (ACIS 2012).

Month	Mean Temperature	30 Year Mean Monthly Temperature
January	-12.7	-10.1
February	-11.4	-7.0
March	-6.1	-1.4
April	4.8	6.5
May	10.5	13.1
June	16.9	18.5
July	23.4	22.2
August	21.0	21.2
September	14.2	15.1
October	9.5	7.7
November	-0.8	-0.9
December	-4.2	-8.1
Average	**5.4**	**6.4**

[1] The mean monthly temperatures were determined using average daily temperatures.

Vegetation

Three soil series (Opal, Cabba, and Wayden) were selected for this study, each supporting a different plant community. The Opal soil series was classified as a clayey ecological site with a current plant community of western wheatgrass (*Pascopyrum* *smithii*), blue grama (*Bouteloua gracilis*), sedges (*Carex* Spp.), fringed sagewort (*Artemisia frigida*), and prostrate knotweed (*Polygonum aviculare*) on both the prairie dog town (PDT) and Control sites (off the prairie dog town). The clayey ecological site had a historic climax plant community (HCPC) of green needlegrass (Nassella *viridula*) and western wheatgrass. Under heavy, continuous season-long grazing the green needlegrass decrease and blue grama and buffalograss (*Buchloe dactyloides*) increase (USDA-NRCS 2012d).

Table 3.2. Monthly precipitation (mm) for McLaughlin, South Dakota for 2011 and the 30-year average (ACIS 2012).

Month	Monthly Mean	30 Year Mean
January	29.2	11.8
February	28.4	13
March	24.4	26
April	95.3	41.6
May	102.4	72.3
June	149.1	81.1
July	26.2	55.9
August	145.8	54.5
September	14.2	34.6
October	36.8	36.6
November	0.3	13.1
December	11.4	14.1
Total	**663.5**	**454.6**

The Cabba soil series was classified as a shallow loamy ecological site with a current plant community of western wheatgrass, prairie junegrass (*Koeleria macrantha*), blue grama, sedges, fringed sagewort, and dandelion (*Taraxacum officinale*) on the Control site. On the PDT, the plant community comprised of western wheatgrass, blue grama, green needlegrass, sedges, fringed sagewort, deervetch (*Lotus unifoliolatus*), and sweetclover (*Melilotus spp.*). The HCPC for the shallow loamy ecological site was western wheatgrass, needlegrass, and plains muhly (*Muhlenbergia cuspidata*) (USDA-NRCS 2012f).

The Wayden soil series was classified as a shallow clayey ecological site with a current plant community of western wheatgrass, prairie junegrass, blue grama, needle and thread (*Hesperostipa comata*), green needlegrass, Kentucky bluegrass (*Poa pratensis*), yellow coneflower (*Ratibida columnifera*), deervetch, curlycup gumweed (*Grindelia squarrosa*), silverleaf scurfpea (*Pediomelum argophylla*), and Indian breadroot (*Pediomelum esculenta*) on the Control site. The dominant species were western wheatgrass, blue grama, deervetch, wooly plantain (*Plantago patagonica*), fetid marigold (*Dyssodia papposa*), and woodsorrel (*Oxalis corniculata*) on the PDT. The HCPC for the shallow clayey ecological site was western wheatgrass and warm season mid grasses (USDA-NRCS 2012e).

Soils

Opal soils are classified as fine, smectitic, mesic Leptic Haplusterts (USDA-NRCS 2012h). This soil series is found primarily in central South Dakota, mostly west of the Missouri River. Opal soils are moderately deep, fine clays found on gently sloping terrains with a 0-25% slope formed from clayey residuum derived from shale parent material. This soil series is well-drained with medium to very high runoff, depending on the slope, and very slow permeability; however, after periods of drought, permeability may be rapid due to large cracks in the soil. Opal soils are found on the backslope, with the down slope shape linear and the across slope shape convex to linear (USDA-NRCS 2012b).

The typical pedon for this soil series contains the following horizons: A, Bss1, Bss2, Bkss, Cyz1, Cyz2, Cr1, and Cr2 (USDA-NRCS 2012h). The A horizon is five cm thick and grayish brown clay, with moderate medium and fine granular structure. There are many fine and medium sized roots found in this horizon. The Bss1 horizon is about 20 cm thick and grayish brown clay. The structure of this horizon is moderate medium and coarse subangular blocky. There are many fine and medium roots associated with this horizon. A characteristic of this horizon is the presence of nonintersecting slickensides, with cracks 1.25 cm wide. There are 1% pebbles present and a slight effervescence, indicating carbonates present. The Bss2 horizon is 15 cm thick and grayish brown clay. There is weak coarse prismatic structure that is parting to moderate medium and coarse subangular blocky structure. Fine and medium roots are common, but there are less than the above horizons. There are many prominent intersecting slickensides with cracks 2.5 cm wide and a strong effervescence. The Bkss horizon is 25 cm thick and light brownish gray color. The structure is weak coarse prismatic structure parting to moderate medium and coarse subangular blocky structure. There are few fine sized roots. Many prominent intersecting slickensides are present with cracks in the soil 1.25 to 2.5 cm thick. There are many fine and medium accumulations of carbonate and the soil has strong effervescence (USDA-NRCS 2012h).

The Cyz1 and Cyz2 horizons are 12 cm thick and light brownish gray, with many fine yellowish brown mottles present. There are many fine and medium nests of gypsum and other salts. The Cr1 and Cr2 horizons are 63 cm thick and light brownish gray and dark gray soft shale present. There are fine prominent strong brown mottles present. These horizons also have many yellowish brown iron stains in cracks and seams. The Cr1 horizon has many fine nests of gypsum and other salts, while the Cr2 horizon only has few fine nests of salts (USDA-NRCS 2012h).

Opal soils are used both as cropland and rangeland (USDA-NRCS 2012h). The dominant range species for this soil series are western wheatgrass, green needlegrass, blue grama, sideoats grama (*Bouteloua curtipendula*), and sedges. The land capability class for this soil series is 3e, meaning it is suitable for cropping and the dominant limitations are wind and water erosion (USDA-NRCS 2012b). Other soils associated with the Opal soils are the Bullcreek, Chantier, Dupree, Hurley, Labu, Lakoma, Promise, and Sansarc soils (USDA-NRCS 2012h).

Cabba soils are classified as loamy, mixed, superactive, calcareous, frigid, shallow Typic Ustorthents (USDA-NRCS 2012g). This soil series is found in western North Dakota, central and eastern Montana, and northwestern South Dakota. These are shallow loams found on terrains with a slope of 3-60%, and is derived from loamy residuum derived from sedimentary rock parent material. The Cabba soil is well-drained, moderately permeable with a slow to fast runoff depending on the slope. These soils are found on backslopes and shoulders of hills. The downslope shape is convex and the across slope shape is convex and linear (USDA-NRCS 2012a).

The typical Cabba series pedon consists of the following horizons: A, Bk1, Bk2, and Cr (USDA-NRCS 2012g). The A horizon is 7.5 cm thick and grayish brown loam. The structure is moderate fine granular. There are many very fine and fine roots in this horizon. The horizon is slightly effervescent and slightly alkaline. The Bk1 horizon is 13 cm thick and light brownish gray loam. It has weak fine and medium subangular blocky structure. There are many very fine and fine roots, with many very fine pores present. This horizon is strongly effervescent and slightly alkaline. The Bk2 horizon is 18 cm thick and pale brown clay loam. Very fine and fine roots are common as well as very fine pores.

There is strong effervescence in this horizon and it is moderately alkaline. The Cr horizon is 114 cm thick and pale brown. There are a few very fine and fine roots, mainly in the upper part and in vertical cracks. This horizon is strongly effervescent and moderately alkaline (USDA-NRCS 2012g).

Cabba soils are mainly found in rangeland (USDA-NRCS 2012g). The dominant species for this soil series are little bluestem (*Schizachyrium scoparium*), western wheatgrass, needle and thread, prairie sandreed (*Calamovilfa longifolia*), bluebunch wheatgrass (*Pseudoroegneria spicata*), green needlegrass, plains muhly, forbs and shrubs. The land capability class for this soil is 7e, meaning this soil is not ideal for cropland but suitable as rangeland (USDA-NRCS 2012a). A limitation on this soil is water erosion (USDA-NRCS 2012g).

Wayden soils are classified as clayey, smectitic, calcareous, frigid, shallow Typic Ustorthents (USDA-NRCS 2012i). They are found in eastern and northern Montana, western North Dakota, north central Wyoming, and northwestern South Dakota. This soil series is found on sites with 6-40% slope and formed from parent material that is clayey residuum weathered from shale. This soil series is well-drained with slow permeability and slow to rapid runoff, depending on slope. These soils are found on shoulder, backslopes, and summits of hills. The down slope shape is convex and the across slope shape is either linear or convex (USDA-NRCS 2012c).

The typical pedon of the Wayden soil series contains the following horizons: A, Bk, By, and Cr (USDA-NRCS 2012i). The A horizon is 7.5 cm thick and light gray silty clay. The structure is strong, very fine granular. There are many fine and very fine roots. This horizon is slightly effervescent and moderately alkaline. The Bk horizon is 10 cm thick and light gray silty clay. It is a moderate coarse and medium subangular blocky structure parting to a moderate fine subangular blocky. Fine and very fine roots are common with fine pores. This horizon is slightly alkaline with strong effervescence. The By horizon is 20 cm thick and light gray silty clay. The structure is weak coarse, subangular blocky parting to moderate fine subangular blocky. There are fine and very fine roots common in this horizon as well as many gypsum crystals present. This horizon has slight effervescence and moderately alkaline. The Ct horizon is 114 cm thick and olive silty clay shale with yellowish brown moist stains on plates. It is extremely hard and very fine and slakes in water. It has a slight effervescence and moderately alkaline (USDA-NRCS 2012i).

The Wayden soil series is mainly used as rangeland however some areas with gentle slopes can support small grain crops (USDA-NRCS 2012i). The predominant species found on rangeland sites include: western wheatgrass, little bluestem, needle and thread, forbs and shrubs. The land capability class for this soil is 7e, meaning it is not well suited for cropland and the greatest limitation is wind erosion (USDA-NRCS 2012c). Soils associated with the Wayden series include: Amor, Belfield, Bradenburg, Cabba, Flasher, Moreau, Morton, Regeant, Rhodes, Ringling, Sen and Vebar (USDA-NRCS 2012i).

Methods

Infiltration rates were evaluated on the Opal, Cabba, and Wayden soil series in late July 2011. There were three treatments evaluated at each soil series, two on the prairie dog town near the burrow and off burrow site, and a Control site not affected by prairie dog activity. Eight infiltrometers were randomly placed on the Control and sixteen infiltrometers were placed on the prairie dog town. Eight prairie dog burrows were randomly selected for each soil series, with eight infiltrometers placed 30 cm from the hole center and eight placed 200 cm from the hole center.

A single-ring infiltrometer was used to determine infiltration rates (Sarrantonio et al. 1996). An aluminum ring (i.e., a 15 cm i.d. irrigation pipe cut to a 15 cm length) was inserted into the soil to a depth of 7.5 cm to obtain infiltration rates. There were two separate applications of water applied to the enclosed space of the ring with each application being equivalent to a 25.4 mm depth within the ring. The time it took for each application of water to infiltrate into the soil was recorded using a stopwatch. Data taken from the second water application was used for analysis to compensate for any potential differences in antecedent water content among the treatments.

Soil water content was sampled using two different methods to a depth 0-10 cm. A step-down probe was used to collect samples from the off burrow sites and control. A trowel was used for samples near the burrow. The trowel was used because soils 30 cm from the hole center were excessively loose, and a suitable core could not be made with the step-down probe in the core barrel. Gravimetric soil water content was determined for each sample by measuring the difference in mass before and after drying at 105°C for 24 hours (Gardner, 1986).

Penetration resistance was determined using a dynamic cone penetrometer with a 2 kg sliding hammer and a 60 cm drop height (Herrick and Jones, 2002). The number of hammer blows needed to penetrate a 5 cm soil depth was recorded in each treatment. Measurements were made in triplicate near each of the eight infiltrometer sites at 30 cm and 200 cm from the hole center. The measurements were made within 200 cm from each of the eight infiltrometers on the control. Measurements were converted into energy (joules) and the mean was calculated from the three measurements taken near each infiltrometer.

Statistical Analysis

Treatment and application effects for the infiltration rates were analyzed using a nested design with the distances from the mound center being nested within the mound. The PROC MIXED procedure (Version 9.2 of the SAS System for Windows, Copyright © 2002-2008 SAS Institute Inc.) was used for the statistical analysis. Means were compared using the LSMEANS procedure with the overall p-value adjusted by using the Tukey procedure. The data were transformed using logarithmic transformation to normalize the data and a $P \leq 0.05$ was considered significant.

For soil water content and penetration resistance, the location effects on these parameters were analyzed. A linear model ANOVA design (Version 4.3 of the SAS Enterprise guide for Windows, Copyright © 2006-2010 SAS Institute Inc.) was used for the statistical analysis. The LSMEANS procedure was used to compare the means with the overall p-value adjusted by using the Tukey procedure. A $P \leq 0.05$ was considered significant.

Results

There were no differences ($P>0.05$) in infiltration rates on the Opal soil series in either the first or second application of water (Figure 3.1). The near burrow infiltration rate was higher than the infiltration rates on the Control ($P=0.0077$) and off burrow ($P=0.0007$) sites for the first application of water on the Cabba soil series. For the second application of water, there were no differences ($P>0.05$) between treatments on the Cabba soil series (Figure 3.2). The infiltration rates were higher on the near burrow site than on the Control (P=0.0001) and off burrow (P=0.0013) sites for the first 25.4 mm on the Wayden site (Figure 3.3). For the second 25.4 mm of water, the Control site had a lower infiltration rate than the near burrow (P=0.0007) and off burrow (P=0.0369) sites.

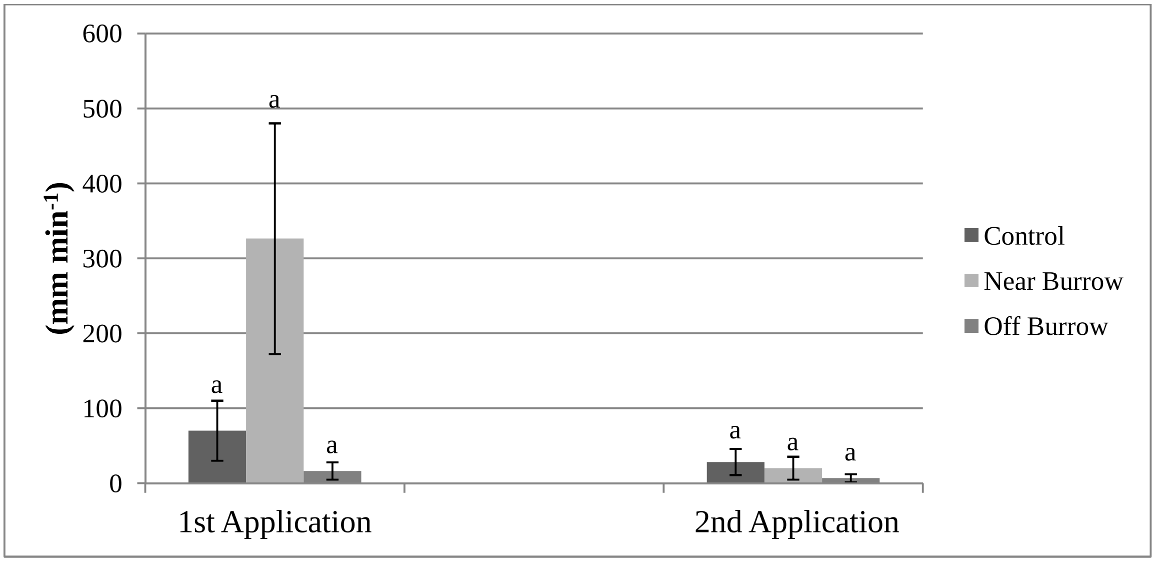

Figure 3.1. Infiltration Rate (mm/minute; ± SE) by treatment for the Opal Soil Series near McLaughlin, SD, July 2011. Values within application with the same letter (a,b) are not significantly different (P>0.05).

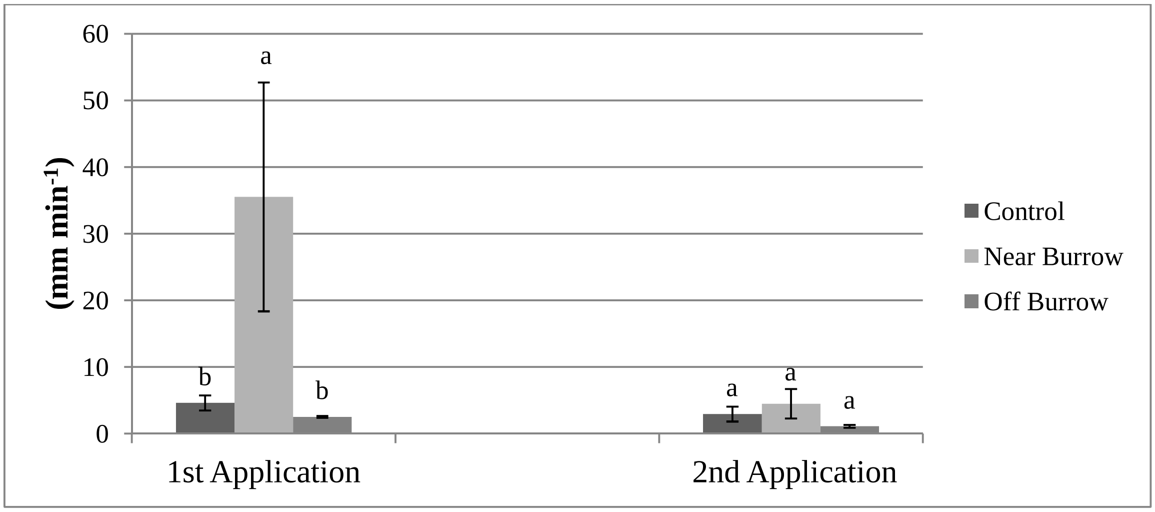

Figure 3.2. Infiltration Rate (mm/minute; ± SE) by treatment for the Cabba Soil Series near McLaughlin, SD, July 2011. Values within application with the same letter (a,b) are not significantly different (P>0.05).

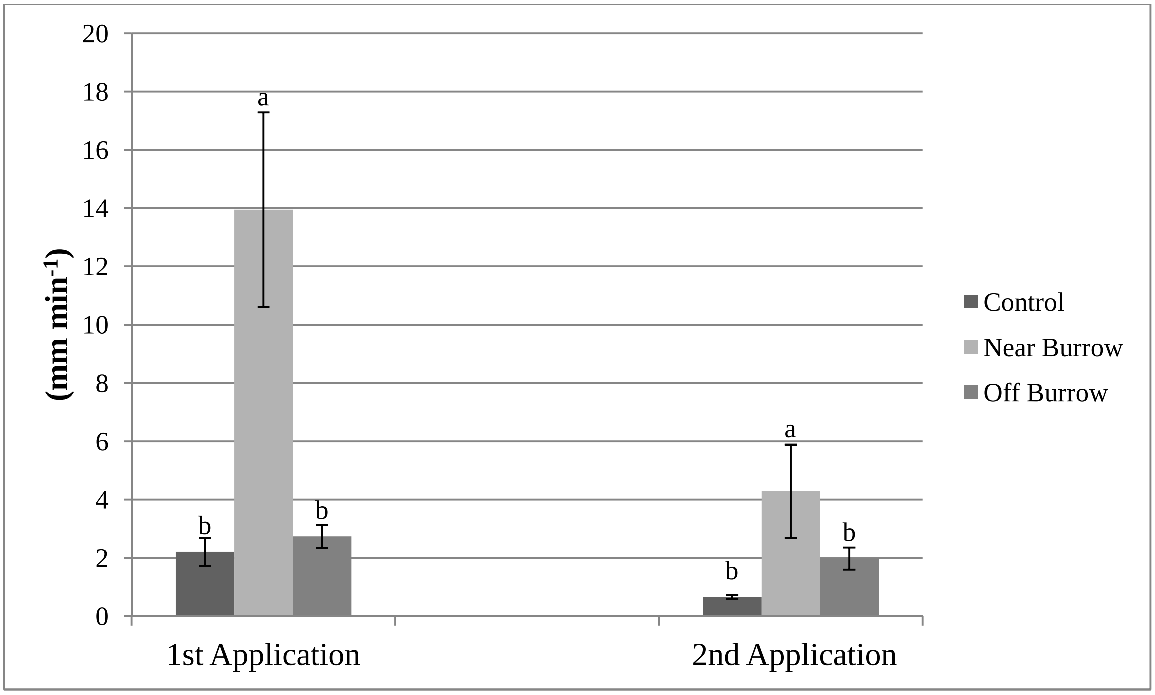

Figure 3.3. Infiltration Rate (mm/minute; ± SE) by treatment for the Wayden Soil Series near McLaughlin, SD, July 2011. Values within application with the same letter (a,b) are not significantly different (P>0.05).

Penetration resistance was higher on the Control (P=0.0001) and off burrow (P=0.0001) sites compared to the near burrow site on the Opal soil series (Figure 3.5). Similarly, the Cabba soil series with the Control (P=0.0001) and off burrow (P=0.0001) sites required more energy to penetrate into the soil than the near burrow site. On the Wayden soil series, the Control had a higher penetration resistance than both the off burrow (P=0.001) and near burrow (P=0.0001) sites, while the off burrow site had a higher penetration resistance (P=0.0002) than the near burrow site.

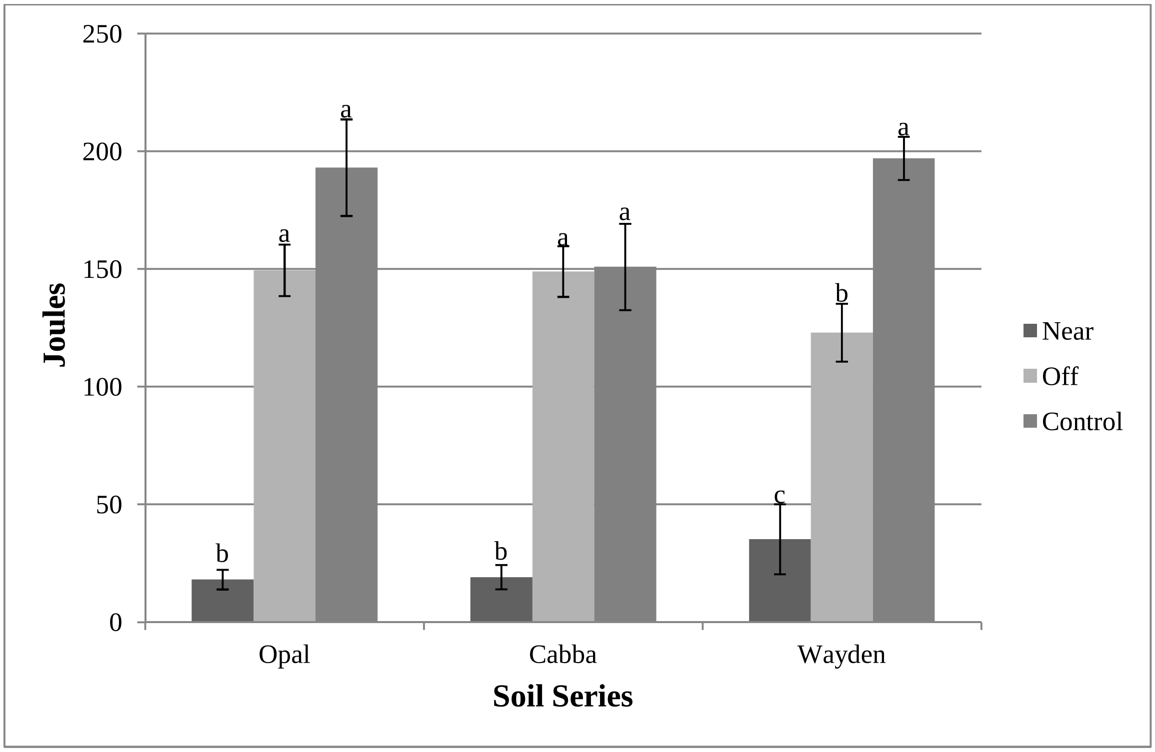

Figure 3.4. Penetration resistance (Joules; ± SE) by treatment for the Opal, Cabba, and Wayden soil series near McLaughlin, SD, July 2011. Values within soil series with the same letter (a,b) are not significantly different (P>0.05).

Discussion

The near burrow site had a faster infiltration rate than both the off burrow and Control sites on the Cabba and Wayden soil series for the first water application. For the second water application, the near burrow site on the Wayden soil series had a higher infiltration rate than both the off burrow and Control sites. Higher infiltration rates were observed near the burrows of ground squirrels (*Spermophilus townsendii* and *Spermophilus elegans*) in southeastern Idaho (Laundre 1993) and pocket gophers (Geomyidae) in northeastern Colorado (Grant et al. 1980) compared to adjacent non-burrow sites. The higher infiltration rates found on the PDTs near the mound was likely facilitated by the loose friable soil condition characteristic of recently deposited soil material (Turner et al. 1973).

Wood et al. (1987) determined that infiltration rates are influenced by soil texture, soil bulk density, vegetation cover, and soil organic matter, with the vegetation cover being most significant. Vegetation slows runoff rates and keeps the water on the soil longer allowing it to infiltrate into soil. With burrowing mammals, there is a possibility that their burrowing activities may lower the soil bulk density on the mound soil associated with the burrows, which also could contribute to increased infiltration rates (Kerley et al. 2004). On the Wayden soil series, the near burrow site was able to take in water more effectively than the off burrow and control sites as indicated by the faster second water application. Since vegetation cover is decreased on prairie dogs towns, this increase in infiltration rates could help reduce runoff and erosion. However, a larger scale landscape assessment should be conducted to more thoroughly evaluate impacts of water movement and erosion on the PDT.

Grant et al. (1980) found higher infiltration rates associated with the mound soils of pocket gophers, though volumetric soil water content was not different between mound and non-mound soils. In our study we measured the gravimetric soil water content and found treatment effects at two locations. The water content was lower on the near (0.11 g g^{-1}) and off burrow (0.12 g g^{-1}) sites than on the Control (0.15 g g^{-1}) for the Cabba soil series. On the Wayden soil series, gravimetric water content for three sampling locations were different, with the near burrow having the lowest (0.07 g g^{-1}) and Control (0.13 g g^{-1}) having the highest soil water content.

The amount of energy needed to penetrate the soil was lowest near the burrow for all soil series; however, penetration resistance on the Opal and Cabba soil series was not different between the off burrow site and the Control. On the Wayden soil series, more energy was required to penetrate the soil on the Control site compared to the near and off burrow sites. This measurement served as a surrogate for soil compaction, with the more physically resistant soils being more compact (Herrick and Jones 2002). A reason for the near burrow sites having a lower penetration resistance is due to the looser more friable soils found in the mounds (Turner et al. 1973). Gifford et al. (1977) found increases in soil compaction were associated with lower infiltration rates. Our findings were similar for the Wayden soil series with the water infiltration rates highest near the burrow site, which corresponded with the near burrow site requiring less energy to penetrate the soil.

Summary and Conclusions

The objectives of this study were to evaluate the differences in infiltration rates between prairie dog colonies and adjacent non-disturbed sites. There were no differences in water infiltration rates and gravimetric water content on the Opal soil series. Soil infiltration rates were higher at the near burrow sites, while gravimetric water content was higher on the Control sites for both the Cabba and Wayden soil series. Penetration resistance was lowest among sites near the burrow on all three soil series.

Soil infiltration rates were highest when compaction was low, especially on shallow soils. Prairie dogs effectively increased soil infiltration rates near burrows, which incorporated the mound spoil. Due to the burrowing activities of the prairie dogs, the soil around the mounds is more friable than non-mound, which aided in increasing the soil infiltration rates.

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CHAPTER 4. GENERAL SUMMARY AND CONCLUSIONS

The main objectives of this study were to 1) evaluate differences in vegetation species diversity and richness and determine differences in selected soil quality parameters between prairie dog colonies and adjacent non-disturbed sites, and 2) evaluate differences in soil water infiltration rates between prairie dog colonies and adjacent non-disturbed sites. In 2010, plant species richness was lower on the prairie dog town for the Opal soil series and higher on the prairie dog town on the Cabba soil series. Plant diversity was higher off of the prairie dog town on the Opal soil series in 2010 and 2011 and on the Wayden soil series in 2010.

Soil type was found to have an overriding influence on differences observed between treatments. The clayey soils (Opal and Wayden) tended to have a lower CEC on the PDT, which was derived by differences in exchangeable calcium. On shallow soils (Cabba and Wayden), total nitrogen was higher on the PDT, which in turn influenced the C:N which was higher on the control. Soil pH was lower on the PDT in the deep clayey soil (Opal) on the surface (0-10 cm) and at the deep depth (60-100 cm), and in the shallow loamy soil (Cabba) in the middle depths (10-30 cm). Ammonium was higher on the PDT in the deep clayey soil (Opal) in the surface soils. Nitrate and phosphorus was higher on the PDT in all three soil series near the soil surface. The differences found between soils on the prairie dog burrow soils and those off the burrows could influence the restoration of the vegetative plant community once prairie dogs are no longer on the landscape. Patches will exist in the community corresponding to mound locations, and these patches will be characterized by increased nutrient availability and lower soil pH.

There were no differences in soil water infiltration rates and gravimetric water content on the Opal soil series. Infiltration rates were higher at the near burrow sites, while water content was higher on the control sites for Cabba and Wayden soil series. There was lower penetration resistance, which served as a surrogate for soil compaction, near burrows on all three soil series.

Infiltration rates were highest when compaction was low, especially on shallow soils. Prairie dogs presumably increase infiltration rates through their burrowing activities, which incorporated the mound spoil and was characterized by low penetration resistance. Accordingly, prairie dogs seem to have an overwhelming effect on soil structural attributes near burrows. However, infiltration rates are influenced not only by prairie dog activities, but also inherent soil properties that vary by soil type.