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Grazing Strategy Effects on Utilization, Animal Performance, Aboveground Production, Species Composition, and Soil Properties on Nebraska Sandhills Meadow

by

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Grazing Strategy Effects on Utilization, Animal Performance, Aboveground Production, Species Composition, and Soil Properties on Nebraska Sandhills Meadow

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Ultrahigh stocking density (a.k.a., mob grazing) is proposed as a management tool that results in greater harvest efficiency, animal performance, aboveground plant production, species richness, and soil carbon content. The study objective was to determine grazing treatment, haying, or non-defoliated control effects on forage utilization, aboveground production, animal performance, and soil properties. In 2010, 25 ha of Sandhills meadow were divided into 2 replications of 3 grazing, a hay, and control treatment. Grazing treatments were a 120-pasture rotation with one grazing cycle (mob), a 4-pasture rotation with one cycle (4PR1), and a 4-pasture rotation with two cycles (4PR2) at stocking densities of 225,000, 7,000, and 5,000 kg ha^{-1}, respectively. Pastures were stocked by yearling steers (365 kg) at 7.4 AUM ha^{-1} from May to August in 2010 to 2017. Hay was harvested annually in July. Control plots were not defoliated. In grazed treatments, aboveground biomass was clipped at ground level to estimate utilization after grazing periods (24 hours, 10 and 15 days,). Aboveground biomass was clipped at ground level annually within experimental units in mid-August. Species composition was determined annually in June. Soil cores were taken in 2010 and 2018 at 0-10 cm and 10-20 cm depths. Utilization in grazed treatments differed by treatment. Mob utilization and trampled vegetation was highest followed by 4PR1 and 4PR2. Harvest efficiency did not differ by treatment. Residual standing live herbage had a treatment by year interaction where mob was usually lowest and 4PR2 was usually highest. Aboveground production did not differ among grazing and hay treatments but was greater for grazed treatments than control. Animal performance differed by treatment and year with steers gaining more in 4PR2 than the other treatments. Cool-season grasses decreased in control but increased in grazed treatments. Warm-season grasses decreased in control and were unchanged in grazed treatments. Prairie cordgrass and white clover were affected by treatment. Soil carbon, nitrogen, and bulk density did not differ among treatments. We concluded that management strategy was a driver of utilization, animal performance, and species composition. After 8 years, mob grazing was not a driver of aboveground production or soil property changes.

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Introduction

The Nebraska Sandhills are known for their ability to support a wide variety of ecosystem services, including ranching operations, wildlife, and recreation. Throughout the history of the Nebraska Sandhills the methods used to manage its resources have changed to allow for higher efficiency and productivity of rangelands. What long ago was open range, shared by everyone who wanted to use the resource, is now partitioned and privately owned. Privately owned grazing lands have led to different methods of resource utilization. Managers of rangeland systems adapt management for multiple outcomes within the social-ecological systems in which they are embedded (Lubell et al. 2013). In the Sandhills the forage resources are used primarily for beef cattle grazing and for hay. There are several grazing methods used by producers, which range from season-long continuous grazing to management-intensive grazing. Ultimately, the grazing strategy that is used often is dependent on the desired effects and preferences of the land manager (Augustine and McNaughton 1998).

The challenge in grazing management is to balance grazing intensity and post defoliation production to sustain total forage production for future grazing (Heitschmidt et. al 1990, Norton et al. 2013). This challenge is met with different strategies of managing a grazing system with the ultimate goal of positively balancing forage resources and animal production (Briske et al 2008). Continuous grazing is an extensive management strategy in which livestock remain in a single pasture throughout an entire grazing season, usually from late May until the end of the growing season, while a spectrum of rotational grazing systems include intensive to extensive management approaches. Simple rotational systems can require more or less management depending on management objectives and the variant of rotational system that is being applied. Simple systems may have four or pastures or more through which livestock are rotated during the grazing season often with the goal of increasing efficiency, grazing distribution, and plant production. Rotational grazing was developed in response to degradation of rangelands in the U.S in the late 19th century (Briske et al. 2003; Briske et al. 2008; Briske et al. 2011; Smith 1895) and is still used by managers today to reduce the amount of time livestock spend in a pasture and to improve distribution over a management unit for higher harvest efficiency. Ultimately, rotational grazing increases recovery time, utilizes plants at different times of the year allowing for more undisturbed growth, and increases even use for better harvest efficiency.

Use of grazing methods characterized by multiple pastures and a high level of management intensity are at the other end of the spectrum. Short duration grazing (SDG) is a management-intensive rotational grazing method developed in the 1960's in Africa (Goodloe 1969). SDG has been claimed to be an advantageous system in areas that have relatively flat topography and humid climates (Holechek et al 1999). Studies with positive effects tended to have higher mean annual precipitation, indicating that SDG is more suited to areas with moderate to high rainfall (Hawkins 2017).

Short duration grazing was claimed to increase forage production and range condition because of improved spatial distribution of grazing, ultimately increasing soil health and diverse plant communities. Evidence to the contrary was noted by Dormaar et al. (1989) where stocking rates were tripled in a 17-pasture SDG system and resulted in degradation to range condition, increased soil bulk density, and incorporated less litter into the soil by hoof action; whereas, protection by exclosure resulted in improvement. Briske et al (2011) summarized 25 SDG and rotational system experiments in which only 3 of the rotational experiments resulted in an improvement of species composition. Hawkins (2017) indicated that stocking rate was a more influential factor in terms of positive response on rangelands than any other factor affecting rangelands.

Short duration grazing is often associated with Savory's cell grazing system. In these systems, even use was to be achieved during relatively short grazing periods followed by longer non-grazing periods that allowed plants to recover without being defoliated by animals again until the next grazing period (Savory and Parsons 1980). Grazing livestock at ultrahigh stocking densities (a.k.a mob grazing) is a SDG method. Mob grazing requires a stocking density ranging from 200,000 kg liveweight ha^{-1} to 1,000,000 kg liveweight ha^{-1} (Redden 2014).

Level of management intensity is important to consider when looking at different types of grazing systems. Management intensity takes into account the infrastructure, labor, and level of human control in the system. From a continuous stocking system to a more management intensive grazing system, the level of input (e.g. labor and infrastructure) costs also increase and ultimately affect the potential economic advantage (Heitschmidt et. al 1990).

Continuous season-long stocking requires no cattle movements through the season so labor, fencing, and water development input costs are relatively low. When comparing a rotational grazing to the continuously stocked system, fencing requirements could be quadrupled or more as the level of cross fencing increases depending on the number of pastures. The less sophisticated efforts needed to implement less intensive systems must be weighed against the increased infrastructure of rotational systems (Teague et al. 2013). At the highest level of management intensity (a.k.a mob grazing), fencing, water, and labor are the components to consider due to the level of human presence needed to manage the system compared to the more extensive systems.

With the addition of management intensive practices, greater harvest efficiency should be expected and forage production may increase if that practice has resulted in a plant community in a higher more productive ecological state. With continuous extensive management and proper stocking rates, level of animal performance is expected to be greater per animal (McCollum and Gillen, 1998), but lower per unit area. This is due to lower grazing pressure, relatively low harvest efficiency, more preferred plant selectivity (patchiness), and grazing vegetative plants multiple times. Selectivity and grazing vegetative growth from previously grazed plants allows for the animal to consume the most energy and nutrient dense forage available at the expense of plants and likely alters competitive interaction within the plant community (Chapman et al. 2007, Anderson and Briske 1995). The inverse is true as the level of management intensity increases, grazing pressure increases and selectivity opportunity declines causing animals to consume more forage that is likely of relatively lower nutritional value.

The fixed cost of fencing and livestock water development can be cost shared with government agencies making them a more viable and cost-effective option for producers with the claimed goal of environmental conservation and increased efficiency. Cross fencing cost associated with implementing a higher level of intensity in rotational systems can take several years to pay off or breakeven even with government subsidies and when considering long-term maintenance costs. This increased breakeven would require stocking rates to increase in order to justify the added costs (Knight et al. 2011, Barnes et al. 2008). As such, land managers have implemented variants of mob grazing systems because of its claimed potential to increase forage production while increasing animal production and income (Savory and Parsons 1980, Gompert 2010).

Elements of Grazing

Primary Production

Primary production of plants includes all plant production in the above and belowground portions of the plant. Aboveground plant production is important to grazing livestock because it is the amount of vegetation that is available for use by grazing animals as forage, and is directly related to carrying capacity. Aboveground plant production can be influenced and manipulated (Holechek et al. 2011) with the use of different grazing systems. Root mass, branch number, vertical and horizontal root distribution, and root longevity all may be reduced by chronic, intensive defoliation (Hodgkinson and Becking 1977). This, in turn, will negatively affect aboveground production.

Elements of grazing that affect production include utilization, harvest efficiency, stocking density, grazing pressure, stocking rate, carrying capacity, spatial distribution of grazing, and timing and frequency of grazing. Manipulating some elements of grazing that increase grazing severity have generally shown a decrease in primary production when compared to non-grazed communities (Milchunas and Lauenroth 1993). Many environmental factors also affect primary production including precipitation, temperature, species composition, soil quality, nutrient availability, pests, and other natural disturbances. But, by in large the most influential factor affecting primary production in perennial grasslands is the annual amount and growing season distribution of precipitation (Milchunas and Lauenroth 1993, Patton et al. 2007).

Botanical Composition

The types of plants being utilized must be considered because the wide range of range plants have different growth habits, potential level of biomass production, stages of growth, and grazing tolerance. Commonly grazed plants on rangelands consist of warm-season grasses, cool-season grass, forbs, and shrubs. A shift in botanical composition could occur due to growing conditions, management, or grazing strategies that favor one functional group or species over another. These changes are not likely to take place quickly. While some botanical changes take place within 2-5 years, many changes take place over 5-10 years, and some only after at least 10 years (Jones et al. 1995). In a 8-year study conducted in the Nebraska Sandhills, an increase of 42% in prairie sandreed was found in a deferred rotation grazing strategy compared to SDG (Stephenson et al. 2013). Cool-season needle grasses (*Heterostipa spp.*) were found to initially nearly double within 5 years of the study but after 10 years no difference could be detected in frequency of occurrence between grazing strategies. These results suggest that response to grazing strategies is dependent upon topography, plant species, and year (Stephenson et al 2013).

Increasing the availability and cycling of limiting nutrients on range and pasture releases forage plants from nutrient restriction that inhibits potential growth. Concentration of nutrients in the soil such as nitrogen (N) and Phosphorus (P) could favor one functional group over another. The application of P to soil may increase legume biomass whereas N application has the potential for greater biomass of grasses (Aydin and Uzun 2005). Different grazing strategies can have an effect on the spatial and temporal distribution and concentration of post-grazing trampled vegetation, residues, and nutrients. It could be inferred that the distribution pattern of nutrients through dung and urine would follow the spatial distribution of grazing.

Grazing strategies that promote uneven distribution of grazing in large areas such as continuous stocking can degrade pastures and shift botanical composition and patchiness; grazing strategies with rest and rotation deter overuse and potentially avoid species composition changes (Teague and Dowhower 2003). Accelerated N cycling from urine and fecal patches will result in higher N in plant tissue. Higher N in plant tissue results in greater likelihood of an area being grazed again and receiving additional animal excreta inputs into soil in that area (Frank and Groffman 1998). Animals revisiting theses patches lead to continual degradation that results in taller perennial species being replaced by shorter perennial species, then replaced by annual grasses, and finally bare ground (Milchunas and Lauenroth 1993; Archer & Smeins 1991).

Utilization

Utilization is the amount of live vegetation biomass that is destroyed or consumed (disappears) in the grazing process. Disappearance can be from livestock consumption, trampling, weathering, fouling, senescence, and consumption by insects and wildlife (Smart et al. 2010); therefore, utilization is usually greater than consumption by livestock alone (Van Dyne and Meyer 1964). Wildlife that heavily utilize grazing resources can be a hindrance to collecting accurate livestock utilization data. Consumption or destruction of forage by insects and wildlife can be a considerable portion of the removed material from a grazing site. Insects can overgraze ranges more severely than domestic livestock and can destroy plant roots, reduce nutritional value, palatability, and destroy seed in severe cases (Holechek et al. 2011).

Forage plants respond differently to different levels of utilization and intensity and can have a positive response when rest and recovery periods between defoliations are increased in length. Large herbivores, particularly livestock, can induce a growth response by plant communities where low levels of herbivory can increase production and high levels of herbivory can decrease production (Patton et al. 2007). Owen (1998) reported that removing more than 50-70% of leaf and stem material can cause plant roots to shrink and die. Volesky et al. (2011) also reported a reduction in root mass associated with frequent defoliation of slender wheatgrass on Sandhills meadow. NRCS (2004) reports that removal of aboveground biomass at 60 to 90% in 50 to 100% cessation in root growth.

The physiology of grazed plants requires sufficient leaf area for photosynthesis and can be measured using leaf area index (LAI). In lightly grazed swards, LAI, photosynthesis, and plant production are at greater levels than for severely grazed swards (Parsons et al. 1983). In general, high grazing intensities coupled with multiple defoliations, have a negative effect on production and community structure because of reduced leaf area (Milchunas and Lauenroth 1993, Oesterheld and McNaughton 1991, Porensky et al. 2017, Pizzio et al. 2017).

Growth stages of plants include germination, vegetative, elongation, reproductive, and seed ripening. The vegetative stage refers to the developmental period comprising leaf growth and development (Moore et al 1991) prior to stem elongation and rapid growth. In the vegetative stage grass plants have the highest likelihood of recovering from herbivory. Once the onset of the elongation stage occurs, the apical meristem has been elevated, is susceptible to removal, and the tiller/plant is less likely to rebound from defoliation or damage caused by grazing (Machinski and Whitham 1989).

Harvest Efficiency

Harvest efficiency is important to livestock producers since range and pasture are often the major or only resource of forage supply in their operations. Harvest efficiency is the proportion of the aboveground biomass that is consumed by the grazing animal in comparison to the total amount of forage that is produced (Smart et al. 2010). Utilization and harvest efficiency are directly related to each other since harvest efficiency is the portion of live plant material that is consumed rather than destroyed or left standing. With a high harvest efficiency, forage removal would increase to allow a producer greater output and ultimately increase revenue in the short term. However, there is a point at which the return of greater harvest efficiency begins to diminish. Harvest efficiency generally increases with increasing grazing pressure but a severe increase in grazing pressure can result in the portion of destroyed, trampled, or fouled vegetation to increase (Quinn and Hervey 1970) resulting in a decline in consumption and harvest efficiency. This increased grazing pressure has negative effects on animal performance and production (Derner et al. 1994 and 2008, Hart and Ashby 1998; Manley et al. 1997, Smart et al. 2010). Repeated extreme utilization of forage plants over time coupled with less than adequate recovery periods can shift plant communities to less productive and less desirable plants such as forbs for consumption by cattle (Patton 2007). This will ultimately decrease carrying capacity for cattle.

Distribution of Grazing

Distribution of grazing effects utilization and harvest efficiency. Uneven distribution can affect utilization by allowing grazing animals to select certain plants more than others as described previously. This effect on utilization can cause plants and areas that are less desirable to livestock to flourish while other plants and areas become overused. This preferential use of specific patches results in uneven animal distribution, which inadvertently increases the stocking rate on preferred patches compared to the entire management unit (Fuhlendorf and Engle 2004). Depending upon the management goals (i.e. wildlife vs. animal production) even or uneven use could be desirable.

In a simple grazing system, uneven distribution can be prevented by decreasing the distance to water (Hart et al. 1993), adding mineral or a supplement to areas that are less frequently visited (Bailey and Welling 1999, Bailey 2004), and decreasing distance to shade. These methods are a good way to mitigate underuse of certain areas and can be implemented by manipulating pasture size, number of animals, and use of fencing on ecological site boundaries. These methods increase harvest efficiency while keeping stocking rate static.

In an ultra-high stocking density system, distribution is very even and a very high percentage of plants in a pasture are utilized, either consumed or trampled. Whereas in a system with relatively low stocking density, such as a simple rotational or continuous stocking, an uneven distribution is expected. Greater utilization does not always mean greater efficiency because utilization refers to two components, trampling (not directly used by the grazing animal) and consumption (directly consumed by the grazing animal). Depending on the growth stage of plants their susceptibility to trampling and damage can vary. As explained previously harvest efficiency is the ratio of consumed forage to total available forage, decreasing selectivity and creating an even distribution of grazing would increase harvest efficiency depending on the plant maturity and characteristics of the plants in the community.

Grazing Pressure

Instantaneous grazing pressure is a measure of animal live weight in relation to the amount of forage available at one point in time. Grazing pressure can be expressed as animal units (demand) per unit weight of forage (supply) (AU/T). Cumulative grazing pressure is the animal unit demand per unit weight of forage over a specified time period. Animal performance and utilization can be affected by changing grazing pressure. An increase in grazing pressure beyond a certain threshold has been found to lead to a decrease in animal performance (Derner et al. 2008; Manley 1997). Intake per animal is also affected by grazing pressure due to the increase of animals per unit of available forage. Smart et. al (2010) reported that there is a peak grazing pressure at which intake is greatest, after which intake per animal begins to decline. Harvest efficiency generally increases with increased grazing pressure; the increased harvest efficiency results in increased animal weight gain per acre but a decrease in animal performance (e.g. average daily gain (ADG)) (Smart et. al 2010).

Stocking Density

Stocking density is the amount of animal unit (weight) per unit area at one point in time (i.e. AU/ha); it is an instantaneous animal-to-land relationship (Allen et al. 2011). Stocking density is directly related to grazing pressure. Hickman et al. (2004) stated that results from comparing late season rest rotation to continuous season long grazing systems indicated that stocking density can influence species diversity (number of different species) and composition (relative amount of each species) whereas grazing system had a much smaller, if any effect on plant community structure.

Literature has also indicated that increasing stocking density increases forage utilization and improves spatial distribution of grazing that would allow an economic benefit to be possible with a sustainable stocking rate (Barnes et al. 2008), which can vary depending on several factors such as temperature and precipitation. However, there are tradeoffs with animal performance since grazing pressure decreases the total amount of quality forage available per animal and diet selectivity decreases due to increased grazer competition and trampling losses (Quinn and Hervey 1970).

Carrying Capacity

The carrying capacity of a land area is referred to as the maximum number of animals an area can support over a time period without degrading the land resource (Allen et al. 2011). Carrying capacity, like stocking rate, can also be over or under estimated and can result in an over or under abundance of forage availability. Over time carrying capacity can also change. As mentioned previously, plant community degradation caused by overuse results in lower potential production of vegetation as well as livestock production potential (Milchunas and Lauenroth 1993, Oesterheld and McNaughton 1991). Good management practices such as proper distribution, rotation, moderate use, and non-grazing periods are all factors that allow carrying capacity to remain the same or increase (Jacobo et al. 2006).

Avoiding degradation to land is the main reason that a carrying capacity is established. Establishing the carrying capacity is accomplished by taking quantitative measurements of grassland production and using them to find an average level of production. Production can also be estimated based on regional data or records for the plant community (Sedivec and Printz 2014). The establishment of the carrying capacity allows the land manager to have a constraint to work within when setting stocking rates and making other management decisions pertaining to forage removal on an annual basis.

Stocking Rate

Stocking rate can also be referred to as the animal demand per unit area per unit time. Stocking rate is commonly put into units of Animal Unit Months (AUM) per ha or Animal Unit Days (AUD) per ha. Forage supply is commonly measured in similar units where one AUM is the equivalent to a commonly used percentage of live weight of 2.3% (310 kg oven dry per AUM, 353 kg air dry per AUM) (Carter 2007). An AUD would then be equivalent to 10.4 kg oven dry and 11.8 kg air dry. The stocking rate is an important element of grazing because its effect on total forage removal and animal performance and has emerged as the most consistent management variable influencing both plant and animal responses to grazing (Briske et. al 2008). Stocking rate selection is the most important management decision for a grazing system according to Holechek et al. (2004).

Stocking rate is commonly adjusted by land managers according to management objectives and practices. Adjustments are often based on environmental factors affecting production such as drought. A change in stocking rate changes the total expected removal of forage in an area because stocking rate determines the forage demand placed on a unit of land. Holechek et al. (1999) defines varying levels of stocking rate, with heavy stocking as a degree of herbage utilization that does not permit desirable forage species to maintain themselves. Moderate stocking is a degree of herbage utilization that allows the palatable species to maintain themselves but usually does not permit them to improve in herbage producing ability. Light stocking rate was defined as a degree of herbage utilization that allows palatable species to maximize their herbage producing ability.

Major vegetation components, including forbs, decline as stocking rate increases and a higher number of animals causes an increase of total forage consumption (Gillen et. al 1998). When comparing high and low stocking rates on mixed grass Wyoming range, Schuman et al. (1999) found a decrease in standing crop of desirable species and an increase in less desirable species such as blue grama (*Bouteloua gracilis*).

Animal performance goals are affected by stocking rate. If a stocking rate is set above carrying capacity, nutrient intake of grazing animals will be less than optimal or required. The greater the stocking rate is set above carrying capacity the greater the decline in performance of animals. Hart et al. (1988) investigated low, moderate, and high stocking rate systems and average daily gain of steers remained high and constant at low stocking rates, then declined at high stocking rates. Derner et al. (2008) also reported that ADG was reduced substantially when a heavy stocking rate is used compared to light and moderate stocking rates in the same grazing system, with moderate stocking rates having the most optimal gains. High utilization associated with higher stocking rates results in degradation of desirable plant communities with a decrease of desirable plants and an increase in less desirable plants; ultimately carrying capacity and livestock production decline. Conversely, as stocking rate decreases below the available amount of forage, the animal's performance is positively affected because there is an adequate amount of nutrition available (Patton 2007).

Timing and Frequency

Rangeland perennial plants are adapted to their environment including the environment's annual cycles. In temperate climates, each plant's annual cycle has a series of growth stages it goes through and then a dormant period. During the vegetative period, perennial grasses begin their growth of tillers with energy reserves that were stored in the previous growing season. Emerged tillers and their leaves photosynthesize and continue to grow with energy they are producing from nutrient uptake and photosynthesis. The leafy vegetative tillers have a high content of cell solubles and are highly palatable to grazing livestock (Holechek et al. 2011). Over the growing season the maturity of plants change in their vegetative and nutritional characteristics (Karn et al. 2006). Onset of plant maturity can be delayed when the plant is grazed during vegetative. However, Jung et al. (1985) noted that forage quality decreased throughout the growing season when comparing continuously-stocked to SDG pastures.

The timing and frequency of grazing during the annual growth cycle has an effect on the plant's ability to store energy, reproduce asexually, and produce seed. When plants are grazed in a vegetative state at the beginning of the grazing season they have plenty of time to store energy before the onset of dormancy. Being grazed in a vegetative stage helps plants to increase tillering and any possible compensatory growth (Oesterheld and McNaughton 1991). Regrowth after being grazed in a reproductive stage takes much longer than from a vegetative state (Holecheck et al. 2011) because removal of the elevated apical meristem is located at or near ground level making it less accessible to grazing animals and less likely to be damaged slowing the growth of the plant (Hyder 1972). The energy storage of nonstructural carbohydrates that plants have going into the dormant season will affect their respiration, winter growth, spring growth, and ability to grow rapidly with the use of stored nonstructural carbohydrates. Root mass and growthand storage of carbohydrates are directly related to grazing intensity (Launchbaugh 1957; Engel 1998; Briske et al. 2008).

Owensby (1977) found that for any stocking rate in an intensive early grazing system, no grazing from mid-July to frost likely allows for sufficient time to store adequate food reserves for vigorous growth the following spring in tallgrass prairie. Toward the middle to the end of the growing season many plants are in their reproductive stages and have produced or are producing seed. At the same time, plants that remained vegetative through the growing season prepare for dormancy by also sending energy into the root reserves. During the dormant period the plants basal metabolism allocates just enough energy to keep it from freezing until the next growing season and any grazing that takes place has little or no effect on plant growth (Willms et al. 1986).

Frequency of grazing studies all indicate a longer recovery period after grazing will result in a more positive response in terms of rate of regrowth (Hibert et al. 1981, Osterheld and McNaughton 1988, and Machinski and Whitham 1989). Grazing is not likely to cause a large amount compensatory regrowth. But, the return interval (recovery period length) associated with different grazing systems plays a large role in the potential amount of vegetative regrowth that can occur (Osterheld and Mcnaughton 1991).

Forage Quality

Forage quality plays an important role in animal performance in terms of average daily gain and reproductive performance. The nutrient content of plants is dependent upon the characteristics and maturity of the plants. Material such as cellulose, hemicellulose, lignin, and secondary compounds contribute to the quality or digestibility of plants (Van Soest 1982). Tissues with the highest soluble to structural ratio typically possess the highest forage quality and are often the most preferred by grazing animals. Secondary compounds function to reduce forage quality of both herbaceous and woody dicots, but are generally less important in deterring herbivory in monocots (McNaughton 1983). The forage quality of tender, less mature forage plants leads to increased consumption of those plants over other more fibrous mature plants creating a patchwork of different levels of utilization across a landscape. Within a pasture variability of forage quality causes the frequent occurrence of patch grazing where animals repeatedly graze the same area to optimize energy and nutrient intake per unit plant biomass even though total biomass may be substantially lower than in less frequently grazed patches (McNaughton 1984). Subsequently, the design of a grazing system relative to manipulation of grazing pressure and grazing frequency are principal drivers of forage quality. In general, long recovery periods and low grazing pressures allow plant tissues to mature and forage quality to decrease compared to more frequent grazing intervals at high grazing pressures (Briske et. al 2008).

Animal Performance

Grazing animal performance can be measured by the amount of weight an animal gains over a period of time (ADG). Performance can also be measured in other terms such as conception rate or body condition depending on objectives of the livestock operation. In terms of range resources forage quality and availability are the two key factors affecting performance of grazing animals. Secondarily, factors that affect forage quality and availability such as stocking density, grazing pressure, and stocking rate in turn also affect the animal production and performance potential. Stephenson et al. (2013) noted in a comparison between a deferred rotational system and SDG over 8 years that there was no difference in animal performance (ADG) between grazing strategies when stocking rate was constant. Other research suggests that there is a negative response in terms of animal performance (ADG and conception rates) in management intensive systems (Manley 1997, Badgery 2017).

Soil Physical and Chemical Properties/Processes in Response to Grazing

Grazing activities, plant growth, and microbial processes have a major impact on soil functions or processes. Above and belowground processes contribute to the pool of available nutrients for growth and C that is stored in the soil. Nutrients (e.g. N and P) cycle through soil, plants, and animals. This cycling is often accomplished through plant litter deposition above the soil surface, root death, sloughing, rhizodeposition, and mucilage production below the soil surface (Van Veen et al. 1991, Reeder et al. 2001). The process of incorporating aboveground material into the soil is sped up when plant material is trampled to the soil surface and/or excreta such as dung or urine, are deposited by grazing animals (Berg et al. 2003, Janzen et al. 1998). By increasing the decomposition rate of plant material and disturbance of the soil surface, habitat for soil microbiota and conditions affecting microbial processes such as aeration limitation, redox, and water filled pore space are influenced (Wakelin 2009). Grazing management strategies have the potential to sequester large amounts of carbon is (Conant 2017, Smith et al. 2008, Lal 2008).

Perennial grass fibrous root growth, senescence, and exudates are a major contributor to the organic matter content and nutrients in the soil (Reeder et al. 2001). Soil fauna and microbial activities play major roles in nutrient cycling and carbon (C) storage by breaking down plant material in the soil and subsequently releasing plant nutrients.

Stored C primarily comes from plant roots, litter, and excreta and can be stored in several forms (Hanson 2000). Soil organic matter is a key component of C storage and an estimated 58% of total SOM is comprised C (Nelson and Sommers 1996). Some C is not bound in the soil and can easily be lost as gas during respiration in the soil (Hanson 2000). Some C is not easily accessed by soil microbes and gets partitioned and somewhat encapsulated or protected in the soil which is stable there, potentially for thousands of years (Jenkinson 1990). It is protected in several ways. First biochemically by binding with clay and silt particles, complex chemical structures that cannot be easily broken down. Secondly, they are protected by physical inaccessibility from soil microbes (Jones and Donnelly 2004).

Nitrogen (N), which is often a limiting nutrient in rangelands, is cycled through the soil and made available for plant uptake once organic matter is mineralized by microbes (Bolan 2004). Excreta deposition has the ability to increase N mineralization twofold when compared to non-grazed grassland (Frank and Groffman 1998). Over a period of 12 years of livestock grazing, in Wyoming, with three different stocking rates in continuous systems, the enhanced transfer of litter C and N into the soil had resulted in a significantly higher accrual of C and N in the top 20 cm of the soil profile of the grazed treatments than in exclosures (Schuman et al 1999 and Reeder and Schuman 2001).

Grazing lands are estimated to contain 10–30% of the world’s soil organic C (Schuman et al 2002, Derner and Schuman 2007). Proper grazing management has been estimated to increase total soil C storage on rangelands from 0.1 to 0.3 Mg C ha $^{-1}$ year^{-1}, new grasslands have been shown to store as much as 0.6 Mg C ha^{-1} year^{-1}, and improved pastures up to 1.4 Mg C ha $^{-1}$ year^{-1} in the top 30 cm of soil (Schuman et al 2002). Soil C storage is variable between semi-arid and sub-humid sites though. In semi-arid environments soil C was found to be higher under grazed treatments and lower under non-grazed treatments; whereas, the trend sub-humid climates was the reverse (Henderson 2000). Precipitation and temperature are the primary drivers of potential for increased soil C accumulation.

Grasslands play an important role in C sequestration and can have double the amount of C storage compared to cropland (Franzluebbers 2005). Once litter and dead plant roots have been introduced into the soil profile, C can then be stored in various forms some of which are protected and less likely to be removed from the soil while others are unprotected and likely to mobilize and be removed (Hanson 2000). The rate of photosynthetic C assimilation depends on soil fertility, climate, and management, which, in addition to other soil and plant factors, influence rates of C return to the atmosphere (Cotrufo et al. 2015; Prescott 2010; Morgan et al. 2010).

In grasslands, the much of soil organic carbon (SOC) (42%) is stored in the top 20 cm of the soil profile and the amount stored is significantly correlated to climate and soil texture (Jobbágy and Jackson 2000). In a grassland synthesis conducted by Pineiro et al. (2010), SOC was found to increase, decrease, or remain the same under different grazing management. Root contents, which are primary drivers of SOC, were higher in the wettest and driest locations on grazed areas compared to non-grazed areas. Nearly all sites in an intermediate precipitation range (400-850mm) showed decrease or no change in SOC content. Pineiro et al. (2010) also suggested that N is the limiting factor for soil organic matter production in rangeland and can be increased through grazing management aimed at increasing N retention on the landscape.

Soil water availability can be limiting in many range environments. Water is stored in and percolated through the soil and the amount of water is constantly in flux because of precipitation, infiltration, and plant uptake. The ability for plants to access soil water can be inhibited if animal activities on the soil surface such as grazing are too great causing an increase in bulk density depending on the soil type (Daniel et al. 2002; Daddow and Warrington 1983). Soil water was negatively affected by stocking rate when comparing grazed to non-grazed pastures in several experiments compiled by Greenwood and McKenzie (2001). According to Van Havern (1983), significant compaction can also occur at high levels of grazing intensity on rangeland soils. Finer soils in heavily grazed pastures are often more likely to be easily compacted. Warren et al (1986) tested three relatively low stocking densities in comparison to high density systems and found that at a relatively low density of 2.7 AU/ha, a significant decrease in water infiltration rate can occur in wet and dry silty clay soils. Changes in soil bulk density are a result of decreased aggregate stability, biotic crusts, and organic matter content. Animal trampling can potentially break aggregates in certain soils, causing increases in bulk density (Briske et al 2011; Thurow 1991). However, in several experiments, it was found that breaking biological crusts through hoof action in relatively dry sandy soils actually decreases infiltration, inhibits C sequestration, and causes sand to become unstable and erode more easily (Marticorena et al 1997; Barger 2006; Thomas 2012).

Overall, grazing is a net positive effect for grassland plant production and soil function in most cases. Proper stocking rate is the most important factor allowing continual plant productivity. Grazing at the right stocking rate removes and redistributes nutrients needed for plant growth without degradation of individual plants and plant communities. Without grazing, or other forms of defoliation, grasslands can degrade because of accumulation of dead plant material causing slow rates of nutrient return to the soil and a change in the environmental conditions at the soil surface. Rapid rates of nutrient cycling favor nutrient availability and total plant tissue production. The plant-grazing animal relationship influences soil properties and the short- and long-term composition and production of grassland biomes.

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Chapter 1: Utilization and Forage Quality

Introduction

Grazing strategies on grazing lands can be used in several ways and vary depending on the goal of the producer or land manager. Different strategies, stocking rate and timing of grazing, can affect elements of the landscape such as species composition (Stephenson et al. 2013), ground cover, plant functional groups (Teague and Dowhower 2003; Milchunas and Lauenroth 1993), and soil chemical and physical properties (Conant et al. 2017, Lal 2007). Managers are particularly interested in these strategies for optimum use of resources and optimizing profit. The management challenge is to realize optimum forage plant production and even spatial and temporal distribution of grazing so that high levels of forage production efficiency and grazing efficiency are achieved without causing site degradation (Norton et al., 2013). Elements of grazing that are manipulated to optimize plant production and use include timing and frequency of grazing, distribution of grazing, and grazing intensity (including stocking rate and stocking density) (Fuhlendorf and Engle 2004, Bailey 2004). Forage consumption, forage quality, and animal performance and production are also affected by the manipulation of the various elements of grazing.

In the Nebraska Sandhills, the primary goal of most land managers is beef production through the use of various grazing systems (Redden 2014). Types of grazing systems that are used include continuous, simple rotational, and management intensive systems (MIG) (Augustine and McNaughton 1998). Each of these systems use different strategies to influence vegetation, soil, and livestock responses.

With continuous stocking, cattle are present in one pasture for the duration of a grazing season. Continuous stocking employs unrestricted and uninterrupted access to a pasture throughout the growing season (The Forage and Grazing Terminology Committee, 1992). With a proper stocking rate, continuous stocking has been shown to have the most favorable response by cattle in terms of daily gain (McCollum and Gillen, 1998). In season-long continuous stocking, livestock have a tendency to concentrate near water, livestock mineral, shade and areas that offer more palatable or nutritious forage. They also develop well-trodden trails radiating from water points and other favored areas, creating a diverse array of impacts over the landscape. The ultimate expression of livestock behavior in large pastures is uneven distribution of grazing that concentrates grazing pressure in localized areas and leaves the remainder lightly grazed (Norton et al 2013). In most cases less intensive management does little to mitigate problems such as uneven grazing distribution or high levels of animal selectivity on plants. The less sophisticated efforts needed to implement less intensive systems must be weighed against the increased infrastructure of rotational systems (Teague et al. 2013).

As time within a pasture increases, the amount of use or pressure exerted on certain plants becomes greater. Derner et al. (1994) found that as the time spent within a pasture increased the total number of tillers defoliated increased and the total number of tillers defoliated more than once increased. In an attempt to create an index of stocking rates and grazing pressures, Smart et al. (2010) confirmed that as grazing pressure increased utilization increases quadratically at the detriment of cattle average daily gain decreasing linearly. Patterns, levels of use, plant community structure, and ground cover can also be affected and manipulated in a grazing system based on factors distance to water with level of use decreasing as distance to water increases (Hart et al. 1993, Todd 2005, Bailey 2005). Simple rotational and MIG systems commonly are used to avoid multiple defoliations, patchiness, and other negative side effects often associated with continuous stocking. Patchiness is less likely to develop in rotational and MIG systems due to factors that affect grazing distribution and harvest efficiency such as shorter distance to water and increased grazing pressures (Teague and Dowhower 2003) that are commonly associated with these grazing strategies.

Simple rotational and MIG systems require higher amounts of management than continuous stocking. Simple rotational and MIG require varying degrees of complexity including cross fencing, water development, and personnel to move cattle from pasture to pasture (Knight et al. 2011; Barnes et al. 2008). Simple rotational grazing systems are characterized by moving grazing animals through three to six pastures during the grazing season often with only a single occupation in each pasture. Management intensive systems usually have relatively short grazing periods requiring numerous pastures (>6) and/or multiple occupations per pasture during the grazing season (Savory and Parsons 1980). The ultimate goal for rotational grazing systems is to increase plant production and grazing efficiency by manipulation of elements such as stocking rate, timing of grazing, distance to water and shade, and frequency of grazing. These elements can increase harvest efficiency through more even distribution (Smart et al. 2010) and by limiting vegetation overuse and manipulating timing and intensity of use from year to year which would promote productive plants and communities over time.

Ultrahigh stocking density (a.k.a mob grazing) is a MIG grazing strategy used to achieve high utilization while minimizing grazing frequency and maximizing recovery period length (Savory 1980). Ultrahigh stocking density grazing requires stocking densities of 84,000-1,120,000 kg of animal liveweight ha^{-1} in order to achieve even distribution and a high level of utilization (Schmidt 2011). According to several practitioners, mob grazing can be implemented in degraded or low-production areas in order to increase plant production, species diversity, soil productivity through hoof action and trampling, and animal production (Peterson 2014, Gompert 2010, Savory 1980).

Grazing pressure, forage utilization, and animal performance are interrelated. As grazing pressure increases animal performance tends to decline but utilization and animal production per unit area increases (Derner et al. 1994 and 2008, Hart and Ashby 1998; Manley et al. 1997, Smart et al. 2010). Mob grazing is a more extreme expression of increased forage utilization through the means of increased grazing pressure. Often, the objective of mob grazing is to have the grazing animal trample the standing vegetation that is not consumed so that carbon (C) and other nutrients are not sequestered in standing vegetation through the remainder of the growing season. The resulting increased rate of nutrient cycling is to improve soil properties and plant composition and production (Peterson 2014).

The principal purpose of this research was to compare mob grazing, 4-pasture rotational systems, a conventional hay treatment, and a control (not defoliated) in terms of soil and vegetation responses. The study was designed to test whether the high level of trampling associated with mob grazing resulted in increased soil organic matter and plant production. The objective of this portion of the study was to determine forage utilization and yearling cattle performance on a subirrigated meadow when using mob grazing (ultrahigh stocking density) or 4-pasture rotational systems. Forage utilization included both trampling and disappearance (intake) and animal performance was measured as average daily gain. I expected utilization of standing live herbage to be greater in mob pastures than in 4-pasture rotational (relatively low to moderate stocking density) pastures because of the greater amount of trampling. A secondary hypothesis was that animal performance would be greater in the 4-pasture rotational treatments because of lower stocking densities.

Materials and Methods

Study Site

Research was conducted at the University of Nebraska Barta Brothers Ranch located 11 km northwest of Rose, NE (42˚13'13"N, 99˚38'27"W). The 30-year average precipitation (1988 to 2018) was 578 mm and the average temperature in January was -3.4°C and the average temperature in July was 23.8°C (High Plains Regional Climate Center, 2018).

The study was conducted on subirrigated and wet subirrigated ecological sites. The subirrigated and wet subirrigated sites are found on interdunes and stream valleys. The slope is less than 3%. The water table is seasonally high under these sites. For subirrigated sites, the depth to rusty spots and iron stains in the soil or saturation is 46 to 91 cm, and there are no visible surface salts. The slope of wet subirrigated sites is 0 to 1%. Soils of wet subirrigated sites are generally saturated and depth to rusty spots and iron stains is 45 to 90 cm (USDA-NRCS, 2017). Approximately 10% or 450,000 ha of the Nebraska Sandhills are comprised of subirrigated or wet subirrigated ecological sites (Bleed and Flowerday 1998).

Soils of the study area are mixed, mesic Aquic Ustipsamments and mixed, mesic Typic Psammaquents. The soils are comprised mostly of Els loamy sand and Tryon loamy fine sand. Vegetation on the study site was dominated by cool-season plant species. Common cool-season grasses were quackgrass (*Elymus repens (L.) Gould*), timothy (*Phleum pretense L.*), Kentucky bluegrass (*Poa pratensis L.*), and reed canarygrass (*Phalaris arundinacea L.*). Warm-season grasses were less prevalent and included big bluestem (*Andropogon gererdii* Vitman), indiangrass (Sorghastrum nutans (L.) Nash), switchgrass (Panicum virgatum L.), and prairie cordgrass (*Spartina pectinata* Bosc). Red and white clover (*Trifolium pretense L.* and *Trifloium repens L.*) were the most prevalent forbs; however, yarrow (*Achillea millefolium L.*), dandelion (*Taraxicum officinale* F.H. Wigg), and aster species were also common. Sedges (*Carex spp.*) and rushes (*Eleocharis R. Br.* and *Juncus L.*) were also commonly found throughout the study site. Prior to the beginning of the study in 2010 the meadow was hayed annually in the summer for the last several decades.

Treatments

The study site (25 ha) was divided into 2 blocks (North and South) with five treatments in each block. The 5 treatments were 3 grazing treatments and 2 non-grazed treatments in a randomized complete block design (Figure 7). The grazed treatments were ultrahigh stocking density (mob), 4-pasture rotation with on grazing cycle (4PR1), and 4-pasture rotation with two grazing cycles (4PR2). All grazed treatments had the same stocking rate of 7.4 AUM ha^{-1}. Yearling steers with an average initial weight of 365 kg were used in the grazing treatments. The non-grazed treatments were an annual mid-July haying treatment, and a control. The control had no livestock grazing or haying during the study.

Stocking density in the mob treatment was set at 225,000 kg live weight ha $^{-1}$. This stocking density was within what practitioners of mob grazing have reported from

200,000 to 1,000,000 kg live weight ha $^{-1}$ (Redden 2014). Within the mob grazing plots, a total of 36 yearling steers were rotated through 120 pastures (0.06 ha each) over a 60-day period, and the steers were moved to a new pasture twice daily. Grazing began in a different quadrant each spring. Timing of steers pasture moves were at 0700 and again at 1400. The morning pasture was left open and available to the steers to return to until the next day at 0700. Fresh water and salt were available to the steers and were located at one end of the pasture and were moved with the cattle each day. Grazing in the mob treatment began in mid-June in every year of the study from 2010 to 2017. One objective of the study was to induce high levels of trampling (60% or greater) in the mob pastures, so grazing in the mob was delayed until June to allow for grasses to begin elongating which would increase the amount of stem biomass available for trampling through the grazing season Gompert (2010).

The 4PR1 grazing treatment 60-day grazing season began at the same time as the mob treatment to allow for direct comparison with the mob treatment. This treatment had 4, 0.4-ha pastures grazed by 9 steers for 15 days. Steers were rotated through each pasture once during the grazing season. Stocking density was 7,000 kg of livestock weight ha $^{-1}$. Fresh water and salt were available to the steers at all times and the salt was located within 10 m of the water.

The 4PR2 grazing treatment had an 80-day grazing season beginning at a time (on or around 20 May) when there was abundant vegetative forage plants and few elongated tillers. The treatment consisted of 4, 0.6 ha pastures that were grazed twice during the grazing season. Stocking density was 5,000 kg ha $^{-1}$ and 10 steers grazed the treatment pastures. The first and second occupations of each pasture were about 10 days each with the first occurring between 20 May and 1 July and the second occurring between 2 July and 10 August. The grazing season for the 4PR2 treatment was set up to end at the same time as the mob and 4PR1 treatments. Fresh water and salt were available to the steers at all times and the salt was located within 10m of the water.

Hay plots were 1 ha each, harvested for hay in mid-July annually. Hay plot production data was only collected in years 2010, 2011, 2017, and 2018 of the study. The hay was put-up in big round bales (700 kg each) and removed from the meadow shortly after harvest. Control plots were located in each block and were 1 ha in size. Control plot data was collected at the end of each grazing season. No livestock grazing or haying took place in the control plots over the course of the study.

Utilization, Trampling, and Disappearance

Prior to steers entering a pasture in the 4PR treatments ten, 1-m^2 exclosures were randomly placed in the pasture. At the end of an occupation in a pasture, exclosures were removed and a quadrat (25 x 100cm) was placed in the middle of each exclosure area and standing vegetation was clipped at ground level and sorted into standing live and standing dead categories and placed into separate brown paper bags. Litter also was collected from the soil surface of each quadrat and placed in a paper bag. One quadrat also placed 1 m directly north of the exclosure and clipped using the same protocol as inside the exclosure. Clipped material was sorted into standing live, litter, standing dead, and trampled categories outside of the exclosure. Trampled vegetation was current years shoots or parts of shoots that were on the soil surface, standing but visibly kinked beyond the ability to regrow, or at a 45° angle or less to the soil surface; attached and detached portions of the plants were considered trampled. Samples were dried in a forced-air oven at 60˚C to a constant weight and the final component weights were recorded. Utilization was defined as the live aboveground plant tissue that was destroyed (trampled or consumed) during the grazing process and was calculated as the difference between standing live inside and standing live outside plus trampled. Utilization data was collected in all years of the study except for 2012. Data was excluded for 2016 due to an incorrect sampling method.

In the mob pastures, one day prior to occupation, ten quadrats (25 x 100 cm) were placed down the center of the pasture that would be occupied during the first half of the next day. Vegetation within the quadrats was clipped at ground level, gathered, separated into standing live, standing dead, and litter, and placed in separate paper bags. On the next morning, the steers entered the pasture and were moved to the next pasture in the early afternoon. Once steers were moved, quadrats were placed 1 m north of the pre-grazing quadrat and clipped to ground level. Vegetation was separated into standing live, standing dead, litter, and trampled components and placed in paper bags. All samples were dried in a forced air oven at 60°C until weight was constant and then the final weight was recorded.

Yield, percentage T, percentage disappearance/harvest efficiency, and percentage utilization were calculated for each grazing period in each of the pastures. SLin was standing live vegetation inside of the exclosure or pre-grazing. SLout was standing live vegetation outside the exclosure or post-grazing. In/out were the identifying suffixes used for the rotational treatments and the mob treatment respectively.

$$\textit{Yield (kg}\cdot\textit{ha}^{-1}\textit{)} = (\text{SLin(g)}*40) \div \text{pasture size (ha)}$$

Percentage Trampled = (T ÷ SLin) · 100

Percentage Disappearance = [(SLin – SLout + T) ÷ (SLin)] · 100

Disappearance takes into account any removal of forage in the system other than that consumed by livestock. For the purposes of this study, forage was assumed to be consumed by livestock only.

Percentage Utilization = [(SLin – SLout) ÷ (SLin)] · 100

Animal performance

Animal weight gain was measured every year of the study at the end of the 60 and 80-day grazing seasons. Steers that were used in this study were a mixed beef breed (*Bos taurus*). They were limit-fed a forage ration for five days and then weighed for two consecutive days at the University of Nebraska Eastern Nebraska Research and Extension Center (UNL-ENREC) near Mead, NE prior to shipment to the Barta Brothers Ranch and placement in treatment pastures. The initial weight of the steers was calculated as the average of the two initial weights taken. At the end of the grazing season the steers were returned to ENREC, placed on a forage ration, and the same process to calculate initial weights was used to calculate the final weights of the steers. The end weights were the average of the two post grazing weights taken at ENREC.

Forage Quality

Forage quality analysis was conducted on utilization samples collected during 2010, 2011, 2013, and 2017. On each of 4 clipping dates, four randomly selected samples of standing live herbage were selected from the 10 clipped samples in each pasture. The four samples were split into two pairs and each pair of samples were then mixed together and ground to pass through a 1-mm screen. These samples were collected and composited each time utilization clipping was conducted. The ground samples were analyzed for N content and neutral detergent fiber (NDF) on a dry matter (DM) basis. Nitrogen analyses were conducted with a LECO FP-528 N analyzer (LECO, Inc., St. Joseph, MO) using standard methods (AOAC 1996). The NDF analyses were conducted with an ANKOM Fiber Analyzer (Ankom Inc., Fairport, NY). For NDF analyses, an ANKOM bag was filled with 0.5 g of a standing live herbage ground sample. Bags were heat sealed and placed in a bag suspender in neutral detergent solution in the fiber analyzer. Samples were agitated for 90 minutes and rinsed three times with boiling distilled water. Bags were placed in a forced-air oven at 60° C and allowed to dry for 24 hours before weighing.

Forage quality could not be compared by date during the grazing season because clipped samples were taken at slightly different times every year as well as at different intervals within year. For this reason, data for the average forage quality of the entire grazing season were used to determine differences between years and treatments.

Statistical Analysis

Data were analyzed using a proc GLIMMIX mixed-model analysis of variance (ANOVA) and the lsmeans statement to separate the main effects in SAS (SAS Studio 5.1) for animal performance as ADG, utilization in terms of harvest efficiency and trampled, and forage quality in terms of CP and NDF. Treatment was nested within year, which was nested within replication by block. Probability values less than 0.10 were considered significant.

Results

Precipitation and Temperature

Based on data collected at the Barta Brothers Ranch Headquarters, average annual precipitation from 2010-2017 was 650mm and average precipitation from April through September average precipitation was 406 mm (Figure 1.1). Average temperature at the ranch was 8.9°C annually and 16.7°C during the growing season (April-October). With the exception of severe drought in 2012, annual precipitation ranged from 4.8% lower to 28.5% greater than that of the 30-year mean (578 mm). In 2012, annual precipitation was 51.4% lower than the 30-year mean. Excluding 2012, growing season precipitation ranged from 9.8% lower to 41.8% greater than that of the 30-year mean. Mean annual temperature was 10.5°C and growing season temperature was 17.6°C during the course of the study.

Utilization

Percentage Trampled

Percentage trampled herbage differed by treatment (P = 0.09). Trampled herbage was 1.8 times greater in the mob treatment than the 4PR1 treatment and 2.8 times greater than the 4PR2 treatment (Figure 1.2). Overall, trampling in the mob treatment averaged 52%, slightly less than our target of 60%.

Percentage Disappearance/ Harvest Efficiency

Harvest efficiency average 39% for the mob treatment and 55.1% and 48% for the 4PR1 and 4PR2 treatments, respectively (Figure 1.2). However, there were no significant differences; likely because of the high variances among years in each treatment. Overall, harvest efficiency averaged 47.4% of the available standing live herbage in a pasture.

Total Utilization

There was a treatment by year interaction for utilization (P = 0.054). Utilization differed among the three grazing treatments in all years except for 2013 when 4PR1 and mob were not different (Table 1.1). Utilization was generally lowest in the 4PR2 treatment averaging 65.8%; whereas, utilization remained relatively high throughout the study period for the 4PR1 and mob treatments at 83.3% and 90.6%, respectively (Figure 1.2).

Residual Standing Live

There was a treatment by year interaction for residual standing live herbage (P=.054). Residual standing live was about 2 times greater in the 4PR1 pastures than in the mob pastures in all years except for 2013 when there was no difference between the two treatments (Table 1.2). Residual standing live for 4PR2 was greater than the other treatments in all years, averaging 2 times greater than the 4PR1 treatment and 3.6 times greater than the mob over the course of the study. Residual standing live was about 2 times greater for the 4PR1 pastures than the mob pastures in all years except 2010 and 2013.

Forage Quality

Neutral detergent fiber and crude protein

Neutral detergent fiber of the pre-grazing biomass samples did not differ among treatments. But, NDF did differ by year (p = 0.004), it was greatest in 2013 (69.1%) and lowest in 2017 (61.4%) with 2010 and 2011 at intermediate levels (65.5 and 65.3%, respectively). Crude protein content of pre-grazing biomass in 4PR2 was greater than that of 4PR1 in 3 of 4 years (2010, 2013, and 2017) (P = 0.035) (Table 1.3). Crude protein content of 4PR2 clipped biomass was greater than mob in 2 of 4 years (2010 and 2017).

Crude protein content in 4PR1 and mob differed in 2013 only when CP content for 4PR1 biomass samples was lower than that of the mob.

Animal Performance

In all years (2011-2017), ADG for steers in the 4PR2 treatment was greater than that for steers in the 4PR1 and mob treatments (P= 0.0018) (Table 1.4). Daily gain of steers in 4PR1 was greater than mob in all years except in 2013 and 2017, when there were no differences.

Discussion

As expected, utilization was the greatest in the mob pastures. At the ultrahigh stocking density, the cattle in the mob pastures grazed more actively than in the 4PR pastures. Redden (2014) reported that the cattle in the mob pastures moved relatively rapidly as a group from one end of a pasture to the other and tended to leap frog through the 95 m length of the pasture. Leap frogging was due to the inability of cattle to continue grazing with the group without going around the whole herd to get to the next feeding station. Number of steps taken by the grazing cattle during the grazing season was compared among the mob and 4PR treatments in 2013 (Redden et al. 2014); on a daily basis cattle in the mob pastures took 50% more steps than the cattle in the 4PR pastures. The greater utilization on the mob pastures was driven by the high level of trampled vegetation on the mob pastures compared to the 4PR pastures (Table 1.2).

Although spatial distribution of grazing in the pastures was not measured, the even distribution of trampled vegetation in the mob pastures (Figure 1.3) compared to that in the 4PR pastures (Figure 1.4) demonstrates the relatively even spatial distribution of grazing in the mob pastures. Because of the even grazing distribution and the high level of trampling/utilization on the mob pastures, standing residual was low in the mob pastures (<10% on average; Table 1.2 and Figure 1.2); therefore, the ultrahigh stocking density associated with mob grazing was effective in minimizing the amount of standing vegetation following grazing. Proponents of mob grazing commonly cite the importance of minimizing the amount of standing vegetation following grazing because standing vegetation decomposes slower than trampled vegetation, thus reducing the rate of nutrient cycling (Peterson 2014, Gompert 2010). The 4PR2 pastures were the least evenly grazed as made evident by the relatively high levels of standing residue (Table 1.2). The patchiness and high levels of standing residual were very evident in the second cycle through the 4PR2 pastures in most years. Based on field observations, cattle tended to focus their grazing in the second cycle on patches that had been grazed fully in the first cycle and that were dominated by vegetative tillers rather than on patches that had been grazed lightly in the first cycle and were dominated by elongated or reproductive tillers. Other research (e.g. Chapman et al. 2007) report that cattle will choose sites with the highest value to them in terms of forage quality and nutrient density if given free choice.

The relatively low amount of trampling in the 4PR2 treatment (19%) compared to the 4PR1 (28%) (Figure 1.2) was likely because of the difference in stage of growth of a large percentage of plants in the last half of the grazing season. In the last half of the grazing season, 4PR1 steers were in pastures that had not been grazed earlier in the season and that were dominated by mature tillers; therefore, they tended to trample more standing live plants as they were grazing. The 4PR1 animals had a higher likelihood of trampling vegetation simply because of the greater amount of plants in the elongation or reproductive stage than in the 4PR2 pastures.

Even distribution of grazing on the mob pastures appeared to be driven by grazing pressure (AU $T^{-1}$of forage DM) as well as stocking density. The overall mean instantaneous grazing pressure for the mob treatment at the beginning of grazing periods was 104.6 AU T^{-1} compared to 4.1 AU T^{-1} for 4PR1 and 3.8 AU T^{-1} for 4PR2. The high grazing pressure likely was a principal factor affecting grazing behavior and the resulting grazing distribution (Barnes et al. 2008, Barnes 2002). Grazing pressure also has an effect on animal response, and might partially explain the difference in weight gain between the mob and 4PR steers. Derner et al. (2008) and McCollum et al. (1999) concluded that increasing grazing pressure, such as in short duration systems has a negative effect on ADG of yearling steers when compared to continuous stocking. The effect of grazing pressure on animal performance can be explained simply by less selectivity of the highest quality forage available, overall quantity of forage changes very little if at all.

We expected the high level of trampling in the mob pastures to negatively impact the harvest efficiency of the mob treatment compared to the 4PR treatments. Although harvest efficiency did not differ among treatments, harvest efficiency was relatively low for the mob treatment (39%; Figure 1.2). With only two replications, the high variance among years within the treatments reduced the likelihood of detecting differences. Harvest efficiency in the mob pastures was less than 39% in four of the six years that harvest efficiency was estimated; in the other two years (2014 and 2015), harvest efficiency was 47% and 48%. The relatively high estimates in 2014 and 2015 cannot be explained.

Harvest efficiency on mob-grazed pastures can vary considerably and is largely dependent on the amount of vegetation trampled and the residual standing vegetation. The amount or percentage of vegetation trampled and left remaining standing is determined by such factors as growth stage of the dominant plants and grazing pressure. Harvest efficiency on ranches practicing mob grazing in 2012 and 2013 in the Nebraska Sandhills was relatively similar compared to our estimates and ranged from 32 to 43% (Wingeyer et al. unpublished data). Gerrish and Morrow (1999) reported a high harvest efficiency (68%) in a different management intensive grazing system. The relatively low harvest efficiency in our mob pastures was likely a result of the later growth stages of the principal forage plants and the high grazing pressure which resulted in high levels of trampling. The balance between harvest efficiency and percentage trampled is important in evaluating mob grazing.

Within a forage species, physiological stage of growth at harvest is the most important factor in determining forage quality (Ball et al. 2001). Vallentine (2001) reported that as a plant matures, its usable energy decreases significantly. In general, forage plants in the mob and the 4PR1 pastures were at similar stages of growth at the times of grazing throughout the grazing season. Each time the cattle were moved in each of the two treatments, they moved into a pasture that had not been grazed earlier in the season. As the grazing season continued, the forage quality of each of the newly entered pasture’s forage became increasingly more mature. The plant stage of growth of the available forage advancing from vegetative to reproductive over the two month grazing season and declining leaf:stem ratios, resulted in declining forage quality. The forage quality of the 4PR2 likely remained relatively high throughout the grazing season because a high percent of plant shoots/tillers remained in the vegetative stage for much of the grazing season. Not only were the vegetative tillers of high forage quality, the 4PR2 steers were also allowed to graze them repeatedly due to the twice over rotation. For instance, timothy was a common and an important forage plant species on the study site. According to Ball et al (2001), timothy has an 18% and 49% CP and NDF content, respectively, in the leaf and 5% and 73% CP and NDF content, respectively, in the stem of a mature plant with a leaf to stem ratio of .42:1. The leaf to stem ratio, although not quantified, was visibly greater than 0.42:1 in the 4PR2 pastures at all times since most plants were vegetative throughout the grazing season.

The differences in animal performance among treatments was likely a function of forage quality and intake. The relatively high CP content (Table 1.3) and low NDF of available forage in the 4PR2 pastures likely were principal factors in affecting the high ADG of the 4PR2 cattle; and the low ADG of the mob and 4PR1 cattle was likely related to the low forage quality in these pastures. In a study feeding free choice Sandhills meadow hay to steers, steer DMI was 6.6 kg hd^{-1} d^{-1} resulting in an ADG of 0.73 kg hd^{-1} d^{-1} (Meyer 2010). An estimated intake of individual steers for this study was averaged at 7.73, 9.70, and 6.34 kg hd^{-1} d^{-1} for the 4PR1, 4PR2, and mob treatments respectively. Much of the differences in animal performance could have been driven simply by intake and forage quality.

Our results do not agree with some of the anecdotal claims of mob grazing proponents of better animal performance. Gompert (2010) reported that 60% of producers practicing mob grazing saw no change, 20% saw a decrease, and 20% saw an increase in animal performance. The mean of 51% trampled in the mob treatment also agree with an earlier on-ranch study (Wingeyer et al. unpublished data) that reported an average of 53% trampling on Sandhills meadows that were mob grazed.

Our study was designed more to achieve heavy trampling in order to induce a soil and plant response rather than a positive animal response. Other forms of mob grazing that allot a greater amount of forage to be utilized for intake, may result in greater rates of weight gain. According to Peterson (2014) adapting the stocking density based on the situation in a pasture, such as an area with a mature growth stage, will drive the resulting animal performance up or down.

Management Implications

Mob grazing, when implemented in the manner that was used in this experiment, did not result in an increase in harvest efficiency or animal performance when compared to conventional rotational grazing strategies. Mob grazing, using ultrahigh stocking densities, is reported to greatly increase the rate of soil development by minimizing the amount of standing vegetation and maximizing the amount of trampled vegetation on the soil surface. The study was designed for the cattle to trample as much as 60% of the standing vegetation and, to favor the likelihood of high levels of trampling, initiation of grazing of mob pastures was delayed until mid-June when the dominant cool-season grasses were in elongation to reproductive stages of growth. This approach likely limited harvest efficiency and forage intake. The results of this study demonstrated that the conditions required for high levels of trampling negatively impacts forage quality and ADG. Mob grazing when implemented in this manner would not be recommended for producers to optimize efficiency of forage use and animal performance. The increased level of infrastructure and management involved would not result in a greater level of production per unit of land area.

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Figures

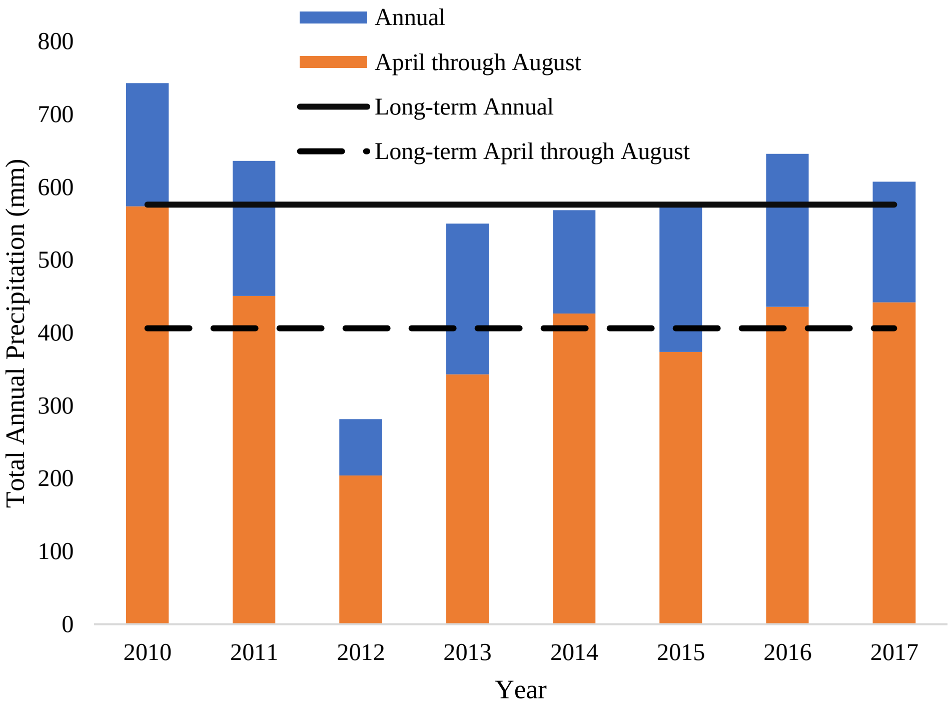

Figure 1.1 April through August and annual precipitation (mm) recorded at the Barta Brothers Ranch from 2010 to 2017 and the long-term average April through August and annual precipitation (30-year mean) (High Plain Regional Climate Center 2018).

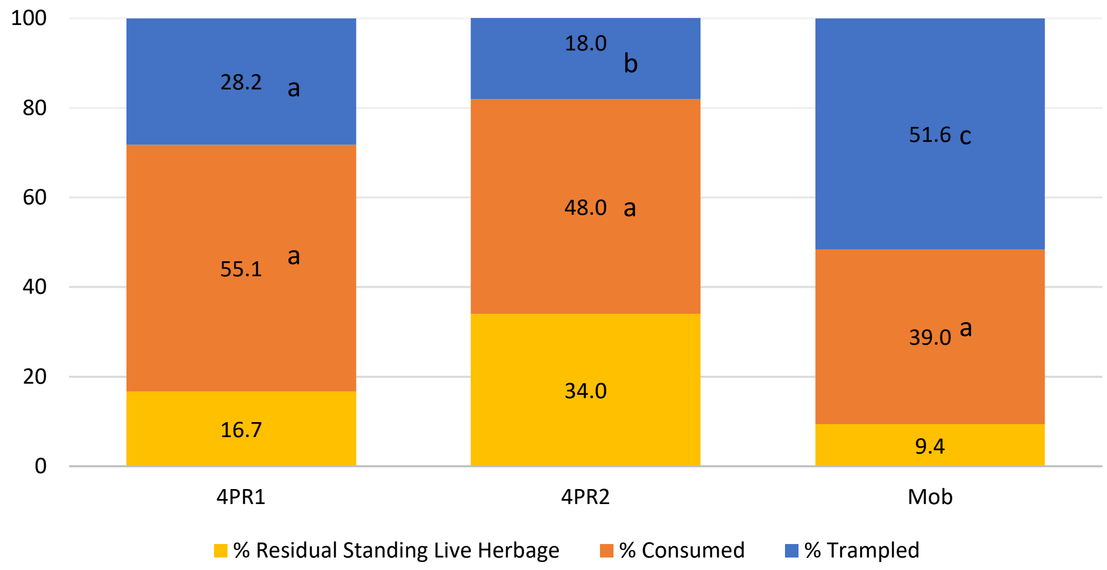

Figure 1.2 Average percent consumed (disappearance) and trampled and percent residual standing live herbage in 4PR1, 4PR2, and mob grazing treatments, 2010-2017.
$^{a\text{-}c}$ Different uppercase letters within bar component indicate treatment difference at $p<0.10$.

Figure 1.3. Mob steers moved from the morning pasture (strip on right) to the afternoon pasture. Note uniformity of grazing height of vegetation in the morning pasture.

Figure 1.4. Steers in a 4PR2 pasture near the end of a 10-day grazing period. Note the patchiness of grazing height of vegetation.

Tables

Table 1.1 Mean utilization (%) for 4PR1, 4PR2, and mob treatments in 2010 and 2011 and 2013 through 2017.

	Year					
	%					
Treatment	2010	2011	2013	2014	2015	2017
4PR1	82 ^{Aab}	85 ^{Aa}	85 ^{Aa}	87 ^{Aa}	81 ^{Ab}	80 ^{Ab}
4PR2	58 ^{Bd}	71 ^{Bab}	60 ^{Bc}	64 ^{Bbc}	75 ^{Ba}	68 ^{Bb}
Mob	88 ^{Cbc}	92 ^{Cab}	86 ^{Ac}	94 ^{Ca}	92 ^{Cab}	91 ^{Cab}

[1] Different uppercase letter within columns differ ($P < 0.10$).

[2] Different lowercase letters within rows differ ($P < 0.10$).

Table 1.2 Percentage of residual standing live herbage in 4PR1, 4PR2, and mob treatments 2010-11 and 2013-2017

	Year					
	%					
Treatment	2010	2011	2013	2014	2015	2017
4PR1	18 ^{Aab}	15 ^{Aab}	15 ^{Aab}	13 ^{Aa}	19 ^{Ab}	20 ^{Ab}
4PR2	42 ^{Ba}	29 ^{Bcd}	40 ^{Bab}	36 ^{Bbc}	26 ^{Bd}	32 ^{Bc}
Mob	12 ^{Cab}	8 ^{Cbc}	14 ^{Aa}	6 ^{Cc}	8 ^{Cbc}	9 ^{Cabc}

[1] Means with different uppercase letter within columns differ ($P < 0.10$).

[2] Means with different lowercase letters within rows differ ($P < 0.10$

Table 1.3 Crude protein content (%) of pre-grazing, clipped biomass samples in 4PR1, 4PR2, and mob treatments in 2010, 2011, 2013, and 2017

	Year --------------------------------------%--------------------------------------			
Treatment	2010	2011	2013	2017
4PR1	6.7^{Aab}	7.2^{Ab}	6.5^{Aab}	5.6^{Aa}
4PR2	8.5^{Ba}	7.3^{Ab}	8.7^{Ba}	7.8^{Bab}
Mob	6.7^{Aa}	7.6^{Aab}	7.8^{Bb}	5.6^{Ac}

[1] Different uppercase letter within columns differ ($P < 0.10$).

[2] Different lowercase letters within rows differ ($P < 0.10$).

Table 1.4 Average daily gain (kg head^{-1} day^{-1}) in 4PR1, 4PR2, and mob treatments 2011-2017

	Year -------------------------------------kg head^{-1} day^{-1}--------------------------------------						
Treatment	2011	2012	2013	2014	2015	2016	2017
4PR1	0.32^{Aa}	0.32^{Aa}	0.31^{Aa}	0.56^{Ab}	0.08^{Ac}	0.26^{Aa}	0.13^{Ac}
4PR2	0.93^{Ba}	0.52^{Bc}	0.66^{Bb}	0.70^{Bb}	0.58^{Bc}	0.63^{Bbc}	0.50^{Bc}
Mob	0.13^{Cc}	0.19^{Cb}	0.25^{Abc}	0.43^{Ca}	-0.13^{Cd}	0.10^{Cc}	0.07^{Acd}

[1] Different uppercase letter within columns differ ($P < 0.10$).

[2] Different lowercase letters within rows differ ($P < 0.10$)

Chapter 2: Grazing method effect on vegetation characteristics of Nebraska Sandhills subirrigated meadows

Introduction

Plant communities vary widely in grasslands. Communities range from diverse native plant communities to homogenous, exotic plant communities. These plant communities all have varying degrees of productivity and complexity and attractiveness to land managers. In order to maintain productive grasslands within different plant communities, land managers have developed and used many different grazing strategies (Briske et al. 2008). A grazing strategy is a plan on how to graze livestock on a defined area with the strategy based on the manager's animal production and resource-management objectives (Stubbendieck and Reece 1992) and personal preferences (Augustine and McNaughton 1998).

Intensity, timing, and frequency of grazing along with the forage utilization of grasslands are critical components of grazing strategies and are the principal drivers of the production and composition of plant communities on grazing lands (Porensky et al. 2017, Pizzio et al. 2017). Stocking rate (animal unit demand per unit area over a period of time) and stocking density (animal unit demand per unit area at an instance in time) are grazing tools used to control the intensity of grazing and the harvest efficiency on grazing lands. Harvest efficiency is the total amount of forage consumed in relation to the total available forage. Livestock producers on grazing lands commonly have a goal of achieving high harvest efficiencies for the purpose of optimizing livestock production without causing site degradation (Manley et al. 1997). Stocking density is frequently reported (Norton et al. 2013) as a tool to manipulate harvest efficiency and the amount of standing and trampled plant material remaining after grazing. Manipulating stocking density is a practice that grazers use to affect the distribution of grazing over time and space. Practices such as increasing stocking density and decreasing grazing period length lead to less plant selectivity by grazing animals (Briske et al. 2008, Stubbendieck and Reece 1992). With less selectivity, more of the total forage that is available to the animal is consumed in order to maintain the animal's fill and nutritional requirements. Higher, more spatially uniform amounts of trampling, which decrease the amount of residual standing forage and/or harvest efficiency, are also an outcome of increasing the density of animals in a land area.

Short duration grazing (SDG; a.k.a., management intensive grazing) focuses on stocking density and time control of grazing as the principal means to decrease selectivity through even distribution (Hart et al. 1993); and to increase the harvest efficiency and/or trampling for greater overall utilization (Barnes et al. 2008, Stubbendieck and Reece 1992). Simple rotational and continuous systems have lower stocking densities and lower harvest efficiencies. Harvest efficiency in continuous and rotational systems is commonly 25 to 30% (Holechek et al. 2000); whereas, SDG systems can have harvest efficiencies of 30 to 40% (Stubbendieck and Reece 1992).

Ultrahigh stocking density or mob grazing is a system that takes the principles of SDG and intensifies them. Compared to SDG systems that have stocking densities of 56,000 to 280,000 kg animal liveweight ha^{-1} (Peterson 2014), ultrahigh stocking density starts at 280,000 kg ha^{-1} and can exceed 1,120,000 kg ha^{-1} (Peterson 2014). Reduced selectivity, even distribution, high utilization, short grazing periods, and long recovery periods are the most important products and components in ultrahigh or mob systems (Lemus 2011) and they are achieved with these very high stocking densities. These stocking densities are claimed to increase soil health through nutrient cycling, increase litter mass as a result of hoof action, and longer recovery period lengths (Peterson 2014). Gompert (2010) recommended that 60% of the forage should be consumed and the other 40% should be pushed to the ground or consumed. Anecdotally, producers using ultrahigh stocking densities claim that they have realized an increase in desirable plant species and wildlife along with a decrease in input costs by increasing stocking density to ultrahigh levels (Gordon 2011, Peterson 2014, Gompert 2010).

Selectivity of cattle and plant tolerance to grazing and disturbance are important determinants of plant community composition. Selectivity cannot be controlled by changing animal numbers alone (Augustine and McNaughton 1998). However, a change in management (time, intensity, and frequency of grazing) may alter the foraging habit of cattle which in turn would alter the potential for species composition change due to grazing selectivity. This manipulation of the foraging habit of cattle is one of the main outcomes of ultrahigh stocking density.

Ultrahigh stocking density negates selectivity by grazing animals by limiting the instantaneous forage allowance of the most desired plants and plant parts available at any point during a set grazing period. Animals are forced to consume the less desirable plants and lower quality plant parts in order to meet their fill requirements. Selective foraging of palatable species over the long term increases the abundance of less palatable and chemically or otherwise defended species resulting in overall decreased aboveground production of palatable species and eventually lowering the nutrient return rate into the soil (Pastor and Cohen 1997). In terms of livestock production, desirable species include palatable species that also have a high biomass production potential. The goals of ultrahigh stocking density are to decrease selectivity, shorten grazing periods, and increase trampling. These strategies are intended to increase the aboveground production and species richness by using longer recovery periods and by speeding up nutrient cycling through rapid inclusion of plant material into the soil.

Sandhills meadows were once dominated by native warm-season tallgrasses including big bluestem (*Andropogon gerardii*) and Indiangrass (*Sorghastrum nutans*) (Poole 1914, Rydberg 1895, Tolstead 1942), but composition of many meadows now are a mixture of introduced, defoliation-resistant, cool-season grasses, such as quack grass (*Elymus repens*), timothy (*Phleum pretense L.*), smooth bromegrass (*Bromus inermus*), and creeping foxtail (*Alopecurus arundinaceus Poir.)*, and sedges (*carex spp.*). The shift likely occurred because of repeated annual hay harvest in mid-summer (Brejda et al. 1989, Coady and Clarke 1993) and the introduction of well-adapted cool-season grasses (Brouse 1930). Typically haying takes place in July in the Sandhills (Volesky et al. 2011). July also happens to be when elongating warm-season grasses are more susceptible to damage from defoliation because of the elevated location of their growing points in mid-summer (Moore and Nelson 2017).

The objective of this study was to evaluate the effect of mob grazing, simple rotational systems, haying and no treatment on aboveground plant production species composition on Sandhills meadows over the 8 years of the study (from 2010 through 2017). We hypothesized that under a mob grazing system there would be an increase in plant production compared to the other grazed and non-grazed treatments. We also hypothesized that mob grazing would result in less post-grazing standing dead herbage and more litter deposition than other grazing treatments. A third hypothesis was that there would be an increase in aboveground production of desirable plant species, such as native warm-season grasses and legumes, in the mob treatment compared to the other grazed and non-grazed treatments.

Materials and Methods

Study Site

Study Site

Research was conducted at the University of Nebraska Barta Brothers Ranch located 11 km northwest of Rose, NE (42˚13’13”N, 99˚38’27”W). The 30-year average precipitation (1988 to 2018) was 578 mm and the average temperature in January was -3.4°C and the average temperature in July was 23.8°C (High Plains Regional Climate Center, 2018).

The study was conducted on subirrigated and wet subirrigated ecological sites. The subirrigated and wet subirrigated sites are found on interdunes and stream valleys. The slope is less than 3%. The water table is seasonally high under these sites. For subirrigated sites, the depth to rusty spots and iron stains in the soil or saturation is 46 to 91 cm, and there are no visible surface salts. The slope of wet subirrigated sites is 0 to 1%. Soils of wet subirrigated sites are generally saturated and depth to rusty spots and iron stains is 45 to 90 cm (USDA-NRCS, 2017). Approximately 10% or 450,000 ha of the Nebraska Sandhills are comprised of subirrigated or wet subirrigated ecological sites (Bleed and Flowerday 1998).

Soils of the study area are mixed, mesic Aquic Ustipsamments and mixed, mesic Typic Psammaquents. The soils are comprised mostly of Els loamy sand and Tryon loamy fine sand. Vegetation on the study site was dominated by cool-season plant species. Common cool-season grasses were quackgrass (*Elymus repens (L.) Gould*), timothy (*Phleum* *pretense L.*), Kentucky bluegrass (*Poa pratensis L.*), and reed canarygrass (*Phalaris arundinacea L.*). Warm-season grasses were less prevalent and included big bluestem (*Andropogon gererdii* Vitman), indiangrass (Sorghastrum nutans (L.) Nash), switchgrass (Panicum virgatum L.), and prairie cordgrass (*Spartina pectinata* Bosc). Red and white clover (*Trifolium pretense L.* and *Trifloium repens L.*) were the most prevalent forbs; however, yarrow (*Achillea millefolium L.*), dandelion (*Taraxicum officinale* F.H. Wigg), and aster species were also common. Sedges (*Carex spp.*) and rushes (*Eleocharis R. Br.* and *Juncus L.*) were also commonly found throughout the study site. Prior to the beginning of the study in 2010 the meadow was hayed annually in the summer for the last several decades.

Treatments

The study site (25 ha) was divided into 2 blocks (North and South) with five treatments in each block. The 5 treatments were 3 grazing treatments and 2 non-grazed treatments in a randomized complete block design (Figure 7). The grazed treatments were ultrahigh stocking density (mob), 4-pasture rotation with on grazing cycle (4PR1), and 4-pasture rotation with two grazing cycles (4PR2). All grazed treatments had the same stocking rate of 7.4 AUM ha^{-1}. Yearling steers with an average initial weight of 365 kg were used in the grazing treatments. The non-grazed treatments were an annual mid-July haying treatment, and a control. The control had no livestock grazing or haying during the study.

Stocking density in the mob treatment was set at 225,000 kg live weight ha^{-1}. This stocking density was within what practitioners of mob grazing have reported from 200,000 to 1,000,000 kg live weight ha^{-1} (Redden 2014). Within the mob grazing plots, a total of 36 yearling steers were rotated through 120 pastures (0.06 ha each) over a 60-day period, and the steers were moved to a new pasture twice daily. Grazing began in a different quadrant each spring. Timing of steers pasture moves were at 0700 and again at 1400. The morning pasture was left open and available to the steers to return to until the next day at 0700. Fresh water and salt were available to the steers and were located at one end of the pasture and were moved with the cattle each day. Grazing in the mob treatment began in mid-June in every year of the study from 2010 to 2017. One objective of the study was to induce high levels of trampling (60% or greater) in the mob pastures, so grazing in the mob was delayed until June to allow for grasses to begin elongating which would increase the amount of stem biomass available for trampling through the grazing season Gompert (2010).

The 4PR1 grazing treatment 60-day grazing season began at the same time as the mob treatment to allow for direct comparison with the mob treatment. This treatment had 4, 0.4-ha pastures grazed by 9 steers for 15 days. Steers were rotated through each pasture once during the grazing season. Stocking density was 7,000 kg of livestock weight ha $^{-1}$. Fresh water and salt were available to the steers at all times and the salt was located within 10 m of the water.

The 4PR2 grazing treatment had an 80-day grazing season beginning at a time (on or around 20 May) when there was abundant vegetative forage plants and few elongated tillers. The treatment consisted of 4, 0.6 ha pastures that were grazed twice during the grazing season. Stocking density was 5,000 kg ha $^{-1}$ and 10 steers grazed the treatment pastures. The first and second occupations of each pasture were about 10 days each with the first occurring between 20 May and 1 July and the second occurring between 2 July and 10 August. The grazing season for the 4PR2 treatment was set up to end at the same time as the mob and 4PR1 treatments. Fresh water and salt were available to the steers at all times and the salt was located within 10m of the water.

Hay plots were 1 ha each, harvested for hay in mid-July annually. Hay plot production data was only collected in years 2010, 2011, 2017, and 2018 of the study. The hay was put-up in big round bales (700 kg each) and removed from the meadow shortly after harvest. Control plots were located in each block and were 1 ha in size. Control plot data was collected at the end of each grazing season. No livestock grazing or haying took place in the control plots over the course of the study.

Annual Aboveground Production

In each year of the study, aboveground production was estimated in mid-August. In the 4PR1 and 4PR2 treatments, there were 2 or 3, 1m^2 cage exclosures per pasture with a total of ten exclosures per replication in each treatment. In mid-May each year, the cages were relocated within the pastures to capture the effects of the previous years' grazing on production. In the mob treatment, a total of ten exclosures were used with 2 or 3 cages placed randomly in each quadrant of the mob grazed pastures. One quadrant, identified in relation to its location by cardinal direction, contained 30 subpastures (0.06 ha in size). The exclosures in the mob pastures were also moved in mid-May prior to grazing. In mid-August, a quadrat (0.25 m^2) was placed in the middle of each exclosure and hand-clipped at ground level. The clipped vegetation was sorted and placed into bags by the categories of standing live, standing dead, and litter. Shortly after collection, the samples were dried in a forced air-oven at 60°C to a constant weight, then the weight was recorded. In the hay and control treatments, exclosures were not needed and 10 quadrats were randomly placed in each plot and clipped and processed as described for the pastures.

Botanical Composition, Ground Cover, and Basal Cover

Species composition, ground cover, and basal cover were estimated every year during the study in mid to late June. Measurements were taken using the modified step-point method (Owensby, 1973). In the 4PR, hay, and control treatments, the modified step point measurements were taken at 150 randomly-located points in each pasture/plot. In the mob treatment, each replication was divided by quadrant and each quadrant had 75-150 step point measurements taken at random locations. At each point, ground cover was recorded litter, bare ground, or plant base. Manure was considered to be litter. If the tip of the step point tool landed on a plant base, the species of that plant was recorded. If the ground cover was litter or bare ground the species of plant nearest to the tip of the step point in an 180° arc in front of the point was recorded.

Plants at each step point were categorized into 1 of 5 functional groups that included sedges and rushes, forbs, cool-season grasses, and warm-season grasses. Sedges and rushes, and cool-season grasses were combined to create a cool-season graminoid category. The most prevalent species over the 8 years of the study included sedges, red clover, white clover, quackgrass, Kentucky bluegrass, timothy, prairie cordgrass, and big bluestem. These species also composed the largest parts of their respective functional groups in most years.

Statistical Analysis

Data were analyzed using proc GLIMMIX in SAS (SAS Studio 5.1). Aboveground production for the control and defoliated treatments were analyzed for 2012 through 2018 using the lsmeans statement for each of the aboveground production variables (standing live, standing dead, and litter). All aboveground production variables (standing live, standing dead, and litter) for the hay treatment were analyzed against the control separately since data was not collected for the hay treatment from 2012 through 2016 and could not be directly compared to the grazed treatments. An initial ANOVA analysis was conducted on the warm-season grasses, cool-season grasses, sedges, forbs, and cool-season graminoids. For the purpose of the functional group and species analysis, sedges and rushes were classified together in the sedge category since they are both grass-like plants. Variables tested in the initial functional group ANOVA analysis that had a treatment by year interaction were tested further with the use of an ANCOVA and contrast statements. The ANCOVA contrast statements were developed to compare 2 contrasts: 1) the slopes of the control v. all other defoliated treatments and 2) the slopes of all other defoliated treatments vs. the mob treatment. Year was treated as a continuous variable and the slopes of the lines for each treatment by functional group were tested for differences.

Individual species were analyzed by percent change over time (mean of 2010 and 2011 v. mean of 2017 and 2018). P values less than 0.10 were considered significant for all statistical analyses unless otherwise specified.

Results

Precipitation and Temperature

Based on data collected at the Barta Brothers Ranch Headquarters, average annual precipitation from 2010-2017 was 650mm and April through September average precipitation was 406 mm, average temperature at the ranch was 8.9°C annually and

16.7°C during the growing season (April-October) (Figure 2.0). With the exception of severe drought in 2012, annual precipitation ranged from 4.8% lower to 28.5% greater than that of the 30-year mean (578 mm). In 2012, annual precipitation was 51.4% lower than the 30-year mean. Excluding 2012, growing season precipitation ranged from 9.8% lower to 41.8% greater than that of the 30-year mean. Mean annual temperature was 10.5°C and growing season temperature was 17.6°C during the course of the study.

Annual Aboveground Production, Litter, and Standing Dead Herbage

There was a treatment by year interaction for annual aboveground production (p = 0.0585) (Table 2.1). In 4 of the study years (2013-2015, and 2018) grazed treatments had greater aboveground production than the control. Aboveground production in the grazed treatments trended upward on average and aboveground production in the control and hay treatments trended downward over the course of the study. Standing dead herbage differed by year (p = 0.0045) and treatment (p = 0.056) (Figure 2.8 and Figure 2.10). All grazed treatments had less standing dead herbage than the control, and the grazing treatments did not differ among eachother. On average, the control had 52, 103, and 64% greater standing dead herbage than the 4PR1, 4PR2, and mob treatments, respectively. Litter differed by year (p = 0.097) and treatment (p = 0.003) (Figure 2.9 and Figure 2.11). All grazed treatments had less litter than the control. On average, control litter was 239, 522, and 332% greater than 4PR1, 4PR2, and mob treatments, respectively. Hay had less litter (p = 0.058) than the control, 590 and 2593 kg^{-1} ha, respectively, in the 4 years that were analyzed (2010,2011,2017, and 2018) and no other vegetation components were significantly different between the two treatments.

Functional Group Composition

There was a treatment by year interaction for percentage cool-season grasses ($p = 0.02$), warm-season grasses ($p = <0.0001$), and cool-season graminoids ($p = 0.0321$). In most years, the percentage composition of cool-season grasses in the 4PR1, 4PR2, and mob pastures did not differ (Figure 2.1); whereas, in most years, cool-season grasses were less common in the control than in the 4PR, mob, and hay treatments. Percentage composition of cool-season grasses was also lower in the hay than the 4PR and mob treatments in most years. In the ANCOVA analysis of slopes, the control showed a significant decrease in cool-season grasses ($P = 0.021$) and an increase in warm-season grasses ($P = <0.0001$) when compared to all other treatments.

For the 8 years of the study, percentage composition of warm-season grasses did not differ among the 4PR1, 4PR2, and mob treatments (Figure 2.2); whereas, in most years, warm-season grass composition in the control was greater than in the 4PR, mob, and hay treatments. Warm-season grass composition in the 4PR1 was less than the hay in 2010, 2016, and 2018. Warm-season grass composition in the 4PR2 was less than in the hay in 2016 and 2018; whereas, warm-season grass composition in the mob was greater than hay in 2016 and 2018.

In the last 3 years of the study (2016-2018), 4PR1 and 4PR2 cool-season graminoid composition differed (Figure 2.3) and 4PR1 and 4PR2 did not differ from mob in any years. In about half of the years, percentage composition of cool-season graminoids was greater in the control than 4PR pastures. In 2010 and 2017, cool-season graminoids were more common in the control than in the mob. In most years, cool-season graminoid composition was greater in the control than in the hay plots. In 4 years (2012, 2014, 2016, and 2017) cool-season graminoids were greater in the 4PR1 pastures than in the hay; whereas, cool-season graminoid composition in 4PR2 pastures was greater than the hay plots only in 2014. Mob cool-season graminoid composition was greater than hay in 2012 and 2014 and less than hay in 2010.

The functional groups that had a treatment by year interaction for percentage composition in the initial overall analysis (cool-season grasses, warm-season grasses, cool-season graminoids) were then analyzed a second time with contrasts to see if there was a difference in the slopes of their trend lines. The contrasts analyzed each variable's slope in two ways: (1) control slope v. all other defoliated slopes and (2) all other defoliated slopes v. mob slope. For the control in contrast 1, slope of the line of cool-season grass change was negative and decreased significantly (p = 0.021) compared to the slopes of the other treatments (Figure 2.1). Slope of the line of warm-season grass change in the control was positive and increased significantly (p = <0.0001) compared to the other treatments (Figure 2.2). No other contrasts were significant.

Percentage composition of forbs and sedges differed by treatment (p = 0.0217 and p = 0.0584, respectively) (Figure 2.4 and Figure 2.5) and year (p = 0.0317 and p = 0.0008 respectively) (Figure 2.6 and Figure 2.7). Sedge composition did not differ among grazed treatments. Sedge composition in the control was greater than all other treatments except for the hay, and 4PR2 and mob did not differ from hay. Sedge composition did not differ between the first year of the study (2010) and the last 4 years of the study. Sedges were increasing in 2010 and 2011 and peaked at nearly 40% in 2012 and 2013 differing from all other years, until they began to decrease back to their starting levels of 15% to 25% in 2014 through 2018. Forb composition was less than 20% in all treatments. Forb composition in 4PR1, control, and mob did not differ and was less than 13%. Forb composition of 4PR2 and hay did not differ. Forb composition peaked in 2014 similar only to 2015. Forb composition was not different in the first 4 years or 2018.

Relative Species Composition

Warm-Season Grasses. The species composition of the warm-season grasses, big bluestem and prairie cordgrass, remained relatively constant in the grazed treatments and increased in the control and hay treatment (Table 2.2). However, the change in composition did not differ (p=0.14) among treatments for big bluestem. Mean composition of big bluestem for the study site was 1.6 ± 1% in the first two years of the study and was 4.2 ± 3.5% in the last two years. There was a treatment effect for the change in composition of prairie cordgrass (p = 0.002). Prairie cordgrass composition change did not differ among the grazed treatments and tended to decline during the course of the study. Change in prairie cordgrass composition was greatest for the control, increasing from 7.7 ± 3% to 22.7 ± 9.5%, and intermediate for the hay treatment where prairie cordgrass composition increased from 5.7 ± 3% to 8 ± 9.5% over the course of the study.

Cool-season graminoids. For the cool-season graminoids (Table 2.2), quackgrass and Kentucky bluegrass mean composition of species began at 5.2 ± 3% SE and ended at 23.3 ± 10.4% SE and from 11.4 ± 3% SE to 18.4 ± 5% SE, respectively, while timothy and sedges began at 17.1 ± 6% SE and ended at 10.2 ± 4.6% SE and from 31.9 ± 5% SE to 10.8 ± 2.9% SE, respectively. However, change in composition of each of the cool-season graminoids did not differ (p>0.28) among the treatments.

Forbs. The two primary forbs, (red clover and white clover) responded to the treatments differently over the course of the study (Table 2.2). Red clover composition tended to decrease over time; however, the change in composition of red clover did not differ (p=0.67) among treatments. White clover composition increased over time for the grazed and hay treatments while white clover composition declined on the control. From 2010-2011 to 2017-2018, percentage composition of white clover increased from 3.6 ± 2% SE to 7.8 ± 4.5% SE on average for the grazed and hay treatments and decreased from 1.7 to 0.2% for the control. Percentage change in composition of white clover was greater (p=0.09) for the grazed treatments than the control; change in composition for the hay treatment did not differ from the grazed treatments and the control.

Discussion

Annual Aboveground Production

The hypothesis that mob grazing would result in more aboveground plant production did not hold true. When compared to mob grazing, continuous and simple rotation systems with longer grazing periods increase the likelihood of repeated grazing of palatable plants which has the potential of decreasing the vigor and longevity of grazed plants. Longer grazing periods also likely lower instantaneous grazing pressure and allow for selective/patchy grazing, favoring non-palatable plant species and resulting in a decline of the palatable, productive plant species (Pastor and Cohen 1997). With mob grazing, the very short grazing periods, high instantaneous grazing pressure, and spatially even distribution of use across a grazing unit reportedly minimize selective grazing and spread grazing pressure across all plants (Gompert 2010, Johnson 2012, Redden 2014). The palatable, productive plant species, therefore, are not disproportionately heavily used and remain vigorous and productive (Peterson 2014). The extremely wide range of stocking densities and the two grazing cycles in 4PR2 on a diverse meadow allowed for testing of these claims. Differences in plant production among the grazing treatments was minimal and there was little to no evidence that production was favored by ultrahigh stocking density over the 8 years of the study. Although there are no reports in the scientific literature of aboveground plant production response to ultrahigh stocking densities, Briske et al. (2011) reported that plant production is not affected by the high stocking densities of short duration grazing compared to continuous grazing and simple rotational grazing systems. As is commonly reported, aboveground plant production was much more responsive to year, and the associated varying amounts of annual precipitation, than to grazing strategy/system (Milchunas and Lauenroth 1993, Milchunas et al. 1994, Patton et al. 2007). In a synthesis study of 236 worldwide sites (Milchunas and Lauenroth 1993) suggest that differences in aboveground net primary production are more sensitive to environmental and ecosystem variables than grazing variables.

Aboveground plant production did not differ among the grazing treatments in any year of the study except in 2015 when it was greater for mob and 4PR2 than for 4PR1. Volesky et al. (2011) noted that on Sandhills meadow, aboveground biomass and root production of cool-season grasses, including slender wheatgrass (*Elymus trachycaulus Gould*), did not decline in response to increasing intensity and/or frequency of defoliation. Quackgrass, also an *Elymus,* and Kentucky bluegrass were the prominent cool-season exotic grasses on our study site. Similar to slender wheatgrass, quackgrass and Kentucky bluegrass are grazing tolerant and well adapted to the growing conditions on meadows (Dunn et al. 2016). The prevalence of these species may be a reason why the gradient of grazing intensity and frequency among the grazing treatments did not appear to affect their relative composition through the course of the experiment.

Overall, aboveground production trended upward regardless of grazing treatment from 2012 through the end of the study in 2018 but trended downward for the control and hay treatments. Holechek et al. (2006) found that grazing exclusion decreased productivity of grasses 14% and total vegetation productivity by 4% across 11 studies. We assume that the buildup of standing dead herbage and litter coupled with lack of nutrient cycling from excluding grazers in our control treatment led to a decline in production over the 8 years of the study. Also, removal of aboveground biomass and lack of grazer induced nutrient cycling in the hay treatments likely contributed to the decline in aboveground production over the course of the study.

The year effects on standing dead herbage were not as clear. Standing dead peaked in 2014 and 2017. The spike in 2014 could not be attributed to an increase in previous year production (Table 2.1); however, the 2017 peak could have been caused by a relatively high aboveground production in 2016. Year effect on relative amount of litter was assumed to be a function of the upward trend in the absolute amount of residual standing live herbage and overall fairly constant amount of trampled herbage over the course of the study. These 2 factors together would have caused more standing biomass to be trampled leading to the increase in litter in each subsequent year of the study.

The hypothesis that mob grazing would have a greater amount of litter and less standing dead did not hold true. There was no apparent difference in the amount of standing dead and litter between the mob treatment and the other grazed treatments as claimed by practitioners and proponents such as Gompert (2010) and Peterson (2014). With the high stocking density and grazing pressure, mob grazed treatments should have had less standing dead herbage than the other grazed treatments since trampling was very high in the mob treatment. However, since standing live herbage did not differ among treatments in most years, subsequent year standing live would be assumed to be the same. Litter would also be assumed to be greater in the mob grazed treatment due to the high amounts of trampled vegetation. However, litter that was trampled to the soil surface would have had more opportunity to decompose sooner than other treatments. Making litter incorporation into the soil more rapid during the current years' growing season would potentially not allow for a difference to be realized in the subsequent years' litter measurement. Comparing grazed treatments to the control was the only analysis that resulted in differences for any response variable.

Functional Group and Species

Percentage cool-season grass composition trended upward with statistically similar slopes for all defoliated treatments while warm-season composition remained flat with similar slopes among defoliated treatments. Inversely, the slope of cool-season grass composition in the control trended downward and warm-season grass composition trended upward. Most of the cool-season grasses on the study site were exotic species and all warm-season grass species on the study site were native. In a study in the flooding pampa of in a subhumid region in Argentina, Sala et al. (1986) noted that grazing exclusion retarded exotic species and favored native species. These species composition results from a relatively wet, low topographical positon seem to agree with the findings of this study on sandhills subirrigated meadow.

The cool-season graminoid treatment by year interaction was likely a result of the cool-season grass interaction coupled with the large decrease of sedge in relation to plants of other functional groups and individual species. Except for prairie cordgrass and white clover defoliation treatments did not appear to have an effect on individual species. But treatment did affect functional group composition. Defoliation versus no defoliation was what really had the impact on functional group and species, not grazing or haying strategy.

According to anecdotal observations by producers in the Nebraska Sandhills warm-season grasses would be expected to increase under grazing on meadow (Volesky, Schacht personal communication). The results of the relative increase in cool-season grasses rather than warm-season grasses under grazing could be explained by the amount of heavy competition from exotic species like quackgrass on the site, coupled with the timing of grazing that likely favored cool-season grasses. In a study conducted on German upland pastures that had been mowed 16 years prior and were of similar functional group composition, Jerrentrup et al. (2015) noted an increase in quackgrass as well as other cool-season grasses, forbs, and legumes on all swards with treatments grazed by cattle only, sheep only, or cattle and sheep. Ehrenreich and Aikman (1963) developed a list of a range of native species that differ in their resistance to defoliation. Defoliation resistant species found on this meadow included Kentucky bluegrass, timothy, and sedge. Non-defoliation resistant species found on the study site were big bluestem and Indian grass. Native warm-season grasses such as big bluestem and prairie cordgrass remained unchanged or decreased under grazing. Based on field observations, other native warm-season grasses also decreased but they were uncommon species and their composition changes were not analyzed. Our results could not statistically confirm defoliation resistance on this study site.

The most prevalent forbs on the study site, white clover and red clover, responded differently to the treatments over time (Table 2.2). White clover tended to increase and red clover tended to remain the same. Other studies (Jerrentrup et. al 2015, White and Knight 2007, Nolan et. al 2001, Volesky et al. 2004) have also observed an increase in white clover composition in response to defoliation, in varying topographic positions (including meadows), soil types, and climates. The defoliated treatments often had a much more open canopy and created spaces, albeit at different times for each treatment throughout the grazing season, for the opportunistic, shorter statured species such as white clover to thrive. These results were similar to what Volesky et al. (2004) observed on Sandhills wet meadow. This opening in the canopy likely contributed to the greater abundance of white clover (Pederson 1995). Matches (1992), in a grass clover mixed pasture found that red clover is not tolerant of trampling; swards that were trampled had less red clover overall than non-grazed pastures. However, the resulting response of red clover on the defoliated treatments in this study indicate that a statistical decrease in red clover did not take place on this study site in any treatment at any amount of trampling.

Management Implications

In terms of annual aboveground production, all grazing strategies on the subirrigated meadow were found to have a positive effect on annual aboveground plant production to the non-defoliated control. However, the hypothesis that mob grazing would result in more aboveground plant production compared to other grazing treatments does not hold true. Production is influenced more by year than by treatment. A producer could expect a decline in plant production after several years if a meadow had no defoliation such as the control treatment. A producer could also expect a decline in plant production over time from haying with a removal of a high level of biomass and nutrients.

In terms of functional group composition on Sandhills meadows, meadows that are comprised primarily of exotic cool-season grasses, red clover, and big bluestem could expect relative composition of those grasses to remain the same or have very little change under a variety of grazing or hay strategies. The hypothesis that relative composition of desirable warm-season grasses and forbs would increase and cool-season exotics would decrease with grazing did not hold true. The high instantaneous grazing pressure and short grazing periods did not influence species composition, thus the high input costs of fencing, water development, and labor cannot be justified by favorable changes in production and composition. Not only was there no response to mob grazing over the 8 years of the study but the production and composition on the other grazing treatment pastures did not differ from that of mob. The Sandhills meadow plant communities dominated by cool-season graminoids appear to be well adapted to a wide range of grazing strategies (including frequency and timing of grazing, stocking density, grazing pressure, and recovery period.) A producer could expect to see an increase in some individual species such as prairie cordgrass if a do-nothing management strategy was implemented. Species such as prairie cordgrass are negatively impacted by summer grazing, positively impacted by a lack defoliation, and intermediately to haying. White clover would be expected to increase due to any of the grazing strategies commonly used in the Sandhills. White clover responds favorably to grazing, intermediately to haying, and not favorably to the lack of defoliation and management in non-grazed controls.

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Figures

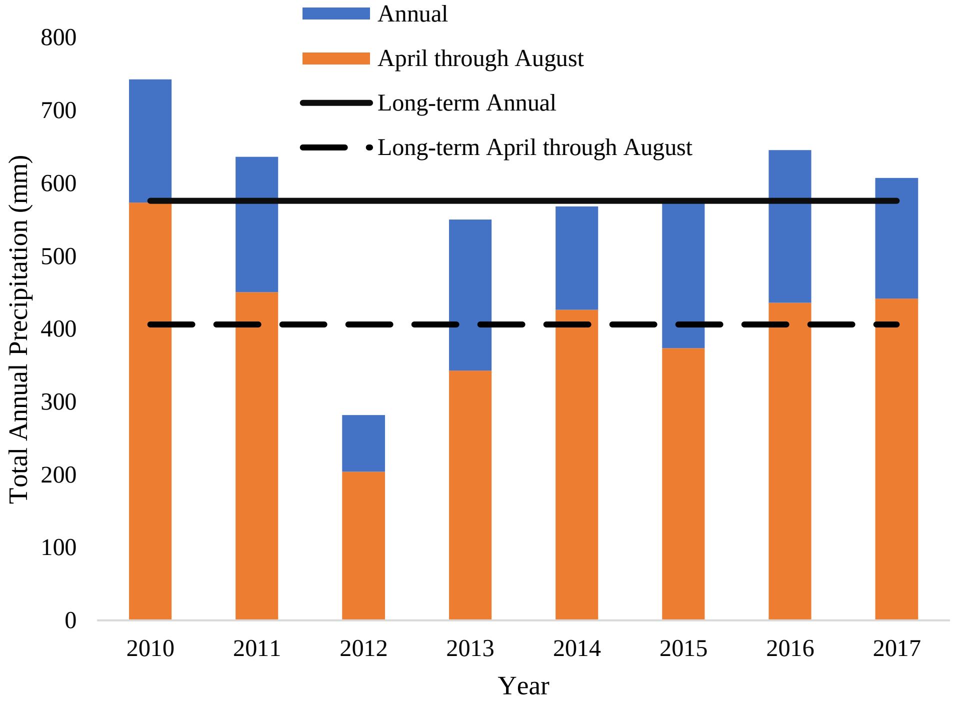

Figure 2.0 April through August and annual precipitation (mm) recorded at the Barta Brothers Ranch from 2010 to 2017 and the long-term average April through August and annual precipitation (30-year mean) (High Plain Regional Climate Center 2018).

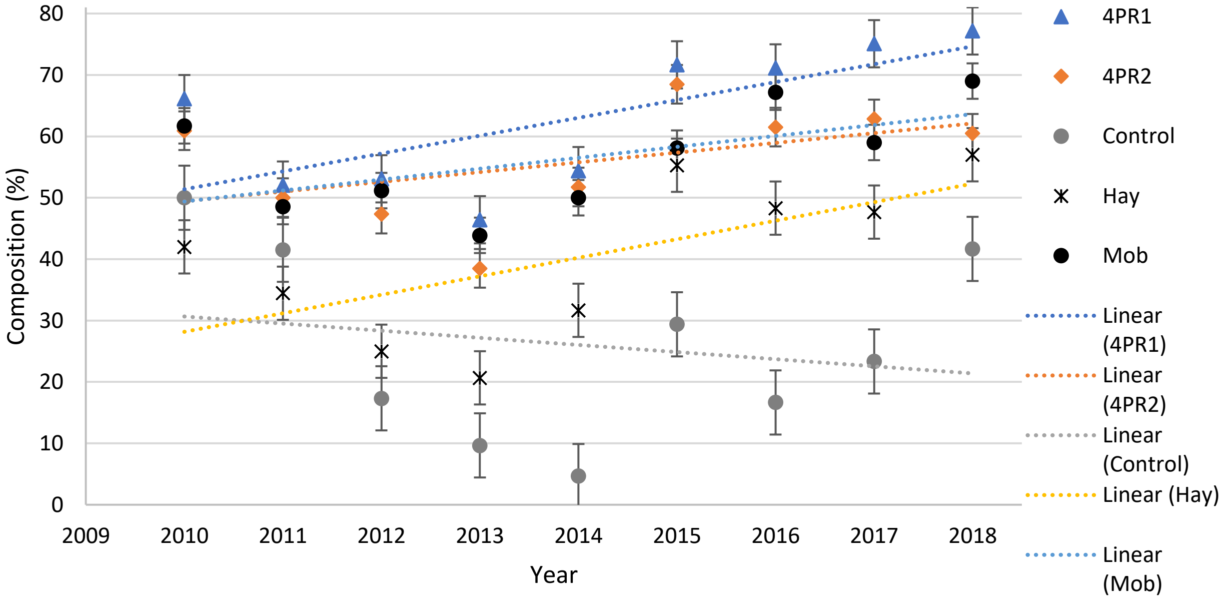

Figure 2.1 Cool-season grass composition (%) for all treatments from 2010 to 2018. 4PR1 is a four-pasture rotation with one grazing cycle and 4PR2 is a four-pasture rotation with two grazing cycles.

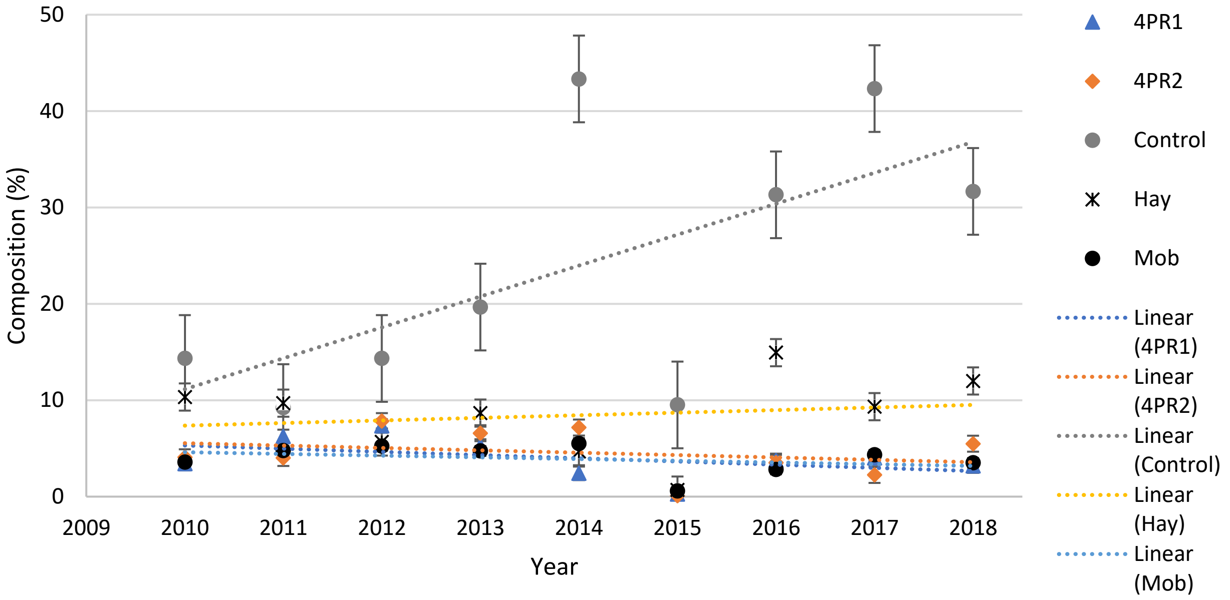

Figure 2.2 Warm-season grass composition (%) for all treatments from 2010 to 2018. 4PR1 is a four-pasture rotation with one grazing cycle and 4PR2 is a four-pasture rotation with two grazing cycles.

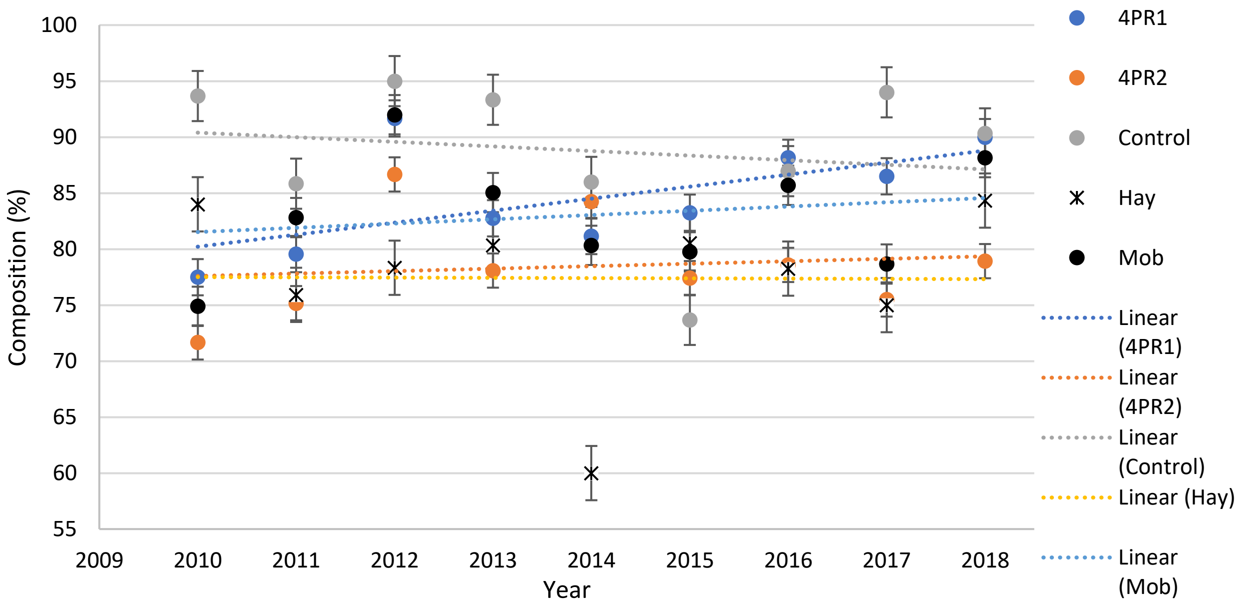

Figure 2.3 Cool-season graminoids composition (%) for all treatments from 2010 to 2018. 4PR1 is a four-pasture rotation with one grazing cycle and 4PR2 is a four-pasture rotation with two grazing cycles.

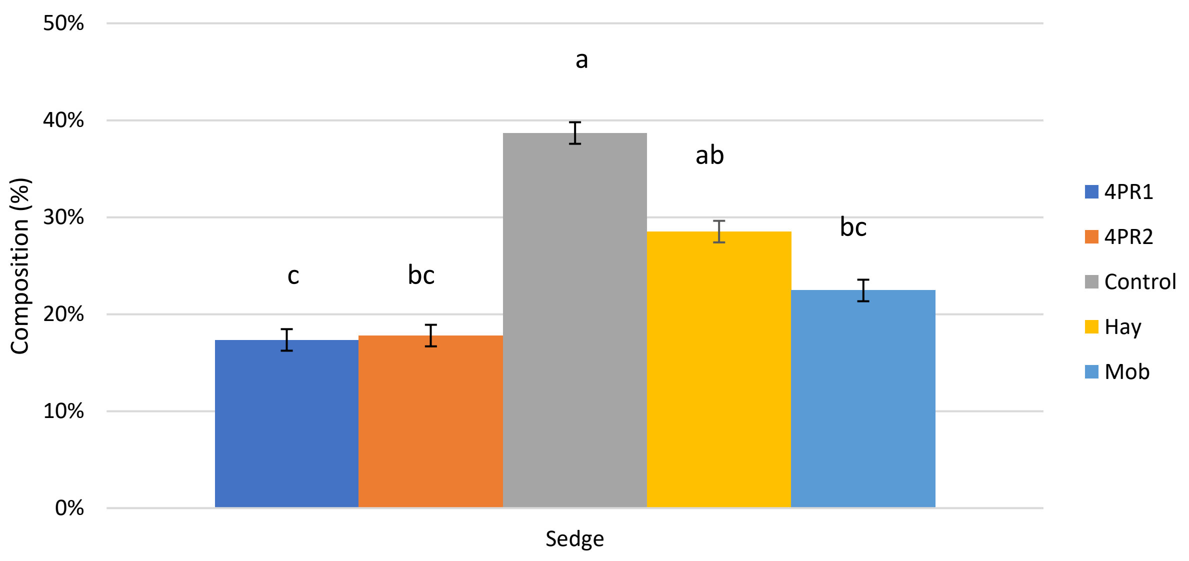

Figure 2.4 Mean percentage sedges by treatment (4PR1, 4PR2, mob, hay, and control).
[1] Percentages with different letters indicate significant difference by treatment ($p < 0.10$)

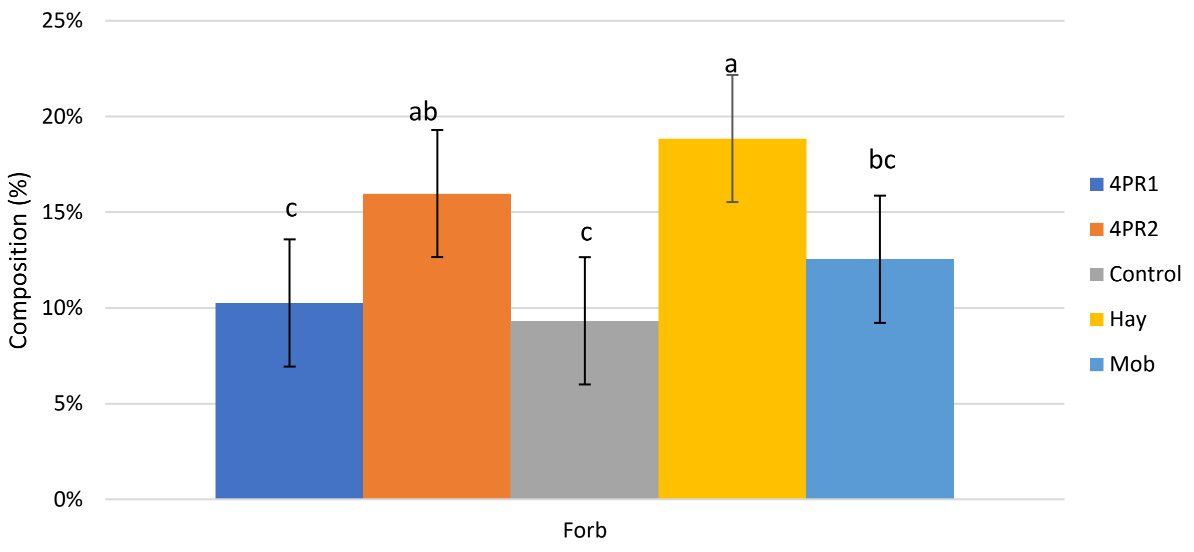

Figure 2.5 Mean percentage forbs by treatment (4PR1, 4PR2, mob, hay, and control).
[1] Percentages with different letters indicate significant difference by treatment ($p < 0.10$).

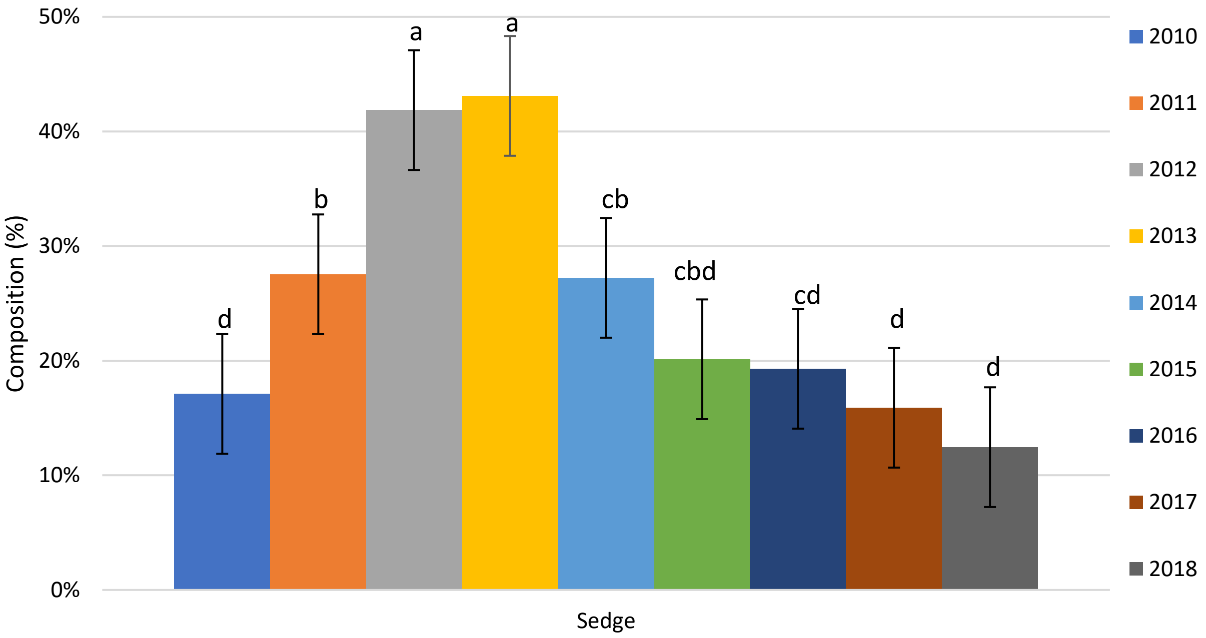

Figure 2.6 Mean percentage sedges by years (2010-2018)
[1] Percentages with different letters in indicate significant difference by year ($p < 0.10$)

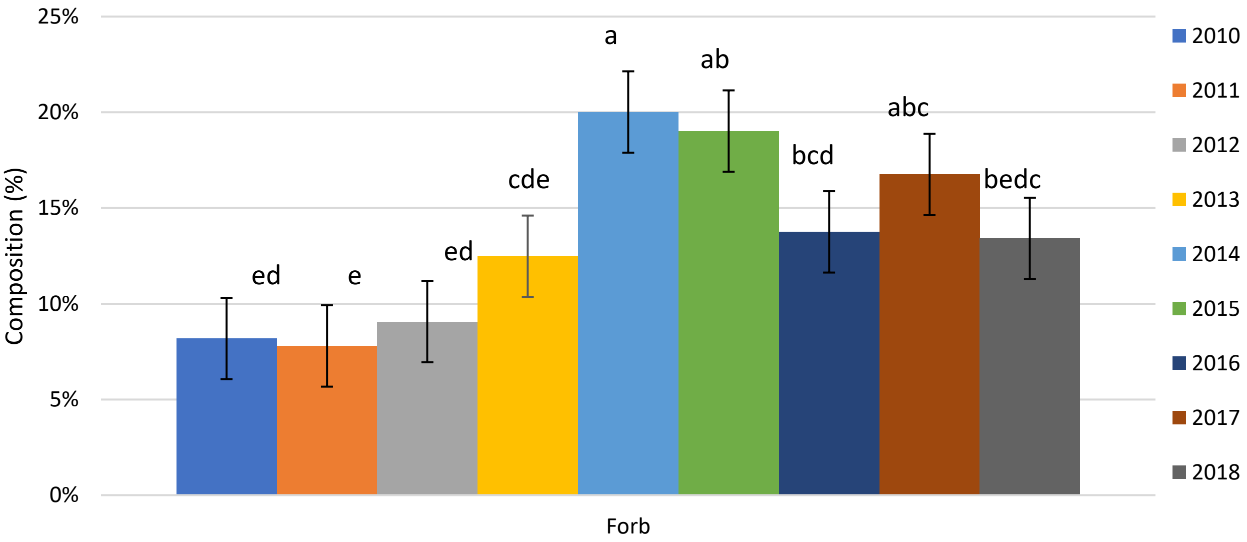

Figure 2.7 Mean percentage forbs in all treatments and by year (2010-2018)
[1] Percentages with different letters in indicate significant difference by year ($p < 0.10$)

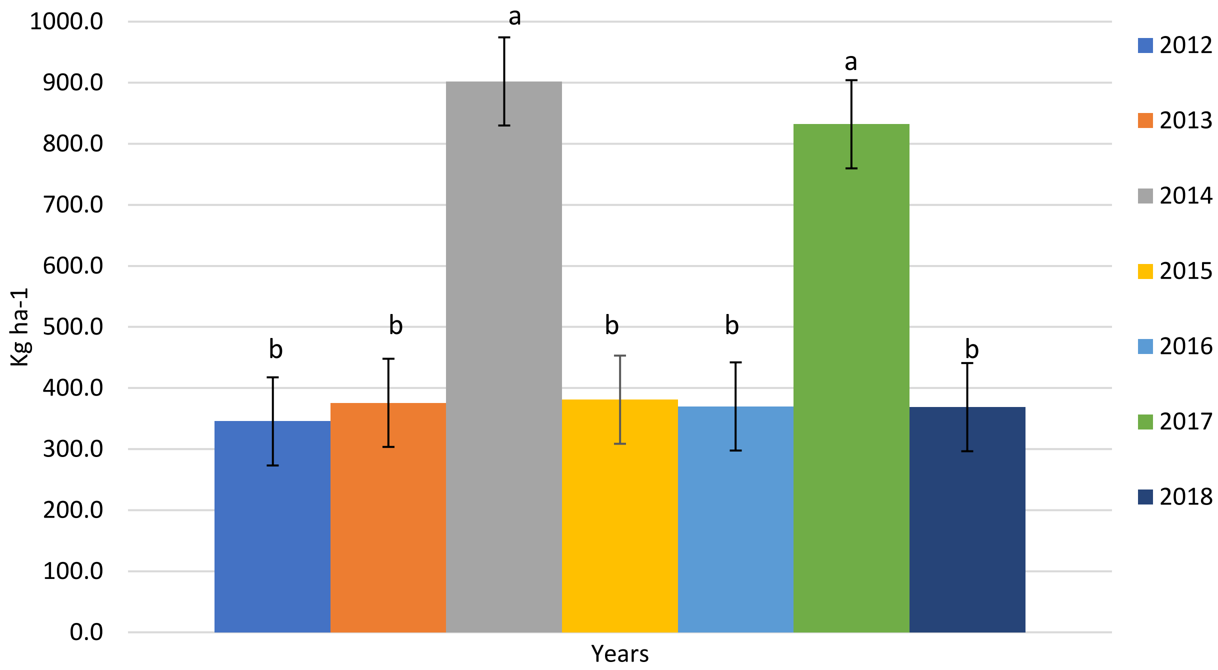

Figure 2.8 Mean Standing dead biomass by year (2012-2018).
[1] Means with different letters indicate significant difference ($p < 0.10$)

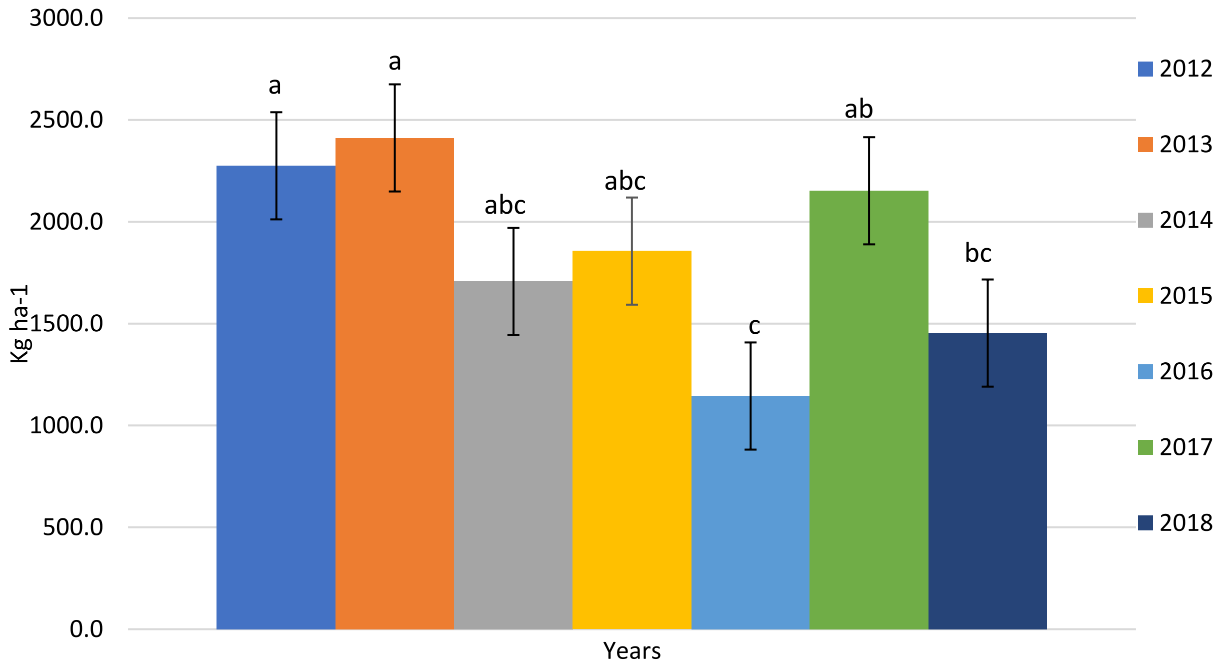

Figure 2.9 Mean litter biomass by year (2012-2018).
[1] Means with different letters over indicate significant difference ($p < 0.10$)

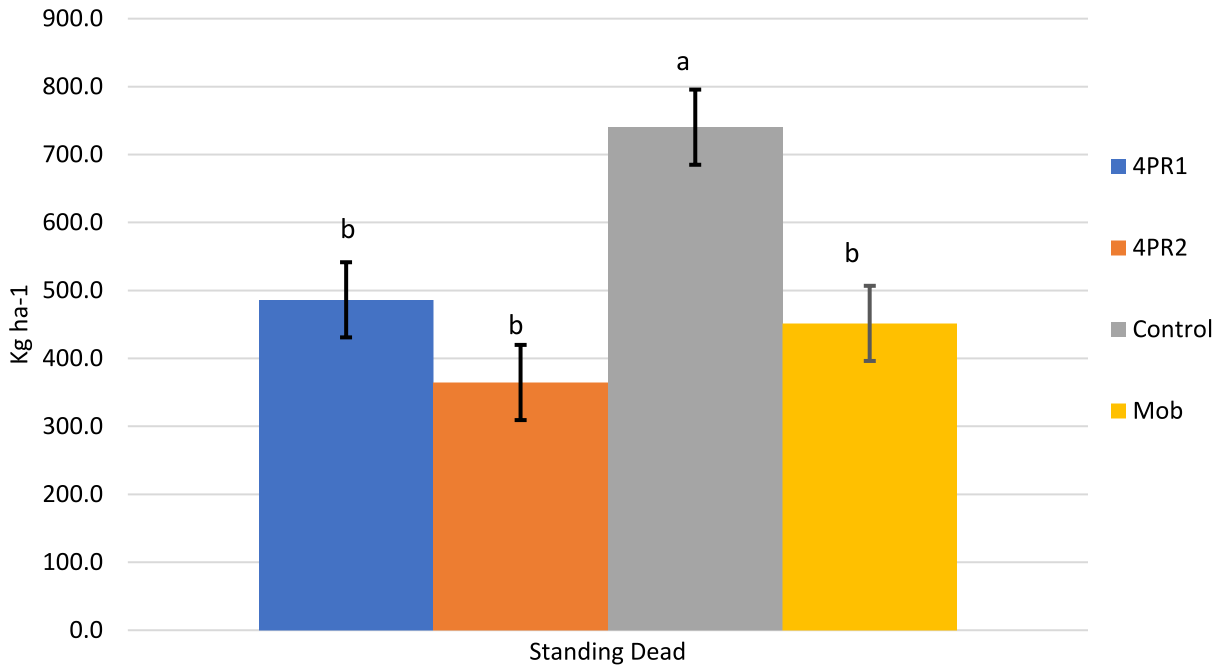

Figure 2.10 Mean standing dead biomass by treatment (4PR1, 4PR2, mob, and control)
[1] Means with different letters indicate significant difference ($p < 0.10$)

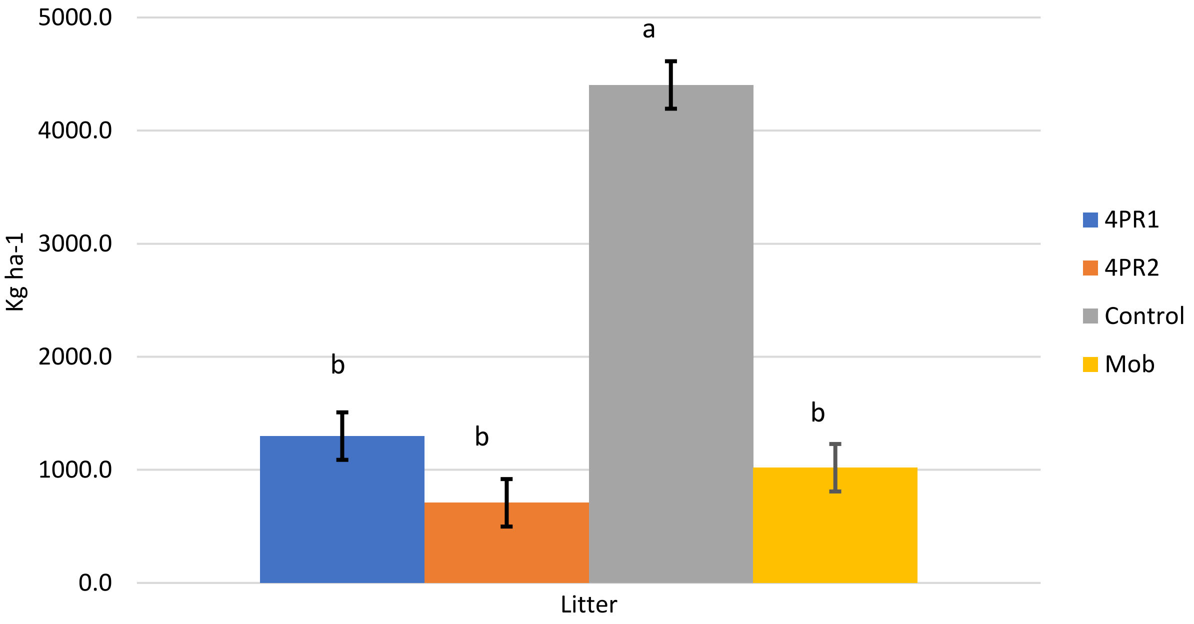

Figure 2.11 Mean litter biomass by treatment (4PR1, 4PR2, mob, and control).
[1] Means with different letters indicate significant difference ($p < 0.10$)

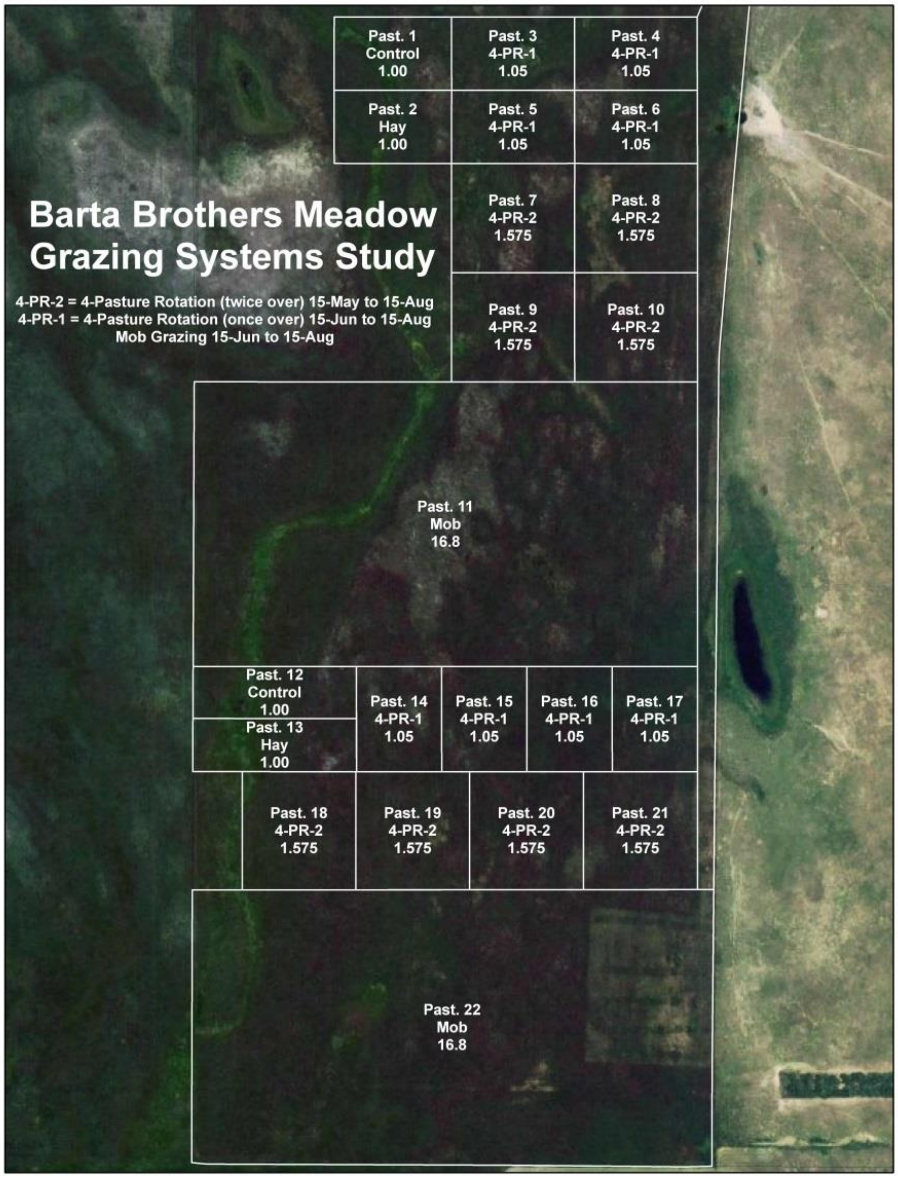

Figure 2.12 Aerial view of the Barta Brothers meadow study site. The top of the map is oriented North. Pastures 1 through 11 are in the North block. Pastures 12 through 22 are in the south block. 4PR1 is a four-pasture rotation with one grazing cycle and 4PR2 is a four-pasture rotation with two grazing cycles.

Tables

Table 2.1 Treatment by year interaction for standing live herbage (kg ha^{-1}) in 4PR1, 4PR2, mob, and control for 2012-2018. 4PR1 is a four-pasture rotation with one grazing cycle and 4PR2 is a four-pasture rotation with two grazing cycles.

				Year			
Treatment	2012	2013	2014	2015	2016	2017	2018
4PR1	4501^{Aac}	4433^{ABac}	4556^{Aac}	4468^{Ac}	5405^{Aac}	4553^{Aac}	6555^{Ab}
4PR2	4367^{Aa}	4173^{ABba}	4870^{Aac}	5821^{BCd}	5544^{Abc}	4218^{Aa}	6513^{Ae}
Mob	3950^{Aa}	4742^{Aabcd}	5264^{Abcd}	5519^{CDc}	5294^{Acd}	4498^{Aad}	6692^{Ae}
Control	3678^{Aa}	3623^{Ba}	3583^{Ba}	4656^{ADbd}	5764^{Ac}	4061^{Aab}	4645^{Bd}

[1] Means with different uppercase letters within columns differ ($P < 0.10$).

[2] Means with different lowercase letters within rows differ ($P < 0.10$).

Table 2.2 Percentage change of individual species by treatment for the first 2 years (2010/2011) versus the last 2 years (2017/2018) of the study. 4PR1 is a four-pasture rotation with one grazing cycle and 4PR2 is a four-pasture rotation with two grazing cycles.

			Treatment			
Species	4PR1	4PR2	Mob	Hay	Control	Treatment p value
Warm-season grass						
Big bluestem	-0.25	0.3	0.7	4.3	8	0.14
Prairie cordgrass	-1.1^{C}	-1.2^{C}	-1.3^{C}	2.8^{B}	15^{A}	0.002
Cool-season grass						
Quackgrass	28.3	19.2	21	19.3	2.5	0.28
Timothy	-8.5	-11.4	-8.3	-1.2	-5.3	0.35
Kentucky bluegrass	8.9	7.7	3.2	5	10.3	0.72
Sedge	-21.3	-17	-15.8	-29.7	-21.5	0.50
Forb						
Red clover	-0.4	-1.1	-2.5	-1.3	-2.5	0.67
White clover	4.2^{A}	6.3^{A}	3.4^{A}	2.7^{AB}	-1.5^{B}	0.09

[1] Means with different letters within rows differ ($P < 0.10$).

Chapter 3: Grazing method effect on soil characteristics of Nebraska Sandhills subirrigated meadows

Introduction

Soil C on range and perennial grazing lands can be driven by several factors. Key factors to changing soil include, soil texture, addition of organic material, the quality of the organic material, soil biology, and abiotic factors (i.e, temperature, moisture) (Dignac et al. 2017). The soil texture and chemistry influence the soil's ability to retain carbon and other nutrients. The level of nutrient cycling is increased in a grazed pasture setting and is affected by the grazing disturbance to the grassland plant communities above the soil surface (Conant et al. 2017). Disturbances during grazing include trampling, removing plant material, and transforming plant material into dung and urine. Changes in soil surface properties occur due to aboveground disturbances over an extended period of time. Differences in grazing management can affect the amount of organic material incorporated, however, the degree and rate of decomposition will be influence by the quantity and quality of the organic materials (Budge et al. 2010). Organic material quality can be determined by factors like lignin and nitrogen content (Aerts 1997) that affect their ability to be consumed by microbes.

The flux of water and nutrients in grasslands is influenced by management and land use changes that can lead to loss or gain of carbon stocks (Conant et al. 2017). Each growing season, varying amounts of the above and belowground portions of grassland plants are utilized by herbivores, insects, and soil organisms (Wardle 2002). A portion of the aboveground vegetation is either trampled into or near the soil surface or consumed by animals (Janzen et al. 1998). A portion of the aboveground plant that is senesced is often left standing and may not be readily incorporated into the soil. However, portions of the aboveground and belowground plant parts that are senesced or trampled decompose and subsequently some fraction may be transformed into soil organic matter (SOM) (Janzen et al. 1998, Berg et al. 2003) and SOM is comprised of approximately 58% soil organic carbon (SOC) (Pribyl 2010; Nelson and Sommers 1996). Plants consumed by herbivores are either excreted back onto the soil surface rapidly or retained by the consumer (Bol et al 2004). Excreted materials, such as dung and urine, are readily available to be further decomposed by soil organisms (Bardgett and Wardle 2003).

The substrate that contributes to SOM include plant litter deposition above the soil surface, root death, decomposition, sloughing, rhizodeposition, and mucilage production below the surface (Van Veen et al. 1991, Reeder et al. 2001). Cycling and decomposition rates depend on several abiotic factors including temperature, moisture, as well as biotic factors such as quantity and quality of the organic materials and soil biology (Cotrufo et al. 2015, Prescott 2010). Nutrients released from the decomposition of organic material are available for plant uptake but can also be lost via leaching and/or gaseous emissions.

Soil C can be stored within soil aggregates but much of it is also respired during decomposition. Soil C is found often within the top 20 cm of the soil surface (Jobbágy and Jackson 2000) and can be susceptible to loss into the atmosphere as CO_2 gas (Hanson 2000). Soil organic C storage and decreased disturbance has the potential to increase the overall health of soils through improved aggregation (Bronick & Lal 2005). Increasing SOM will also increase soil hydrologic function and water retention (Yang et al. 2014) which are key factors to supporting plant production necessary for livestock production in grasslands. Improved grazing management, fertilization, sowing legumes and improved grass species, irrigation, and conversion from cultivation may lead to increased soil C with a potential C addition of 0.1 to 1 Mg C ha^{-1} $year^{-1}$ (Conant et al. 2017).

Factors such as litter quality can also affect the decomposition of organic materials (Córdova et al. 2018, Stark et al. 2007, Budge et al. 2010). Litter quality is most often related to the chemical characteristics of the litter, such as carbon:nitrogen ratios and/or lignin content (Aerts 1997). Temperature/climate also has an effect on decomposition rates of litter of varying quality (Fierer et al. 2005). Grazing management (i.e. stocking density and frequency and timing of grazing), the quantity and quality of biomass removed, residual biomass quantity and quality, and plant species and communities are factors that affect soil and potential soil C retention (Bardgett and Wardle 2003).

Much of the organic matter contributed to the soil is in the form of root material. The shoot:root ratio at peak standing crop is commonly used to estimate the C inputs from the root biomass left in the soil at harvest (Bolinder et al. 1999). A review of several shoot to root ratios in natural grassland studies ranged from 0.16 to 1.75 (Bolinder et al. 2002). Factors that influence aboveground biomass production, such as climate, soil fertility and management, will also affect shoot:root ratios (Bolinder et al. 2002).

Soil organic matter that is stored long term is protected in several ways. It is protected biochemically by binding with clay and silt sized particles, physically protected or occluded in a clay-aggregate matrix, and forming complex recalcitrant chemical structures (Jones and Donnelly 2004). Some of the C is stored in stable soil macro-aggregates that have C turnover rates of thousands of years according to (Jenkinson 1990, Paul et al. 1997). A large amount of the occluded SOM comprises a pool having an intermediate (10 –15 yr) residence time, but it can decompose more quickly with disturbance such as tillage. More active organic matter, consisting of microbial biomass and labile organic matter, such as plant detritus and other easily decomposed matter, cycles more rapidly but makes up only 3–5% of total SOM (Darrah, 1996; Joffre & Ågren, 2001).

Although there is strong evidence to link grazing management to soil C sequestration, there is still uncertainty in just how much C can be sequestered in grazing lands. Ojima et al. (1993) suggested that grasslands were a C sink capable of sequestering 0.6 to 1.8 Pg C yr^{-1} worlwide. Schuman et al. (2002) also suggested grasslands are a sink for C and that grazing intensifies the C sequestration anywhere from 0.1 to 0.6 Mg ha^{-1} yr^{-1}. However, soil C sequestration is likely a function of several site-specific characteristics such as climate, soil, and vegetation (McSherry and Ritchie 2013). A broad estimate of sequestration potential cannot be uniformly applied to all grazing lands (Ogle et al 2004) due to inherent variability in soils, management, and environmental factors. This variability also means that some soils may have the potential to sequester more C than others. Therefore, there is a threshold or steady state in soils that allots only so much C to be stored until another perturbation occurs (Janzen et al.1998). Net C storage estimates include C inputs and outputs or losses and the change in SOC depends on input of plant litter relative to that of soil respiration (Janzen et al. 1998). The form of the C that is stored is also important because some C is stored in a stable state while others are stored in less stable states which can be affected by litter quality (Cotrufo et al. 2015).

Stocking density, timing of grazing, plant maturity, and plant height affects the relative portion of standing forage that is trampled during a grazing period. Ultrahigh stocking density treatments (200,000 kg ha^{-1}) trample as much as 60% of the standing live herbage in a Nebraska Sandhills subirrigated meadow study site (Redden 2014, Gompert 2010) and the C and N content of the aboveground biomass on a Sandhills meadow averaged 43 and 1.3% respectively (Johnson 2012).

The objectives of this study were to compare the effects of different rotational grazing treatments, with ultrahigh and low stocking densities, on SOC stocks on a Sandhills meadow over 8 years of grazing. The hypothesis that an increased level of trampling of aboveground vegetation associated with ultrahigh stocking density would increase C storage in the soil by increasing dead plant C input, and increasing the density of dung and urine pulses. Ultrahigh stocking densities that results in a greater amount of trampled herbage will result in a measurable increase in total soil C stocks in the 0-10 and 10-20 cm soil depths.

Materials and Methods

Study Site

Research was conducted at the University of Nebraska-Lincoln Barta Brothers Ranch located 11 km northwest of Rose, NE (42˚13'13"N, 99˚38'27"W). Long term average temperature during the growing season, measured at the Ainsworth NE weather station from 1981 to 2010, was 17˚ C. Long term precipitation averaged 578 mm annually, with 77% of the precipitation occurring between April and September (High Plains Regional Climate Center, 2017). Based on data collected at the Barta Brothers

Ranch Headquarters, average precipitation from 2010-2017 was 650mm, average temperature was 8.9°C annually and 16.7°C during the growing season (April-October). The growing degree days averaged 4918 annually.

The study was conducted on a meadow dominated by the subirrigated ecological sites. Approximately 10% or 450,000 ha of the Nebraska Sandhills is subirrigated or wet subirrigated ecological sites (Bleed and Flowerday 1998). The slope is less than 1 to 3%. The subirrigated and wet subirrigated sites are found on interdunes and stream valleys. The water table is seasonally high under these sites rising to 15 to 45 cm depth from the surface (USDA-NRCS, 2017). For subirrigated sites redoximorphic features are observed at soil depths between 450 to 900 mm (USDA-NRCS, 2017).

Soils of the study area are mixed, mesic Aquic Ustipsamments and mixed, mesic Typic Psammaquents. The soils are comprised mostly of Els loamy sand and Tryon loamy fine sand. Study soil clay content was 8.9 g kg^{-1} at 0-10 cm depth and 7.9 g kg^{-1} at 10-20 cm depth.

Vegetation on the study site is dominated by cool-season plant communities. Cool-season grasses that are most commonly observed on the study pastures are quackgrass (*Elymus repens (L.) Gould*), timothy (*Phleum pretense L.*), Kentucky bluegrass (*Poa pratensis L.*), and reed canary (*Phalaris arundinacea L.*). Warm-season grasses are less prevalent and include big bluestem (*Andropogon gererdii* Vitman), indiangrass (Sorghastrum nutans (L.) Nash), switchgrass (Panicum virgatum L.), and prairie cordgrass (*Spartina pectinata* Bosc). Red and white clover (*Trifolium pretense L.* and *Trifloium repens L.*) were the most prevalent forbs. Sedges and rushes (*carex spp., Eleocharis R. Br.* and *Juncus L.*) were also commonly found throughout the study site.

Less prevalent forbs that are also commonly found throughout the site also included yarrow (*Achillea millefolium L.*), and dandelion (*Taraxicum officinale* F.H. Wigg). Prior to the initiation of the study in 2010, the meadow was hayed annually in the summer for the last several decades.

Treatments

The study site (25 ha) was divided into 2 blocks (North and South) with five treatments in each block. The 5 treatments were 3 grazing treatments and 2 non-grazed treatments in a randomized complete block design. The grazed treatments were ultrahigh stocking density (mob), 4-pasture rotation with one grazing cycle (4PR1), and 4-pasture rotation with two grazing cycles (4PR2). All grazed treatments had the same stocking rate of 7.4 AUM ha^{-1}. Yearling steers with an average initial weight of 365 kg were used in the grazing treatments. The non-grazed treatments were an annual mid-July haying treatment, and a control. The control had no livestock grazing or haying during the study.

Stocking density in the mob treatment was set at 225,000 kg live weight ha $^{-1}$. This stocking density was within what practitioners of mob grazing have reported from 200,000 to 1,000,000 kg live weight ha $^{-1}$ (Redden 2014). Within the mob grazing plots, a total of 36 yearling steers were rotated through 120 pastures (0.06 ha each) over a 60-day period, and the steers were moved to a new pasture twice daily. Grazing began in a different quadrant each spring. Timing of steers pasture moves were at 0700 and again at 1400. The morning pasture was left open and available to the steers until the next day at 0700. Fresh water and salt were available were located at one end of the pasture and were moved with the cattle each day. Grazing in the mob treatment began in mid-June in every year of the study from 2010 to 2017. One objective of the study was to induce high levels of trampling (60% or greater) in the mob pastures, so grazing in the mob was delayed until June to allow for grasses to begin elongating which would increase the amount of stem biomass available for trampling through the grazing season Gompert (2010).

The 4PR1 grazing treatment 60-day grazing season began at the same time as the mob treatment to allow for direct comparison with the mob treatment. This treatment had 4, 0.4-ha pastures grazed by 9 steers for 15 days. Steers were rotated through each pasture once during the grazing season. Stocking density was 7,000 kg of livestock weight ha $^{-1}$. Fresh water and salt were available to the steers at all times and the salt was located within 10 m of the water.

The 4PR2 grazing treatment had an 80-day grazing season beginning at a time (on or around 20 May) when there was abundant vegetative forage plants and few elongated tillers. The treatment consisted of 4, 0.6 ha pastures that were grazed twice during the grazing season. Stocking density was 5,000 kg ha $^{-1}$ and 10 steers grazed the treatment pastures. The first and second occupations of each pasture were about 10 days each with the first occurring between 20 May and 1 July and the second occurring between 2 July and 10 August. The grazing season for the 4PR2 treatment was set up to end at the same time as the mob and 4PR1 treatments. Fresh water and salt were available to the steers at all times and the salt was located within 10m of the water.

Hay plots were 1-ha each harvested annually for hay in mid-July. Hay plot production data were collected in 2010, 2011, 2017, and 2018 of the study. The hay was put-up in big round bales (700 kg each) and removed from the meadow shortly after harvest. Control plots were located in each block and were 1-ha in size. Control plot vegetation data was collected at the end of each grazing season. No livestock grazing or haying took place in the control plots over the course of the study.

Soil Sample Collection and Processing

Soil sample cores were collected in the spring in 2010 before grazing initiation (baseline) and in 2018 at the end of the grazing study (i.e last grazing in 2017). 8 samples per pasture were taken for the 4PR (32 total per replication), hay, and control. 13 samples were taken for each quadrant of the mob pastures (52 total per replication). Core samples were taken in zero contamination sleeves using a step-in soil probe to a depth of 20 cm. Once the soil cores in the sleeve were removed from the probe, they were placed in cooler and transported to the lab. Core samples were kept at 0 ^{o}C or less until lab analysis could be conducted. Each core was separated into two distinct layers, the 0–10 cm and 10–20 cm mineral layers, and pooled within each layer.

Bulk Density

Field moist soil cores for each depth were weighed and then oven dried at 105° C for 24 hours to determine gravimetric water content. The bulk density of each soil depth was determined using volume of each soil depth and the oven dried sample mass. Bulk density was calculated using the following equation (Eq.1):

$$\text{BD of each depth (Mg m}^{-3}\text{)} = \text{(oven dried soil mass) / (soil volume)} \quad \text{[Eq. 1]}$$

Carbon, N, C:N ratio

Samples at each depth were homogenized by milling soil to an average of 149 microns using a SPEX sample prep 8000D Mixer mill (Metuchen, New Jersey, USA). About 80 to 100 mg of the finely milled samples were loaded into tin foil cups and then rolled into a small leak-proof ball with the index finger and thumb before placing the sample into the analyzer carousel. Soil C and N for each soil depth and treatment were analyzed using a Thermo Scientific, Flash 2000 Organic Elemental Analyzer (Waltham, MA, USA). Sample were combusted at 1800° C and CO_2 and N were captured and quantified by a thermo conductivity detector.

A calibration curve was developed for each set of 75 samples. The calibration curve included 5 tins filled with increasing amounts of aspartic acid (5mg then doubled sequentially for each of the next 4 tins), 2 tins filled with 80 to 100 mg of standard soil (Aksarben), and 2 tins that were empty.

Carbon Stock

Soil organic carbon (SOC) stock was calculated using the equation (Eq. 2) as described by Saiz et al. (2016). This approach accounts for bulk density and concentrations given depth intervals as well as any gravel fractions. However, gravel fraction in this study was insignificant. SOC was calculated according to the following formula.

$$\mu_d \, (\text{Mg OC ha}^{-1}) = BD_d \times OC_d \times D / 10 \qquad \text{[Eq. 2]}$$

where:

μ_d is SOC stock (Mg OC ha^{-1})
BD_d is soil bulk density (g cm^{-3})
OC_d is the concentration of OC in soil (< 2 mm; mg OC g^{-1}soil)
D is soil depth interval (cm)

Statistical Analysis

Data were analyzed using a proc GLIMMIX mixed-model analysis of variance (ANOVA) and the ls means statement to separate the main effects for treatment and depth in SAS Studio 5.1 (2018, Cary, NC, USA). An overall mean of the entire study site was used as the baseline soil C, N, C:N, and bulk density for 2010. The 2018 experimental units were the mob, 4PR1, 4PR2, hay, and control treatments by block, and depth. Each 2018 treatment mean was subtracted from the 2010 baseline mean to create a corrected C, C:N, and bulk density value. The differences between the study site means for 2010 and treatment means 2018 for depth and block were then analyzed. Probability values less than 0.10 were considered significant.

Results

Bulk Density

The bulk density of the soil on the study site did not differ by treatment or depth from the 2010 baseline compared 2018 (Table 3.1). Mean bulk density of the soil at this site as a whole in 2010 for the 0-10 cm depth was 0.92 g cm^{-3} and 1.56 g cm^{-3} for the 10-20 cm depth. In 2018 mean bulk density for the 0-10 cm and 10-20 cm depths was 1.18 g cm^{-3} and 1.69 g cm^{-3}, respectively.

Percent Soil Carbon and C Stock

Soil C content did not differ among treatments or by depth from 2010 to 2018 (Table 3.2). Mean soil C of the site as a whole in 2010 (baseline) was 2.6% for the 0-10 cm depth and 0.66% for the 10-20 cm depth. Eight years after grazing, mean soil C was 2.8% for 0-10 cm depth and 0.6% for the 10-20 cm depth.

There was no difference in C stock between baseline in 2010 and the final year of sampling in 2018. Carbon stock averaged over the entire site was 2.42 and 1.02 Mg OC ha^{-1} in the 0-10 cm and 10-20 cm depths respectively (Table 3.2). The 2018 mean C stock was 3.31 and 1.01 Mg OC ha^{-1} in the 0-10 cm and 10-20 cm depths, respectively.

Soil C:N Ratio

Soil C:N did not differ by treatment or depth between 2010 and 2018 (Table 3.1). Mean C:N of the site as a whole in 2010 was 10.3 for 0-10 cm and 8.9 for 10-20 cm. After treatments had been applied for 8 years, mean C:N was 18 for the 0-10 cm depth and 6.6 for the 10-20 cm depth.

Discussion

The results of this study did not support the hypothesis that there would be an increase in soil C as a result of the increased management intensity associated with mob grazing. On ranch data from an unpublished mob grazing study at UNL (Wingeyer et al. unpublished 2014) also indicated that soil C of Sandhills meadows that were mob grazed did not differ from meadows hayed or rotationally grazed at low stocking densities. Soil organic matter on these meadows ranged from 3 to 3.4% (1.9% SOC) slightly lower than our site.

The lack of differences over time and among treatments for C and N could be due to the overall lack of inputs that are necessary to increase C content. Aboveground C content of standing live forage averaged 43% ± .48 based on forage quality analysis that was conducted in 2013, and available C in aboveground biomass was similar in all treatments (Table 3.3). Factors affecting the inclusion of aboveground organic material into this soil included trampling, amount of standing dead herbage, and litter amount.

Duiker (2018) suggests that the level of plant residue that is converted to SOM is 10-20%. From that 10-20% that is converted to SOM and only 58% of SOM is SOC in most soils (Pribyl 2010; Nelson and Sommers 1996) and very little of that SOC is converted to stable soil C. The level of trampling was higher in the mob pastures ($p = 0.09$) 51.6% (2192 kg ha^{-1}) compared to 28.2 (982 kg ha^{-1}) and 18.7% (673 kg ha^{-1}) in the 4PR1 and 4PR2 pastures respectively. The increase in trampling by mob grazing is one of the key factors that practitioners have claimed to benefit the soil when compared to traditional strategies (Gompert 2010). Based on Duiker's (2018) conversion estimation (15%), and given the amount of trampled material in the mob, 4PR1, and 4PR2 (2192, 982, and 673 kg ha^{-1}, respectively) 328, 147, and 101 kg ha^{-1} of SOM would actually enter into the soil, respectively. From that only (Nelson and Sommers 1996) 190, 85, and 59 kg ha^{-1}, respectively, would end up as SOC annually.

Given the conversion and composition of the vegetation (high C:N), variable seasonal distribution of precipitation, relatively short time period of this study, very little SOC difference would be expected between grazing treatments based on aboveground inclusion of vegetation from trampling. Regardless of the amount of vegetation included into the soil, the annual addition of C into the soil must also be retained. As suggested by Six et al. (2002) soils have a threshold of how much SOM or C they can hold based on physical and chemical constraints of different soil types such as clay content and cation exchange capacity.

The level of standing dead herbage and litter was not different among grazed treatments but all grazed treatments had less standing dead and litter than the control ($p = 0.06$ and $p = 0.03$ respectively). Litter averaged 1008 kg ha^{-1} in the grazed treatments from (2012 to 2018) and 4400 kg ha^{-1} in the control (2012 to 2018). Standing dead herbage in the grazed treatments averaged 433 kg ha^{-1} and 740 kg ha^{-1} in the control

(2012 to 2018). The control had more standing dead and litter material available for incorporation into the soil but lacked a physical mechanism to actually incorporate it.

Overall, litter and standing dead herbage were distributed relatively uniformly within each of the respective treatments. Animal excreta was quite variably distributed across 4PR treatment and relatively uniformly for the mob treatment, based on visual observation (not quantified).

The lack of difference in C for all treatments over the 8 years on the study site could be due to several factors that are not completely understood. Several possible explanations include soil temperature, moisture, texture, N availability and other factors affected the metabolic activity and community structure of soil microorganisms. These factors can have large effects on decomposition rates (Stewart et al. 2008, Feng et al. 2011) affecting the overall C content in soils.

At this study site, the soil surface is often wet early in the spring through early summer, after that the surface dries out. This drying out coincides with the timing of grazing of this study. When heavy trampling from mob grazing began in early to mid-June the soil surface was going into the dry phase (See weather data in chapter 2 and 3). Although temperature was conducive to high amounts of soil biotic activity surface moisture was on the decline. This decline in soil moisture at the time of the litter introduction via trampling might have resulted in less decomposition. Low litter quality in terms of C:N is also a possible limiting factor of decomposition. Lower decomposition rates over all treatments would cause soil C stock to remain relatively unchanged. Additionally, physical incorporation of plant material into the soil may be limited after animal activity ceased at the end of each grazing period.

There could also be a C threshold that limits the amount of C a given soil type can hold/retain based on the physiochemical processes that stabilize or protect organic compounds (Six et al. 2002). The soils on this study site were loamy sand with low clay content. Soils that do not have high clay contents would be less likely to retain soil C (Hassink 1997) such as the sandy soils (86 g sand 100 g^{-1} soil, 8 g clay 100 g^{-1} soil clay) found on this meadow. Sandy soils have less potential to aggregate, and clay retains more soil C due to relatively high surface area and clay-C interactions (Conant et al. 2003). Thus, results regarding change in SOC on this loamy sand meadow soil could have been driven by low clay content and high sand content (8% and 86% respectively). According to web soil survey (2018), the soils on this meadow would have around 2% SOM in the 0-10 cm depth. Our resulting C values suggest that the baseline organic matter content of this meadow in 2010 was already higher than an average Els or Tryon sandy loam like this one from the soil survey. This could potentially explain why no increase in C was detected. This meadow soil could be at its maximum C potential.

Another hypothesis is that some of the C in soil is tied up in aggregates and is chemically and physically protected within different aggregates sizes or fractions (Six et al. 2002). Conant et al. (2003) suggests that silt and clay soils have high potential to tie up soil C in aggregates. The aggregate fraction can also provide C distribution and may be sensitive in detecting management induced changes ((Sollins et al. 1996, Ryals et al. 2014). Conant et al. (2003) evaluated management intensive grazing to extensive grazing and hay treatments on soil C fractions and found that that soil C under intensive grazing was greater than extensive grazing or haying. Whole differences in whole soil C were not found among treatments and between years in our study, C in soil size fraction may provide additional insights how grazing management affects the soil C and N. However, given the small amount of potential aggregation in this 8% clay soil, SOC protection in aggregates is not likely.

An increase in soil bulk density in a sandy soil would likely not occur as a result of grazing, simply due to the physical mechanics of sandy soils. Because sandy soils have less overall pore space than silt and clay they would be less susceptible to compaction (Singer and Munns 2006; Daddow and Warrington 1983) or an increase in bulk density.

High rates of trampling, low animal performance, and high management intensity are justified by producers because there is a proposed tradeoff between these factors and an increase in soil health and function. However, 8 years after grazing, our results suggest less forage consumption, and decreases in animal performance with the mob grazing strategy. Animal performance was lowest in the mob grazed treatment at 0.14 kg day^{-1} weight gain compared to 0.20 and 0.64 kg day^{-1} in the 4PR1 and 4PR2, respectively. The lower grazing pressure and the higher forage quality in the 4PR2 pasture, especially in the last half of the grazing season during the second cycle, likely was the cause of the increased weight gain of the 4PR2 steers. There was no difference among grazing treatments in plant species composition, aboveground plant production, and soil C stock in this heavily cool-season meadow pasture. The cost of increasing management intensity with no increase in animal performance would need to be offset by an increase in SOC, plant production, and species composition if mob grazing was to be a viable management strategy. Additional research should address the interactions of dead plant materials with urine and dung as well as soil retention of root C inputs and the mineral C and N residence times relative to the CO_2 respiration rates of soil microbes.

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Tables

Table 3.1. Bulk Density (gm cm^{-3}) for baseline mean (2010) and treatment means (2018) for all treatments and depths

Year	Treatment	Depth (cm)	Bulk density (gm cm^{-3})	SE +/-
2010	All	0-10	0.92	0.30
		10-20	1.56	0.12
2018	4PR1	0-10	1.17	0.03
		10-20	1.66	0.00
2018	4PR2	0-10	1.26	0.01
		10-20	1.72	0.00
2018	Control	0-10	1.15	0.14
		10-20	1.64	0.02
2018	Hay	0-10	1.14	0.14
		10-20	1.67	0.02
2018	Mob	0-10	1.19	0.03
		10-20	1.76	0.06

[1] 4PR1 = 4-pasture rotational grazing with one cycle.

[2] 4PR2 = 4-pasture rotational grazing with two cycles.

Table 3.2. C, N, C:N, and C stock for baseline mean (2010) and treatment means (2018) for all treatments and depths

Year	Treatment	Depth (cm)	Mean C (g $100g^{-1}$)	SE +/-	Mean N (g $100g^{-1}$)	SE +/-	C:N	SE +/-	C Stock (Mg C ha^{-1})
2010	All	0-10	2.63	0.83	0.26	0.08	10.25	1.18	2.42
		10-20	0.66	0.15	0.09	0.05	8.91	2.46	1.02
2018	4PR1	0-10	2.79	0.36	0.30	0.02	9.20	0.23	3.31
		10-20	0.68	0.16	0.12	0.03	6.99	1.59	1.15
2018	4PR2	0-10	2.62	0.52	0.32	0.08	8.54	0.03	3.38
		10-20	0.52	0.12	0.12	0.05	6.24	0.93	0.92
2018	Control	0-10	3.11	0.44	0.25	0.09	12.44	7.98	3.55
		10-20	0.60	0.19	0.15	0.12	6.62	6.39	0.99
2018	Hay	0-10	2.57	0.40	0.13	0.11	19.77	32.37	2.91
		10-20	0.57	0.13	0.13	0.10	7.72	4.08	0.95
2018	Mob	0-10	2.84	0.14	0.13	0.09	22.48	12.11	3.38
		10-20	0.59	0.06	0.20	0.00	5.24	1.36	1.05

[1] 4PR1 = 4-pasture rotational grazing with one cycle.

[2] 4PR2 = 4-pasture rotational grazing with two cycles.

Table 3.3 Total C of standing live herbage (kg C ha^{-1}) in the 4-pasture rotational grazing with one cycle (4PR1), 4-pasture rotational grazing with 2 cycles (4PR2), mob, and control for 2012-2018.

	Year						
Treatment	2012	2013	2014	2015	2016	2017	2018
4PR1	1936	1906	1959	1921	2324	1958	2819
4PR2	1878	1794	2098	2503	2384	1814	2800
Control	1581	1558	1541	2002	2479	1746	1997
Mob	1698	2039	2263	2373	2277	1934	2878