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Grazing Method Effects on Forage Production, Utilization, Animal Performance and Animal Activity on Nebraska Sandhills Meadow

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By

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Grazing Method Effects on Forage Production, Utilization, Animal Performance and Animal Activity on Nebraska Sandhills Meadow

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A study was conducted on a subirrigated meadow in the Nebraska Sandhills to determine differences in aboveground plant production, utilization, trampling, harvest efficiency, ground cover, plant functional group composition and animal performance among four grazing treatments. Grazing treatments included ultrahigh stocking density, four-pasture rotation with one occupation (4-PR-1), and four-pasture rotation with two occupations (4-PR-2). Pastures were grazed from May to August in 2014 and 2015 at equal stocking rates within years but varied among years. Stocking densities were 225,000 kg ha^{-1} for ultrahigh stocking density, 7,000 kg ha^{-1} for 4-PR-1, and 5,000 kg ha^{-1} for 4-PR-2. Aboveground plant production did not differ among treatments. Litter mass was 2 to 4 times greater in control treatments but there were no differences among grazed treatments. Standing dead biomass did not differ among treatments. Utilization was greater in ultrahigh stocking density treatments than 4-PR-1, likely due to trampling amounts, which were greatest in ultrahigh stocking density. Remaining herbage was lowest in ultrahigh stocking density treatments. Cool-season grass composition was greatest in the 4-PR-1 treatment and lowest in the control treatment. Warm-season grass composition was greatest in 2015 for grazed treatments and in 2014 for the control treatment. Sedges and rushes did not differ among grazed treatments. Percentage forbs did not differ among treatments and peaked in 2014. There were no treatment effects on ground cover; including litter, bare ground and plant base hits. In 2014, steer daily gains among all treatments were not different. In 2015, steer average daily gains in the 4-PR-2 were greater than ultrahigh stocking density and 4-PR-1 daily gain.

Key Words ultrahigh stocking density; mob grazing; functional group composition; aboveground plant production; animal performance

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Introduction

Grazing management strategies include a number of different tools and practices that can be used to achieve a variety of animal, plant, and soil objectives on grazinglands. Grazing strategies can be used to control the timing, intensity and frequency of defoliation of vegetation cover, which are key factors in affecting plant production and composition. Timing refers to season or time of grazing relative to plant development stage (Kirby et al., 2000). Timing can be used to manipulate botanical composition of rangelands by such strategies as increasing grazing pressure when target plant species are at a growth stage susceptible to grazing. Applying high grazing pressure in the spring has been used in the mixed-grass grazinglands of the central Great Plains to target invasive cool-season grasses, such as smooth bromegrass (*Bromus inermis* Leyss), and favor the native warm-season grasses (Smith and Owensby, 1978). Frequency of grazing refers to the number of times within a growing season that a plant is subject to defoliation. Frequency and intensity of grazing can alter the species composition of a pasture and may lead to successional changes (Hart et al., 1993).

Grazing intensity refers to the amount of defoliation resulting from animal demand placed on forage (Vallentine, 2000) and is quantified in terms of stocking rate and grazing pressure. Stocking rate is defined as animal unit demand per unit area per unit time (Committee and others, 1974); whereas, cumulative grazing pressure refers to animal unit demand per unit plant biomass per unit time. Grazing pressure is the best descriptor of intensity because it quantifies the demand placed on available plant biomass: however, grazing pressure is infrequently used by practitioners because it requires measures of plant biomass. Stocking density, another commonly used measure of grazing intensity, is defined as animal unit demand per unit area (AU/ha) at a point in time (SRM Glossary Global Rangelands, 1998), or grazing intensity at a point in time. Stocking density increases as animal numbers per unit area are increased and/or pasture size decreases. Another objective of grazing strategies can be to improve grazing distribution throughout a pasture, and stocking density has been used as a tool to achieve greater grazing distribution (Barnes et al., 2008; Savory and Butterfield, 1998). Grazing pressure and stocking density are directly related and at some level of stocking density, grazing pressure becomes so high that selectivity of grazing animals is compromised and use of the available plant biomass is even (Gompert, 2010; Peterson, 2010, 2014). Hickman et al. (2004) found that animal density was a key factor in simplifying plant diversity and species composition. Ultrahigh stocking densities (>200,000 kg live weight ha^{-1}) are reported to result in extremely high grazing pressure and even use of pasture forage (Gompert, 2010).

The amount of defoliation during grazing is referred to as utilization (%) and includes the amount of available plant biomass consumed by the grazing animal and the amount trampled in the grazing process (Committee and others, 1974). The plant material trampled by grazing animals gradually decomposes becoming litter and later adds to soil organic matter. Increased soil organic matter increases potential plant production and alters plant functional group composition, generally toward higher yielding plant species (Savory, 1988). Higher stocking density is reported to increase the amount of trampling, which leads to higher organic matter and nutrient cycling, thereby increasing overall plant production (Gompert, 2010). The amount of plant material that is trampled increases with advancing stages of plant growth and maturity (Gade and Provenza, 1986).

With a greater percentage of plant material being trampled, there is less available to be consumed by grazers which results in lower harvest efficiency. Grazing strategies that favor trampling can lower harvest efficiency.

Grazing strategies influence stocking density by manipulating grazing period length and pasture size. Continuous grazing employs unrestricted and uninterrupted access to the grazing pasture throughout the growing season (The Forage and Grazing Terminology Committee, 1992). Lack of rotation throughout pastures during the growing season leads to low stocking density in order to supply enough forage for the entire growing season. Management intensive grazing strategies were developed to shorten grazing period length and provide forage plants with the time to recover from grazing (Vallentine, 2000); thereby, overcoming small scale heterogeneity and improve plant and animal productivity as well as grazing efficiency compared to continuous grazing. Deferred rotation grazing includes multiple pastures with one herd, with a different pasture left ungrazed each year until after seed-set (Vallentine, 2000). Rotational grazing systems, i.e., deferred rotation grazing, result in a moderate stocking density. Short duration grazing or management intensive grazing are rotational grazing systems which implement high stocking densities with one herd grazing twelve pastures or more with short grazing periods and two grazing cycles or more per year (Vallentine, 2000). Management intensive grazing systems most typically employ high stocking densities and claim to improve grazing distribution and harvest efficiency compared to stocking densities found in more conventional grazing strategies such as season-long continuous grazing and simple rotation systems. Grazing strategies such as mob grazing use ultrahigh stocking densities of 200,000 kg ha^{-1} or greater to optimize grazing distribution (Gompert, 2010).

When equal but inverse changes are made to stocking density and length of grazing period, the same stocking rate exists. While stocking rate does not change, animal response may differ (Vallentine, 2000). Increasing stocking density and stocking rate commonly increases gains per hectare, but decreases average daily gain in grazing animals. Low stocking density grazing strategies favor selective grazing of high quality forage, as well as revisiting previously-grazed areas. Consequently, greater animal performance is often a characteristic of these strategies compared to high stocking density strategies. High and ultrahigh stocking density grazing strategies limit selectivity while increasing evenness of grazing and decreasing individual animal performance (Johnson, 2012; Redden, 2014). Studies have reported that there is a linear relationship as grazing pressure increases, individual animal performance decreases (Hart and Ashby, 1998; Manley et al., 1997).

There have been mixed responses to grazing strategies in terms of botanical composition (Reece et al., 1996; Volesky et al., 2004). Stephenson et al. (2013) reported that after 10 years under short duration grazing and deferred rotation grazing there were no changes to plant functional group composition. Johnson (2012) and Redden (2014) reported that meadow grazing strategies including simple rotational strategies, continuous grazing and ultrahigh stocking density did not change plant functional group composition.

The objectives of this study were to determine plant composition, herbage production, utilization, harvest efficiency and animal performance (average daily gain) in response to four different grazing strategies on Sandhills subirrigated meadow. I hypothesized that ultrahigh stocking density would result in greater aboveground plant production, increased utilization because of improved grazing distribution, no change in relative plant functional group composition, and lower animal performance when compared to more conventional rotational grazing strategies and continuous grazing.

Materials and Methods

Study Site

Research was conducted at the University of Nebraska-Lincoln Barta Brothers Ranch in the eastern Sandhills of Nebraska (lat 42˚13’13”N, long 99˚38’27”W). January long-term average temperature is -6.8˚C and July long-term average temperature is 22.5˚C. The long-term average annual precipitation is 576 mm with about 76% of the annual precipitation occurring from April through September (High Plains Regional Climate Center, 2016).

The study area consists of subirrigated and wet subirrigated ecological sites. Subirrigated ecological sites are found on interdunes and stream valleys. The slope is less than 3%. The water table usually is within 1 m of the soil surface during the growing season. The depth to rusty spots and iron stains in the soil or saturation is 45 to 90 cm. No visible surface salts are associated with this site (USDA-NRCS 2016). The wet subirrigated site is found on interdunes and stream valleys commonly within proximity to subirrigated sites with a slope of 0 to 1%. The water table is usually at or above the soil surface during the growing season, with a 15 to 45 cm depth to rusty spots and iron stains in the soil or saturation (USDA-NRCS 2016).

Soils of the study area are Els loamy sand, Els-Ipage complex, Tryon loamy fine sand, Valentine fine sand, Valentine loamy fine sand and Valentine-Els complex. Vegetation cover was dominated by exotic, cool-season grasses including redtop bent (*Agrostis stolonifera* L.), quackgrass (*Elymus repens* L.) timothy (*Phleum pratense* L.), Kentucky bluegrass (*Poa pratensis* L.), and smooth bromegrass (*Bromus inermis* Leyss.). Several species of sedges (*Carex spp*. L.) and rushes (*Juncus* spp. L.) were also common. Warm-season grasses were less common and included big bluestem (*Andropogon gerardii* Vitman), switchgrass (*Panicum virgatum* L.) and Indiangrass (*Sorghastrum nutans* L.). Exotic legumes, red clover (*Trifolium pratense* L.) and white clover (*Trifolium repens* L.), were prevalent throughout the study area. Common forbs included yarrow (*Achillea millefolium* L.), blackeyed Susan (*Rudbeckia hirta* L.), and Missouri goldenrod (*Solidago missouriensis* Nutt.). The study site was part of a hay meadow that had been cut for hay annually in July for the last several decades.

Grazing Treatments

Prior to the application of the grazing treatments, the meadow was hayed annually in July. A total of 25.2 ha was divided into two replications of five treatments in a randomized complete block design. The grazing treatments included (1) a 120-paddock ultrahigh stocking density rotation with a single occupation within a grazing season, (2) a 4-pasture rotation with a single occupation (4-PR-1), (3) a 4-pasture rotation with two occupations (4-PR-2), (4) a mid-July haying, and (5) a control with no defoliation. The treatment pastures were grazed by 365 kg yearling steers. A summary of pasture characteristics and management details is provided in Table 1.1. This paper reports on the 5th and 6th years of a longer-term study that was initiated in 2010.

The ultrahigh stocking density treatment was achieved by moving the steers through 120, 0.06 ha paddocks, with two paddocks grazed per day. Water and salt medicated with chlorotetracycline (CTC) for pinkeye prevention was moved each day to the new paddocks and placed 10 m from water. Steers were moved to fresh paddocks at about 0700 hours and 1400 hours. The initiation of the grazing season was June 17 in 2014 and June 12 in 2015 when the dominant cool-season grasses were at elongation and reproductive stages of growth with a high stem:leaf ratio. These turn-in dates are late when the objectives are to optimize forage use and animal performance; however, these dates were selected to maximize the likelihood of a high percentage of trampling, thus providing the conditions to test the effect of high percentage trampling on soil properties and vegetation composition and production. The target for percentage trampling in the ultrahigh stocking density treatment paddocks was 60%.

The grazing season dates and length (60 days) for the 4-PR-1 treatment was the same as for the ultrahigh stocking density treatment so that these two treatments would be comparable except for grazing period length and stocking density. Grazing period length in each of the four 4-PR-1 treatment pastures was 15 days, for a total of 60 days in the grazing cycle. Grazing period length in each of the 120 ultrahigh stocking density treatment paddocks was 0.5 day, for a total of 60 days in the grazing cycle. The 4-PR-2 treatment was designed with the objective of optimizing forage use and animal performance. Turn-in date (May 29 in 2014 and May 22 in 2015) was timed such that the dominant cool-season grasses were at a vegetative stage of growth through much of the first cycle. Two 40-day cycles were part of the 4-PR-2 treatment to increase the availability of high quality forage throughout the grazing season. The first cycle began in late May, and the second in mid-July. The grasses grazed in the first cycle were expected to grow following defoliation and again be mostly vegetative in the second cycle, thus resulting in good quality forage and animal performance in the second cycle. The length of the grazing season was timed to end on the same day as the other two grazing treatments so that all experimental cattle could be moved off the study area and be weighed at the same time. Water tanks and mineral were available in each of the paddocks as the steers rotated through the paddocks.

Control plots were 0.4 ha in size, with two replications. No defoliation was implemented on control pastures.

Hay plots were also 0.4 ha in size, with two replications. Hay was mowed with a sickle bar mower at a height of 5 to 10 cm and baled into large round bales. Hay was harvested in mid-July which is typical of Nebraska Sandhills meadows. The hay treatment was not included in the analysis of 2014 and 2015 aboveground plant production data because the hay plots were inadvertently hayed prior to the sampling date in 2014. However, the hay treatment was included in the analysis of the ground cover and plant functional group composition data because the early 2014 hay harvest did not affect sampling of ground cover and plant functional group composition.

The continuously grazed pastures were each 0.75 ha in size, with two replications. The pastures were grazed by 4 steers for 60 days. The continuously grazed treatment was added to the study site in 2010. Because it is not part of the randomized complete block design of grazing treatments, it is included in the animal performance (ADG) analysis, but is excluded from other analyses.

Add a paragraph on describing the continuous treatment and explaining why it is included in the weight gain analysis and not the others

Aboveground Plant Production

Aboveground plant production was estimated in mid-August in 2014 and 2015. Two or three 1-m^2 exclosures were randomly placed in each paddock of the 4-PR-1 and 4-PR-2 treatments and in each quarter of the ultrahigh stocking density treatment, for a total of ten, 1-m^2 exclosures in each replication of each treatment. Exclosures were moved each year before cattle arrived in May in order to capture the effect of the previous years' grazing treatment on aboveground production. Quadrats (0.25 m^2) were placed inside each exclosure and all standing vegetation was clipped at ground level. In the control and hay pastures, ten quadrats were randomly placed and all standing vegetation was clipped at ground level in mid-August. Clipped vegetation was sorted into standing live herbage (SLH) and standing dead herbage (SDH) and placed in labeled paper bags. Litter was also collected and placed in labeled paper bags. Samples were dried in a forced-air oven at 60˚C to a constant weight and the final weight was recorded.

Trampling, Harvest Efficiency and Utilization

Ten, 1-m^2 exclosures were randomly placed in each pasture of the 4-PR treatments immediately prior to occupation by cattle. The ten exclosures were placed in new random locations in the 4-PR-2 pastures prior to the second occupation. When cattle were moved from a pasture, a 0.25-m^2 quadrat was placed in each exclosure and all standing vegetation was hand-clipped at ground level and litter was collected. A quadrat was also placed 1 m north of each exclosure and all vegetation was clipped at ground level and litter was collected. In the ultrahigh density treatments, sampling occurred every other week through the grazing season each year beginning two weeks after grazing began. One day prior to grazing in a paddock, ten 0.25-m^2 quadrats were randomly placed within the paddock and all standing vegetation within the quadrat was hand-clipped at ground level and litter was collected. One-day post grazing, ten 0.25-m^2 quadrats were placed 1 m north of the previously clipped quadrat and all vegetation was hand clipped at ground level and litter was collected. All clipped samples were sorted into SLH, SDH, and trampled plant material (TR), and then placed in labeled paper bags. Trampled herbage was defined as any tillers that had been broken off from the plant's base or were still attached but bent to a 45˚ angle or less from the soil surface. Samples were dried in a forced-air oven to a constant weight at 60˚C and final weight was recorded. Weights were used to calculate herbage yield to date, percentage trampled, harvest efficiency, utilization, and instantaneous grazing pressure upon entry of and exit from each sampled paddock.

[1] Herbage yield (kg·ha-1) = PreSLH within a pasture ÷ pasture size in ha,

[2] Percentage trampled (%) = (TR ÷ PreSLH) x 100,

[3] Harvest efficiency (%) = [((PreSLH – (PostSLH + TR)) ÷ PreSLH] x 100,

[4] Utilization (%) = [(PreSLH – PostSLH) ÷ PreSLH] x 100,

Instantaneous grazing pressure at the time cattle were turned into the pasture

[5] $(AU \cdot Mg^{-1})$ = AUs in a pasture ÷ PreSLH in a pasture;

Instantaneous grazing pressure at the time cattle were removed from the pasture

[6] $(AU \cdot Mg^{-1})$ = AUs in a pasture ÷ PostSLH in a pasture;

Experimental unit was the 4 paddocks combined in the each of the 4-PR-1 replications and the 4-PR-2 replications and the 120-pastures in each of the ultrahigh density replications. Estimates of herbage yield, percentage trampled, harvest efficiency, utilization, and instantaneous grazing pressure was calculated for each pasture sampled and averaged over the experimental unit.

Plant Functional Group Composition

Basal cover, plant functional group composition, and ground cover were estimated using the modified step-point method (Owensby, 1973) in late June each year. One hundred and fifty randomly selected points were sampled within each pasture of the 4-PR-1, 4-PR-2, control, and hay treatments. Each replication of the ultrahigh stocking density treatment was divided into quarters and 75 random samples were taken. Ground cover was identified as bare ground, litter, or plant base. When a plant base was hit, the species of that plant was recorded. If bare ground or litter was hit, the nearest plant to the point of the step-point tool was recorded by species. Composition data from 2010 to 2013 was included in the analysis (Johnson, 2012; Redden, 2014).

Animal Performance

Weight gain was measured for all cattle each year. Mixed beef breed steers were limit-fed for five days then weighed for two consecutive days at the University of Nebraska-Lincoln Agricultural Research and Development Center (ARDC) prior to being transported to the research site. The average of the two weights was used as the beginning weight for each animal. At the end of the grazing season, animals returned to the ARDC. They were again limit-fed for five days and the same process was used to calculate final weight. Daily gain was calculated from difference between final and beginning weight divided by number of grazing days.

Statistical Analysis

Data were analyzed using a mixed-model analysis of variance (ANOVA) and the lsd statement to separate the main effects in SAS (SAS Studio 3.2). Treatment was nested within year, which was nested within replication by block for aboveground plant production. For species composition, individual species were grouped into plant functional groups and the analysis examined change over the entire six years of the study using lsmeans in SAS. Animal performance was analyzed also using lsmeans statement in SAS. Treatment was nested within year, which was nested within replication by block. Probability values less than 0.05 were considered significant.

Results

Precipitation and Temperature

Total annual precipitation in 2014 and 2015 was 4% and 5% greater than the 30-year mean, respectively (Table 1.2). Total growing season precipitation (April – September) was greater than the 30-year mean (42.0 cm) in 2014 (48.1 cm) and 2015 (47.0 cm). Mean growing season temperatures were greater than the long-term growing season mean (17.5˚C) in 2015 (17.8˚C) and lower than the 30-year mean in 2014 (16.8˚C, Table 1.3).

Aboveground Plant Production

Aboveground herbage production averaged 4760 kg ha^{-1} during the two years of the study. There were no treatment, year, or interaction effects on this variable.

Litter

In both years, litter mass in the control plots was 2 to 4 times greater than in the grazed pastures (Table 1.4). There were no differences in litter mass among the grazed treatments. Mean litter mass in the control treatment across years was 3910 kg ha^{-1}. Mean litter mass among grazed treatments in both years was 1070 kg ha^{-1}.

Standing Dead

Standing dead biomass was over two times greater in 2014 than 2015, 900 kg ha^{-1} vs 380 kg ha^{-1}, respectively. There were no differences among treatments.

Utilization, Trampling and Harvest Efficiency

Utilization is the combined effects of trampling and harvest efficiency (consumption) of live plant material. There was significant year by treatment interaction for utilization. In both years, utilization in the ultrahigh stocking density pastures was greater than in the 4-PR-2 (Table 1.5). In 2014, utilization in the 4-PR-1 was not different from the ultrahigh stocking density treatment and both were 39% greater than 4-PR-2 treatment. In 2015, utilization in ultrahigh stocking density was 7% greater than 4-PR-1 and 18% greater than 4-PR-2; 4-PR-1 utilization was greater than that of 4-PR-2. Percentage utilization in the 4-PR-2 was 10% greater in 2015 than 2014. Utilization did not differ between 2014 and 2015 for ultrahigh density and 4-PR-1 treatments.

Percentage trampled in the ultrahigh stocking density pastures (45%) was greater than in the 4-PR-1 (31%) and 4-PR-2 (19%) pastures, and percentage trampled was greater for the 4-PR-1 than the 4-PR-2 treatment. Percentage trampled did not differ between years.

Harvest efficiency did not differ among treatments or between years. Mean harvest efficiency over treatments and years was 50%.

There was a significant year by treatment interaction for percent remaining standing live herbage (P= 0.0137). Standing live herbage was lower in the ultrahigh stocking density treatment that the other two treatment in 2014; in 2015, standing live herbage did not differ between ultrahigh stocking density and 4-PR-1 but it was less for ultrahigh stocking density than for 4-PR-2 (Table 1.6). In 2014, remaining herbage in the 4-PR-2 treatment was 6 and nearly 3 times higher than the ultrahigh density and 4-PR-1, respectively. In 2015, remaining herbage in the 4-PR-1 and 4-PR-2 treatments were 2.5 and 3.25 times that of the ultrahigh stocking density treatment.

Plant Functional Group Composition

Cool-Season Grasses

Among the grazed treatments, cool-season grass botanical composition generally declined in 2011 and 2012 and was lowest in 2013 but increased in 2014 and 2015 (Table 1.7). Within the 4-PR-1 treatment, cool-season grass composition followed a similar pattern with the greatest percent composition in 2010 and 2015 and was lower in 2011 through 2014. In the ungrazed control, percent cool-season composition was greatest in 2010, and declined each subsequent year through 2014. In 2015, percentage composition of cool-season grasses was higher than the previous two years, but did not recover to the same level as 2010.

Cool-season grass percent composition across treatments was generally greatest in the 4-PR-1 treatment and lowest in the control treatment (Table 1.7). In 2011, there were no differences among treatments. There were no differences between cool-season grass composition in the 4-PR-2 and ultrahigh stocking density treatments.

Warm-season grasses

Percentage warm-season grass composition was greatest in 2015 in all grazed treatments (Table 1.8). In the control, warm-season grass composition was greatest in 2014. Warm-season grass composition in the hay treatment fluctuated throughout the years, and was greatest in 2015. In 2013 and 2014, warm-season grass composition was greatest in the control treatment. In all other years, there were no differences among treatments.

Sedges and rushes

Percentage composition of sedges and rushes generally did not vary among treatments (Table 1.9). In 2013, sedge and rush percentage composition was greatest in the control. In 2015, sedge and rush percent composition was lowest in the control. In all other years, there were no differences among treatments within years. In the grazed treatments, sedge and rush percentage composition was greatest in 2015. In the control, sedge and rush composition was greatest in 2013. There were no differences among years in the hay treatment.

Forbs

Percentage composition of forbs did not differ among treatments; however, forb composition varied by year (Table 1.10). Over the years, percent composition of forbs ranged from 2% to 21%, and was greatest in 2014 and lowest in 2015.

Ground cover

There were no treatment effects for litter ground cover; however, there was a year effect (Table 1.11). Percentage litter was lowest in 2015 (91%). There were no treatment effects for percentage of bare ground; however, there was a year effect. Bare ground percentage was the lowest in 2012 and 2014 with 0.48 and 0.63%, respectively. There were no treatment effects for plant base cover; however, there was a year effect (Table 1.11). Percentage plant base was highest in 2015 (3.5%) compared to all other years.

Animal Performance

There was a year by treatment interaction for average daily gain ($P=0.017$). In 2014, steer daily gains among all treatments were not different and averaged 0.60 kg day^{-1} (Table 1.12). In 2015, steer average daily gains in the 4-PR-2 and continuously grazed were not different and were greater than ultrahigh stocking density and 4-PR-1 daily gain. Ultrahigh density steer daily gains were lowest in 2015 (-0.12 kg day^{-1}).

Discussion

I hypothesized that ultrahigh stocking density would result in greater aboveground plant production, increased utilization because of improved grazing distribution, no change in relative plant functional group composition, and lower animal performance when compared to more conventional rotational grazing strategies and continuous grazing.

However, herbage production was not different in the ultrahigh stocking density treatment pastures than any other treatment pastures. Utilization was greatest in the ultrahigh stocking density treatments (Table 1.5). Because harvest efficiency did not differ, the difference in utilization was because of the high amount of trampling in those treatment pastures compared to other treatments (Table 1.6). Utilization in the 4-PR-2 treatment pastures is low due to shorter more vegetative growth in those pastures because pastures were grazed twice, allowing grazing of vegetative regrowth late in the growing season. Low utilization in the 4-PR-2 treatment pastures may also be because cattle were grazing on shorter, more vegetative growth in the first cycle of grazing resulting in more even use. Additionally, many patches were left underutilized because of lower grazing pressure in the second cycle combined with cattle concentrating grazing on preferred vegetation grazing lawns selected in the first grazing cycle. Field observations were that in the first two pastures of the first cycle, grazing pressure was higher which resulted in evenness of grazing and less selectivity, and in the last two pastures of the first cycle, there was more forage available, resulting in lower grazing pressure, more selective grazing, and establishment of grazing lawns. In the second cycle, the first two pastures had even regrowth of forage and led to very selective grazing and consumption of high quality forage. In the last two pastures of the second cycle, grazing lawns of preferred vegetation that were established in the first cycle were revisited.

Proponents of ultrahigh stocking density grazing suggest that an increase in percentage of herbage trampled leads to greater soil health and an increase in aboveground plant production (Gompert, 2010b). In 2014, there was a greater percentage of trampling in the ultrahigh stocking density treatments than the 4-PR-1 and 4-PR-2 treatment pastures, but it did not lead to differences in aboveground plant production in either year, which is similar to what was reported by Redden (2014) and Johnson (2012) in the first four years of the study. Added organic matter to the soil over time and reportedly increases aboveground plant production (Gompert, 2010). This has led to claims that ultrahigh stocking density results in increased plant production and potential livestock production; however, in this study, plant production in ultrahigh stocking density pastures did not differ from the control and other treatment pastures and steer performance was the lowest in the ultrahigh stocking density pastures (Table 1.12).

Litter biomass accumulates and is increased in a non-grazed control compared to most grazing strategies (Beckman, 2014; Naeth et al., 1991). Practitioners of ultrahigh stocking density report that litter decomposition rate is increased compared to continuous grazing or simple rotational grazing (Peterson, 2014); however, no differences were seen in litter accumulation among ultrahigh stocking density treatments and other grazing treatments in either year (Table 1.4).

There was not a clear response to treatment in patterns of standing dead vegetation. Although no differences were found within years between treatments, there was more standing dead vegetation in 2014 than 2015 in the ultrahigh stocking density, 4-PR-1 and 4-PR-2 treatments. Harvest efficiency did not appear to influence standing dead vegetation as it did not differ between the two years in any treatments. Utilization was least in the 4-PR-2 treatment in 2014 (Table 1.5), but did not lead to an increase in standing dead vegetation or litter in 2015.

Harvest efficiency was high (50%) and did not differ among treatments. A harvest efficiency of 50% is greater than expected (Heitschmidt et al., 1987) and greater than reported by Redden (2014) and Johnson (2012). However, percentage trampling differed among treatments. Trampling was likely low in the 4-PR-2 treatment because of a combination of factors. In the first two pastures of the first grazing cycle, grazing pressure was relatively high (4.14 AU Mg^{-1}) because early in the season, plants grew rapidly, which resulted in evenness of grazing and less selectivity. Grazing pressure was lower in the second grazing cycle (3.67 AU Mg^{-1}) resulting in many plants/patches going ungrazed or lightly grazed and establishment of grazing lawns. Utilization also was lowest in both years for the 4-PR-2 treatment (Table 1.5), and while harvest efficiency did not differ among treatments, trampling was also lowest in both years in the 4-PR-2 treatment which likely led to a decrease in utilization. Johnson (2012) reported that an earlier grazing start date led to greater utilization in 2011, although that is unlikely because an earlier start date did not affect utilization in 2015. Redden (2014) hypothesized that lower aboveground plant production led to greater utilization, however, there were no differences in aboveground plant production for those pastures that differed in utilization in 2014 and 2015. Higher trampling percentage in the 4-PR-1 treatment was likely because of higher grazing pressure and mature plants in the last half of the grazing season. The relatively high grazing pressure in ultrahigh stocking density generally resulted in more trampling and led to very little live vegetation (< 10%) remaining standing (Table 1.6) and about 45% of pre-graze live vegetation being trampled. High trampling rates are commonly a goal of ultrahigh stocking density grazing (Gompert, 2010). However, in 2014 and 2015, in the 5th and 6th years of grazing, there were no responses in terms of plant production and composition.

Differences in plant maturity and quality seemed to play a large role in utilization due to trampling as well as animal performance. Concentrating ultrahigh stocking density in the early part of the growing season when plants are mostly vegetative could yield different results. Leafy, vegetative plants are less susceptible to trampling and could lead to higher harvest efficiency (or greater nutrient intake); therefore, animal performance might be greater when ultrahigh stocking densities are applied earlier in the season.

Redden (2014) and Johnson (2012) reported that the general decline in cool-season grass composition in 2011 (Table 1.7) was likely due to extreme rainfall events in which cool-season grasses were inundated for 10-20 days which may have resulted in drowning those species. Redden also reported the severe drought in 2012 had a detrimental effect on cool-season grasses, however, cool-season grass composition increased to pre-drought levels and reached a peak in 2015. It does not appear that the decline in cool-season grasses led to an increase in warm-season grasses (Table 1.8) or sedges and rushes (Table 1.9). Over the 6 years, percentage composition of cool-season grasses, warm-season grasses and sedges/rushes peaked in 2015; however, percentage composition of forbs was lowest in 2015 (Table 1.10). In 2014, percent composition of cool-season grasses, warm-season grass and sedges/rushes were relatively low, while percent composition of forbs was greatest in 2014. The reason for this pattern of functional group response to treatments is not clear. Percent composition of forbs was not affected by treatments. Forbs included introduced legumes (red and white clovers). I expected the forbs/legumes to increase in composition as has been reported (JD Volesky, personal communication) because legumes are reported to respond positively to open canopies. However, we did not see such a response. An increase in warm-season grass composition was expected (Vermeire and Bidwell, 1985), but warm-season grass composition was greater in the control treatment in 2013 and 2014 (Table 1.8).

Ultrahigh stocking density and 4-PR-1 treatments resulted in poor animal performance (Table 1.12). Redden (2014) and Johnson (2012) also reported poor animal performance in these treatments but did not identify obvious reasons for lower performance. Poor performance of cattle grazing in these treatments is likely associated with low nutrient intake in the last half of the grazing season when cattle were moving into pastures not yet grazed. Most plant species were near maturity at this time and had a low leaf:stem ratio. Conversely, cattle in 4-PR-2 and continuously-grazed treatment pastures had access to regrowth of grasses that had been grazed earlier in the season, providing higher nutrient intake. Redden (2014) reported that there was no difference in NDF or CP content in the 4-PR-2 treatments compared to other grazing treatments, but that steers grazing those treatments establish grazing lawns in the first occupation of the pastures, then return to the same grazing lawns in the second occupation to graze highly nutritious regrowth. Johnson (2012) reported greater CP content in the 4-PR-2 treatment compared to 4-PR-1 and ultrahigh stocking density after July 15, likely due to high quality vegetative regrowth late in the grazing season as well as increased availability of clovers late in the growing season.

Management Implications

Short grazing periods associated with ultrahigh stocking density grazing are reported anecdotally to improve animal performance in grazing animals (Barnes et al., 2008; Gompert, 2010) but experimental studies have not been conducted that validate those reports. Results of our study showed that ultrahigh stocking density grazing strategies implemented in mid-growing season did not produce greater animal performance compared to lower stocking densities. Overall, the lack of increased aboveground production as well as animal performance in ultrahigh stocking density grazing strategies does not justify the increased cost in both labor and implementation (fencing, water and increased movement of grazers) associated with implementation of this grazing strategy. Plant and animal responses to ultrahigh stocking density grazing implemented during other parts of the growing season (mid-May to early July) may be different.

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Tables

Table 1.1. Pasture characteristics and stocking information by treatment for both years in the four-pasture rotation with a single occupation (4-PR-1), four-pasture rotation with two occupations (4-PR-2) and 120-pasture ultrahigh stocking density treatments for 2014 and 2015. Grazing season for 4-PR-2 treatments was 80 days while 4-PR-1 and ultrahigh density treatments had 60-day grazing seasons.

	Treatment		
	4-PR-1	4-PR-2	Ultrahigh density
Total treatment area (ha)	1.7	2.6	6.8
Pasture size (ha)	0.43	0.64	0.06
Number of steers	9	10	36
Days of grazing per pasture	15	20	0.5
Stocking rate (AUM · ha^{-1})	7.4	7.4	7.4
Stocking density (kg · ha^{-1})	7,000	5,000	225,000

Table 1.2. Precipitation during 2010 - 2015 and the long-term (30-year) mean at the UNL Barta Brothers Ranch near Rose, Nebraska.

	2010	2011	2012	2013	2014	2015	Long-Term Mean
		--------------	--------------	------cm------	--------------	--------------	--------------
January	2.2	1.8	0.2	0.6	0.0	0.3	0.9
February	1.1	2.5	2.7	3.3	1.1	0.8	1.7
March	3.7	2.2	1.5	3.1	2.4	0.0	2.7
April	8.9	5.2	10.3	4.8	3.9	4.4	6.5
May	8.7	9.4	3.5	9.2	2.2	8.7	7.8
June	26.8	15.0	1.2	10.9	23.2	11.4	10.8
July	5.9	6.4	0.8	2.0	6.2	7.8	6.1
August	7.1	9.0	4.6	7.4	7.1	5.2	5.7
September	4.3	2.1	1.2	4.9	5.5	9.7	5.1
October	3.2	8.9	0.2	6.2	2.9	4.7	4.6
November	0.7	0.5	1.1	1.5	0.3	3.3	1.5
December	1.7	0.5	0.8	1.0	2.1	1.3	1.2
Annual Total	74.3	63.6	28.2	55.0	56.9	57.5	54.6

Table 1.3. Temperature during 2010 – 2015 and the long-term (30-year) mean at the UNL Barta Brothers Ranch near Rose, Nebraska.

	2010	2011	2012	2013	2014	2015	Long-term Mean
	--------------------------(˚C)---------------------------						
January	-6	-8	-1	-4	-4	-3	-4
February	-6	-5	-3	-3	-8	-4	-3
March	4	1	10	-1	1	6	3
April	11	8	11	4	8	10	9
May	13	13	16	14	14	13	14
June	20	19	23	19	19	21	20
July	23	25	27	22	21	23	23
August	23	23	22	23	22	21	22
September	17	16	17	19	17	19	17
October	11	11	8	8	11	12	9
November	2	3	2	1	-1	3	2
December	-4	-2	-3	-7	-3	-2	-4
Annual mean	9	9	11	8	8	10	9

Table 1.4. Litter mass (kg ha^{-1}) in the 120-pasture ultrahigh stocking density treatment, four-pasture rotation with a single grazing occupation (4-PR-1), four-pasture rotation with two grazing occupations (4-PR-2) and the control in 2014 and 2015.

Treatment	Litter
	----(kg ha^{-1})----
Ultrahigh density	1014^{B}
4-PR-1	1577^{B}
4-PR-2	622^{B}
Control	3914^{A}

^{ABC}Different uppercase letters within columns differ ($p<0.05$)

Table 1.5. Utilization of standing live herbage (%) in the 120-pasture ultrahigh stocking density rotation, four-pasture rotation with a single grazing occupation (4-PR-1) and four-pasture rotation with two grazing occupations (4-PR-2) in 2014 and 2015.

Treatment	2014	2015
	-----------------(%)-----------------	
Ultrahigh Density	94^{Aa}	92^{Aa}
4-PR-1	87^{Aa}	86^{Ba}
4-PR-2	65^{Bb}	75^{Ca}

^{ABC}Different uppercase letters within columns differ ($p < 0.05$)
^{abc}Different lowercase letters within rows differ ($p < 0.05$)

Table 1.6. Remaining standing live herbage (%) in the 120-pasture ultrahigh stocking density, four-pasture rotation with a single occupation (4-PR-1) and four-pasture rotation with two occupations (4-PR-2) treatments for 2014 and 2015.

Treatment	2014	2015
	-----------------(%)-----------------	
Ultrahigh Density	6^{Ba}	8^{Ba}
4-PR-1	13^{Ba}	20^{Aa}
4-PR-2	36^{Aa}	26^{Ab}

^{ABC}Different uppercase letters within columns differ (p<0.05)
^{abc}Different lowercase letters within rows differ (p<0.05)

Table 1.7. Cool-season grass composition (%) in the 120-pasture ultrahigh stocking density treatment, four-pasture rotation with a single grazing occupation (4-PR-1), four-pasture rotation with two grazing occupations (4-PR-2), control and hay treatments, 2010-2015.

Treatment	2010	2011	2012	2013	2014	2015
	-------------------------------(%)-------------------------------					
Ultrahigh density	57^{ABab}	49^{Abc}	49^{ABbc}	44^{ABc}	50^{Aabc}	23^{Ba}
4-PR-1	65^{Aa}	52^{Ab}	51^{Ab}	46^{Ab}	54^{Ab}	12^{Ba}
4-PR-2	59^{ABab}	50^{Abc}	45^{Bbc}	38^{Bc}	52^{Abc}	11^{Ba}
Control	50^{BCa}	42^{Aab}	25^{Cbc}	10^{Dcd}	4^{Bd}	39^{Abc}
Hay	43^{Ca}	33^{Aa}	30^{Ca}	20^{Ca}	21^{ABa}	24^{ABa}

^{ABC}Different uppercase letters within columns differ ($p<0.05$)
^{abc}Different lowercase letters within rows differ ($p<0.05$)

Table 1.8. Warm-season grass composition (%) in the 120-pasture ultrahigh stocking density treatment, four-pasture rotation with a single grazing occupation (4-PR-1), four-pasture rotation with two grazing occupations (4-PR-2), control and hay treatments, 2010-2015.

Treatment	2010	2011	2012	2013	2014	2015
	-------------------------------(%)-------------------------------					
Ultrahigh density	4^{Ab}	5^{Ab}	8^{Ab}	5^{Bb}	6^{Bb}	18^{Aa}
4-PR-1	4^{Ac}	6^{Abc}	9^{Ab}	6^{Bbc}	2^{Bc}	17^{Aa}
4-PR-2	5^{Ab}	4^{Ab}	11^{Ab}	7^{Bb}	7^{Bb}	21^{Aa}
Control	14^{Ab}	10^{Ab}	19^{Ab}	20^{Ab}	43^{Aa}	23^{Ab}
Hay	10^{Aab}	11^{Aab}	7^{Ab}	10^{Bb}	5^{Bb}	20^{Aa}

^{ABC}Different uppercase letters within columns differ (p<0.05)
^{abc}Different lowercase letters within rows differ (p<0.05)

Table 1.9. Sedge and rush composition (%) in the 120-pasture ultrahigh stocking density treatment, four-pasture rotation with a single grazing occupation (4-PR-1), four-pasture rotation with two grazing occupations (4-PR-2), control and hay treatments, 2010-2015.

Treatment	2010	2011	2012	2013	2014	2015
	-----------------------------------(%)-----------------------------------					
Ultrahigh density	30^{Abc}	41^{Ab}	37^{Abc}	40^{Bbc}	25^{Ac}	58^{Aa}
4-PR-1	24^{Ac}	38^{Ab}	35^{Ab}	39^{Bb}	25^{Ac}	71^{Aa}
4-PR-2	25^{Ab}	36^{Ab}	35^{Ab}	39^{Bb}	27^{Ab}	68^{Aa}
Control	32^{Aab}	39^{Aab}	52^{Aab}	65^{Aa}	38^{Aab}	28^{Bb}
Hay	39^{Aa}	45^{Aa}	55^{Aa}	53^{Aba}	25^{Aa}	55^{Aa}

^{ABC}Different uppercase letters within columns differ ($p<0.05$)
^{abc}Different lowercase letters within rows differ ($p<0.05$)

Table 1.10. Forb composition (%) across treatments, 2010-2015.

Year	%Forb
2010	8^{BC}
2011	8^{BC}
2012	6^{CD}
2013	12^{B}
2014	21^{A}
2015	2^{D}

^{ABC}Different uppercase letters differ ($p<0.05$)

Table 1.11. Ground cover (%) of litter, bare ground and plant bases across treatments, 2010-2015.

Year	%Litter	%Bare ground	%Plant base
2010	94^{CD}	4.00^{AB}	2.10^{B}
2011	96^{BC}	3.23^{AB}	1.18^{BCD}
2012	98^{AB}	0.48^{C}	0.41^{D}
2013	94^{CD}	2.73^{BC}	1.88^{BC}
2014	99^{A}	0.63^{C}	0.75^{CD}
2015	91^{D}	5.47^{A}	3.52^{A}

^{ABC}Different uppercase letters within columns differ ($p<0.05$)

Table 1.12. Average daily gain (kg steer^{-1} day^{-1}) of yearling cattle in the 120-pasture ultrahigh stocking density, four-pasture rotation with a single occupation (4-PR-1), four-pasture rotation with two occupations (4-PR-2) and continuously grazed treatments for 2014 and 2015.

Treatment	2014	2015
	------kg day^{-1}------	
Ultrahigh Density	0.44^{Aa}	-0.12^{Cb}
4-PR-1	0.56^{Aa}	0.08^{Bb}
4-PR-2	0.70^{Aa}	0.58^{Aa}
Continuous	0.69^{Aa}	0.51^{Aa}

^{ABC}Different uppercase letters within columns differ ($p<0.05$)
^{abc}Different lowercase letters within rows differ ($p<0.05$)

Chapter 2: Grazing Strategy Effects on Steps Taken by Yearling Steers

Abstract

Grazing strategy is reported to affect animal movement and energy expenditure. Activity (steps taken) of yearling steers (Bos taurus L.) was studied using three different grazing strategies on Sandhills subirrigated meadow at the University of Nebraska-Lincoln Barta Brothers Ranch 11 km northwest of Rose, Nebraska. The grazing strategies were a 4-pasture rotation with a single occupation, a 120-pasture rotation with a single occupation (ultrahigh stocking density), and continuous grazing; there were two replications of each strategy. The research was conducted during a 60-day grazing period from mid-June to mid-August in 2013, 2014 and 2015. Each pasture in the 4-pasture rotation was 0.42 ha and grazed by 10 steers for 15 days and each pasture in the 120-pasture rotation was 0.14 ha and grazed by 36 steers for 0.5 day. The continuously grazed pastures were each 0.75 ha and were grazed by 4 steers for 60 days. In each year, two to four steers in each treatment replication were randomly selected and fitted with IceCube pedometers for the entire 60-day grazing period. We hypothesized that steps taken would increase as pasture size increased and as the length of grazing time in a pasture increased, thus steers in continuously grazed pastures would have the greatest number of steps taken while steers in the ultrahigh stocking density pastures would have the least number of steps per day. However, steers in ultrahigh stocking density pastures in 2013 took 40% more steps than steers in other treatment pastures through most of the grazing season. In 2014, steers in ultrahigh stocking density pastures took a greater number of steps in mid-July (39% greater) and late-July (30% greater) only.

Key Words

ultrahigh stocking density; pedometer; animal activity; continuously grazed; steps

Introduction

Over half a grazing animal's day is spent walking and grazing (Anderson and Kothmann, 1980) which can increase an animal's maintenance requirement by as much as 25% (Di Marco and Aello, 2001). Energy costs expended by grazing animals and their associated performance are a direct function of the time spent grazing and the number of steps taken. Steps taken per day can be affected by grazing strategies, distance to water, and location or distribution of highly palatable plants (Hepworth et al., 1991).

Steps taken per day can be influenced by pasture factors independent of grazing strategy. Distance to water is known to affect energy expenditure through the number of steps taken per day (Hepworth et al., 1991). Distribution of livestock water points in a pasture is a principal driver in affecting number of steps taken by grazing cattle (Hart et al., 1993), with number of steps taken increasing as the distances between water points increase. Weather can also affect grazing animals' distribution on a landscape due to actions cattle take to govern body temperature (Harris et al., 2002); changes in temperature and precipitation can reduce grazing because cattle may walk long distances to seek shade or shelter (Lyons et al., 2002). Topography is a principal factor that affects grazing distribution. There is a negative correlation between steepness of slope and distribution of cattle on the slope (Tate et al., 2003). Cattle often abstain from grazing slopes greater than 10% (Cook, 1967). Distribution of preferred plant communities and distance to highly palatable plants also is correlated to number of steps taken by grazing animals (Hepworth et al., 1991; Nash et al., 1999). Pasture size and shape affect grazing distribution mostly because larger and longer pastures tend to have greater distances between water points.

Stocking density (kg of animal live weight ha^{-1}) is another management tool that can be used to manipulate grazing distribution; increased stocking density results in increased grazing pressure and more even distribution of grazing (Gerrish and Morrow, 1999; Vallentine, 2000). As stocking density increases, there is less forage available per animal unit at any point in time, leading to a higher proportion of available forage being consumed. Likewise, low stocking densities can result in uneven grazing distribution because grazing animals preferentially graze areas known to have palatable forage (Norton et al., 2013). Stocking densities are most commonly increased by reducing pasture size and, correspondingly, increasing number of pastures within a management unit and reducing grazing period length.

Grazing strategies can affect the distribution of grazing and have been used as a tool to increase evenness of grazing distribution (Barnes et al., 2008; Savory and Butterfield, 1998). Norton et al. (2013) found that smaller pasture size and increased stocking density can increase grazing time in previously neglected areas and will optimize grazing distribution in the management unit as a whole. With increased stocking density and smaller pasture size, availability of the most desirable plants and plant parts are low at any point in time. However, Burboa-Cabrera et al. (2003) found that stocking densities as high as 54 steers ha^{-1} (15,230 kg animal live weight ha^{-1}) did not have an effect on spatial distribution of grazing in small pastures (<1.15 ha) of warm-season tallgrasses. Gompert (2010), Dennis (2012) and Peterson (2011) have reported that even spatial distribution of grazing can only be attained at ultrahigh stocking densities where selectivity of grazing is minimized (Haymes, 2013; Scully, 2014). Gompert (2010) recommends stocking density greater than 200,000 kg live weight ha^{-1} for ultrahigh stocking density in order to capture animal impact and herd effect. Herd effect is described by Allan Savory (1988) as the impact following many animals moving together or milling around together, trampling dead plant material and breaking the soil surface.

Performance of grazing animals on pasture stocked at ultrahigh stocking densities compared to lower stocking densities is low (Redden 2014). Reasons for the low performance have not been tested but a number of possible causes have been identified, including relatively low dry matter and nutrient intake and increased steps taken and energy expended while grazing. Smart et al. (2013) found that steers grazing in ultrahigh stocking density treatments (200,000 kg live weight ha^{-1}) took more steps per day than steers grazing in lower stocking density treatments. It was unclear whether the higher number of daily steps being taken was due to the grazing strategy, including stocking rate and length of grazing period, or the herd size effect because they were confounded (Smart, 2013). Redden (2014) found that ultrahigh stocking density led to an increase in steps taken per day compared to other lower stocking density grazing treatments. Grazing animals in pastures expend more energy than those housed indoors, partially due to walking to graze (Osuji, 1974). Productivity of range ruminants is fairly low partially because of intake limitations (Allison, 1985). Coupling relatively low productivity with increased energy expenditure could likely lead to poor animal performance. Livestock production may be related to number of steps taken and the energy expenditure required to take more steps each day.

Grazing animal activity has been measured by pedometers, global positioning system (GPS) collars, time lapse cameras, and visual observation. Pedometers can be used as an accurate, inexpensive and non-laborious means for measuring grazing cattle activity. Pedometers do not provide spatial or directional information, but they provide more accurate information (e.g., steps taken) for arriving at estimates of energy expenditure while grazing than GPS collars or observation (Walker et al., 1985).

The objective of this study was to determine the number of steps taken per day by yearling steers on Sandhills meadow in response to three different grazing strategies during the growing season. Grazing strategies included four-pasture rotation, continuous season-long, and a 120-pasture rotation at an ultrahigh stocking density (mob grazing). I hypothesized that the number of steps taken per steer per day and animal performance would be less for ultrahigh stocking density grazing due to the small pasture size and high grazing pressure which can cause animals to quickly consume forage and spend less time searching.

Materials and Methods

Study Site

Research was conducted at the University of Nebraska-Lincoln Barta Brothers Ranch in the eastern Sandhills of Nebraska (lat 42˚13’13”N, long 99˚38’27”W). January long-term average temperature is -6.8˚C and July long-term average temperature is 22.5˚C. The long-term average annual precipitation is 576 mm with about 76% of the annual precipitation occurring from April through September (High Plains Regional Climate Center, 2016).

The study area consists of subirrigated and wet subirrigated ecological sites. Subirrigated ecological sites are found on interdunes and stream valleys. The slope is less than 3%. The water table usually is within 1 m of the soil surface during the growing season. The depth to rusty spots and iron stains in the soil or saturation is 45 to 90 cm. No visible surface salts are associated with this site (USDA-NRCS 2016). The wet subirrigated site is found on interdunes and stream valleys commonly within proximity to subirrigated sites with a slope of 0 to 1%. The water table is usually at or above the soil surface during the growing season, with a 15 to 45 cm depth to rusty spots and iron stains in the soil or saturation (USDA-NRCS 2016).

Soils of the study area are Els loamy sand, Els-Ipage complex, Tryon loamy fine sand, Valentine fine sand, Valentine loamy fine sand and Valentine-Els complex. Vegetation cover was dominated by exotic, cool-season grasses including redtop bent (*Agrostis stolonifera* L.), quackgrass (*Elymus repens* L.) timothy (*Phleum pratense* L.), Kentucky bluegrass (*Poa pratensis* L.), and smooth bromegrass (*Bromus inermis* Leyss.). Several species of sedges (*Carex spp*. L.) and rushes (*Juncus* spp. L.) were also common. Warm-season grasses were less common and included big bluestem (*Andropogon gerardii* Vitman), switchgrass (*Panicum virgatum* L.) and Indiangrass (*Sorghastrum nutans* L.). Exotic legumes, red clover (*Trifolium pratense* L.) and white clover (*Trifolium repens* L.), were prevalent throughout the study area. Common forbs included yarrow (*Achillea millefolium* L.), blackeyed Susan (*Rudbeckia hirta* L.), and Missouri goldenrod (*Solidago missouriensis* Nutt.). The study site was part of a hay meadow that had been cut for hay annually in July for the last several decades.

Grazing Strategies

Prior to the application of the grazing treatments, the meadow was hayed annually in July. A total of 25.2 ha was divided into two replications of five treatments in a randomized complete block design. The grazing treatments included (1) a 120-paddock ultrahigh stocking density rotation with a single occupation within a grazing season, (2) a 4-pasture rotation with a single occupation (4-PR-1), (3) a 4-pasture rotation with two occupations (4-PR-2), (4) a mid-July haying, and (5) a control with no defoliation. Two replications of season-long continuous grazing were implemented in 2011. Each replication was fenced with electric fencing and the pastures were grazed by yearling steers between May and August in each year from 2010 through 2015. The steers were a mixture of beef breeds, were mostly 15 to 17 months of age, and had an average weight of 365 kg. Salt medicated with chlorotetracycline (CTC) for pinkeye prevention was provided in salt tubs in all pastures for the entire grazing season and placed 10 m from water. This paper reports on the fifth and sixth years of a longer-term study that was initiated in 2010.

Animal activity measurements were recorded in the 4-PR-1, continuously grazed and ultrahigh density treatments in 2014 and 2015, the fifth and sixth years of application of grazing treatments. Grazing season length for the three treatments was 60 days each year, from mid-June to mid-August. These dates were selected to maximize the likelihood of high percentage trampling, thus providing the conditions to test the effect of high percentage trampling on soil properties and vegetation composition and production. Stocking rate remained consistent among treatments over the two years. Stocking densities varied among treatments (Table 2.1).

The ultrahigh stocking density treatment was achieved by moving the steers through 120, 0.06 ha paddocks, with two paddocks grazed per day. Water and salt medicated with chlorotetracycline (CTC) for pinkeye prevention was moved each day to the new paddocks and placed 10 m from water. Steers were moved to fresh paddocks at about 0700 hours and 1400 hours. The initiation of the grazing season was June 17 in 2014 and June 12 in 2015 when the dominant cool-season grasses were at elongation and reproductive stages of growth with a high stem:leaf ratio. These turn-in dates are late when the objectives are to optimize forage use and animal performance; however, these dates were selected to maximize the likelihood of a high percentage of trampling, thus providing the conditions to test the effect of high percentage trampling on soil properties and vegetation composition and production. The target for percentage trampling in the ultrahigh stocking density treatment paddocks was 60%.

The grazing season dates and length (60 days) for the 4-PR-1 treatment was the same as for the ultrahigh stocking density treatment so that these two treatments would be comparable except for grazing period length and stocking density. The 4-PR-1 and ultrahigh stocking density treatments were designed with the objective of optimizing conditions favorable to achieving 60% trampling, which is the target for building soil according to Gompert (2010). Turn-in date (June 17 in 2014 and June 12 in 2015) was timed such that the dominant cool-season grasses were at an elongation stage of growth. The length of the grazing season was timed to end on the same day for all grazing treatments so that all experimental cattle could be moved off the study area and be weighed at the same time. Water tanks and mineral were available in each of the paddocks as the steers rotated through the paddocks.

Continuously grazed pastures were 0.75 ha in size, with two replications. Four steers grazed in each replication for the entirety of the 60 day grazing season. Water tanks and mineral were available in each of the pastures.

Animal Activity

Two steers in 2014 and four steers in 2015 were randomly selected within each replication of the ultrahigh density, 4-PR-1, and continuous treatments. Each steer was fitted with an IceCube pedometer (IceRobotics Inc. Edinburgh Scotland) on the cannon bone on one of the front legs. The IceCube pedometers counted number of steps taken at a rate of 4 hertz (4 samples second^{-1}) every 15 minutes. Pedometers were fitted on animals immediately prior to the date the steers were placed on the pastures and remained on the steers for the entirety of the grazing season. Upon culmination of the grazing season, pedometers were removed and data were downloaded, summarized and analyzed. Data were summarized and analyzed as steps taken per hour and per day. Five, 3-day periods were selected from the grazing season, including late June; early, mid- and late July, and early August periods, when the least amount of other research activity was occurring to minimize effects on animal activity.

Animal Performance

Weight gain was measured for all cattle each year. Mixed beef breed steers were limit-fed for five days then weighed for two consecutive days at the University of Nebraska-Lincoln Agricultural Research and Development Center (ARDC) prior to being transported to the research site. The average of the two weights was used as the beginning weight for each animal. At the end of the grazing season, animals returned to the Agricultural Research and Development Center (ARDC). They were again limit-fed for five days and the same process was used to calculate final weight. Daily gain was calculated from difference between final and beginning weight divided by grazing days.

Statistical Analysis

Data were analyzed using a mixed-model analysis of variance (ANOVA) and the lsd statement to separate the main effects in SAS (SAS Studio 3.2). Treatment was nested within year, which was nested within replication by block for aboveground plant production. Plant functional group was analyzed for change over the entire six years of the study using lsmeans in SAS. Animal performance was analyzed also using lsmeans statement in SAS. Treatment was nested within year, which was nested within replication by block. P values less than 0.05 were considered significant.

Results

Animal Activity

There was a year x treatment x grazing period interaction in steps taken per day. In 2014, steers in the ultrahigh stocking density treatment took 25 to 35% more steps per day than steers in the 4-PR-1 treatment in all periods with the exception of the early August period when there was not a difference (Fig. 2.1). Steers in the ultrahigh stocking density pastures took 39% more steps than those in the continuously-grazed pastures in mid-July; otherwise, there either was no difference between ultrahigh density steers and continuous steers or the continuous steers took more steps than the ultrahigh density steers. Steers in the continuously-grazed pastures took 53% and 24% more steps than steers in the 4-PR-1 pastures in late June and early July, respectively, but there were no differences in the two treatments in the last three periods.

In 2015, steers in the ultrahigh stocking density pastures took 26 and 58% more steps daily than 4-PR-1 steers in early July and late July, respectively (Fig. 2.2). Steps taken per day did not differ between the ultrahigh density and continuous steers in any period except for early July. The number of steps taken per day by steers in the continuous treatment and 4-PR-1 treatment were not different in any period aside from early July.

Within a 24-hour period, steps taken per hour by ultrahigh density steers was highest at 0700 – 0800 hours and 1400 - 1500 hours, which corresponds to the time steers were moved to a fresh pasture (Figures 2.3 and 2.4). Another peak of steps per hour occurred in late evening (1900 - 2000 hours). Periods of the greatest activity for 4-PR-1 and continuously grazed steers was generally similar to ultrahigh density, but steps per hour increased noticeably in the morning and afternoon grazing bouts. Moves in the ultrahigh stocking density pastures likely affected grazing bouts in the other treatment pastures because all pastures were within 215 m of an ultrahigh density pasture.

Animal Performance

The year by treatment interaction in average daily gain (ADG) approached significance with a $p = 0.0547$ (Table 2.2). Steers in the continuously-grazed pastures had greater ADG than ultrahigh stocking density steers in both years and 4-PR-1 steers in 2015. Average daily gain did not differ between steers in ultrahigh stocking density and 4-PR-1 pastures in either year. ADG was greater in 2014 than 2015 for both ultrahigh density and 4-PR-1 treatment steers. There was no difference between gain in the continuously-grazed pastures in 2014 and 2015.

Discussion

I hypothesized that steers in the ultrahigh stocking density pastures would take fewer steps per day than steers in the other treatments because of the small pasture size and higher grazing pressure in the ultrahigh stocking density pastures. However, ultrahigh steers took as many or more steps than the other treatment steers. I expected greater grazing pressure in the ultrahigh density pastures to result in the steers to quickly consume forage and spend less time searching. Redden (2014) suggested that the increase in animal activity under ultrahigh stocking density is likely a result of the multiple daily moves and pasture rectangular shape.

Steps taken by ultrahigh density steers peaked in late July (Figures 2.2 and 2.3) when the dominant cool-season plants generally were in a late reproductive growth stage. Most plants were tall and coarse and largely unpalatable and susceptible to trampling. This may have caused the steers to take more steps in search of better quality forage (Ganskopp and Bohnert, 2009). Redden (2014) and Johnson (2012) reported that forage quality declined over the length of the grazing season as grasses matured. The reason for the steers to tend to take relatively few steps in August is not certain. The relatively low number of steps taken in the first two periods of the grazing season may have been because the dominant cool-season grasses were mostly immature and high-quality at this time. Most tillers were vegetative and leafy which may have resulted in fewer steps taken to consume high quality forage. To minimize steps taken, ultrahigh stocking density grazing might be best implemented in the first half of the growing season (mid-May to early July) to avoid grazing during the reproductive stage of growth when forage is lower quality, which is associated with a high number of steps taken.

In 2014, both continuously-grazed pastures were in areas of relatively high human activity. A complementary study was conducted in the vicinity of the continuously-grazed pastures and the steers apparently were sensitive to the traffic, thereby, taking more steps. There was particularly high human activity in the first two periods of 2014, which may have played a role in the high number of steps taken by continuously-grazed treatment cattle. The human activity was not in the vicinity of the other treatment pastures. Steers in the 4-PR-1 treatment frequently took fewer steps than other treatments in 2014. This may be due to a lack of human activity influence seen in the continuously-grazed pastures as well as a lack of leapfrog effect anecdotally observed by Redden (2014) in which the first steers into a new paddock began grazing immediately, resulting in the remainder of the herd moving around the first individuals in search of fresh forage. This perpetuated for the length of the ultrahigh stocking density grazing paddock, increasing the number of steps being taken. In the early August period no differences were observed in either year.

Walking while grazing can increase energy expenditure in grazing animals by as much as 10% (Havstad and Malechek, 1982; Osuji, 1974). The increase in energy expenditure can negatively impact animal performance (Barnes et al., 2008).Energy expenditure coupled with dry matter intake appears to have an impact on animal performance (Allison, 1985; Osuji, 1974). There is not a discernable relationship between steps taken per day and animal performance. 4-PR-1 grazing cattle generally took the fewest steps; however, the ADG of those steers was not consistently higher than other treatment steers. Poor performance of cattle grazing in the 4-PR-1 and ultrahigh density treatments is likely associated with low nutrient intake in the last half of the grazing season when cattle were moving into pastures not yet grazed where plants were mature with lower leaf:stem ratio and lower quality. Conversely, cattle in continuously-grazed pastures had access to regrowth of grasses that had been grazed earlier in the season, providing higher nutrient intake.

Management Implications

Short, intensive grazing periods associated with ultrahigh stocking density grazing are reported anecdotally to improve animal performance in grazing animals but experimental studies have not validated those reports (Barnes et al., 2008; Gompert, 2010). Results of our study showed that ultrahigh stocking density grazing strategies did not produce greater animal performance compared to lower stocking densities. Ultrahigh stocking densities also resulted in grazing animals taking as many or more steps than other lower stocking density treatments. The effect of a greater number of daily steps being taken by grazing animals may reduce animal performance (Barnes et al., 2008; Havstad and Malechek, 1982; Osuji, 1974). Overall, the lack of increased animal performance in ultrahigh stocking density grazing strategies does not justify the increased cost in both labor and implementation (fencing, water and increased movement of grazers) associated with implementation of this grazing strategy. Ultrahigh stocking density grazing implemented earlier in the growing season (mid-May to early July) may result in better animal performance but would likely reduce the amount of trampled vegetation which is an important objective with ultrahigh density grazing.

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Tables and Figures

Table 2.1. Pasture characteristics and stocking information by treatment for both years in the four-pasture rotation with a single occupation (4-PR-1), 120-pasture ultrahigh stocking density, and continuously grazed treatments for 2014 and 2015. Grazing season was 60-days.

	Treatment		
	4-PR-1	Continuous	Ultrahigh density
Total treatment area (ha)	1.7	1.51	6.8
Pasture size (ha)	0.43	0.75	0.06
Number of steers	9	4	36
Days grazing per pasture	15	60	0.5
Stocking rate (AUM · ha^{-1})	7.4	7.4	7.4
Stocking density (kg · ha^{-1})	7,000	1,340	225,000

Table 2.2. Average daily gain (kg steer^{-1} day^{-1}) of yearling cattle in the 120-pasture ultrahigh stocking density, four-pasture rotation with a single occupation (4-PR-1), and continuously grazed treatments for 2014 and 2015.

Treatment	2014	2015
	---------kg day^{-1}---------	
Ultrahigh Density	0.44^{Ba}	-0.12^{Bb}
4-PR-1	0.56^{ABa}	0.08^{Bb}
Continuous	0.69^{Aa}	0.51^{Aa}

^{ABC}Different uppercase letters within columns differ ($p<0.05$)
^{abc}Different lowercase letters within rows differ ($p<0.05$)

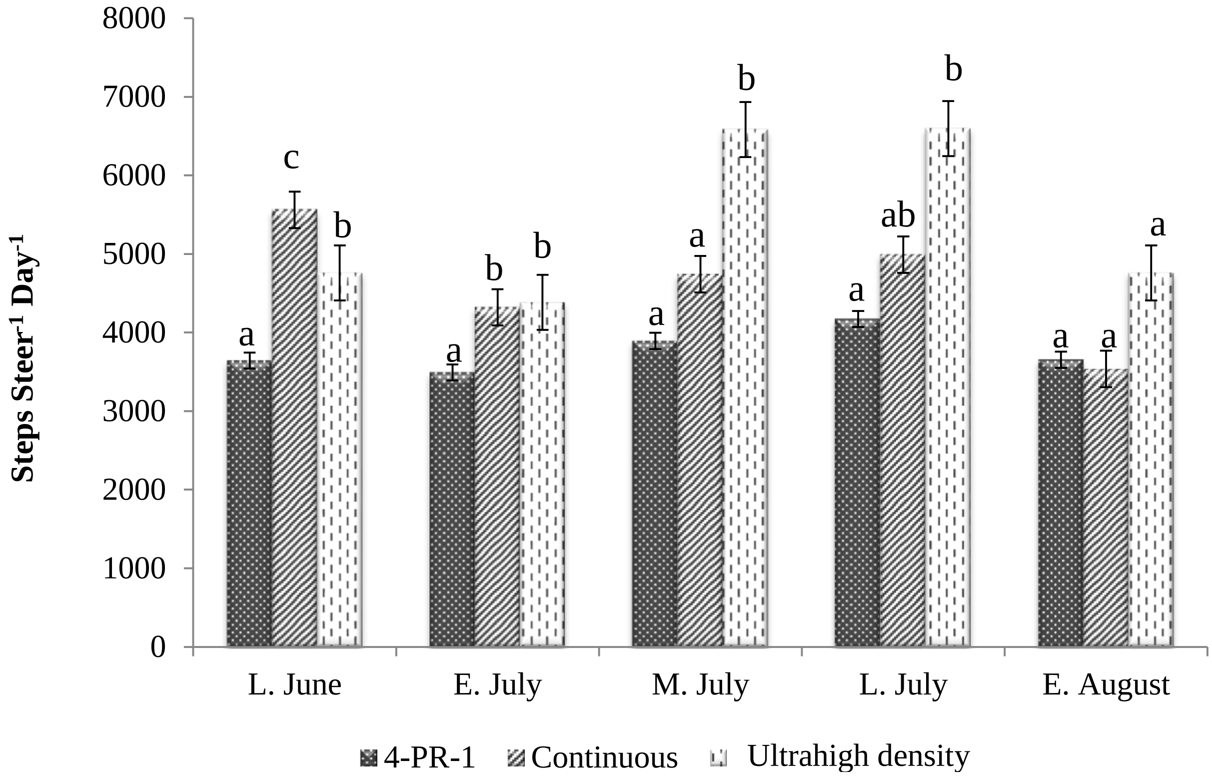

Figure 2.1. Steps taken per day during each of five, 3-day periods by individual yearling steers in the four-pasture rotation with a single occupation (4-PR-1), continuously grazed and 120-pasture ultrahigh stocking density treatments in 2014. Treatments with different letters significantly differ within periods ($p < 0.05$).

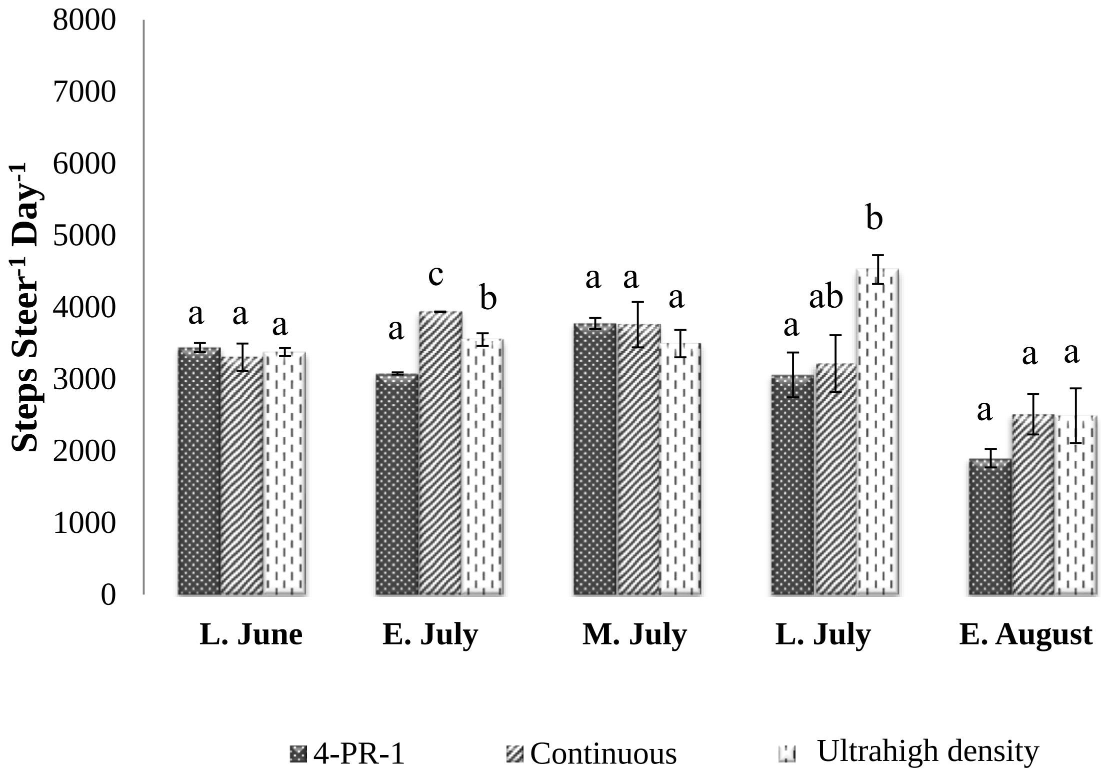

Figure 2.2. Steps taken per day during each of five, 3-day periods by individual yearling steers in the four-pasture rotation with a single occupation (4-PR-1), continuously grazed and 120-pasture ultrahigh stocking density treatments in 2015. Treatments with different letters significantly differ within periods ($p < 0.05$).

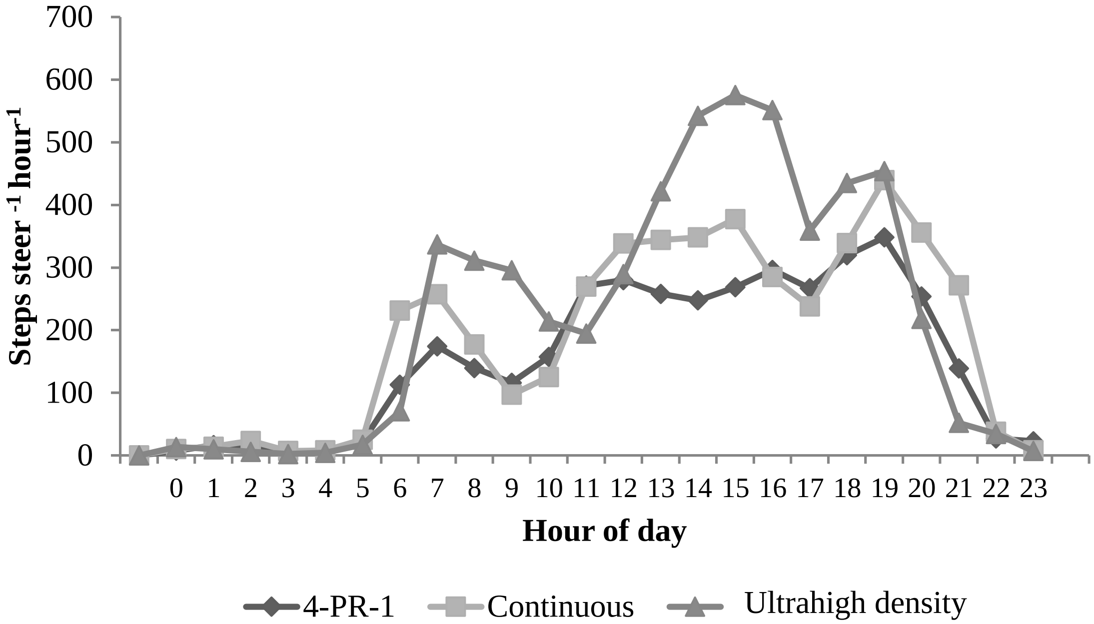

Figure 2.3. Average of steps taken per hour in the four-pasture rotation with a single occupation (4-PR-1), continuously grazed and 120-pasture ultrahigh stocking density treatments in 2014.

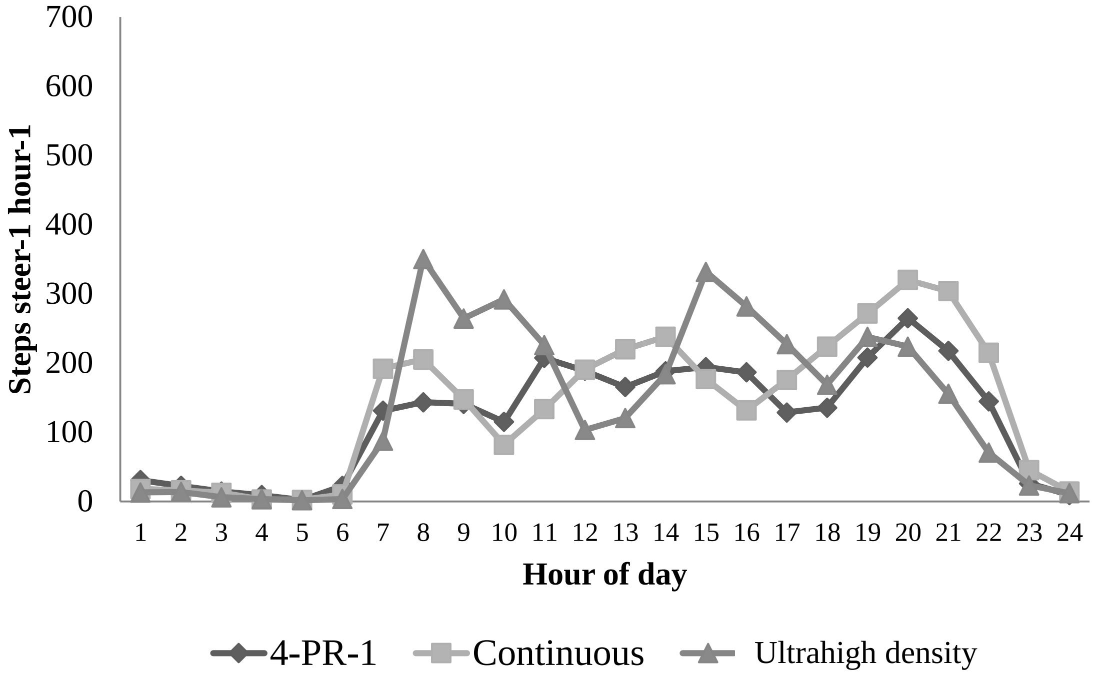

Figure 2.4. Average of steps taken per hour in the four-pasture rotation with a single occupation (4-PR-1), continuously grazed and 120-pasture ultrahigh stocking density treatments in 2015.