5-2012

Stocking Density Affects Trampling and Use of Vegetation on Nebraska Sandhills Meadow

Jordan R. Johnson
University of Nebraska-Lincoln

Stocking Density Affects Trampling and Use of Vegetation on Nebraska Sandhills Meadow

by

Jordan R. Johnson

A THESIS

Presented to the Faculty of

The Graduate College at the University of Nebraska

In Partial Fulfillment of Requirements

For the Degree of Master of Science

Major: Agronomy

Under the Supervision of Professor Walter H. Schacht

And Professor Jerry D. Volesky

Lincoln, Nebraska

May, 2012

Stocking Density Affects Trampling and Use of Vegetation on Nebraska Sandhills Meadow

Jordan R. Johnson, M.S.

University of Nebraska, 2012

Advisors: Walter H. Schacht and Jerry D. Volesky

Ultrahigh stocking density (113,000 kg of beef per ha to as high as 1 million kg per ha) or mob grazing has been suggested to build soil, increase forage production and plant diversity, and improve grazing distribution compared to less intensive grazing systems. Experimental evidence does not completely support such conclusions. The overall focus of this research is based on the approach of building soil by optimizing above ground plant growth coming in contact with soil surface by trampling 60% of above ground plant growth. The objective of the study was to compare the effect of mob grazing and simple rotational grazing systems on forage utilization, harvest efficiency, percentage of plant mass trampled, and animal performance of grazing cattle on a subirrigated meadow in the Nebraska Sandhills. The three different grazing methods compared in this study were: ultrahigh stocking density with a single grazing period (mob grazing); 4-pasture rotation with a single grazing period (4-PR-1); and 4-pasture rotation with two grazing period (4-PR-2). Cattle were rotated through 120 mob-grazed pastures and 4 pastures in each of the 4-pasture rotation treatments in 2010 and 2011. In 2010, the

stocking density for mob grazing, 4-PR-1, and 4-PR-2 treatments was 224,170 kg·ha^{-1}, 7,472 kg·ha^{-1} and 4, 982 kg·ha^{-1}, respectively, and 201,753 kg·ha^{-1}, 6,725 kg·ha^{-1} and 4, 982 kg·ha^{-1}, respectively, in 2011. The stocking rates were uniform for the grazing treatments at 8.15 AUM·ha^{-1} in 2010 and 7.41 AUM·ha^{-1} in 2011. Grazing period per pasture for the mob grazing, 4-PR-1, 4-PR-2 grazing treatments was 0.5, 15, and 20 days, respectively. In 2010, steers trampled 58%, 39%, and 17% of the available standing crop in the mob, 4-PR-1, and 4-PR-2, respectively. Percent trampled was 62%, 29%, and 19% for mob, 4-PR-1, and 4-PR-2, respectively in 2011. High percentage of trampling in the mob grazed pasture reduced forage intake resulting in low weight gains (0.13 kg·d^{-1}). This long-term study will determine the effect trampling on soil organic matter, physical properties, and vegetation dynamics.

Table of Contents

List of Tables

Chapter 2: Stocking Density Affects Trampling and Use of Vegetation on Nebraska Sandhills Meadow

List of Figures

Chapter 2: Stocking Density Affects Trampling and Use of Vegetation on Nebraska Sandhills Meadow

Introduction

Rangeland health is the degree to which the integrity of the soil, vegetation, water and air as well as the ecological process of the rangeland ecosystem are balanced and sustained (USDA, NRCS 1997). Grazing management strategies have been developed in an effort to sustain efficient use of forage resources for livestock. Grazing is a key factor in influencing plant community structure, soil chemical and physical properties, and the distribution and cycling of nutrients within the plant-soil system (Schuman et al. 1999). Grazing can also partially control the quantity and chemical composition of soil organic matter and the distribution of carbon (C) and nitrogen (N) in soil profiles (Dormaar et al. 1990; Smoliak et al. 1972). Since plant-available N is usually the limiting nutrient to grass production in semiarid Great Plains, the quantity and chemical composition of soil organic matter is crucial to N and C cycling and primary production and thus overall ecosystem productivity (Schuman et al. 1999).

Management intensive grazing strategies have been developed to control timing, frequency, and selectivity of grazing to obtain the optimal or desired response of the vegetation and grazing animal (Dwyer et al. 1984). Savory and Parson (1980) introduced the concept of short duration grazing (SDG) in which several paddocks were established by subdividing a pasture, animals were moved every few days allowing for 30 or more days of recovery, and the set of paddocks were grazed multiple times during a growing season. The resulting high stocking density was viewed essential to SDG as it created a "mob" –type grazing where animals did not graze selectively and the high density hoof action created a seedbed, improved water infiltration conditions, and trampled organic matter into the soil (Savory and Butterfield 1999). Hoof action is said to break up surface crusts, aid water infiltration, incorporate litter and manure into the soil, speed nutrient cycling, and buries seeds to help new plants become established (Savory 1983). Since the late 1990s, the mob grazing component of SDG has been developed into a strategy independent of SDG. Unlike SDG, paddocks in mob grazing generally are occupied a single time during the growing season and timing of grazing is such that vegetation in paddocks should be close to the reproductive stage as possible to maximize the amount of plant tissue trampled into the soil (Gompert personal communication). A primary objective of mob grazing is to build soil by trampling a high percentage of above-ground vegetation into the soil. This objective is achieved with the use of ultrahigh stocking density, commonly reported to be between 113,000 and 1,130,000 $kg{\cdot}ha^{-1}$ of beef at a point in time.

Major advantages of intensively-managed grazing systems are to enhance forage utilization (Stuth et al. 1981), improve grazing distribution (Savory and Butterfield 1999), and increase carrying capacity by as much as 25 to 100% (Merrill 1954; Savory and Parsons 1980). Gompert (2009) reported that mob grazing can increase forage productivity by 2 to 4 fold and enhance grassland health by rapid soil development and carbon storage. These ultrahigh stocking density practices are proposed to be well-suited for highly productive grasslands (i.e., subirrigated meadows, irrigated pasture, and dryland pasture of high yielding introduced or improved native grass) where production potential and ecosystem resilience are high (Volesky and Schacht 2010).

Reports from mob grazing practitioners suggest this grazing system has thickened stands, improved plant diversity, and increased herbage production. This increased herbage production under mob grazing would allow increased stocking rates and greater profitability for livestock producers (Gompert 2009).

Chapter 1: Literature Review

Sandhills

The Sandhills, located in north central Nebraska, encompass about 5.16 million ha of rangeland (Adams et al. 1998). This region is characterized by grass-stabilized sand dunes that were formed by deposition of loose sand, mostly during the last 8,000 years (Pye and Tsoar 2009). The dunes form mounds or ridges of various shapes and sizes across the landscape. They are as high as 0.122 km, as long as 32 km, and have slopes as steep as 25%. The depression between the dunes varies from small bowls measuring from 0.045 to 0.100 km in diameter to large flat meadows that can be more than a kilometer wide and sometimes run for kilometers in length (Poole 1914). Subirrigated meadows occur on nearly level bottomlands, upland basins, foot slopes, and stream terraces. The Nebraska Sandhills is the largest sand-dune area in the Western Hemisphere and one of the largest grass-stabilized dune regions in the world (Bleed and Flowerday 1989).

Sandhills prairie is a perennial grassland containing a mixture of tallgrass, mid-grass and shortgrass prairie species which include both warm-season and cool-season taxa along with sedges, forbs, woody plants, and a few succulents (Harrison 1980; Potvin and Harrison 1984; Weaver and Albertson 1956). Plant species vary in density and distribution along gradients of soil texture and soil moisture-holding capacity (Barnes et al. 1984; Potvin 1993). Barnes and Harrison (1982) examined plant and soil water relationships in a typical Nebraska Sandhills prairie. Deep-rooted C_4 species, sand bluestem (*Andropogon hallii* Hack.) and prairie sandreed [*Calamovilfa longifolia* (Hook.) Scribn.], which are common on upper, coarser sandy soils showed significantly greater water stress on fine textured soils than on dune sands. The C_3 species, western wheatgrass

[*Agropyron smithii* (Rydb.) Á. Löve] and needleandthread [*Hesperostipa comata* (Trin. & Rupr.) Barkworth] are most abundant on finer textured soils that provide substantial moisture during their peak activity in the spring. The C_4 species showed more conservative water use patterns than the C_3 species as significantly lower leaf conductances in the C_4 species were measured when soil water was abundant. The C_3 species appeared to use more available water and rapidly deplete surface soil moisture as a result of high transpiration rates. Therefore, Barnes and Harrison (1982) suggested that the spatial and temporal variability in available soil moisture determines the vegetation patterns in this system.

The climate of the Sandhills region is typical of mid-continental, semi-arid prairie region, similar to the central Great Plains. Average annual precipitation ranges from 580 mm in the east to 430 mm in the extreme west. Approximately 76% of the average rainfall occurs during the April-to-September growing season (HPRCC 2011). Precipitation from October through March is usually as snow. The average annual snowfall ranges from 558 mm to 711 mm along the southern edge to around 1140 mm in the North. The melting snow increases the stored soil moisture and serves as an important source of water in the spring for early plant growth (Wilhite and Hubbard 1989). The frost free period is 130-155 days (Neild 1977).

Sandhills Subirrigated Meadows

Subirrigated meadows are found primarily in the northern and northeastern Sandhills. They are well-watered but not soggy, level land. Soils are fine sand well supplied with silt, clay, and organic matter that are poorly drained (Bleed and Flowerday 1998). The surface layer is generally darker in color because of the organic matter and ranges from 15 to 60 cm thick. The soil water table generally is within 1 to 2 m of the soil surface, during most of the year, and the roots of the plants can usually reach it (Poole 1914).

The vegetation is a productive mixture of exotic cool-season grasses, native sedges and rushes, native warm-season tall grasses, and exotic legumes. The dominant plants are taller grasses (Bleed and Flowerday 1998) that form a dense sod. The dominant cool-season grasses include red-top (*Agrostis stolonifera* L.), timothy (*Phleum pretense* L.), Kentucky bluegrass (*Poa pratensis* L.), quackgrass (*Elymus repens* Gould), Scribner panicum (*Panicum oligosanthes* Schult. var. scribnerianum [Nash] Ferald), and Wilcox panicum (*Panicum wilcoxianum* Vasey). Several species of native sedges (*Carex spp.)* and rushes (*Equisetum spp., Eleocharis spp.,* and *Juncus spp.*) are also common. Native warm-season grasses include big bluestem (*Andropogon gerardii* Vitman), prairie cordgrass (*Spartina pectinata* Link), and Indiangrass [*Sorghastrum nutans* (L.) Nash]. Common exotic forbs are the legumes red clover (*Trifolium pratense* L.) and white clover (*Trifolium repens* L.).

Use of Meadows

Subirrigated meadows in the Nebraska Sandhills are mostly used for hay production. The total annual production ranges from a low of 4,200 kg of biomass·ha^{-1} to over 6,600 kg of biomass·ha^{-1}, air-dry weight in favorable years. Meadow hay forms an important part of livestock enterprises in the Sandhills. Hay is fed to livestock during the winter months when deep snow blankets the grass making it difficult for livestock to graze. It can also be used during calving season to provide easily accessible forage to cows. Hay harvest takes place in late June through July, generally after forage has reached full maturity. Grazing subirrigated meadow during the growing season may result in larger growth rates of animals and more rapid replenishment of body condition than would occur on marginal quality meadow. In excellent range condition, suggested stocking rates can be as high as 4 animal unit month per hectare. ($AUM \cdot ha^{-1}$). Spring grazing may also delay forage maturity enough that producers would have the options to harvest hay at less mature stand with high nutritional value or wait until complete growth and harvest for tonnage rather than nutritional value (Horney et al. 1996).

Grazing subirrigated meadows can reduce inputs of harvested forage and reduce feed costs. An early meadow grazing program can cut several weeks worth of hay out of the spring feeding program. A 4-year study conducted by Adams et al. (1994) looked at the effects of extending common grazing dates for cattle by grazing upland range during the winter and subirrigated meadows in May. Common grazing dates in the uplands range from about 15 May through 15 October or they can be continuously grazed for the entire year. The results illustrated that for a ranching operation with adequate meadow and winter range resources, the best forage management strategy involves grazing subirrigated meadows over winter and grazing meadows again in May. Clark and Coady (1992) conducted a survey of Nebraska Sandhills ranches and estimated that about 50% contained some subirrigated meadows and only 14% of the meadows are grazed in the spring during the growing season.

A high percentage of the meadows that are hayed are also grazed during late fall and winter. However, over the last 20 years, there has been a trend where more meadows are grazed during the summer. This is especially true for ranchers that have made changes such as later calving. With later calving, less hay is fed so ranchers are looking at grazing some of the meadows as an alternative. Another similar reason for grazing a meadow is to extend the grazing season and use meadows (Volesky personal communication). Adams et al. (1994) reported most advisors suggest grazing meadows as an option if the meadow is not too wet or if the ranch is not worried about it being damaged by grazing. Compared to upland range, it is suggested to use more intensive grazing systems on meadows because of the ability to regrow (similar to irrigated pasture).

Physiology and Morphology of Perennial Grasses

Plant growth is the increase in size that is accompanied by changes in form, structure, and general state of complexity of the plant (Dahl and Hyder 1997). Growth and maintenance of plants are influenced by photosynthesis. Photosynthesis converts energy from the sun, carbon dioxide from the atmosphere, and water and minerals from the soil into food for the plant. Water availability is the primary factor determining plant growth. Water is necessary in photosynthesis and also transports minerals from the soil into the plant (Holechek et al. 2004). There are four primary growth periods of a perennial plant: vegetative, elongation, reproductive, and seed ripening (Moore et al. 1991).

Roots and Rhizomes

The root system of plants performs two primary functions: anchorage and uptake of water and nutrients. Roots also serve as a reservoir of meristems, and are involved in absorption and transport of water and nutrients. Roots are branching structures, with laterals emerging from nodes. Nodes are the point of origin of a branch in a root system

(Fitter 1991). Another function of grass roots is to bind the soil together preventing soil erosion (Allaby and Garrett 2004).

Rhizomes are horizontal stems that run below ground (Beard 1973). Stolons are modified stems and run along the surface of the soil by horizontal stem elongation (Evans 1958). Rhizomes may either be continuous, producing aerial shoots quickly as in quack grass, or terminal, when their apices turn up and emerge as phototropic shoots e.g., Kentucky bluegrass (Oakley and Evans 1921). Stolons have continuous growth and form roots and shoots at their nodes as they grow. Rhizomes and stolons produce adventitious roots that emerge from nodes rather than from the base of the plant.

Stems

A stem is an elongated axis that develops in the shoot apical meristem through continual cell division (Hopkins and Hüner 2004). Young stems are often referred to as shoots. The stems are divided into nodes and internodes. Nodes are the points at which leaves and flowers attach and arise. Internodes are lengths of stem between two nodes (Dahl 1995). As the plant begins growing, internode cells begin to elongate and the nodes begin to move apart. The specific arrangement of stem tissues may vary with age. In grasses, the vascular tissues are arranged in bundles that are scattered throughout the core of the parenchyma tissue. These bundles support the stem. Young stems produce concentric rings made up of xylem and phloem that enclose a central pith of parenchyma. The principal functions of stems are the translocation of nutrients and water, storage of nutrients, and support of the plant.

Phototropic shoots are grouped into short, long, and reproductive shoots. During vegetative growth, all annual and perennial grasses elongate very little when producing short shoots (Jewiss 1966). Short-shoot plants are well adapted to mowing and grazing because the shoot apex remains below the cutting or grazing height allowing production of new leaves to continue (Hyder 1972).

In long shoots, internodes elongate while the apex remains vegetative. As internode elongation begins, the shoot apex and leaf intercalary meristems elevate as well. Grazing or cutting below the shoot apex stops leaf differentiation. Tillering from axillary buds of the crown can replace leaves, but it is a slow process (Dahl 1995).

Crowns

A crown refers to any section of stem base where two or more nodes remain close together (Dahl 1995). The number of basal leaves produced and the potential number of tillers and adventitious roots are indicated by number of nodes in the crown. Grasses can have vertically oriented crowns or horizontal crowns that lie on the soil surface (Hyder et al. 1975). Vertical crowns grow themselves out of the ground in a process of sequential tillering while internodes must elongate to elevate the growing point above the crown in grass clumps that have dead centers (Dahl 1995).

Crowns remain in close quarters, may be located above or below the soil surface and lack chlorophyllous cells; therefore, photosynthesis in the crown area is usually low. Crown growth and maintenance is supported by carbon produced by the photosynthetic system (Coyne et al. 1995). Large stores of carbohydrates are often found in crowns and utilized in early growth and initiation of new tillers (Deregibus et al. 1982).

Inflorescences

A grass shoot is subject to the stimuli that cause the process of floral induction (Dahl 1995). A reproductive shoot, developed from a vegetative shoot, goes through this process to developing inflorescences (Hyder 1972; 1974). Timing of growth of plant inflorescences is generally prior to significant growth of the photosynthetic system or at a time when most active growth has stopped and leaves are nearly mature (Coyne et al. 1995). Mowing and grazing of leaves on reproductive shoots above the rudimentary inflorescences keeps the culm obligated to grow even though the developing shoot may remain leafless. If the inflorescence is removed, further growth of that shoot is ceased and tillering at the base is induced (Rechenthin 1956; Hyder 1972).

Carbon Storage

Surplus carbon may be stored and utilized during periods when there are high construction demands (Mooney 1972). Storage is a major plant function and can be defined as building up resources in a plant that can be utilized in the future for growth or other functions (Chapin et al. 1990).

Accumulation of carbon occurs when the resource supply of a plant exceeds demands for growth and maintenance. The accumulated carbon can be lost from the plant or contribute to future growth. Reserves are formed when accumulated products are stored within the plant cells. Reserve formation competes for resources with plant growth and defense. Plants utilize these reserves when building a productive and competitive system or at unpredictable times such as defoliation, when the productive system is entirely destroyed. The seasonal construction of reproductive parts also utilizes reserves rather than using current photosynthate (Mooney 1972). Recycling prevents the loss of compounds by salvaging components of growth to form materials that support additional growth (Chapin et al. 1990).

Plant Community Vigor

Heavily depleted reserves in annual regrowth cycles of plants have an extensive amount of reserves to replenish during growing season. A short season with poor weather can significantly reduce the pool of available carbohydrates for the following year (Fonda and Bliss 1966). Cook (1966) reported that the depletion of reserves in palatable perennials by grazing can shift the competitive balance toward nonpalatable species and result in a change in plant community composition.

Productivity

A plant's productivity, survival, and success are a function of its pattern of carbon utilization, as well as its capacity for carbon assimilation (Oechel and Lawerence 1981). Carbon assimilation by green plants is a photosynthetic process localized in sub-cellular organelles called chloroplasts that depends upon organic carbon derived from carbon dioxide in processes driven by light energy (Coyne et al. 1995). Monsi and Murata (1970) suggested that a small change in carbon allocation from leaves to stems or roots may impact the nutrient uptake, water relations, and total carbon assimilation of a plant. Thus, a change in carbon utilization may directly affect how a plant competes with other plants, a plant's resource-use efficiency, and its recovery from disturbances such as fire or grazing (Coyne et al. 1995). Growth, maintenance respiration, and carbohydrate storage are major carbon sinks where carbon is utilized. In herbaceous plants, maintenance respiration has been estimated to be approximately 1% to 4% of the carbon present in the biomass (or dry weight) per day (McCree 1974). Larcher (1980) estimated that growth respiration was between 3 and 10 times that of maintenance respiration for actively growing plant parts.

Carbon Seasonal Cycles

Seasonal storage of carbohydrates is a regulated process of reserve accumulation, distribution, and storage. It also could be interpreted as accumulation in response to supply and demand (Zimmerman 1971). As supply continues to increase after most active growth has been completed and demand declines, reserve products begin to accumulate. The accumulated products can be lost from the plant or can be contributed to future growth (Chapin et al. 1990). Partitioning of reserves into storage may compete with defense, growth, or reproduction (Coyne et al. 1995). In seasonal climates, storage of carbohydrates reserves is fundamental to the extension of the life cycle and initiation of growth in the following season when favorable conditions return (Schulze 1982). Carbohydrates are stored in cells throughout the plant, but greatest concentrations are found in perennating organs. During rapid plant growth when construction and respiration rate demands are great, carbohydrate reserves decrease. As growth rates decline or when the most active growth has been completed, reserves begin to concentrate again (Coyne et al. 1995). In temperate latitudes, stored carbohydrates decline drastically as perennial grasses resumes growth in the spring. Carbohydrate reserves decrease in perennating organs (stems, stem bases, roots, rhizomes, and bulb) during rapid growth of the plant when construction and respiration demands are great. Reserves begin to accumulate again in these organs when most active growth has been completed (Coyne et al. 1995).

Nitrogen Uptake

Nitrogen (N) is often the limiting element in plant growth. The ingestion and excretion of N by range herbivores affect the availability, distribution, and chemical form of N in the ecosystem. Higher plants utilize N in many ways including: uptake, storage, translocation, and incorporation of N into organic form (Coyne et al. 1995). Plant N uptake primarily occurs through the roots (Coyne et al. 1995; Haynes 1986a).

Nitrogen is available through wet and dry deposition, biological fixation, and synthetic fertilizers. Wet and dry deposition is atmospheric nitrogen, in the form of NH_3, NO_x, and particulates, which is transferred to the soil system by precipitation or wind (Haynes 1986b). Biological fixation of N_2 is accomplished by free-living bacteria, symbiotic cyanobacteria, rhizocoenoses, actinomycete nodule symbiosis, and rhizobium symbiosis (Haynes 1986b). Rhizobium symbiosis is estimated at 25% of the global biological N-fixation. Nitrogen fixed by microbes becomes available to plants upon microbial death. Burns and Hardy (1975) stated that input into a range ecosystem from N-fixation can be substantial. Synthetic fertilizers play a minor role as N sources for range plants, with only a small portion of the more mesic range ecosystem receiving commercial fertilizers (Coyne et al. 1995)

Most N uptake by plants through roots is in the nitrate (NO_3-) form but may also be in the form of ammonium (NH_{4+}) which is reduced to amides in the root (Pate 1980). Nitrate uptake requires energy and plants exhibit a diurnal pattern with the greatest absorption taking place at midday (Pearson and Steer 1977). Haynes (1980) reported that N uptake can occur either by passive diffusion through the epidermis of the root or by active uptake at the outer cell membrane or plasmalemma. Ions then can be transported through a system known as symplast (Larcher 1980). Uptake of NO^-_3 is an active process requiring energy that has been shown to be restricted by inhibitors of RNA and protein synthesis, while also affecting inhibition of respiratory and oxidative phoshorylation (Tomkins et al. 1978; Jackson et al. 1973). NO^-_3 may be transported through the xylem to the shoot (Mooney 1972).

Nitrogen uptake through the leaves is known as foliar uptake. Foliar uptake appears to occur through diffusion into stomata and subsequently into the intercellular spaces of leaves, where active uptake occurs. Urea solutions are the primary forms of soluble N that are taken up by foliar absorption (Haynes 1986a). Ammonia (NH_3) is most likely the most absorbed N-containing gas and is produced in large amounts near the soil surface (Denmead et al. 1976). In rangeland ecosystems, NH_3 near the soil surface comes from urine and dung patches of livestock and is absorbed by the plant canopy. While the capacity to absorb NH_3 through the foliage has been shown, the importance of this process in range plants growing in arid or semi-arid environments remains to be quantified (Coyne et al. 1995).

Nitrogen Storage

In many rangeland ecosystems, N is an element that limits plant productivity and its preservation and reuse within the plant become important. Nitrogen use efficiency and recycling allows perennial plants to maintain high levels of productivity. Nitrogen storage acts as a buffer between the resource supply and the demand for N in growth (Coyne et al. 1995).

Nitrogen can be stored in all organs of the plant but only temporarily in organs such as leaves and root hairs. Storage in these organs is temporary because of the usually short life span. Most long-term storage is located in cell cytoplasm and membranes of perennating organs of the plant (Coyne et al. 1995). Chapin et al. (1990) and Chapin and Shaver (1988) reported that N is commonly stored as specialized proteins, RuBisCO, amino acids, nucleic acids, and nitrate. Nitrogen storage compounds can serve multiple roles in plants. Hsiao (1973) suggested that an amino acid may serve as principal storage or as an osmoticum, and has been linked with drought hardiness.

Herbivores benefit from the high concentrations of resources in storage compounds (Bloom et al. 1985). Locations of stored resources within belowground organs in herbaceous and grass plants are protected from defoliation. They are usually maintained in nongrowing or slowly growing tissue and utilized in the future growth of plants (Coyne et al. 1995).

Nitrogen Seasonal Cycles

Nitrogen in an ecosystem is cycled with a direct interchange between the ecosystem and the atmosphere (Coyne et al. 1995). Recycling of nitrogen storage within the plant is critical because nitrogen is a limiting element (Chapin et al. 1990). Nitrogen storage varies daily as well as seasonally, depending upon supply and demand within the plant. During the day, N stored reserves may be reduced to produce RuBisCo (Coyne et al. 1995) or reduced in the roots (Bloom et al. 1985).

As perennial plants begin to rapidly grow in the spring, stored reserves of nitrogen and carbon are utilized. As growth slows, the plant is able to replenish the reserves

(Tromp 1970; Chapin et al. 1980; 1986). The process of seasonal storage can be interpreted as accumulation of nitrogen in response to supply and demand (Clark 1977; Trlica and Singh 1979).

Large quantities of nitrogen in storage organs may be required to support the plants active growth after a dormant period due to the low availability of nitrogen in the soil. As soil temperatures rise and with an adequate supply of water, microbial mineralization of organic matter results in an increased nitrogen supply available for plant uptake. In young tissue high concentration of nitrogen is diluted as growth and construction of cell wall material continues (Coyne et al. 1995). Coppock et al. (1983) suggested that C_4 grasses may exhibit greater seasonal decline in nitrogen content of leaves compared to C_3 grasses. Thus, nitrogen reserves show a seasonal cycle with high levels during the winter or dormant period and rapid depletion with the onset of new growth. Rapid growth is often supported more by stored nutrients than by concurrent absorption (Tromp 1970; Clark 1977; Chapin 1980). In the spring, photosynthesis in the leaves produce nutrients to replenish the nitrogen pools demanded by stems and large roots. Storage organs are slowly replenished during the summer by absorption from the soil and in autumn by translocation from senescing leaves (Greenwood 1976; Chapin 1980).

History of Grazing Systems in the Great Plains

The first agricultural use of the Great Plains was livestock grazing of open rangeland (Klipple and Costello 1960). The formal study of grazing rangelands began after 1900 (Lodge 1970). As cattle and sheep numbers increased in the western states prior to the 20th century, continuous heavy overgrazing resulted in many western rangelands reaching their peak of degradation. In the early 20th century a concerted nationwide effort to conserve rangelands swept the grazing community and federal government agencies. The consequences of overused rangeland, such as sustainability of livestock production and ecological diversity and balance of native rangelands, were beginning to be understood (Heady 1999; Holechek et al. 2004).

At the beginning of the 20th century, specialized grazing systems that rotated grazing animals through several pastures were introduced (Briske et al. 2008). Arthur Sampson conducted the first recorded grazing study in 1913 located in northeastern Oregon (Sampson 1913). Sampson (1913) concluded that depleted rangeland can be restored. He achieved this by dividing a rangeland parcel into two units and deferring summer grazing on each unit in alternating years. He and other range management pioneers developed the foundation of grazing management concepts focused on using grazing systems/strategies to improve or maintain rangeland condition while ensuring sustainable livestock production. Sarvis (1923) and Black et al. (1937) examined deferred rotation grazing and reported that weight gains on cattle were greater for a deferred rotation grazing system than a season-long continuous grazing system. However, a study in Alberta found no difference in weight gains between cattle grazing in a continuous systems and a three pasture deferred rotation. There were no differential effects on vegetation after 9 years, and after 12 years. (Thompson 1938; Hargrave 1947).

From the 1930s to the 1950s studies began to focus on the effects on the range vegetation and on cattle weight gains through grazing systems. These grazing systems consisted of two or more pastures that were deferred in the spring and a from time to time not grazed in the summer or fall (Lodge 1970). Since then, rangeland scientists have provided increased data on grazing systems success and failure in many different ecological regions (Sampson 1951; Holechek et al. 1999; Briske et al. 2008). This has resulted in numerous different types and variations of grazing systems.

Stocking Density

Definition

Stocking density is the animal demand per unit area at any instant time. Stocking rate is the animal demand that has been or will be made per unit of area over a period of time. Stocking rate is interrelated with stocking density. The same stocking rate exists, but not necessarily accompanied by the same plant and animal response, when equivalent but inverse changes are made in stocking density and the length of grazing period. For example, the stocking rate of 50 AUMs per 50-ha unit remains the same whether realized by: (1) 10 animal units over a 5-month continuous grazing period, (2) 50 animal units during a single grazing period reduced to 30 days, or (3) 50 animal units that graze for 6 days during each of five distinct grazing periods during the same grazing season (Vallentine 2001).

The significance of stocking density as a grazing management tool was emphasized by Savory and Parson (1980) when they described short duration grazing (SDG). This system was managed by subdividing a pasture into several paddocks. A single herd of animals is moved every few days allowing for 30 or more days of recovery, and the set of paddocks are grazed multiple times during a growing season. The resulting high stocking density was viewed essential to SDG as it created a “mob” –type grazing where animals did not graze selectively but uniformly and completely utilize (consume or trample) the available forage. Since the later 1990s, the mob grazing component of SDG has been developed into a strategy independent of SDG. Unlike SDG, a paddock in mob grazing generally is occupied a single time during the growing season and timing of grazing is such that vegetation in paddocks should be as close to the reproductive stage as possible to maximize the amount of plant tissue trampled into the soil (Gompert personal communication). Primary objectives of mob grazing are build soil by trampling a high percentage of above-ground vegetation into the soil and to evenly use standing vegetation. These objectives are achieved with the use of ultrahigh stocking density, commonly reported to be between 113,000 and 1,130,000 $kg \cdot ha^{-1}$ of beef at any point in time.

Distribution of Grazing and Harvest Efficiency

Grazing distribution is the dispersion of animals during grazing over a management unit or area. Harvest efficiency is the percent of the total standing crop by weight that is ingested, or the percent of the total cumulative forage disappearance by weight that is ingested. The dispersion of grazing animals and associated harvest efficiency within a grazing management unit or area is an important aspect in grazing management. The goal of grazing management is to obtain the maximum safe grazing use over as wide of an area as possibly without overgrazing it. Major advantages of intensively-managed grazing systems are to enhance forage utilization (Stuth et al. 1981), improve grazing distribution, and increase carrying capacity by as much as 25 to 100% (Savory and Parsons 1980).

Large increases in stocking density can change the spatial distribution of grazing and can cause animals to graze the landscape more uniformly. By increasing the number of paddocks per herd, stocking density can be increased 20 to 50 times, compared with continuous stocking without changing the system stocking rate. Kothmann (2009) reported that ranchers using high stocking density have observed significant reductions in area-selective grazing problems. Mob grazing has been anecdotally reported to thicken stands and increase diversity and herbage production through the animal impact and herd effect placed on the grassland. Increased herbage production and/or increased harvest efficiency will allow an increase in stocking rates and profitability for the livestock producer (Gompert 2009).

A study at the Utah Agricultural Experiment Station site southeast of Miner's Peak on Cedar Mountain, at the boundary of Washington and Iron Counties, Utah tested the hypothesis that utilization is more even at the higher stocking densities of smaller paddocks (Barnes et al. 2008). Mean absolute deviation (heterogeneity) of utilization estimates by plot was compared in paddocks of sizes and stocking densities representing increasing subdivision from two-paddock deferred rotation grazing (DRG) to 16-, 32-, and 64-paddock, two cycle intensive rotational grazing (IRG). These 70-, 4-, 2-, and 1-ha paddocks were grazed for 7 wk, 4 d, 2 d, and 1 d, respectively, at 32 AUD·ha^{-1} during 2000 and 34 AUD·ha^{-1} during 2001. Intensive rotational grazing stocking densities were 4, 8, and 16 AU·ha^{-1} during 2000 and 4.25, 8.5, and 17 AU·ha^{-1} during 2001. Deferred rotation grazing stocking densities were 0.46 AU·ha^{-1} in 2000 and 0.49 AU·ha^{-1} in 2001. In 2000, five of six, and in 2001, seven of seven small paddocks representing IGR after first of two grazing cycle were grazed with less heterogeneity than two large DRG paddocks after the entire season of grazing. In 2001 after the second grazing cycle, cumulative grazing intensities of all paddocks were equal. However, Barnes et al. (2008)

point out that lower proportions of unutilized quadrats in the IRG paddocks than the larger DRG paddocks is consistent with Norton's (1994) hypothesis that livestock tend to be more evenly distributed in smaller paddocks at higher stocking densities, such that forage actually encountered and available to animals is increased.

The relationship between stocking density and grazing distribution was studied in eastern Nebraska pastures seeded to a warm-season, tall-grass mixtures and grazed at four stocking densities: 9, 18, 27, and 54 steers·ha^{-1} (Burboa-Cabrera et al. 2003). Four pastures were divided into four paddocks ranging in size from 0.18 to 1.12 ha. Ten steers averaging 282 kg grazed the paddocks within each pasture from June to late August in 1995 and 1996 for three consecutive cycles (12, 36, and 24 d). They report that stocking densities as high as 54 steers·ha^{-1} on warm-season, tall-grass mixtures do not appear to be a major factor in affecting spatial grazing distribution or utilization selection.

Herd Effect/Trampling

The principal objective of improving or maintaining the vigor and production of a forage resource may be achieved by increasing available soil water through improved rainfall infiltration rate and reduction of runoff loss. Hoof action is said to break up surface crusts, improve water infiltration conditions, incorporate litter and manure into the soil, increase the rate of nutrient cycling, and bury seeds to help new plants become established. Researchers of intensive rotational grazing systems have hypothesized that intense trampling activity associated with high stocking density will enhance rainfall infiltration and reduce erosion (Goodloe 1969; Savory and Parsons 1980; Walter 1984).

An increase in stocking density results in an increase in hoof action (Savory 1983; Savory and Butterfield 1999). Zero, light, or heavy trampling, followed by rain, buried 20, 28, and 45%, respectively, of seeds of four grass species in a study conducted by Winkel et al. (1991). However, under a 10-pasture intensively-managed rotational grazing system, nearly all crested wheatgrass seedlings were destroyed by trampling (Salihi and Norton 1987).

Hart et al. (1988) reported that dividing an area management unit into more pastures, assuming that travel distance to water was unchanged, did not increase the total area trampled but would concentrate the effect in fewer days. The cattle are moved more often where pastures are divided up compared to a season-long continuous grazing system, resulting in the cattle being more concentrated in smaller pastures. Thus, Hart et al. (1988) indicated that the trampling effect would be achieved in a shorter amount of time.

Minerals and water are nutrients that can be circulated from soil to plants to animals to soil numerous times. The uptake, utilization, and release of a nutrient into a form that can be reused is known as a nutrient cycle. Each nutrient serves separate functions in the animal. Grazing animals can alter the pathways of nutrient cycles, as well as the amount of nutrients released by decomposition, and returned back to pastures. If grazing animals are not present, nutrients in vegetation leach directly into the soil or return to the soil. Invertebrates and microorganisms within the soil reduce the amount of residue by decomposition and consumption (Heady and Child 1994).

Grazing by large herbivores increases nutrient cycling rates due to several mechanisms: releasing nutrients, by reducing particles size but also by accelerating the rate of nutrient conversion from an organic to inorganic form available to plants. Fecal nitrogen is largely insoluble and becomes available to plants only after incorporation into the soil by soil fauna and mineralization by microorganisms. Nitrogen in urine is readily or rapidly becomes available (Simpson and Stobbs 1981). Proteins and amino acids are converted to NO_3- and NH_4+ (Vallentine 2001).

Soil Response

Soil is the primary factor determining the potential for forage production. Soil is comprised of minerals, organic materials, and living forms (Holecheck et al. 2004). Vallentine (2001) stated that grazing animals have the potential to impact the soil in the following ways: (1) soil compaction, (2) penetrating and disrupting the soil surface, (3) infiltration, and (4) erosion. The interaction of many site, soil, weather, and vegetation factors will determine the influence hoof action will have on the soil. Grazing management has been generally based on the timing and amount of forage removed.

The concept of herd effect has become highly controversial in scientific circles, with some practitioners supporting the concept while range and pasture scientists generally discount the concept (Vallentine 2001). Dormaar et al. (1989) reported that high hoof action associated with high herd density reduced soil moisture, increased bulk density, did not significantly incorporate litter into the soil, and decreased fungal biomass. A study in central Utah that looked at cattle under short-duration grazing, found that the hoof action was minimal in breaking up the standing vegetation and mixing it with the surface soil (Balph and Malecheck 1985).

Ian Mitchell-Innes is a Holistic Management (HM) certified educator who weaves HM theories into his teaching of mob grazing (Hautua 2011). Mitchell-Innes has practiced this type of grazing on natural grassland in his native South Africa, and believes soils will improve over time because of the return of plant residue to the ground by animal trampling. Improved soils will increase diversity of plant species and provide drought resilience. There is a potential for changes in bacterial and mycorrhizal fungi populations as a pasture shifts in composition from grass to grass/legumes pastures. Mitchell-Innes' goal is to observe the pasture for an increase in diversity of species which can contributed to greater palatability (Hautau 2011).

Greg Judy, a mob grazing advocate, suggest that the benefits of mob grazing are realized through the short episodes of high animal impact (84,000 to 560,400 $kg \cdot ha^{-1}$) followed by long recovery periods (Schmidt 2011). Longer recovery periods allow plants to develop much deeper root systems, which can draw moisture and minerals that are unavailable to shallower rooted plants. Plants that have healthy roots can better withstand drought. They have increased canopy above ground during regrowth, which helps keep the soil cool and helps plants remain alive and growing longer into the growing season.

Soil Organic Matter

Soil organic matter dynamics are complex and affected by many factors such as temperature, precipitation, vegetation, soils, and management practices (Burke et al. 1989). Infiltration rate and sediment production were measured for 2 years on 3 pastures from an intensively-managed rotational grazing system (Warren et al. 1986). The pastures were 32, 24, and 16 ha in size with fixed stocking rate but three stocking densities: 1.47, 1.96, and 3.13 $AU \cdot ha^{-1}$, respectively. Warren et al. (1986) reported that measured infiltration rates did not support the hypothesized beneficial hydrologic advantage of increased stocking density via manipulation of pasture size and numbers. The authors concluded that rest, rather than intensive livestock activity, appears to be the key to soil hydrologic stability.

Dormaar et al. (1989) found that short-duration grazing systems stocked at twice to triple the recommended rate of 0.8 AUM·ha^{-1} significantly affected a number of chemical and physical properties of the soil. A loss in organic matter or differential rates of organic matter accumulation and/or decomposition was evident in the grazed treatments compared to the rested treatments. Soil moisture was always significantly higher in soils of the rested treatments. Bulk densities increased significantly and hydraulic conductivity at the 0 to 3 cm depth was reduced by the grazing regime compared to rested treatments. Soil carbon and nitrogen content were also lower on the grazed pastures.

Research at the High Plains Grasslands Research Station near Cheyenne, Wyoming, looked at grazed pastures for 11 years at a heavy stocking rate (67 steer-days·ha^{-1}) (Manley et al. 1995). Three management systems were compared to continuous light grazing (22 steer-days·ha^{-1}) and to livestock exclosures. Soil organic carbon and nitrogen response were evaluated by collecting soil samples to 91 cm depth. After 11 years, soils had increased amounts of carbon and nitrogen in the surface 30 cm on the grazed pastures compared to native rangeland where livestock were excluded. However, soil carbon and nitrogen below 30 cm was similar among all grazing treatments.

Fescue grasslands grazed at a heavy intensity of 0.2 $ha \cdot AUM^{-1}$ had less soil organic carbon than grasslands grazed at 0.8 $ha \cdot AUM^{-1}$ (Johnston et al. 1971). Smoliak et al. (1972) reported that the soil carbon content increased on a native prairie grazed for 19 years at 2.5 $ha \cdot AUM^{-1}$ compared to 1.7 $ha \cdot AUM^{-1}$.

Nonetheless, under mob grazing, significant amounts of organic matter can be increased in the soil through controlled root die off and trampling of above ground plant material (Peterson 2010).

Plant Response

Hart et al. (1988) reported that grazing systems and stocking rates did not significantly affect basal cover of blue grama, western wheatgrass, total cool-season graminoids, lichens, forbs and half-shrubs, or total vegetation. A seven year short-duration rotation grazing study in west Texas (Dahl 1986) reported that differences in species composition occur only because of yearly weather changes. Reece (1986) suggested that change in species composition caused by grazing management may not be seen for several years.

Research conducted in the northern mixed grass prairie of Wyoming looked at how three grazing strategies (continuous, rotationally deferred, and time-controlled) affected stocking capacity, forage production and range condition (Manley et al. 1997). Three stocking rates applied under light, moderate, and heavy grazing averaged 21.6, 47.0, and 62.7 $steer\text{-}day \cdot ha^{-1}$, respectively. Grazing pressures were 11.0 to 90.1 $steer\text{-}day \cdot Mg^{-1}$ of forage dry matter produced. Bare ground and cover of warm-season grasses, forbs, and lichens were greater under heavy stocking, whereas litter, western wheatgrass, and total cool-season graminoids were greater under light stocking. Stocking rate and grazing strategy had no effect on above-ground biomass and little effect on below-ground biomass. Under heavy stocking, percent of above-ground biomass contributed by forbs increased, especially under time-controlled rotational grazing, while that of western wheatgrass decreased.

A 5-year study on fescue rangeland at the Shipwheel Ranch in Alberta, Canada compared botanical composition of grazing excluded areas to a 17-pasture, short duration grazing system (Dormaar et al. 1989). The pastures were stocked at twice to triple the recommended rate of 0.8 $AUM \cdot ha^{-1}$. Increased grazing pressure reduced range condition from 50.0% to 39.2% compared to the grazing excluded range condition which increased from 51.6% to 56.2% of climax community during the same time. At the end of the 5 year study, the frequency of rough fescue decreased 6.0% in the grazing excluded area compared to 0.7% in the grazed pasture.

Research on tallgrass prairies in Oklahoma indicated an increased herbage production in rotational grazing systems (Cassels et al. 1995). An 8-pasture rotational grazing system was compared to a continuous grazing system. Within each grazing system the units were randomly allocated to one of six levels of stocking rate ranging from 127 to 225 kg $live\text{-}weight \cdot ha^{-1}$. These stocking rates represented moderate to very heavy rates for this range type. Herbage standing crop was measured in July and September. Total stocking rate was inversely related to total, live, and dead standing crop. All standing crop-stocking rate relationships were linear. A similar study also reported a linear decline in standing crop as stocking rate increased under rotational grazing (Ralphs et al. 1990).

A 10-year study compared a 4-pasture, DR grazing system with an 8-asture, SDG system at the Barta Brothers Ranch near Rose, NE to determine differences between grazing systems in standing crop and botanical composition (Stephenson 2010). Fifty to 100 cow-calf pairs grazed pastures (47 ha) from 15 May to 15 October in both single (DR grazing system) and multiple (SDG system) for 10 years. Standing crop data was collected biannually within 240 grazing exclosures placed at 4 topographic positions common to the Sandhills. Botanical composition was collected using frequency of occurrence transects to collect vegetation data. In 2001 and 2007, standing crop increased and the frequency of occurrence of desirable plant species increased more in the DR grazing system compared to the SDG system. However, Stephenson (2010) indicated that standing crop biomass and frequency of occurrence were more affected by topographic position and year than by grazing systems treatments.

Animal Response

In a SDG system, cattle gains are expected to increase because animals are continually faced with younger and more nutritious forage throughout the growing season (Kothmann 2009). However, multiple studies reported that as grazing pressure or stocking rate increases, gains on cattle on rangeland decline, usually linearly (Manley et al. 1997; Hart and Ashby 1998; Hart et al. 1988). Manley et al. (1997) reported that average daily gain of steers decreased linearly as grazing pressure increased regardless of grazing strategy. In another study that calculated the relationship between grazing pressure index (GPI) and heifer gains, it was reported that average daily gains of heifers decreased linearly as GPI increased (Hart and Ashby 1998). Hart et al. (1988) also found that average daily gains of steers remained high and constant at low grazing pressure, will declined at high grazing pressure. Gains remained constant at 0.95 kg·d^{-1} until grazing pressure exceeded 29.0 steer days per tonne of forage, then declined.

Stephenson (2010) indicated that the average daily gains of spayed heifers (0.84 kg·d^{-1}) did not differ between DR grazing system and SDG grazing system in the 10-year study. Average daily gain of calves was greater in a repeated season-long grazing system stocked at 0.33 AU·ha^{-1} compared to a high-performance SDG system stocked at 0.64 AU·ha^{-1} in west-central South Dakota (Volesky et al. 1990). Calves gained 0.52 and 0.68 kg·d^{-1} in the repeated season-long system compared to 0.39 and 0.62 kg·d^{-1} in the high-performance SDG system in 1983 and 1984, respectively. The stocking rate for the SDG system was 35 and 25% higher than the repeated season-long system during 1983 and 1984, respectively. Heifers on the SDG increased weight gains by 6.3 kg·ha^{-1} compared to continuously grazed heifers in the second year of the study. Data from these trials show that properly managed high-performance SDG system may allow only modest increases in stocking rate and result in a slight increase in livestock production per area; however, individual animal performance may be reduced.

Management of ultrahigh stocking densities in mob grazing can constitute a challenge regarding animal response. Terry Gompert, extension educator, reported that in the majority of instances animals will gain weight or maintain condition, but has observed animals lose weight in some mob grazing herds (Kidwell 2011). Nonetheless, if the forage and livestock are managed properly, livestock performance can be excellent (Peterson 2010). Practitioners of mob grazing emphasize the importance of forage harvest efficiency. It must be monitored closely to ensure proper intake, nutrition and livestock health (Gompert 2010; Peterson 2010; Smith Thomas 2012; Kidwell 2011).

Management Practices

Grazing land management refers to the art and science of planning and directing the development, maintenance, and use of grazing lands to obtain optimum, sustained returns based on management objectives (Vallentine 2001). Intensive grazing management strategies have been developed to control timing, frequency, and selectivity on the vegetation to obtain the optimal or desired response of the vegetation and the grazing animal (Dwyer et al. 1984).

Timing of Grazing

Determining when to harvest the standing forage crop during the growing season with grazing animals must consider: (1) plant factors, (2) physical site factors, (3) animal factors, and (4) economic and management factors. Perennial plants survival requires sufficient carbohydrates reserves to survive during the winter, initiate spring growth, and provide new growth following defoliation. Early season defoliation of native plants followed by nongrazing during the remainder of the growing season has often had less impact than severe defoliation late in the growing season. Late growing season grazing is a critical period for many perennial forage plants, and adequate time should be provided after grazing and before dormancy for total available carbohydrate accumulation and bud development (Vallentine 2001). Grazing systems should provide recovery periods that allow individual plants time to produce adequate leaf area to restore carbohydrate reserves between defoliations (Waller et al. 1986).

Timing of grazing may be manipulated to accomplish other objectives as improving vegetation diversity/resilience or soil quality and N recycling. Mob grazing systems have been reported to increase plant diversity (Peterson 2010; Thomas Smith

2012; Gompert 2010; Schmidt 2011). Plant diversity is important for nutritional need of livestock as well as mineral cycling. The more diverse the plant community, the more resilient the pasture in withstanding stress, such as drought. Gompert (2010) recommended the mob grazing period start later in the growing season so that 60% of standing crop can to be trampled into the soil. While the tops of the plants are eaten by the livestock and will be recycled as urine or manure, the portions of the plant that are not eaten are trampled into the ground by the cattle hooves. This can enhance nutrient recycling and soil organic matter formation. Peterson reported that by keeping a much taller canopy through a longer portion of the year, a manager can better control harvest efficiency and trampling of plant material (Smith Thomas 2012).

Intensity of Grazing

The proportion of the current years forage production that is consumed or trampled by grazing animals from a single plant, a species, or the vegetation is known as defoliation intensity (Heady and Child 1994). Vallentine (2001) referred to grazing intensity as the amount of animal demand placed on available standing crop and the resulting level of defoliation made during grazing. Heavy grazing and trampling over long periods of time can also affect rainfall impact and infiltration into the soil. It has been suggested that available forage decreases as grazing intensity increases (Vallentine 2001). As stocking rate increases, stocking density and the intensity and frequency of defoliation also increases. Heitschmidt and Stuth (1991) concluded that in the short term, a decline in available forage occurs because the rate forage being grazed exceeds the rate of growth. In the long term, the interaction effects of abiotic and biotic factors on plant growth and plant successional processes also resulted in forage decline. A study on mixed grass range in Montana found that low range condition correlated closely with heavy grazing during summer but less closely with heavy grazing in winter (Houston and Woodward 1966).

Mob grazing practitioners suggest that the benefits of mob grazing are realized through short episodes of high animal impact (84,000 to over 1,120,000 $kg \cdot ha^{-1}$) followed by long recovery periods (Schmidt 2011). Ultrahigh stocking densities increase the amount of trampled plant material. High percentage of trampled plant material and long recovery periods (grazed once per growing season) can increase soil organic matter and improve soil health resulting in increase plant diversity and forage production.

Suitability for Range and Pasture

Stoddart (1960) suggested that the management of range, including the grazing system used, may have a noticeable influence on its grazing capacity. While differences in capacity due to grazing systems are not always significant, grazing systems may account for considerable differences in grazing influences, capacity, and returns. The integration of grazing systems on range and pastures is based on the best season of use. Seasonal suitability grazing may be defined as grazing the various range or pasture vegetation types, subtypes, and/or condition class areas when it is most advantageous to the vegetation, the livestock or both (Valentine 1967).

Mob grazing as a holistic management can be implemented on degraded range and pasture lands where soil health is poor or in healthy range and pastures. Management of timing and intensity in mob grazing are used to restore soil health and improve plant diversity and forage production (Gompert 2010).

Conclusion

Research has shown inconsistent results on the benefits of ultrahigh stocking densities to herbage production, plant composition, soil buiding, and livestock production. Manley et al. (1997), Hart et al. (1988), and Cassels et al. (1995) reported herbage production and plant composition showed no positive effects due to higher stocking density. Soil building was negatively correlated to increased hoof action. Hoof action decreased soil moisture, increased bulk density and did not incorporate litter into the soil surface (Dormaar et al. 1989). Warren et al. (1986) concluded that rest, rather than intensive livestock activity, appears to be the key to soil hydrologic stability. Livestock production is negatively affected as stocking densities increase (Volesky et al. 1990; Manley et al. 1997; Hart et al. 1988). In summary, the review of the literature presented, indicates that high stocking densities does not benefit herbage production, plant composition, soil building, and livestock production, but improves animal distribution (Hart et al. 1988).

Nonetheless these studies on high stocking densities, Manley et al. 1997, Hart et al. 1988, Cassels et al. 1995, Dormaar et al. 1989, and Warren et al. 1986, had lower grazing intensity than the ultrahigh stocking density advocates are practicing. Mob grazing practitioners reported in the literature review, have all indicated that mob grazing can build soils, increase forage production, plant diversity, and livestock distribution compared to less intensive grazing systems (Gompert 2010; Schmidt 2011; Peterson 2010; Thomas Smith 2012; Kidwell 2011; Savory 1983; Savory and Butterfield 1999). No scientific based research has been reported on the effects of mob or ultrahigh stocking densities on building soils, increase forage production, plant diversity, and improve grazing distribution.

Literature Cited

Adams D.C., R.T. Clark, S.A. Coady, J.B. Lamb, and M.K. Nielsen.1994. Extended grazing system for improving economic returns from Nebraska sandhills cow/calf operations. *Journal of Range Management*. 47:258-263.

Adams, D.C., R.T. Clark, P.E. Reece, and J.D. Volesky. 1998. Research and education for managing resources within the Nebraska Sandhills: the Gudmundsen Sandhills laboratory. *Rangelands*. 20:4-8.

Allaby, M. and R. Garrett. 2004. Grasslands. *In:* Biomes of the earth. Infobase Publishing. p. 81-142.

Balph, D.F. and J.C. Malechek. 1985. The application of behavioral concepts to livestock management. *Utah Science.* 47:78-85.

Barnes, P.W. and R.T. Harrison. 1982. Species distribution and community organization in a Nebraska Sandhills mixed prairie as influenced by plant/soil-water relationships. *Oecologia*. 52:192-201.

Barnes, M.K., B.E. Norton, M. Maeno, and J.C. Malechek. 2008. Paddock size and stocking density affect spatial heterogeneity of grazing. *Rangeland Ecology and Management.* 61:380-388.

Barnes, P.W., A.T. Harrison, and S.P. Heinisch. 1984. Vegetation patterns in relation to topography and edaphic variation in Nebraska Sandhills prairie. *Prairie Naturalist*. 16:145-158.

Beard, J. B. 1973. Turfgrass: science and culture. Prentice-Hall, Inc., Englewood Cliffs, N. J. p. 658.

Black, W.H., A.L. Baker, V.I. Clark, and O.R. Mathews. 1937. Effect of different methods of grazing on native vegetation and gain of steers in Northern Great Plains. U.S. Dep. Agr. Tech. Bull. 547. p. 19.

Bleed, A.S. and C. A. Flowerday. 1998. Introduction. *In:* Bleed, A.S. and C. A. Flowerday. [EDS.] An atlas of the sand hills. Lincoln, NE, USA: Conservation and Survey Division Institute of Agriculture and Natural Resources University of Nebraska-Lincoln. p. 1-16.

Bloom, A. J., F. S. Chapin, III, and H.A. Mooney. 1985. Resource limitation in plants-an economic analogy. *Annual Review of Ecology, Evolution, and Systematics*. 16:363-392.

Briske, D.D., J.D. Derner, J.R. Brown, S.D. Fuhlendorf, W.R. Teague, K.M. Havstad, R.L. Gillen, A.J. Ash, and W.D. Willms. 2008. Rotational grazing on Rangeland:

reconciliation of perception and experimental evidence. *Rangeland Ecology. and Management.* 61:3-17.

Burboa-Cabrera, F.R., W.H. Schacht, and B.E. Anderson. 2003. Utilization and grazing distribution of cattle at 4 stocking densities. *Journal of Range Management.* 56:328-333.

Burke, I.C., C.M. Yonker, W.J. Parton, C.V. Cole, K. Flach, and D.S. Schimel. 1989. Texture, climate, and cultivation effects on soil organic matter content in U.S. grassland soils. *Soil Science Society of America Journal*. 53:800-805.

Burns, R.C. and R.W.F. Hardy. 1975. Nitrogen fixation in bacteria and higher plants. Springer-Verlag, New York. p. 189.

Cassels, D.M., R.L. Gillen, F.T. McCollum, K.W. Tate, and M.E. Hodges. 1995. Effects of grazing management on standing crop dynamics in tallgrass prairie. *Journal of Range Management*. 48:81-84.

Chapin, F.S., III, 1980. The mineral nutrition of wild plants. *Annual Review of Ecology, Evolution, and Systematics*. 11:233-260.

Chapin, F.S., III, D.A. Johnson, and J.D. McKendrick. 1980. Seasonal movement of nutrients in plants of differing growth forms in an Alaskan tundra ecosystem: implications for herbivory. *Journal of Ecology.* 68:189-209.

Chapin, F.S., III, G.R. Shaver, and R.A. Kedrowski. 1986. Environmental controls over carbon, nitrogen, and phosphorus chemical fractions in *Eriophorum vaginatum* L. in Alaskan tussock tundra. *Journal of Ecology.* 74:167-195.

Chapin, F.S., III, and G.R. Shaver. 1988. Differences in carbon and nutrient fractions among arctic growth forms. *Oecologia* 77:506-514.

Chapin, F.S., III, E.D. Schulze, and H.A. Mooney. 1990. The ecology and economics of storage in plants. *Annual Review of Ecology, Evolution, and Systematics*. 21:423-447.

Clark, R.T. and S.A. Coady. 1992. Ranch management practices in the Sandhills of Nebraska: managing the ranch business. Agr. Res. Division, Inst. Agr. and Natur. Resources, Univ. Nebraska-Lincoln, Res. Bull. RB-316.

Clark, F.E. 1977. Internal cycling of ^{15}N in shortgrass prairie. *Ecology* 58:1322-1333.

Cook, C.W. 1966. Carbohydrate reserve in plants. Utah Agric. Exp. Sta., Utah Resource Ser. 31:1-47.

Coppock, D.L., J.K. Detling, J.E. Ellis, and M.I. Dyer. 1983. Plant-herbivore interactions in North American mixed-grass prairies. I. effects of black-tailed prairie dogs on intraseasonal aboveground plant biomass and nutrient dynamics and plant species diversity. *Oecologia* 56:1-9.

Coyne, P. I., M. J. Trlica, and C. E. Owensby. 1995. Carbon and nitrogen dynamics in range plants. *In:* D. J. Bedunah and R. E. Sosebee. [ed.] Physiological ecology and developmental morphology. Soc. For Range Manage. Denver, CO.

Dahl, B.E. 1986. The West Texas experience in short duration grazing. *In:* J.A. Tiedeman [ed.] Short duration grazing. Washington State Univ., Pullman. p. 103-116.

Dahl, B. E. 1995. Development morphology of plants. *In:* D.J. Bedunah and R.E. Sosebee. [ed.] Physiological ecology and developmental morphology. Soc. For Range Manage. Denver, CO.

Dahl, B.E. and D.N. Hyder. 1997. Development morphology and management implications. *In:* R.E. Sosebee [ed.] Rangeland plant physiology. Range Sci. Series No. 4. Soc. For Range Manage. Denver, Colo. p. 257-290.

Denmead, O.T., J.R. Freney, and J.R. Simpson. 1976. A closed ammonia cycle within a plant canopy. *Soil Biology and Biochemistry.* 8:161-164.

Deregibus, V.A., M.J. Trlica, and D.A. Jameson. 1982. Organic reserves in herbage plants; their relationship to grassland management. *In:* M. Rechcigl, Jr. [ed.] Handbook of agriculture productivity. Vol. I. Pant Productivity. CRC Press, Boca Raton, FL. p. 315-344.

Dwyer, D.D., J.C. Buckhouse, and W.S. Huey. 1984. Impacts of grazing intensity and specialized grazing systems on the use and value of rangeland: Summary and recommendations. *In:* Developing strategies for rangeland management. National Research Council/ National Academy of Sciences, Westview Press, Boulder, CO. p. 867-884.

Dormaar, J.F, S. Smoliak, and W.D. Willms. 1990. Distribution of nitrogen fractions in grazed and ungrazed fescue grassland Ah horizons. *Journal of Range Management*. 43:6-9.

Dormaar, J.F., S. Smoliak, and W.D. Willms. 1989. Vegetation and soil responses to short duration grazing on fescue grasslands. *Journal of Range Management.* 42:252-256.

Evans, M.W. 1958. Growth and development in certain economic grasses. Ohio Agr. Exp. Sta. Agron. Series 147:1-123.

Fitter, A.H. 1991. Characteristics and functions of root systems. *In:* Y. Waisel, A. Eshel and U. Kafkafi. [ed.] Plant roots: the hidden half. Marcel Dekker, Inc., New York. p. 3-25.

Fonda, R. W., L.C. Bliss. 1966. Annual carbohydrate cycle of alpine plants on Mt. Washington, New Hampshire. Bull. Torrey Bot. Club 93:268-77.

Goodloe, S. 1969. Short duration grazing in Rhodesia. *Journal of Range Management.* 22:369-373.

Gompert, T. 2009. The power of stock density. *In*: Proc.: Grazing Lands Conservation Initiative's 4th National Conference on Grazing Lands. Sparks, NV.

Gompert, T. 2010. The power of stock density. *In*: Proc.: Nebraska Grazing Conference. Kearney, NE.

Greenwood, E.A.N. 1976. Nitrogen stress in plants. *Advances in Agronomy*. 28:1-35.

Hargrave, H. J. 1947. Progress report 1937-1947. Can. Range Exp. Sta., Can. Dep. Agr., Manyberries, Albert.

Hart, R.H. and M.M. Ashby. 1998. Grazing intensities, vegetation, and heifer gains: 55 years on shortgrass. *Journal of Range Management*. 51:392-398.

Hart, R.H., M.J. Samuel, P.S. Test, and M.A. Smith. 1988. Cattle, vegetation, and economic responses to grazing systems and grazing pressure. *Journal of Range Management*. 41:282-28.

Harrison, T.A. 1980. The Niobrara Valley Preserve: its biogeographic importance and description of its biotic communities. A working report to the Nature Conservancy. On file with: U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Fire Sciences Laboratory, Missoula, MT. p. 116.

Hautau, M. 2011, Setpember/October. Ian Mitchell-Innes on Mob Grazing. *Passages: Sustainable Food and Framing Systems Newsletter.* p. 1, 3, 11. Retrieved from http://www.pasafarming.org/resource/ Passages_92_PAGES.pdf.

Haynes, R.J. 1986a. Uptake and assimilation of mineral nitrogen by plants. *In:* R.J. Haynes [ed.] Mineral nitrogen in the plant-soil system. Academic Press, London. p. 303-358.

Haynes, R.J. 1986b. Orgin, distribution, and cycling of nitrogen in terrestrial ecosystem. *In* R.J. Haynes [ed.] Mineral nitrogen in the plant-soil system. Academic Press, London. p. 1-44.

Haynes, R.J. 1980. Ion exchange properties of roots and ionic interaction within the root apoplasm: their role in ion accumulation by plants. *Botanical Review*. 46:75-99.

Heady, H.F. 1999. Perspective on rangeland ecology and management. *Rangelands.* 21:23-33.

Heady, H.F. and R.D. Child. 1994. Rangeland ecology and management. Westview Press, San Francisco, Calif.

Heitschmidt, R.K., and J.W. Stuth (Eds.). 1991. "Grazing management: an ecological perspective." Timber Press, Portland, OR. p. 259.

Holechek, J.L., R.D. Pieper, and C. Herbel. 2004. Range management: principles and practices. 5th ed. Upper Saddle River, NJ: Prentice-Hall. p. 607.

Hopkins W.G. and N.P.A. Hüner. 2004. Introduction to plant physiology. Wiley, New York, p. 1-27.

Horney, M., D.C. Adams, W.H. Schacht, S.S. Waller, T.J. Klopfenstein. 1996. Grazing: an alternative to haying subirrigated meadows in the Nebraska Sandhills. *In*: 1996 Beef Cattle Report. MP 66-A. University of Nebraska-Lincoln. Lincoln, Nebraska. p. 6-7.

Houston, W.R. and R.R. Woodward, 1966. Effects of stocking rates on range vegetation and beef cattle production in the Northern Great Plains. USDA Tech. Bull. 1357.

[HPRCC] High Plains Regional Climate Center. 2011. Climatological data (Nebraska). HPRCC, Lincoln, NE.

Hsiao, T.C. 1973. Plant response to water stress. *Annual Review of Plant Physiology*. 24: 519-570.

Hyder, D.N. 1972. Defoliation in relation to vegetative growth. *In:* V.B. Younger, and C.M. McKell [ed.] Biology and utilization of grasses. Academic Press, New York. p. 304-317.

Hyder, D.N. 1974. Morphogenesis and management of perennial grasses in the United States. *In:* Plant morphogenesis as the basis for scientific management of range resources. Proceeding of the workshop of the U.S./Australia rangeland panel. Berkeley, Calif. March 29-April 5, 1971. U.S. Dep. Agr. Misc. Public. 1271. p. 89-98.

Hyder, D.M., R.E. Bement, E.E. Remmenga, and D.F. Hervey. 1975. Ecological responses of native plants and guidelines for management of shortgrass range. U.S. Dep. Agr. Tech. Bull. 1503. p. 87

Jackson, W.A., D. Flesher, and R.H. Hageman. 1973. Nitrate uptake by dark-grown corn seedlings: some characteristics of apparent induction. *Plant Physiology*. 51:120-127.

Jewiss, O.R. 1966. Morphology and physiological aspects of growth of grasses during the vegetative phase. *In:* F.L. Milthorpe and J.D. Ivins [ed.] The growth of cereals and grasses. Butterworths, London. p. 39-54.

Johnston, A., J.F. Dormaar, and S. Smoliak. 1971. Long-term grazing effects on fescue grassland soils. *Journal of Range Management.* 24:185-188.

Kidwell, B. 2011, March. Mob grazing: High-density stocking builds profits back into the cattle business. *Angus Beef Bulletin.* p. 28-29. Retrieved from http://www.angusbeefbulletin.com/ ArticlePDF/Mob Grazing%2003_10%20ABB.pdf.

Klipple, G.E., and Costello D.F. 1960. Vegetation and cattle responses to different intensities of grazing on short-grass ranges on the Central Great Plains. Tech. Bull. 1216. p. 1-80.

Kothmann, M.M. 2009. Grazing methods: a viewpoint. *Rangelands*. 31:5-10.

Larcher, W. 1980. Physiological plant ecology, 2nd Ed. Springer-Verlag, New York. p. 303.

Lodge, R.W. 1970. Complementary grazing systems for the northern great plains. *Journal of Range Management*. 23:268-271.

Manley, W.A. R.H. Hart, M.J. Samuel, M.A. Smith J.W. Waggoner, Jr., J.T. Manley. 1997. Vegetation, cattle, and economic responses to grazing strategies and pressures. *Journal of Range Management*. 50:638-646.

Manley, J.T., G.E. Schuman, J.D. Reeder, and R.H. Hart. 1995. Rangeland soil carbon and nitrogen responses to grazing. *Journal of Soil and Water Conservation.* 50:294-298.

McCree, K.J. 1974. Equations for rate of dark reactions of white clover and grain sorghum, as functions of dry weight, photosynthetic rate, and temperature. *Crop Science.* 14:509-514.

Merrill, L.B. 1954. A variation of deferred rotation for use under southwest range conditions. *Journal of Range Management*. 7:152-154.

Monsi, M., and Y. Murata. 1970. Development of photosynthetic systems as influenced by distribution of matter. *In:* Prediction and measurement of photosynthetic productivity. PUDOC, Wageningen, The Netherlands. p. 115-130.

Mooney, H.A. 1972. The carbon balance of plants. *Annual Review of Ecology, Evolution, and Systematics*. 3:315-346.

Moore, K.J., L.E. Moser, K.P. Vogel, S.S. Waller, B.E. Johnson, and J.F. Pedersen. 1991. Describing and quantifying growth stages of perennial forage grasses. *Agronomy Journal.* 83:1073-1077.

Neild, R.E. 1997. The freeze-free season. *In:* M.P. Lawson, K.F. Dewey, and R.E. Neild [ed.] Climatic atlas of Nebraska. University of Nebraska Press, Lincoln. p. 29-31.

Norton, T. 1994. The application of grazing management to increase sustainable livestock production. *Animal Production in Australia* 22:15-26.

Oechel, W.C., and W. Lawrence. 1981. Carbon allocation and utilization. *In:* P. C. Miller [ed.] Resource use by chaparral and matorral. Springer-Verlag, Berlin. p. 185-235.

Oakley, R.A. and M.W. Evans. 1921. Rooting stems in timothy. *Journal of Agricultural Research.* 21:173-178.

Pate, J.S. 1980. Transport and partitioning of nitrogenous solutes. *Annual Review of Plant Physiology.* 31:313-340.

Pearson, C.T., and B.T. Steer. 1977. Daily changes in nitrate uptake and metabolism in Capsicum annuum. *Planta Medica.* 137:107-112.

Peterson, D. 2010. High density grazing in Missouri. *In*: Proc.: Nebraska Grazing Conference. Kearney, NE.

Poole, R.J. 1914. A study of the vegetation of the Sandhills of Nebraska. Minn. Bot. Studies 4:187-3 12.

Potvin, M.A.1993. Establishment of native grass seedlings along a topographic/moisture gradient in the Nebraska Sandhills. *American Midland Naturalist* 130:248-261.

Potvin, M.A. and A.T. Harrison. 1984. Vegetation and litter changes of a Nebraska Sandhills prairie protected from grazing. *Journal of Range Management*. 37:55-58.

Pye, K. and H Tsoar. 2009. The formation of sand seas and dune field. *In:* K. Pye and H. Tsoar [ed.] Aeolian sand and sand dunes. Springer-Verlag, Berlin. p. 141-172.

Ralphs, M.H., M.M. Kothmann, and C.A. Taylor. 1990. Vegetation response to increased stocking rates in short-duration grazing. *Journal of Range Management*. 43:104-108

Rechenthin, C.A. 1956. Elementary morphology of grass growth and how it affects utilization. *Journal of Range Management*. 9:167-170.

Reece, P.E. 1986. Short duration grazing: research and case studies in Nebraska. *In:* J.A. Tiedeman [ed.] Short duration grazing. Washington State Univ., Pullman. p. 39-71.

Salihi, D.O., and B.E. Norton. 1987. Survival of perennial grass seedlings under intensive grazing in semi-arid rangelands. *Journal of Applied Ecology.* 24:145-151

Sampson, A.W. 1913. Range improvement by deferred and rotation grazing. U.S. Dept. Agric. Bull. 34.

Sampson, A.W. 1951. A symposium on rotation grazing in North America. *Journal of Range Management*. 4:19-24.

Sarvis, J.T. 1923. Effects of different systems and intensities of grazing upon native vegetation at the Northern Great Plains field station. U.S. Dep. Agr. Bull. 1170. p. 46.

Savory, A. 1983. The Savory Grazing Method or Holistic Resource Management. *Rangelands.* 5:155-159.

Savory, A., and S.D. Parsons. 1980. The Savory grazing method. *Rangelands.* 2:234-238.

Savory, A. and J. Butterfield. 1999. Holistic Management – A New Framework for Decision Making. Island Press. Washington, DC.

Schmidt, J. 2011, January 25. Greg Judy challenges Kansas grazer's assumptions about mob grazing. *The Hutchinson News*. Retrieved from http://www.ksagland.com.

Schulze, E.D. 1982. Plant lifeforms and their carbon, water, and nutrient relations, p.615-676. *In* O.L. Lange, P.S. Noble, C.B. Osmond, and H. Ziegler [ed.] *Encyclopedia of plant physiology,* NS, Vol. 12B. Springer- Verlag, Berlin.

Schuman G. E., J.D. Reeder, J.T. Manley, R.H. Hart, and W.A. Manley. 1999. Impact of grazing management on the carbon and nitrogen balance of a mixed-grass rangeland. *Ecological Applications.* 9:65-71.

Simpson, J.R., and T.H. Stobbs. 1981. Nitrogen supply and animal production from pastures. *In* F.H.W Morley (Ed.), "Grazing Animals." Elsevier Sci. Pub. Co., Amsterdam, Neth., p. 261-287.

Smith Thomas, H. 2012. Mob grazing restores soil health and improves vegetation. *The Stockman Grass Farmer.* 1:6-8.

Smoliak, S., J.F. Dormaar, and A. Johnston. 1972. Long-term grazing effects on Stipa-boiuteloua prairie soils. *Journal of Range Management*. 25:246-250.

Stephenson, M.B. 2010. Effect of grazing systems on livestock performance, botanical composition, and standing crop in the Nebraska Sandhills. University of Nebraska-Lincoln.

Stoddart, L.A. 1960. Determining correct stocking rate on rangeland. *Journal of Range Management*. 13: 251-255.

Stuth, J.W., D.R. Kirby, and R.E. Chmielewski. 1981. Effects of herbage allowance on efficiency of defoliation by the grazing animal. *Grass Forage Sci*ence. 36:9-15.

Thomson, L.B. 1938. Results of experiments 1927 to 1936 inclusive. Can. Range Exp. Sta., Can. Dep. Agr., Manyberries, Alberta.

Tomkins, G.A., W.A. Jackson, and R.J. Volk. 1978. Accelerated nitrate uptake in wheat seedlings: effects of ammonium and nitrite pretreatments and of 6-methylpurine and puromycin. *Plant Physiology.* 43:166-171.

Trlica, M.J. and J.S. Singh. 1979. Arid land ecosystems: structure, functioning and management. Vol. 1, ed. R.A. Perry and D.W. Goodall. Intl. Biological Programme 1,6. Cambridge Univ. Press, Great Britain.

Tromp, J. 1970. Storage and mobilization of nitrogenous compounds in apple trees with special reference to arginine. *In:* L.C. Luckwill and C.V. Cutting [ed.] Physiology of tree crops. Academic Press, London. p. 143-159.

USDA, NRCS. 1997. National range and pasture handbook. USDA, NRCS, Grazing Lands Technol. Inst. 190-vi-NRPH, Washington, D.C.

Valentine, K.A. 1967. Seasonal suitability, a grazing system for range of diverse vegetation types and condition classes. *Journal of Range Management.* 20:395-397.

Vallentine J.F. 2001. Grazing Management. 2nd edition. Academic, San Diego, California, USA.

Volesky, J.D., J.K. Lewis, and C.H. Butterfield. 1990. High-performance short-duration and repeated-seasonal grazing systems: Effects on diets and performance of calves and lambs. *Journal of Range Management.*43:310-315.

Volesky, J.D. and W.H. Schacht. 2010. Does stocking density and grazing duration affect grazing land productivity, use efficiency, and health? Project Proposal. University of Nebraska-Lincoln.

Waller, S.S., L.E. Moser, and B. Anderson. 1986. Understanding grass growth: The key to profitable livestock production. Trabon Print Co. Kansas City, MO.

Walter, J. 1984. Rangeland revolutionary: An interview with Allan Savory. *Journal of Soil and Water Conservation*. 29:235-24.

Warren, S.D., W.H. Blackburn, and C.A. Taylor, Jr. 1986. Soil hydrologic response to number of pastures and stocking density under intensive rotation grazing. *Journal of Range Management.* 39:500-504.

Weaver, J.E. and F.W. Albertson. 1956. Grasslands of the Great Plains. Lincoln, NE: Johnsen Publishing Company. p. 395.

Wilhite, D.A., and K.G. Hubbard. 1989. Climate. *In:* A. Bleed and C. Flowerday [ed.] An atlas of the Sandhills. University of Nebraska Conservation and Survey Division, Resource Atlas No. 5. p 17-28.

Winkel, V.K., B.A. Roundy, and D.K. Blough. 1991. Effects of seedbed preparation and cattle trampling on burial of grass seeds. *Journal of Range Management.* 44:171-175.

Zimmerman, M.H. 1971. Storage, mobilization, and circulation of assimilated, *In:* M.H. Zimmerman and C.L. Brown [ed.] Trees: structure and function. Spring-Verlag, New York. p. 307-322.

Chapter 2:

Stocking Density Affects Trampling and Use of Vegetation on Nebraska Sandhills Meadow

Introduction

Mob grazing entails the use of ultrahigh stocking densities of grazing animals and extremely rapid movement through multiple pastures. When compared to more conventional grazing systems, mob grazing minimizes the length of grazing periods and maximizes the days of non-grazing annually on a grazing unit by greatly increasing the stocking density (Peterson 2010). Replicated research on soil, plant, or animal response to mob grazing does not exist. Practitioners and advisors suggest the best responses result from stocking densities of at least 113,000 kg of beef•ha^{-1} to as high as 1,130,000 kg•ha^{-1} and moving grazing animals several times daily through a series of pastures. Grazed areas are typically grazed once each grazing season and often will not be grazed again until the following year. Practitioners claim that mob grazing can build soils, increase forage production and plant diversity, and improve grazing distribution compared to less management-intensive grazing systems (Gompert 2010). In Missouri, doubling of beef production and reducing costs per unit input as a result of changing grazing systems from management-intensive grazing to mob grazing have been reported (Kidwell 2010).

First introduced by Allan Savory, ultrahigh stocking density grazing is considered to be 113,000 kg•ha^{-1} of beef or more at any given time (Butterfield et al. 2006). With these ultrahigh stocking densities, animal impact and herd effect can occur. Animal impact is the sum total of the direct physical influences herding animals have on the land – trampling, dunging, urinating, salivating, rubbing, and digging. Herd effect is the impact on soil and vegetation produced by a large herd of animals in an excited state and is mainly used as a means of applying high animal impact (Bingham and Savory 1990). During mob grazing, cattle are heavily concentrated on a small area, and a minimal amount of grass is left standing by the time they are moved off the area. Plant shoots are eaten by the livestock and will be recycled as urine or manure and the portions of the plant that are not eaten are trampled to ground level by the animal's hooves. Soil organic matter can be increased through root die off and trampling of above-ground plant material (Peterson 2010). Gompert (2010) recommended the grazing period start later in the growing season so that 60% of available standing crop can to be trampled into the soil. As vegetation reaches the reproductive stage of growth, the leaf:stem ratios are low resulting in a low portion of standing crop being consumed and as much as 60% being trampled. Peterson (2010) claims that trampled plant material keeps the soil surface cooler, which reduces evaporation and improves water infiltration. This helps stimulate nutrient recycling by soil microorganisms and in return, increases plant production.

Ian Mitchell-Innes is a Holistic Management (HM) certified educator who weaves HM theories into his teaching of mob grazing (Hautau 2011). Mitchell-Innes has practiced this type of grazing on natural grassland in his native South Africa and believes soils will improve over time because of the return of plant residue to the ground by animal trampling. With improved soils, diversity of species will increase and provide drought resilience. There is the potential for changes in bacterial and mycorrhizal fungi populations as a pasture shifts in composition from grass to grass/legumes pastures. A change in bacterial and mycorrhizal fungi populations can increase the development of soil organic matter. Mitchell-Innes (Hautau 2011) states that his goal is to manage grazinglands for an increase in diversity of species which can contribute to greater palatability. As a plant matures from leafy, vegetative stage into the stemmy, reproductive stage, protein decreases and fiber increases. Therefore, species that reach highest yields in different seasons can be combined in a grazing system to ensure adequate forage throughout the season, evening out the seasonal yield distribution and increasing palatability (Roberts 1999).

Greg Judy, a mob grazing advocate, suggests that the benefits of mob grazing are realized through the short episodes of high animal impact (84,000 to 560,400 $kg \cdot ha^{-1}$) followed by long recovery periods (Schmidt 2011). Judy claims that longer recovery periods allow plants to develop much deeper root systems, which can draw moisture and minerals that are unavailable to shallow rooted plants. Plants that have healthy roots can better withstand drought. They have fuller canopy above ground during regrowth, which helps keep the soil cool and helps plants remain alive and growing longer into the growing season (Schmidt 2011).

If the forage and livestock are managed properly, livestock performance can be excellent (Peterson 2010). Gompert, however, reported anecdotally that in the majority of cases, animals do not gain weight in herds that are mob-grazed (Kidwell 2010). To ensure weight gain, practitioners emphasize that forage harvest efficiency must be monitored closely to ensure proper intake, nutrition and livestock health (Gompert 2010; Peterson 2010; Smith Thomas 2012; Kidwell 2010).

The overall focus of this research is based on the approach of building soil by optimizing above-ground plant growth coming in contact with soil surface. Trampling 60% of the above-ground plant growth is said to be the threshold (Gompert 2010). Collectively, mob grazing advocates suggest that the soil will improve and plant diversity and forage production as well as animal production will increase. The objective of this study was to compare the effect of mob grazing and simple rotational grazing systems on forage utilization, harvest efficiency, percentage plant mass trampled, and animal performance of grazing cattle on a subirrigated meadow in the Nebraska Sandhills.

Material and Methods

Study Area

The study was conducted in May through August 2010 and 2011 at the University of Nebraska-Lincoln Barta Brothers Ranch (BBR) located in the eastern Sandhills near Rose, Nebraska (42^{o} 13' 32" N, 99^{o} 38' 09" W; elev. 765 m). Climate is typical of mid-continental, semi-arid prairie region. Average annual precipitation is 570 mm with 76% (435 mm) falling from April through September growing season. The 103-year average maximum annual temperature is 16.3°C, and the average minimum temperature is 2.6°C (HPRCC 2011).

The region is characterized by grass-stabilized sand dunes in the form of mounds or ridges of various shapes and sizes. They are as high as 122 m, as long as 32 km, and have slopes as steep as 25%. The depression between the dunes vary from small bowls measuring from 45 to 100 m in diameter to large flat meadows that can be more than a kilometer wide and sometimes run for kilometers in length (Poole 1914). Subirrigated meadows occur on nearly level bottomlands, upland basins, foot slopes, and stream terraces. Ninety percent of the Sandhills region is classified as upland prairie and the remaining 10% is intermixed subirrigated meadows and wetlands (Schacht et al. 2000). The soils on subirrigated meadow are classified as Gannett fine sandy loams (coarse loamy, mixed mesic Typic Haplaquoll).

The study site was a subirrigated meadow dominated by cool-season grasses including: red-top (*Agrostis stolonifera* L.), timothy (*Phleum pretense* L.), Kentucky bluegrass (*Poa pratensis* L.), quackgrass (*Elytrigia repens* (L.) Gould), bluejoint (*Calamagrostis canadensis* (Michx.) P. Beauv.), and reed canarygrass (*Phalaris arundinacea* L). Several species of native sedges (*Carex spp.)* and rushes (*Equisetum spp., Eleocharis spp.,* and *Juncus spp.*) were also common. Native warm-season grasses included big bluestem (*Andropogon gerardii* Vitman), prairie cordgrass (*Spartina pectinata* Link), switchgrass (*Panicum virgatum* L.), and indiangrass (*Sorghastrum nutans* (L.) Nash). Common exotic forbs were red clover (*Trifolium pratense* L.) and white clover (*Trifolium repens* L.).

Treatments

Application of grazing system treatments began in May 2010. Prior to initiation of the study, the meadow was hayed annually in early-July. Five treatments were applied in a randomized complete block design with 2 replications. The 5 treatments were (1) a 120-pasture mob-grazed system (ultrahigh stocking density) with a single grazing period, (2) a 4-pasture rotation with a single grazing period (4-PR-1), (3) a 4-pasture rotation with 2 grazing periods (4-PR-2), (4) a mid-July haying, and (5) a control (no harvest of live standing vegetation). Each replication of the grazing treatments was comprised of the prescribed number of pastures. Electric fencing was used and cattle had drinking water and a mineral mixture available in each pasture.

For the mob-grazed treatment, 40 and 36 yearling steers in 2010 and 2011, respectively, were rotated through 120 pastures (0.06 ha each) beginning on 1 July in 2010 and 7 June in 2011. During the 60-day grazing season, the cattle were moved twice daily (at 0700 hours and 1400 hours) so that 2 pastures were grazed each day. Ten steers in 2010 and 9 steers in 2011 were rotated once through the 4 pastures (0.42 ha each) of each replication of the 4-PR-1 treatment. The 60-day grazing season began on 1 July in 2010 and 7 June in 2011 with grazing period length ranging from 13 to 17 days·pasture^{-1}. Ten steers rotated twice through 4 pastures (0.64 ha each) of each replication of the 4-PR-2 treatment. In 2010, the 90-day grazing season started on 19 May and grazing period length ranged from 10 to 13 days·pasture^{-1}. In 2011, the 80-day grazing season began on 18 May and grazing period length ranged from 9 to 11 days·pasture^{-1}. The mob-grazed period started later in the growing season in order to achieve supposedly optimum conditions for trampling 60% of the standing herbage because the cool-season grasses would be in the elongation/reproductive stage. The 4-PR-1 had the same starting date as mob-grazed so that it could be compared directly to mob-grazed – the only difference between the two treatments was grazing period length. The 4-PR-2 was selected as a more conventional, efficient method of grazing meadows – with an early start date to take advantage of vegetation, cool-season growth and a second grazing period to take advantage of new vegetation growth following the first grazing period. In 2010, all standing vegetation on the hay plots (1.0 ha each) was harvested with a sickle bar mower and baled with a large round baler in early-August. The cutting height was 5 to 10 cm and all cut plant material was removed. In 2010, control plots (1.0 ha each) were not harvested during the growing season but standing vegetation was cut and removed during the dormant season in November. In 2011, vegetation on control and hay plots was not cut and removed because equipment and labor was not available.

In 2010, the stocking density for mob-grazed, 4-PR-1, and 4-PR-2 treatments was 494 AU·ha^{-1} (224,170 kg·ha^{-1}), 16 AU·ha^{-1} (7,472 kg·ha^{-1}) and 11 AU·ha^{-1} (4, 982 kg·ha^{-1}), respectively. In 2011, stocking density was 445 AU·ha^{-1} (201,753 kg·ha^{-1}), 15 AU·ha^{-1} (6,725 kg·ha^{-1}) and 11 AU·ha^{-1} (4, 982 kg·ha^{-1}) for mob-grazed, 4-PR-1, and 4-PR-2, respectively. The stocking rates were uniform for the grazing treatments at 8.15 AUM·ha^{-1} in 2010 and 7.41 AUM·ha^{-1} in 2011. Stocking rates and starting grazing dates were adjusted in 2011 because animal performance in 2010 was poor, especially for the mob and 4-PR-1 grazing treatments. Stocking rate was reduced in 2011 to increase forage allowance and improve nutrient intake. Starting grazing dates for mob and 4-PR-1 grazing treatments were moved earlier in the growing season to increase the proportion of the grazing season with vegetative, high quality forage available for grazing.

Herbage Yield

Ten, 1-m^2 exclosures were located randomly in each pasture of the 4-pasture rotational treatments. After the cattle were removed from a pasture, one 0.25-m^2 quadrat was placed inside each cage and 1 m directly north of each cage. In mob-grazed pastures, standing crop was estimated in every fourteenth pasture immediately before and after grazing. Ten, 0.25-m^2 quadrats were located randomly prior to grazing and post-grazing quadrats were located 1 m north of each pre-grazing quadrat location. In each quadrat, all herbage was hand clipped at ground level and all litter and trampled vegetation was gathered. Standing herbage was divided into live (current year's growth) and dead categories. Standing live, standing dead, litter and trampled vegetation were each placed in separate, labeled paper bags. Trampled herbage was identified as any above ground biomass that was stepped on creating an apparent bend or crease on the tiller as well as any tillers that were standing at a 45 degree angle or less. The bags were dried in a forced-air oven at 60^{o} C to a constant weight, and weights were recorded. Biomass estimates of each category were used to calculate herbage yield, percent trampled, harvest efficiency, utilization, and instantaneous grazing pressure in the grazing treatments:

Herbage yield ($kg \cdot ha^{-1}$) = PreSLH within a pasture ÷ pasture size in ha,

Percentage trampled (%) = (TH ÷ PreSLH) x 100,

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

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

Instantaneous grazing pressure at the time cattle were turned into the pasture ($AU \cdot Mg^{-1}$) = AUs in a pasture ÷ PreSLH in a pasture, and

Instantaneous grazing pressure at the time cattle were removed from the pasture ($AU \cdot Mg^{-1}$) = AUs in a pasture ÷ PostSLH in a pasture;

where PreSLH is pre-graze standing live herbage, TH is weight of trampled herbage, PostSLH is post-graze standing live herbage, and AUs is number of animal units. All calculations for herbage yield, percentage trampled, harvest efficiency, utilization, and grazing pressure were made based on a single grazing period when the data was collected. Experimental unit was the 4 pastures combined in the each of the 4-PR grazing treatments and the 120-pastures in the mob-grazed treatment. Estimates of herbage yield, percentage trampled, harvest efficiency, utilization, and instantaneous grazing pressure were calculated for each pasture and averaged over the entire experimental unit. Clipping data on 27 June and 5 July, 2011 were not included in the calculation of instantaneous grazing pressure at the time cattle were removed from the pastures. The pastures were inundated on these dates because of high rainfall which limited clipping and accurate sorting of herbage components.

Botanical Composition and Basal Cover

Botanical composition and ground cover were estimated using the modified step-point method (Owensby 1973). One hundred fifty randomly-selected points were sampled in each pasture of the 4-pasture treatment areas, hay plots, and control plots. Each mob-grazed replication was divided into eighths and 75 randomly-selected points were sampled in each eighth. Ground cover at each point was identified and recorded bare ground, litter, or plant base. For plant base hits, the plant species was identified. The nearest plant to the point was identified when the point hit bare ground or litter. Botanical composition of individual species and functional groups was calculated.

Forage Quality

Forage samples were analyzed for dry matter (DM), crude protein (CP), and neutral detergent fiber (NDF) by standard methods (AOAC 1996). For each clipping date, four pre-graze standing live herbage samples were selected randomly from the 10 samples collected in each pasture and divided in to two subsamples and used in forage quality determination. Samples were ground with a Wiley mill through a 1-mm screen. Crude protein analyses were done with a LECO FP-528 N analyzer (LECO, Inc., St. Joseph, MO) using standard methods (AOAC 1996). In vitro dry matter digestibility (IVDMD) was determined using the Tilley and Terry (1963) method modified by the addition of 1 $g \cdot L^{-1}$ of urea to McDougall's buffer (Weiss 1994). Ruminally fistulated steers were maintained on a smooth bromegrass diet, providing inocula for IVDMD determination. Neutral detergent fiber (NDF) analyses were conducted with an ANKOM Fiber Analyzer (Ankom Inc., Fairport, NY). For NDF analyses, sample bags were filled with 0.5 g of forage sample ground to a pass through a 1 mm screen. 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 drying over at 60° C and allowed to dry overnight before weighing.

Livestock Performance

Average weight of the steers during the season was 320 kg (0.7 AU). All steers were weighed prior to the start of the grazing season at the Agricultural Research and Development Center (ARDC) and delivered by truck to BBR and moved directly to the study pastures shortly after arrival. Following completion of the grazing season, animals were transported back to the ARDC. Initial and final weights were determined using the average of weights taken on two consecutive days following a five day limit feeding period. In the 2010 growing season, steers were not gaining weight, especially in the mob and 4-PR-1 grazing treatments. In early August, 9 steers died in the 4-PR-1 treatment and 2 died in the mob-grazed treatment. The remaining 104 steers were removed from the study site on 13 August, 18 days before the planned completion of the study period, because animal performance continued to be poor and the cause of deaths was unknown. The steers were kept on an adjacent upland pasture, where they did well, until September 1 when they were transported to ARDC and weighed. The steer weights taken at ARDC confirmed that average daily gain was very low for steers on the mob and 4-PR-1 grazing treatment pastures. Steers grazed the study pastures through the entire grazing season in 2011 and were transported to ARDC for weighing at completion of the grazing trial.

Not all pastures were grazed as prescribed in 2010 because of the premature stoppage of the trial. The mob-grazed pastures in the southeastern quarter of both mob-grazed replications and 3 pastures in each of the replication of the 4-PR-1 grazing treatment were not grazed or only partially grazed. Two of the pastures in each of the replications of the 4-PR-2 grazing treatments were not grazed a second time.

Data Analysis

Analysis of variance (ANOVA) procedures were conducted as a split-plot in time experimental design using the Statistical Analysis System with Mixed Procedures (SAS 2008). Least significant difference (LSD) was used to separate least square means when ANOVA showed significance ($P \leq 0.10$).

Results and Discussion

Precipitation Data

Above-average precipitation was received during both years of this study. Total precipitation was 27% and 8% greater than the 30-year average (584 mm), in 2010 and 2011, respectively (Figure 1). Precipitation from 1 April through 30 June 2010 was 94% greater than the average, with much of the rainfall concentrated in June (Figure 2). Precipitation totals from 1 July through 30 September 2010 were 22% lower than average. Precipitation from 1 April through 30 June 2011 was 23% above average and 33% less than for the same period in 2010. Amount of precipitation received from 1 July through 30 September 2011 was 26% less than the average and similar to the same period in 2010. The high amounts of rainfall in May through June of both years resulted in inundated conditions where water was at or above the soil surface. Flooded roads and meadow delayed the turn-in date of the cattle in 2010.

Herbage Yield

Year and treatment had no effect on herbage yield. Average herbage yield over the 2 years and 5 treatments was 5130 $kg{\cdot}ha^{-1}$. Both years were relatively wet and temporal precipitation patterns were similar (Figure 2). Development of treatment differences in response to a single year of grazing was not expected.

Herbage Trampling

There was treatment by year interaction for percentage trampled (Figure 3). In 2010, the percentage trampled in 4-PR-1 was 34% greater than in 2011. Percentage trampled for the mob and 4-PR-2 treatments increased from 2010 to 2011 by 12% and 7%, respectively. Percentage trampled in the mob-grazed pastures was 2 to 3 times greater than in either of the 4-PR treatments. The relatively high percentage trampled on the mob-grazed pastures likely was a result of the ultrahigh stocking density. Although not quantified, field observations indicated that the dominant cool-season grasses on the study site were mostly in an elongation or reproductive stage during much of the grazing season. In the grazing process and at the extremely high stocking density, the cattle appeared to trample much of the stemmy growth while selecting for leaf blades. This was particularly evident in 2010 when grazing began on 1 July. On average, 77% of individual tillers that were trampled in the mob-grazed treatment died within 42 days of being trampled (Table 1). Advisors and practitioners of mob grazing commonly have a target percentage trampled of 60% with the goal of building soil at a relatively high rate

(Gompert 2010). This target of 60% trampling was accomplished in the mob-grazed pastures through the grazing season with a mid to late June starting date. In the 4-PR-2 treatment there was less trampling because in the second cycle cattle concentrated on patches with vegetative plants rather than in patches with the tall, reproductive tillers.

Harvest Efficiency

Harvest efficiency did not differ among treatments or between years. Harvest efficiency averaged 42% over treatments and years (49%, 46%, and 30% for 4-PR-1, 4-PR-2, and mob-grazed treatments, respectively). This harvest efficiency was lower than that reported by Gerrish and Morrow (1999) who found harvest efficiency of 68% under a 3-day rotation in a management intensive grazing (MIG) system. The high grazing pressure associated with MIG usually results in improved grazing distribution and less wastage associated with grazing especially when compared to simpler grazing systems with fewer pastures and longer grazing periods. With the mob-grazed treatment, as already explained, we managed for 60% of the standing herbage to be trampled; therefore, harvest efficiency could not be greater than 40% even if all the remaining standing plant tissue was consumed by the grazing cattle.

Grassing Pressure

There was a treatment effect for instantaneous grazing pressure at the time cattle were turned into the pastures (Figure 4) and for instantaneous grazing pressure at the time cattle were removed from the pasture (Figure 5). Instantaneous grazing pressure is the animal demand per unit weight of forage dry matter at an instant of time; it is an animal/forage relationship (Vallentine 2001). Grazing pressure of the mob treatment at the time cattle were turned into the pasture was 13 times greater than either of the 4-PR treatments in both years. Grazing pressure of the mob treatment at the time cattle were removed from the pastures was 19 times greater than either of the 4-PR treatments in both years. The earlier starting date in 2011 resulted in less available herbage at the beginning of the grazing season compared to 2010 grazing season. The lower available herbage affected average grazing pressure for the entire grazing season. Grazing pressure for the 4-PR treatments did not differ between years. Grazing pressure is the major factor affecting severity of defoliation of individual forage plants. As the grazing pressure increases, so does the intensity of defoliation and the efficiency of harvest. In mob-grazed pastures, the greater grazing pressure resulted in a decrease in harvest efficiency and an increase of percentage herbage trampled. Grazing pressure was greater at the end of the grazing period compared to the beginning of the period. This increase in grazing pressure is due to less herbage available at the end of the grazing period compared to the beginning.

Herbage Utilization

Utilization of the standing herbage averaged over all grazing periods and treatments was 83% in 2011 and 76% in 2010. Increased utilization in 2011 can be attributed to the earlier starting date. Utilization differed among the three grazing treatments (Figure 6). Utilization for mob was 7% and 41% greater than 4-PR-1 and 4-PR-2, respectively. The greater percentage trampled in the mob treatment resulted in a greater utilization. Utilization in 4-PR-1 was 31% greater than 4-PR-2. The percentage trampled in the 4-PR-1 was greater than the 4-PR-2 which influenced the greater utilization in the 4-PR-1 compared to the 4-PR-2. Grazing pressure was low for the 4-PR-2 pastures in the first grazing period likely creating a patchy grazing distribution. In the second period, cattle tended to graze patches that had been created in the first grazing period.

Botanical Composition and Ground Cover

Botanical composition of individual species did not differ between years or treatments. Both years were relatively wet and temporal precipitation patterns were similar (Figure 2). As with herbage yield, development of treatment differences in botanical response in response to a single year of grazing was not expected. Eleven plant species made up 95% of the total botanical composition on the meadow for both years. Those species were red-top, timothy, bluejoint, sedge, rush, quackgrass, reed canarygrass, Kentucky bluegrass, prairie cordgrass, red clover, and white clover.

Treatment affected percentage change from 2010 to 2011 of rush and forb functional groups (Table 2). There was no difference among treatments when looking at percentage change for individual plant species because of the large variance; however, when plant species were combined into functional groups the variance declined and a difference was detected. The greatest amount of increase for these two functional groups was in the control plots. The control plots were mostly in the inundated areas of the study site. Rushes and some forbs [e.g., rush (J*uncus* L.), swamp smartweed (*Polygonum hydropiperoides* Michx.), and broadleaf arrowhead (*Sagittaria latifolia* Willd.)] are known to increase in meadow areas that are particularly wet (Stubbendieck et al. 2011; USDA 2012); therefore, the increase in these two functional groups on the control plots might have been because of extremely wet conditions rather than the experimental treatments.

There was a treatment effect for percentage change of litter. The percentage change of litter in the 4-PR-1 and 4-PR-2 treatments increased while it decreased in the mob, control, and hay treatments throughout the entire grazing season (Figure 7). Standing crop was removed from the control and hay treatments at the end of the 2010 grazing season so there was very little herbage at the end of the season to become litter. The accelerated levels of trampling in the mob treatment pastures may have increased decomposition rates; therefore, resulting in less litter.

Forage Quality

Forage quality data were analyzed and presented by year because dates of collection differed between 2010 and 2011. There was a treatment by date interaction for crude protein (CP) content of the available forage in 2010 (Table 3). During the early part of the season (first cycle for 4-PR-2), the CP content did not differ among treatments because the cattle in all treatment pastures likely were consuming the same types of forage as they moved from one pasture to the next (mostly cool-season grasses that were maturing into the elongation to reproductive stage). In the second cycle of the 4-PR-2 pastures, starting on 9 July, the cattle appeared to be primarily grazing new vegetative growth from plants that had been grazed in the first cycle. New vegetative growth would have higher CP content than elongated or reproductive tillers. Cattle in the mob and 4-PR-1 pastures were grazing elongated and reproductive tillers during this time because there was not a second cycle in these treatments.

The CP content in the 4-PR-2 treatment increased 43% from early July to August 2010 likely because of the increased clover availability in the second grazing cycle. Clovers (e.g., white clover) are particularly opportunistic and thrive in moist habitats that are closely mowed or grazed (Pederson 1995). Crude protein content did not change over time in 2011. Crude protein content remained the same with the advance of the growing season in the 4-PR-1 and mob treatment pastures in 2010 and all three grazing treatments in 2011. The increase and steady protein content differs with the concept that protein content declines with advancing maturity (Worrell et al. 1986; Ventura et al. 1975). A decline in protein content may not have occurred in the 4-PR-1 and mob pasture treatments because the plants were already at the elongation and reproductive stage of growth at the start of the grazing season in 2010; therefore, forage plants were at the elongation and reproductive stages throughout the grazing season. Cool-season grasses in meadows at this location typically begin reproductive stages of growth by mid to late June.

There was a treatment by time interaction for IVDMD in 2011 (Table 4). The IVDMD for the 4-PR-2, 4-PR-1, and mob treatments increased by 16%, 20%, and 2%, respectively, from mid June to late July, with no differences between late July and the first half of August. The usable energy in grasses on a dry matter basis is relatively stable while plants are green and growing but drops somewhat near maturity and following maturity (Vallentine 2001). However, in our study, the lab analysis showed that IVDMD gradually increased later in the growing season in 2011, but no change occurred in 2010. There is no explanation of why this gradual increase occurred during the growing season in 2011. There were no consistent differences in IVDMD among grazing treatments over these dates.

Livestock Performance

Average daily gain (ADG) of the steers was not calculated in 2010 because we were not able to weigh the steers immediately after the premature stoppage of grazing. In 2011, ADG of steers was greater on the 4-PR-2 pastures (0.93 $kg \cdot day^{-1}$) than on the 4-PR-1 (0.33 $kg \cdot day^{-1}$) and the mob (0.13 $kg \cdot day^{-1}$) pastures, and ADG did not differ between the 4-PR-1 and mob-grazed treatments. Gompert (2010) reported on fourteen different mob grazing producers and found that 21% of the producers had increased animal performance, 58% had no change, and 21% had a decrease in animal performance; on average, animal performance did not change. Greater daily gains for 4-PR-2 cattle were likely a result of higher quality available forage, lower grazing pressure, and a greater opportunity for selective grazing. Based on an average of 60% trampling and 10% remaining residue in the mob-grazed pastures, 30% of available forage was consumed which represents 6.6 $kg \bullet AU^{-1}$. Daily forage intake requirements of cattle are about 11.8 $kg \bullet AU^{-1}$ (National Research Council 1996) and our low intake estimates under mob-grazed treatments would support the poor animal performance that was observed.

Management Implications

Mob grazing practitioners claim that the percentage trampled with ultrahigh stocking densities can be increased compared to conventional 4-pasture systems. In this study, ultrahigh stocking densities of cattle resulted in the target level of 60% trampled. Cattle readily adapted to the frequent moves and the stocking density inherent with mob grazing. There is a need for flexibility and management decisions must be made daily to accommodate site conditions or variability in the amount of available forage. After two years of grazing, no conclusions can be made about grazing method effect on soil properties, increased plant diversity, and forage production.

Mob grazing at a 60% trample target does not seem realistic from a livestock production perspective because of the low amounts of forage remaining for consumption and the resulting poor livestock performance and production. With a 60% trampling level, harvest efficiency is low and stocking rates must be low to moderate because of the inadequate amount of forage available for intake by the grazing cattle. With low production per acre and low animal performance, mob grazing is hard to justify unless the practice greatly increases the medium-to-long term production potential of the site. I did not see any indication of increased herbage production or shifts in botanical composition in the first two years of the study. At this stage of the study, there is no certainty of improved herbage and livestock production as a result of mob grazing; and that if there are changes, they will be longer term.

Mob grazing also is commonly used to improve harvest efficiency on many ranches. With less trampling and increased harvest efficiency, however, there likely is less herbage available at the soil surface as an additional source of soil organic matter. Managing for less trampling, leads away from the objective of this study and the guidelines of many proponents of mob grazing – mob grazing can be used to increase the amount of trampled herbage to enhance the rate of soil development. Increasing the rate of soil development can increase forage production. The significance of continuing this research is to determine the effect of trampled herbage on below-ground processes and plant production and the trade-offs between optimizing harvest efficiency for short-term livestock production purposes and optimizing amounts of trampled vegetation for long-term soil development purposes.

Animal performance was lower in the 4-PR-1 treatment, and utilization and percentage trampled was greater when compared to 4-PR-2. In the short term, 4-PR-2 has greater economic returns because of high weight gains. Additionally, there is potential for increased stocking rates and livestock production because of relatively low utilization. The performance of the 4-PR-2 treatment certainly is attractive in the 2 years of this study; however, in the long term, the patchiness of 4-PR-2 may result in lower forage production because species composition may shift to less productive plants on intensively used patches. The use and production dynamics of the 4-PR treatments relative to mob grazing needs to be better understood to make recommendations that have long-term implications.

Literature Cited

AOAC. 1990. Official Methods of Analysis. 16th ed. Association of Official Analytical Chemists, Arlington, VA.

Bingham, S. and A. Savory. 1990. Holistic resource management workbook. Island Press. Washington, D.C. Covelo, California. p. 172-174.

Butterfield, J. Bingham, S. Savory, A. 2006. Holistic Management Handbook: Healthy Lands, Healthy Profits. Island Press, Washington D.C.

Cambardella, C.A., A.M. Gajda, J.W. Doran, B.J. Wienhold, and T.A. Kettler. 1999. Estimation of particulate and total organic matter by weight loss-on-ignition. *In:* R. Lal, J.F. Kimble, and R.F. follett (eds.), Carbon Methods. CRC Press, Boca Raton, FL.

Cambardella, C.A., A.M. Gajda, J.W. Doran, B.J. Wienhold, and T.A. Kettler. 2001. Estimation of particulate and total organic matter by weight loss-on-ignition. p. 349-359. In R. Lal, J.M. Kimble, R.F. Follett, and B.A. Stewart (eds.). Assessment methods for soil carbon. CRC Press, Boca Raton, FL.

Gerrish, J. and R. Morrow. 1999. Grazier's arithmetic. p. 109-112. *In:* J. Gerrish and C. Roberts (ed.) Missouri grazing Manual. MU Extension, Univ. of Missouri-Columbia.

Gompert, T. 2010. The power of stock density. *In*: Proc.: Nebraska Grazing Conference. Kearney, NE.

Hautau, M. 2011. Ian Mitchell-Innes on Mob Grazing. *Passages: Sustainable Food and Framing Systems Newsletter.* September/October. p. 1, 3, 11. Retrieved March 28, 2012, from http://www.pasafarming.org/resource/passages_92_PAGES.pdf.

[HPRCC] High Plains Regional Climate Center. 2011. Climatological data (Nebraska). HPRCC, Lincoln, NE.

Kidwell, B. 2011. Mob grazing: High-density stocking builds profits back into the cattle business. *Angus Beef Bulletin.* p. 28-29. Retrieved March 28, 2012, from http://www.angusbeefbulletin.com/ ArticlePDF/Mob Grazing%2003_10%20ABB.pdf.

National Research Council. 1996. Nutrient Requirements of Beef Cattle. 7th rev. ed. Natl. Acad. Sci., Washington, D.C.

Owensby, C.E. 1973. Modified step-point system for botanical composition and basal cover estimates. *Journal of Range Management.* 26:302-303.

Pederson, G.A. 1995. White clovers and other perennial clovers. p. 227-236. *In:* R.F. Barnes, D.A. Miller, and C.J. Nelson (ed.) Forages, Vol. I: An Introduction to Grassland Agriculture. Iowa State Univ. Press. Ames, Iowa.

Peterson, D. 2010. High density grazing in Missouri. *In*: Proc.: Nebraska Grazing Conference. Kearney, NE.

Poole, R.J. 1914. A study of the vegetation of the Sandhills of Nebraska. Minn. Bot. Studies 4:187-3 12.

Roberts, C. 1999. Plant growth and forage quality. p. 29-36. *In:* J. Gerrish and C. Roberts (ed.) Missouri grazing Manual. MU Extension, Univ. of Missouri-Columbia.

SAS Institute Inc. 2008. SAS/STAT user's guide, version 9.2. Cary, NC.

Schacht, W.H., J.D. Volesky, D. Bauer, A.J. Smart, and E.M. Mousel. 200. Plant community patterns on the upland prairie in the eastern Nebraska Sandhills. *The Prairie Naturalist*. 32:43-48.

Schmidt, J. 2011. Greg Judy challenges Kansas grazer's assumptions about mob grazing. *The Hutchinson News*. Retrieved March 28, 2012, from http://www.ksagland.com.

Smith Thomas, H. 2012. Mob grazing restores soil health and improves vegetation. *The Stockman Grass Farmer.* 1:6-8.

Stubbendieck, J., S.L. Hatch, and N.M. Bryan. 2011. North American wildland plants: A field guide. 2nd edition. Univ. of Nebraska Press. Lincoln, Nebraska. p. 218.

Tilley, J.M.A. and R.A. Terry. 1963. A two-stage technique for the in vitro digestion of forage crops. *Journal of British Grassland Society.* 18:104-110.

[USDA] United States Department of Agriculture. 2012. Natural Resource Conservation Service. Retrieved March 28, 2012, from http://plants.usda.gov.

Vallentine J.F. 2001. Grazing Management. 2nd edition. Academic, San Diego, California, USA. p. 383-384.

Ventura, M., J.E. Moore, O.C. Ruelke, and D.E. Franke. 1975. Effect of maturity and protein supplementation on voluntary intake and nutrient digestibility of pangola digitgrass hays. *Journal of Animal Science.* 40:769.

Weiss, W.P. 1994. Estimation of digestibility of forages by laboratory methods. p. 644-681. *In*: Forage Quality, Evaluation, and Utilizatoin. G.C. Fahey, Jr. ed. Am. Soc. Agronomy, Crom Sci. Soc. America, Soil Sci. America, Madison, WI.

Worrell, M.A., D.C. Clanton, W.W. Stroup, and J.T. Nichols. 1986. Effect of harvest date on meadow hay quality. I. Nutritial attributes, voluntary intake and rate of passage in growing cattle. *Journal of Animal Science.* 63:1527-1537.

Tables and Figures

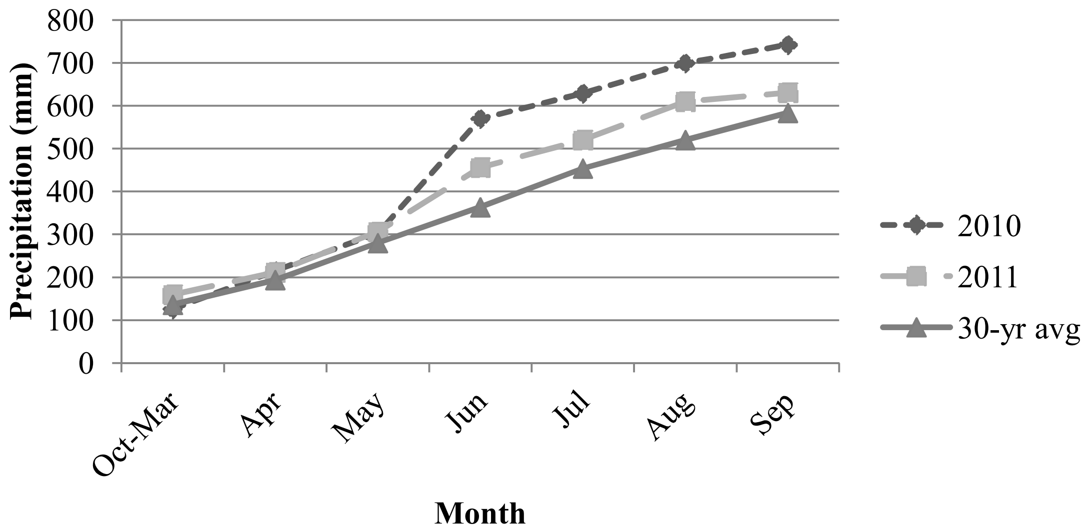

Figure 1. Monthly plant-year precipitation accumulations (mm) for 2010 and 2011 at the Barta Brother's Ranch and the 30-year average monthly accumulation in Ainsworth, NE.

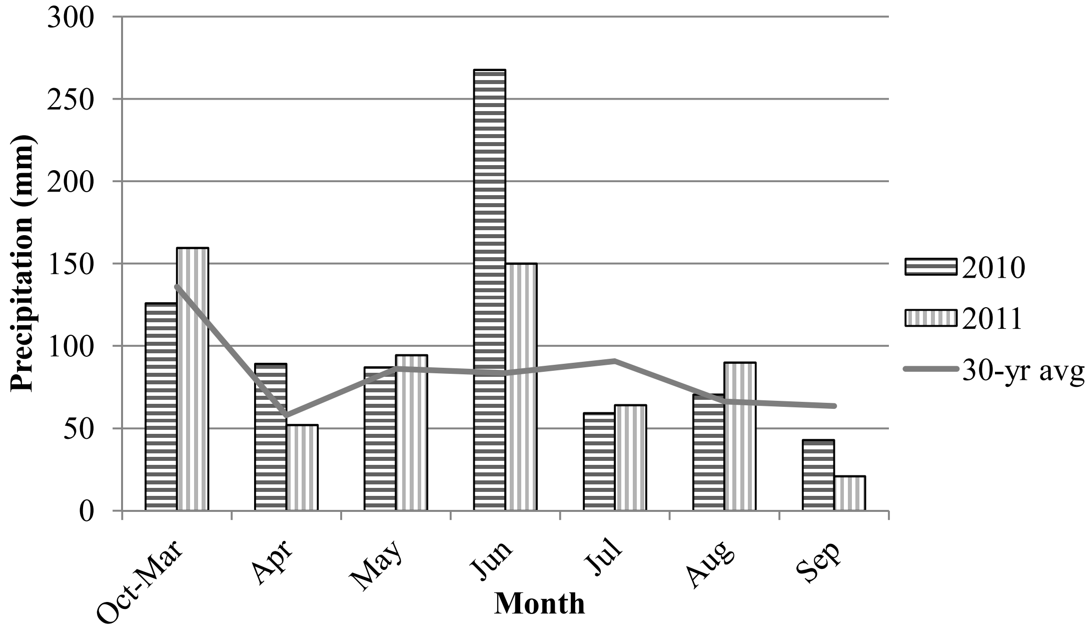

Figure 2. Monthly plant-year precipitation for the Barta Brother's Ranch in the eastern Nebraska Sandhills for 2010, 2011, and the 30-year average.

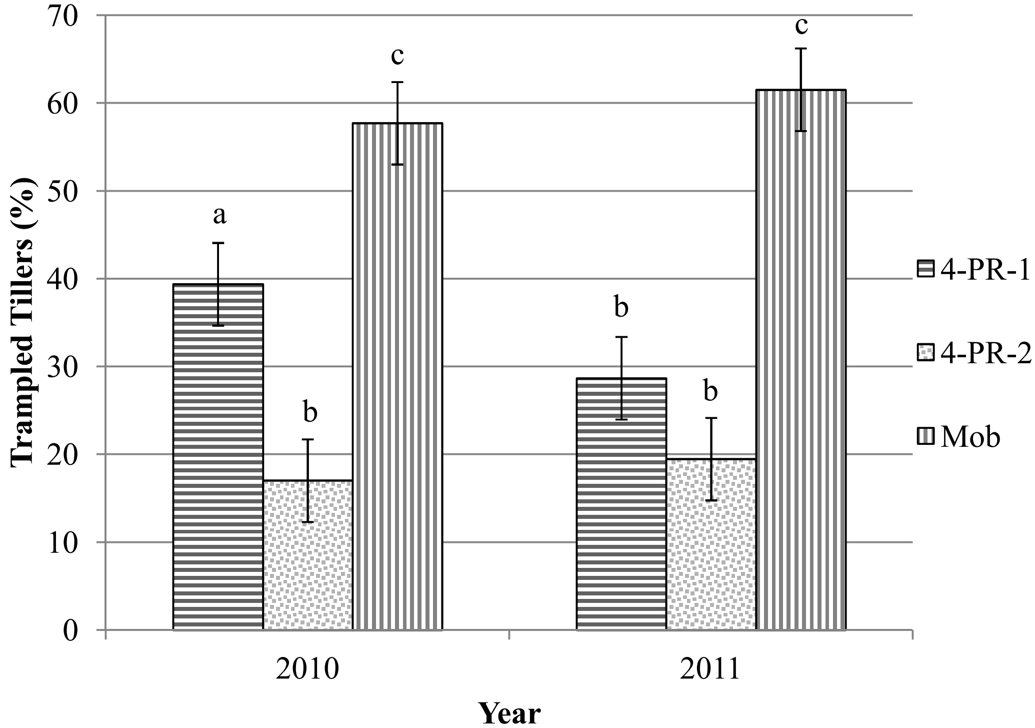

Figure 3. Percentage trampled of 4-pasture rotation with a single grazing period (4-PR-1), 4-pasture rotation with 2 grazing periods (4-PR-2), and a 120-pasture mob-grazed system (Mob). Within years and treatments, means with unlike letters significantly differ ($P < 0.10$).

Table 1. Percentage of individual plant tillers surviving following trampling in mob-grazed system in 2010.

	Kentucky bluegrass			Red-top			Timothy			Sedge		
Days after trampling	living[1]	dying	dead	living	dying	dead	living	dying	dead	living	dying	dead
						---(%)---						
7	100	0	0	100	0	0	100	0	0	100	0	0
14	65	25	5	40	48	10	15	75	8	88	13	0
21	55	28	18	25	40	33	8	73	20	68	30	3
28	47	20	33	17	27	57	10	43	37	33	50	13
35	40	10	50	10	10	80	30	20	45	30	45	25
42	0	30	70	0	0	100	10	10	70	10	20	70

[1] Living, dying, and dead status refers to tillers with no senesence, partial senesence, and total senesence, respectively.

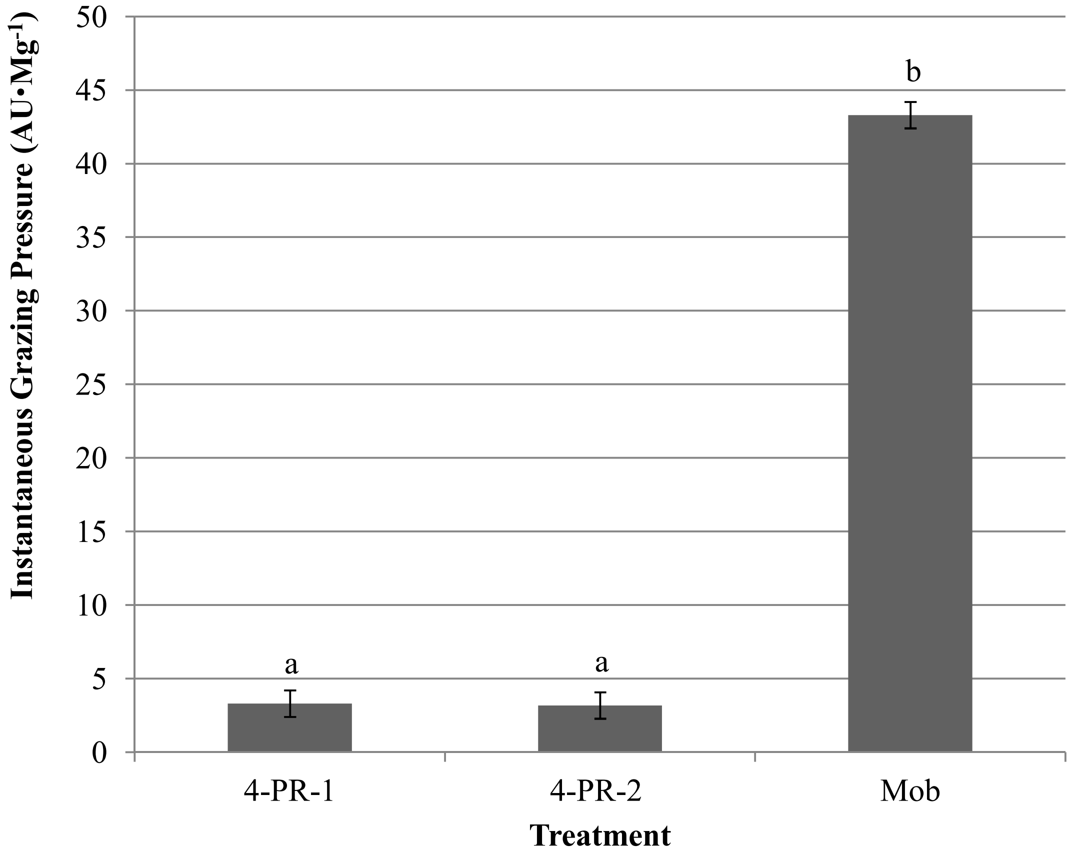

Figure 4. Instantaneous grazing pressure of 4-pasture rotation with a single grazing period (4-PR-1), 4-pasture rotation with 2 grazing periods (4-PR-2), and a 120-pasture mob-grazed system (Mob) at the time cattle were turned into the pasture for 2010 and 2011. Within treatments, means with unlike letter significantly differ ($P < 0.10$).

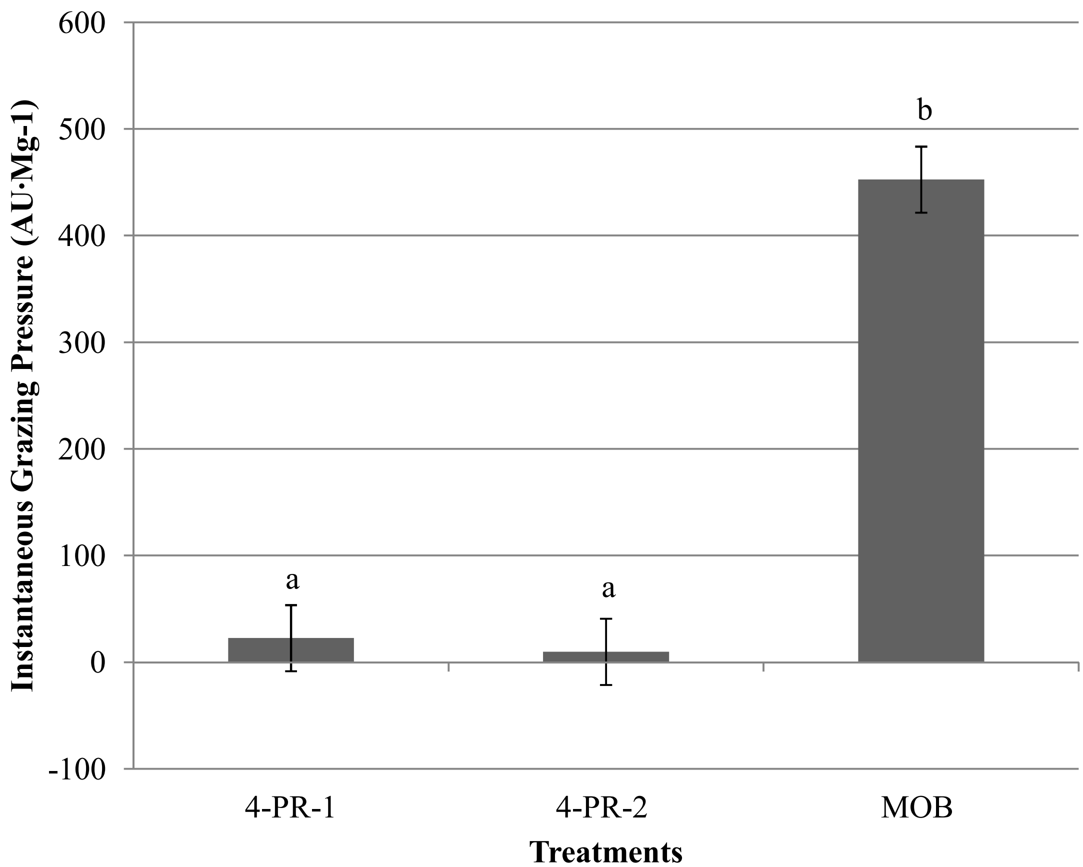

Figure 5. Instantaneous grazing pressure of 4-pasture rotation with a single grazing period (4-PR-1), 4-pasture rotation with 2 grazing periods (4-PR-2), and a 120-pasture mob-grazed system (Mob) at the time cattle were removed from the pasture for 2010 and 2011. Within treatments, means with unlike letters significantly differ ($P < 0.10$).

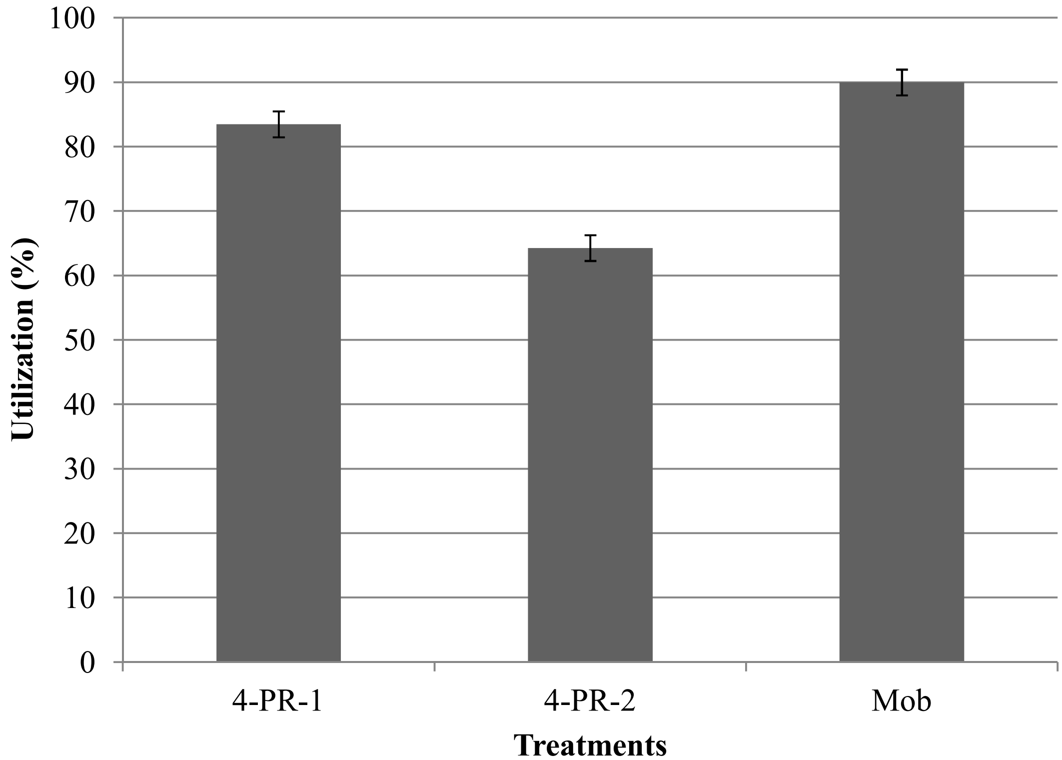

Figure 6. Utilization of 4-pasture rotation with a single grazing period (4-PR-1), 4-pasture rotation with 2 grazing periods (4-PR-2), and a 120-pasture mob-grazed system (Mob) for 2010 and 2011. Within treatments, data means were significantly different from each other ($P < 0.10$).

Table 2. Percentage change in control, hay, 4-pasture rotation with a single grazing period (4-PR-1), 4-pasture rotation with 2 grazing periods (4-PR-2), and a 120-pasture mob-grazed system (Mob) of botanical composition for functional groups from 2010 to 2011.

	Rush				Forbs			
Treatment	2010	2011	Change	S.E.	2010	2011	Change	S.E.
	-------------------------------------%)-------------------------------------							
Control	1.3	6.0	350[a]	55	3.7	8.7	129[a]	23
Hay	6.0	13.0	125[b]	55	8.3	11.3	45[b]	23
4-PR-1	13.1	16.2	39[b]	55	7.3	3.4	-52[c]	23
4-PR-2	13.8	14.6	7[b]	55	11.3	10.3	-7[bc]	23
Mob	14.4	12.0	-13[b]	55	8.6	5.2	-40[bc]	23

[1] Different lowercase letters within columns significantly differ ($P < 0.10$)

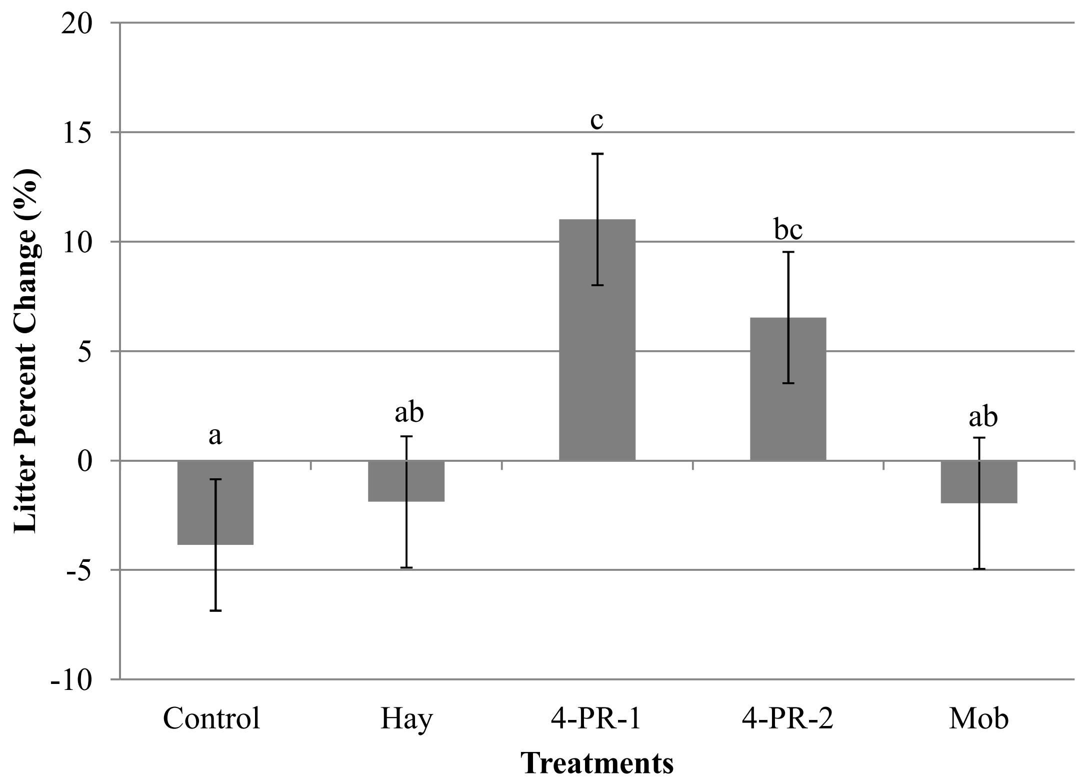

Figure 7. Percentage change in control, hay, 4-pasture rotation with a single grazing period (4-PR-1), 4-pasture rotation with 2 grazing periods (4-PR-2), and a 120-pasture mob-grazed system (Mob) of litter from 2010 to 2011. Within treatments, means with unlike letters significantly differ ($P < 0.10$).

Table 3. Percentage crude protein content in the 4-pasture rotation with a single grazing period (4-PR-1), 4-pasture rotation with 2 grazing periods (4-PR-2), and a 120-pasture mob-grazed system (Mob) in 2010.

Date	4-PR-1	S.E.	4-PR-2	S.E.	Mob	S.E.
	------------------------------(%)------------------------------					
1-15 Jul	6.7^{Ad}	0.4	6.7^{Ad}	0.4	7.0^{Ad}	0.3
16-31 Jul	6.2^{Ad}	0.4	7.7^{Be}	0.4	6.6^{Ad}	0.3
Aug	6.8^{Ad}	0.3	9.7^{Ce}	0.3	6.6^{Ad}	0.3

[1] Different uppercase letter within columns significantly differ ($P < 0.10$).
[2] Different lowercase letters within rows significantly differ ($P < 0.10$).

Table 4. Percentage IVDMD in the 4-pasture rotation with a single grazing period (4-PR-1), 4-pasture rotation with 2 grazing periods (4-PR-2), and a 120-pasture mob-grazed system (Mob) in 2011.

Date	4-PR-1	4-PR-2	Mob
	-----------------------(%)-----------------------		
16-30 Jun	51^{Ad}	51^{Ad}	56^{Ae}
1-15 Jul	56^{Bd}	54^{Bd}	56^{Ad}
16-31 Jul	61^{Cd}	59^{Cd}	57^{Ade}
Aug	59^{BCd}	56^{BCd}	$58^{Ad†}$

[1] Different uppercase letter within columns significantly differ ($P < 0.10$).
[2] Different lowercase letters within rows significantly differ ($P < 0.10$).
† Indicates predicated value.
* Standard error of measurement for percentage IVDMD was 1%.