PRODUCTIVITY AND QUALITY OF SMOOTH BROME PASTURES UNDER CONTINUOUS, ROTATIONAL, AND MOB GRAZING BY SHEEP

by

NATALIE HUMERICKHOUSE

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Major Professor
Peter J. Tomlinson Ph.D.

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Abstract

In recent years, an alternative grazing method to continuous and rotational methods has gained popularity among producers and has been termed mob grazing. Mob grazing uses high animal densities grazing for a short period of time. The objectives of this study were to determine the impact of continuous, rotational, and mob grazing on forage production and the quality of smooth bromegrass (*Bromus inermis* Leyss), along with soil dissolved organic carbon (DOC), microbial biomass carbon (MBC), and dehydrogenase enzyme activity. Twelve paddocks, 4 continuous (40 X 10 m), 4 rotational and 4 mob (15 X 10 m), were designated at the Kansas State University Sheep and Meat Goat Center in Manhattan, KS. Forage quality samples were collected by hand clipping randomly throughout the paddock. Neutral detergent fiber (NDF) and acid detergent fiber (ADF) were determined using ANKOM technology and crude protein (CP) content was calculated by multiplying total nitrogen determined by combustion by 6.25. Soil samples were extracted with 0.5 M K_2SO_4 and analyzed for DOC and MBC using the chloroform-fumigation-extraction method and soil dehydrogenase activity using the colorimetric method. Forage quality declined as the spring grazing season progressed in all treatments. Sheep grazed higher quality forage in the continuous and rotational treatments in the period prior to the spring mob grazing event. No treatment differences were found for DOC, MBC, dehydrogenase, or total forage biomass accumulation. Dissolved organic carbon and soil biological parameters have not been altered by the grazing management. Forage quality was found to be poorest in the mob treatment at the time of grazing. The mob treatment accumulated the greatest amount of aboveground biomass prior to grazing, however season-long total biomass accumulation was not different from the other treatments. Based on this research, in the short-term, there are no advantages of mob grazing over rotational grazing.

Table of Contents

List of Figures

List of Tables

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Chapter 1 - Literature Review

According to the Food and Agriculture Organization of the United Nations (FAO), about 60% of the agricultural land in the world is used for grazing that supports about 360 million cattle and 600 million sheep and goats (FAO 1996). In the United States, the total land area consists of about 904 million ha with the land being used for various purposes. The United States Department of Agriculture, Natural Resources Conservation Service (USDA, NRCS) reports an estimated 27% of land is used for range and pasture for grazing, or about 211 million ha, and an additional 17%, or 42 million ha, is used for grazed cropland, hay land, and grazed forestlands (USDA, NRCS n.d.). Rangeland in the United States is mostly native vegetation that is used for grazing of livestock, and privately owned rangeland accounts for 164 million ha, or about 27%, of the total land area, which is the largest single land cover or use type in the United States (USDA, NRCS n.d.). Pasture used for grazing is classified as improved native pastures or introduced cool-season or warm-season species and comprises 48 million ha, or about 6%, of land in the contiguous United States for grazing (USDA, NRCS n.d.).

Smooth Bromegrass (*Bromus inermis*)

Smooth bromegrass (*Bromus inermis* Leyss) is a perennial, cool-season grass that originated in Russia (Ball et al., 2007). Production can occur from April to October, but a limited amount of production will occur in July and August (Ball et al., 2007). The majority of the total seasonal growth of cool-season grasses occurs in the spring with as much as 60% of the growth being attained by July (Riesterer et al., 2000). Others have also reported production peaks early in the growing season with production declining as the growing season progresses (Paine et al., 1999; Phillip et al., 2001; Popp et al., 1997). Smooth brome is a sod forming grass species that spreads by rhizomes and requires a higher level of fertility, especially nitrogen, than other forages like tall fescue (*Festuca arundinacea* Schreb.) (Ball et al., 2007). Smooth brome is adapted to withstand cooler temperatures, and its range includes the northern and central United States (Ball et al., 2007). Smooth brome can become weakened by close, continual grazing events (Ball et al., 2007).

Grazing Systems

The grazing management of domestic ruminant animals is manipulated within the confines of two common grazing methods, namely continuous and rotational grazing (Sollenberger & Newman 2007). Many studies have been conducted to determine the differences in pasture growth and quality of forage available to livestock in continuous and rotational grazing systems. Differences in forage production and quality were examined between rotational and continuous grazing management systems (Paine et al., 1999), crested wheatgrass (*Agropyron cristatum* (L.) Gaertn) (Olson et al., 1989), direct-seeded alfalfa (*Medicago sativa* L.) pastures (Schlegel 2000), perennial ryegrass (*Lolium perenne* L.) (Marley et al., 2007), native rangelands (Briske et al., 2008), endophyte-free tall fescue (*Festuca arundinacea*) (Burns and Fisher 2011), and in sub-humid cool-season pastures (Oates et al., 2011).

A continuous grazing system is when animals are stocked on the same paddock *continuously* as long as sufficient pasture mass is present. According to the Forage and Grazing Terminology Committee (1992), a more correct term for this practice is continuous stocking because animals do not graze continuously. Additionally, the Forage and Grazing Terminology Committee (1992) indicate that animal numbers are adjusted, added or subtracted, through a process called put-and-take stocking, to maintain pasture mass within target bounds. In contrast, rotational grazing, or the more correct term of rotational stocking by the Forage and Grazing Terminology Committee (1992), is a method that uses recurring periods of grazing and rest among two or more paddocks in a management unit throughout the period when grazing is allowed. Another type of rotational grazing is management intensive rotational grazing which is when animals are stocked on the same paddock for only a short period, one to three days, before being moved to the next paddock (Paine et al., 1999). A farm is subdivided into numerous paddocks and they are grazed sequentially as part of a grazing rotation (Brundage and Peterson 1952). Ideally, grazing of a paddock commences and ends according to pre-determined thresholds of pasture mass (Thomas et al., 1987) or to a pre-determined rest period before the paddock can be grazed again (Ball et al., 2007). These target thresholds usually aim to maintain pasture conditions such that pasture growth and quality is maximized. Actually, achieving these thresholds in a real grazing system can be compromised by edaphic, climatic and management considerations (Forage and Grazing Terminology Committee 1992). Rotational pastures, in a study conducted by Paine et al., (1999), provided higher yields of consistently higher quality

forage than did continuous pastures. Another study conducted to determine forage production and quality in sub-humid cool-season pastures found comparable results to the study by Paine et al., in which rotational grazing out-performed the other treatments compared in the study (Oates et al., 2011). Potential utilizable forage, quantified by incorporating the estimates of refused and non-utilized biomass and relative forage quality were significantly greater under management-intensive rotational grazing when compared to the other treatments (Oates et al., 2011). This means that the forage that was utilized by livestock as well as the forage that was left behind in the rotational system was both of a higher quality when compared to the available and leftover forage of the continuous grazing system (Oates et al., 2011).

In recent years, an alternative grazing method to the traditional continuous and rotational methods has gained popularity and is termed mob grazing. Mob grazing is a variation on the rotational grazing technique (Hay et al., 2012). Similar to rotational grazing, it involves animals periodically grazing the same area of pasture during the growing season, but it differs in terms of pre and post-grazing pasture mass (Hay et al., 2012), the duration of grazing and the duration of rest period (Battini et al., 2007). Mob grazing according to the Forage and Grazing Terminology Committee (1992) is when grazing is done by a relatively large number of animals at a high stocking density for a short period of time. Key differences between mob and rotational grazing are that pasture biomass is allowed to accumulate to greater levels before grazing, animals are allowed to graze to a lower post-grazing biomass, grazing occurs for a "short period of time", typically 12 to 24 hours, and the total pounds of animal per land area at one time is higher (Thomas et al., 1987). This rapid reduction in pasture mass is achieved by having considerably more animals grazing smaller areas than in rotational grazing. Another difference between rotational and mob grazing is that over the entire grazing season mob-grazed paddocks are only grazed one to two times (Salatin 2008) compared to management intensive rotational grazed paddocks which are grazed multiple times per year (Ball et al., 2007). A grazing season is the time period during which grazing can normally be practiced each year or portion of each year (Forage and Grazing Terminology Committee 1992). Thus, it could be the whole year or a very short time period. In order to determine the grazing season, it is usually a function of the forage mass or the amount of available forage and climate (Forage and Grazing Terminology Committee 1992).

Forage Quality

Forage quality is a variable index that can affect animal performance, feed value, forage value, and profits to a producer. Thus, it is important to understand the various components of forage quality. Palatability, intake, digestibility, nutrient content, and anti-quality factors all work together to help determine forage quality (Lambert et al., 2000; Ball et al., 2007).

Palatability is defined as the selective intake or relative preference for forages by animals and is an important component in determining forage quality (Scheaffer et al., 2009). Sheep have been noted to prefer certain forage species over others (Broom and Arnold 1986). Thus, based upon observations by Broom and Arnold (1986), grazing animals will select forbs that are appealing to them; the presence of leaves is always preferred to the stems of plants in a grazing diet (Arnold 1960) and green material is preferred over non-green material (Arnold 1964, Hamilton et al., 1973). Selective defoliation of the leaves of a plant results in an increase in the proportion of stems as a forage species matures. This also results in an increase in the fiber content of the diet indicating a decline in the ratio of leaf to stem content (Chacon and Stobbs 1976). By increasing the fiber content, the plant also becomes tougher to consume, causing the animal to spend more time and energy grazing (Olson et al., 1989). Palatability influences an animal's selection and intake of forage, playing a key role in selection of forage by livestock (Marten 1978).

Nutritive quality is one of the factors that affects forage quality and is expressed as a nutritive value; it also takes into account the digestible energy and efficiency of digestible energy utilization (Lambert and Litherland 2000). A nutritive value relates to the digestibility of the forage consumed independent of voluntary intake, which includes the characteristics of the forage and the growth environment (Lambert and Litherland 2000). Younger, actively growing forage is of higher nutritive value and lower in lignin than that of more mature pasture forage (Brundage and Petersen 1952). In general, the higher the crude protein levels and the lower the fiber content the more available energy in the forage, thus making it a higher quality feedstuff (Ball et al., 2007). The production of home-grown protein in the form of high quality forage reduces the need to purchase protein supplements (Smith 1981).

The feed or forage value is comprised of several components. The digestibility components are acid detergent fiber (ADF) and neutral detergent fiber (NDF) and the nutrient component is crude protein (CP). The measurement of ADF quantifies the portion of cellulose,

lignin, and ash (primarily silica) (Fuller 2004); while, NDF quantifies the portion of total cell wall constituents (Goering and Van Soest 1970) including hemicellulose in the forage (Van Soest et al., 1991). Lignin is the component of cell walls that binds cells together and can be very difficult if not impossible for ruminants to digest (Lambert and Litherland 2000). Thus ADF is used to calculate digestibility and NDF is used to predict potential intake (Osbourn et al., 1974; Reid et al., 1988; Weiss 1994). The major determinants of intake of smooth bromegrass by sheep are fiber content and fiber digestibility (Ellis 1978). These two characteristics of fiber are important in helping to determine forage quality. When fiber content increases, forage quality decreases (Paine et al., 1999).

Protein in forage is usually reported as CP. Crude protein is generally 6.25 times the nitrogen content of forage and is the organic nitrogen that can be converted to protein by microorganisms in the rumen. The use of 6.25 as a multiplier for nitrogen is based on work done by Danish chemist Johan Kjeldahl. Early determinations estimated that the nitrogen content of proteins was about 16%, and protein content divided by the nitrogen content is approximately 6.25 (FAO 2003). Thus, CP is an important positive forage quality measurement. Sheep select plant material highest in nitrogen content with leaves preferred over stems (Arnold 1960). Having higher quality forage available to livestock improves livestock nutrition and production. Several studies have not only compared continuous and rotational stocked systems for forage growth and quality measurements but also for livestock nutrition and production. A positive correlation exists between ingestion rate and amount of forage available to livestock, meaning as the amount of available forage increased so did the ingestion rate (Olson et al., 1989). Thus, in order to maintain intake of high quality forage, it is recommended that paddocks be grazed for two or fewer days during the active growth period of crested wheatgrass (Olson et al., 1989). Similar results have been found in other studies looking at rotational grazing and forage quality. Oates et al. (2011) examined sub-humid cool-season pastures including Kentucky bluegrass (*Poa pratensis* L.), orchardgrass (*Dactylis glomerata* L.), meadow fescue (*Festuca pratensis* Huds.), perennial ryegrass (*Lolium perenne* L.), and white clover (*Trifolium repens* L.). Potential utilizable forage, quantified by incorporating the estimates of refused and non-utilized biomass and relative forage quality were significantly greater under management-intensive rotational grazing when compared to the other treatments (Oates et al., 2011). In another study conducted

by Brundage and Sweetman (1964), the total digestible nutrient utilization of smooth bromegrass was found to be highest under rotational grazing.

Forage quality also affects voluntary feed intake by grazing animals. The most common forage quality index used in the United States is relative feed value (RFV) and is based on the voluntary intake of digestible dry matter by grazing animals (Moore and Undersander 2002). The RFV was developed by the Hay Marketing Task Force which is part of the American Forage and Grassland Council (Rohweder et al., 1978). Due to the index relying heavily on intake of digestible dry matter, two animal responses are often examined, dry matter intake as a percentage of the animal's body weight and digestible dry matter concentration as a percentage of the dry matter even though these two responses are not often correlated (Moore and Coleman 2001). National Forage Testing Association (NFTA) reports RFV values based on the two predicted animals response values of dry matter intake which indicates the percentage of body weight of the animal, and digestible dry matter concentration, which indicates the percentage of dry matter, on laboratory analysis of neutral detergent fiber (NDF) and acid detergent fiber (ADF) (Moore and Undersander 2002). The current equation utilized by NFTA to calculate the RFV, forage quality index is:

120 / NDF Content = Dry Matter Intake (DMI)

88.9 - 0.779 *ADF Content = Digestible Dry Matter (DDM)

RFV = DMI * DDM / 1.29

NDF and ADF content in each equation also quantify the dry matter percentage. The standard of 1.29 was used to determine RFV values so that full bloom alfalfa would have a value of 100, with those forages that have a RFV greater than 100 being of higher overall quality than that of the base 100 of full bloom alfalfa (Moore and Undersander 2002).

Forage quality is also affected by anti-quality issues that occur within the pasture or plant species offered to the grazing animal. Anti-quality factors include fungal toxins, internal parasite contamination, and soil or other contaminants (Lambert et al., 2000). Toxins within the plant are the main threat to animal health and the primary anti-quality concern. Plants can produce toxins themselves or in some instances accumulate toxins making a once acceptable plant species unsuitable for grazing. An example of this would be oat (*Avena sativa* L.), hay and straw as well as redroot pigweed (*Amaranthus retroflexus* L.), as nitrate concentrations in these two species were considered responsible for nitrate poisoning deaths in cattle in Wyoming, Colorado, and

South Dakota (Bradley et al., 1940). The presence of tannins in the forage diet also influence forage quality. Tannins are compounds in some plant species that reduce the degradability of plant proteins in the rumen (Lambert and Litherland 2000). Other anti-quality factors include the presence of protective plant structures such as thorns or the presence of secondary metabolic chemical compounds that dissuade the animals from grazing (Marten 1978). An example of this is wild blue indigo (*Baptisia australis* (L.) R. Br. [Fabaceae]) which contains alkaloids, which due to their bitterness, prevents the animal from selecting the plant when grazing (Burrows and Tyrl 2001). Tall fescue is another forage species in which the presence of a fungal endophyte produces toxic alkaloids that negatively influences animal intake as well as forage quality (Burns and Fisher 2011).

The botanical composition of a pasture also contributes to the overall quality of plant materials available to the animal (Shakhane et al., 2013). A good forage or grass mixture is important to any grazing system as it influences the productivity of the system (Shakhane et al., 2013). Since palatability is important and animals graze based upon preference and selectivity, the presence of younger leaf tissue lower in fiber is essential. Selective grazing is the attempt by animals to maximize nutrient intake (Guy et al., 1981). High selective pressure upon the leaf tissues of desirable plant species can increase the opportunity for competition by other undesirable plant species. A common observation is that over-grazing can result in weedy pastures while under-grazing can lead to the exclusion of lower growing legumes (Shakhane et al., 2013; Dowling et al., 2006). Unimproved pastures also experience an increase in weeds under hard grazing (Radcliffe 1973). Several studies have examined the effect of grazing pressure on the botanical composition of research pasture sites. A study by Shakhane et al., (2013) observed an increased number of thistles (*Carthamus lanatus* L.) on research paddocks that carried lower stocking rates over relatively long grazing periods that suggested the sheep grazing these paddocks had a greater opportunity to repeatedly select species that suited their preference, allowing them to avoid other species such as thistle. Another study comparing the effects of continuous and a form of intensive rotational grazing called time-control grazing on grassland components in southeastern Australia observed that intensive rotational grazing did not appear to have any notable benefits on perennial grass pasture components, but short-term changes related to management caused changes in the composition of cool-season perennial grasses (Dowling et al., 2005). Although stocking rate is the most important factor in animal

production that can influence changes in botanical composition, many other factors also influence changes in the overall composition.

Soil Health

Grazing animal health can also be influenced by the soil and can be linked to soil productivity and environmental quality (Dick et al., 1996). The maintenance of normal soil function in rangeland ecosystems is only possible when adequate plant and litter cover is present to provide protection from soil loss, minimize evaporation and allow soil microorganisms to perform optimally (Thurow 1991; Rietkerk et al., 2000; Bardgett 2005). Several research studies by Blackburn (1975), Thurow et al., (1986 and 1987), and Pluhar et al., (1987), have concluded that the type and amount of vegetative cover has a large influence on soil physical as well as hydrological properties. One of the producer reported benefits of mob grazing, cited in the *Angus Beef Bulletin,* is the large amount of plant cover and litter available to protect the soil surface as well as residue that can be incorporated into the soil by the increased hoof action from the high animal stocking densities (Kidwell 2010). Trampling and senescence during grazing periods of herbage contributed to litter deposition in rotationally stocked smooth bromegrass pastures (Guretzky et al., 2014). The reduction or loss of litter and plant cover from the soil surface results in soil degradation processes that affect soil physical, biological, and hydrological properties. Soil temperature and evaporation increases and soil moisture decreases more quickly on bare soil than soil surfaces protected from sunlight and wind. The risk of erosion also increases, which can accelerate the loss of organic matter and soil (Blackburn 1975; Blackburn et al., 1986), decrease infiltration rates, alter nutrient retention, and negatively affect biological processes that maintain ecosystem functions (Neary et al., 1999; Wright and Bailey 1982). In a study by Teague et al., (2011), heavy continuous grazing was noted to have had negative impacts that included increased bare ground, lower aggregate stability, greater sediment loss and greater penetration resistance than the other grazing systems such as light continuous grazing and multi-paddock rotational grazing. Multi paddock rotational grazing was also noted to have less bare ground, lower soil temperatures and higher levels of soil carbon than continuous grazing at the same stocking rate (Teague et al., 2010).

Plant litter on the soil surface, over time, will be incorporated into the soil and provide benefits to the below-ground soil system through soil improvement. Plant litter and cover above-

ground allow for more consistent temperatures and moisture conditions at the soil atmosphere interface, supporting a robust and diverse below-ground microbial population (Devi and Yavada 2006), enhancing the formation of stable soil aggregates, which aid in water infiltration and help to improve the soil fertility (Herrick et al., 1999). Incorporated plant material also decomposes to form organic matter. The decomposition is facilitated by the soil biological community, including macro e.g. earthworms and micro-organisms e.g. bacteria and fungi (Tegaue et al., 2011).

Organic matter within the soil is composed of about 60% organic carbon and provides many beneficial effects on soil chemical, physical, and biological functions that affect soil quality (Bardgett 2005). One of the most important effects of organic matter in the soil is that it supplies nutrients to support aboveground plant growth, which drives the success of any grazing system. It aids in the absorption of the nutrients, trace elements and cations that are needed by the plant while also preventing nutrient leaching and releasing organic acids that increase plant availability of minerals i.e. iron, aluminum, and calcium (Teague et al., 2011). Through the process of decomposition of organic matter, energy is provided to the organisms and nutrients are released for uptake by microorganisms and plants (Van Veen and Kuikman 1990). Trace element absorption is aided by soil organic matter, as those elements that occur in the soil as insoluble complexes are bound to organic matter components (Stevenson and Cole 1999). Cations are also bound to organic matter, which aids in the absorption of these cations needed by the plant. Organically bound forms of the micronutrient cations are more available to plants than the inorganic forms, e.g. insoluble inorganic precipitates and those held in primary minerals (McLaren and Crawford 1973; Murthy 1982; Mandal and Mandal 1986). Organic matter also aids in soil structural stability, increases the cation exchange capacity and water holding capacity, and buffers soil from major changes in soil pH (Teague et al., 2011).

Organic matter in pasture soils, along with microbial secretions and fungal hyphae, increases the stability of macroaggregates (Tisdale 1994), which helps improve soil structural stability. Soil aggregates are soil particles bonded together by polysaccharides and other complex organic compounds. Organic matter reduces the density of soil and binds soil particles together, stabilizing soil aggregates (Hartel et al., 1999). Cation exchange capacity (CEC) is also influenced by the organic matter content of a soil as organic carbon is able to retain nutrients and water (Teague et al., 2011). The CEC of organic matter in the soil has a higher exchange

capacity than clay particles, and organic matter functional group ionization is highly influenced by pH (Hartel et al., 1999). Soil is also buffered from changes in soil pH due to the presence of organic carbon (Teague et al., 2011). The soil organic matter that is composed of organic carbon has the ability to influence the CEC, thus when the pH changes, the CEC is able to change as well (Sylvia et al., 1999). Stabilized soil aggregates maintain a loose, open, granular condition in soils that allows water to infiltrate and increases the water holding capacity (Stevenson and Cole 1999).

Soil microorganisms regulate the transformation and storage of nutrients (Horwath and Paul 1994). Bacteria and fungi are the primary microorganisms that utilize organic nutrients for growth and development. When microorganisms decompose, they release inorganic nutrients that can be taken up by the plants for use in growth and development or utilized by other microorganisms in the soil. Fungi tend to be more effective at assimilating and storing the nutrients, including carbon, than bacteria (Bardgett and McAlister 1999; De Vries et al., 2006). Therefore, a larger population of fungi in the soil may allow for more nutrient storage and a greater ability to maintain carbon in the system, providing a larger nutrient pool for growing plants (Teague et al., 2011). The fungi to bacteria ratio is a good indicator of the environmental change and health in the soil, and increases in the fungi to bacteria ratio can indicate an improvement in soil health and carbon sequestration (Beare et al., 1992; Yeates et al., 1997; Bailey et al., 2002; De Vries et al., 2006). Organic matter can modify the formation of the microbial community responsible for producing enzymes (Browman and Tabatabai 1978); thus, the use of management practices that minimize the addition of organic matter into the soil may reduce the production and activity of enzymes that impact cycling and supply nutrients needed to support plant growth (Ajwa et al., 1998).

Enzymes produced by the microbial community are an essential component in catalyzing reactions that are necessary for organic matter decomposition and nutrient cycling in the soil (Ajwa et al., 1998). The activity of some soil enzymes can change more quickly than other soil properties, allowing for earlier indications of soil quality improvements or degradations (Dick et al., 1996). Dehydrogenase is an enzyme that can be used as an indicator for soil microbial activity (Dick et al., 1996). The measurement of potential dehydrogenase enzyme activity is useful as this enzyme complex is an integral part of microbial driven oxidation of organic matter (Casida et al., 1964). Enzymes in the soil, such as dehydrogenase, are primarily produced by the

microbial community but can also originate from plant and animal residues (Tabatabai 1994). Many dehydrogenases exist, which are enzymes that catalyze dehydrogenation, and are highly specific (Tabatabai 1994). The biological oxidation of organic compounds is generally a dehydrogenation process, thus the dehydrogenase enzyme system plays an important role in the oxidation of soil organic matter, facilitating the transfer of hydrogen from substrate to acceptor (Tabatabai 1994). The association between dehydrogenase enzymes and active soil microorganisms allows dehydrogenase to be used as an indicator of microbial activity (Skunjins 1976). Dehydrogenase activity is dependent on the total metabolic activity of soil microorganisms (Skunjins 1973), and is often correlated with carbon dioxide release, proteolytic activity, and nitrification potential (Skunjins 1973), as well as microbial respiration when exogenous carbon sources are added to soils (Frankenberger and Dick 1983).

Summary and Research Justification

In the US and other countries, the different aspects of continuous and rotational grazing methods have been extensively studied, including effects on animal production (Brundage & Petersen 1952; Bertelsen et al., 1993; Derner et al., 2008; Burns & Fisher 2011), pasture production and quality (Paine, Undersander, & Casler 1999; Vermeire, Heitschmidt, & Haferkamp 2008; Burns & Fisher 2011; Oates et al., 2011; Bungenstab et al., 2011), soil (Teague et al., 2011) and the environment (Gholamreza et al., 2009; Schwarte et al., 2011). There has not, however, been comprehensive research into the effects of mob grazing on these aspects of the system. Producers and popular press articles have indicated that mob grazing improves forage quality and increases pasture production (Kidwell 2010) as well as marked increases in soil organic matter in just a few years (Newport 2009). Decades of research on pasture herbage mass accumulation suggest that year-round mob grazing should negatively impact overall pasture growth and quality. As plants reach reproductive stages, as is common in mob grazing, ADF and NDF increase and CP decreases, indicating a decline in forage quality. Additionally, the potential exists that season long herbage mass accumulation will decrease under mob grazing. The stage of the plant at the time of grazing can play a key role in accumulation. Increasing grazing intensity of seeded grasses can negatively affect the ground cover (McCartney and Bittman 1994). This disparity between anecdotal observation and established theory means that there is a

pressing need to conduct replicated scientific trials that make unbiased comparisons between traditional grazing methods and the mob-grazing approach.

Mob grazing however, is not a new grazing technique. Mob grazing has been used to compare germplasms and cultivars, such as alfalfa (Bittman and McCartney 1994), and to evaluate cool-season grass species, such as smooth bromegrass persistence (McCartney and Bittman 1994). However, little research has been conducted to evaluate the potential for year-round grazing on established pastures and the effects on animals and forage species that may occur when using mob grazing. Year-round mob grazing may be a viable alternative to traditional continuous or rotational methods. The objectives of this study were to determine the impact of continuous, rotational and mob grazing on forage biomass production, as well as herbage quality, of smooth bromegrass, and to determine the impact of continuous, rotational, and mob grazing on below-ground soil quality measurements i.e. dehydrogenase enzyme activity, microbial biomass, and dissolved organic carbon.

Chapter 2 - Productivity and Quality of Smooth Bromegrass Pasture under Continuous, Rotational, and Mob Grazing by Sheep

Introduction

In the United States, an estimated 301.2 million ha of land is used for livestock grazing, according to the U.S. Department of Agriculture Natural Resource Conservation Service (USDA NRCS n.d.). Grazing lands are grouped into three categories: rangeland, pasture, and other grazing lands. Rangeland in the United States is mostly native vegetation that is used for grazing of livestock. Pastureland includes improved native or introduced warm- or cool-season species. Other grazing lands are any grazed cropland, hay land, or forest land that is used for grazing. Pasture land used for grazing is most commonly improved native or cool-season pastures which comprise about 47.6 million ha, or about 6% of land in the contiguous United States (USDA, NRCS n.d.).

The grazing management of domestic ruminants is manipulated within the confines of two common grazing methods: continuous and rotational grazing (Sollenberger & Newman 2007). These systems are the most common grazing methods in practice, and many studies have been conducted to determine their influence on forage production and quality, such as differences in pasture growth and quality between rotational and continuous grazing management systems (Paine et al., 1999), crested wheatgrass (*Agropyron cristatum* (L.) Gaertn) (Olson et al., 1989), direct-seeded alfalfa (*Medicago sativa* L.) pastures (Schlegel 2000), perennial ryegrass (*Lolium perenne* L.) (Marley et al., 2007), native rangelands (Briske et al., 2008), endophyte-free tall fescue (*Festuca arundinacea*) (Burns and Fisher 2011), and in sub-humid cool-season pastures (Oates et al., 2011).

Comparisons of rotational and continuous stocking systems have shown different results. Paine et al. (1999) reported rotationally-grazed pastures provided greater yields of consistently better quality forage than did continuously-grazed pastures. Similar results were also observed for forage production and quality in subhumid cool-season pastures in rotational grazing systems compared to other treatments (Oates et al., 2011). Furthermore, the forage that was utilized by the livestock, as well as the forage that was left ungrazed in the rotational system, where both of higher quality compared to the available and ungrazed forage of the continuous grazing system

(Paine et al., 1999; Oates et al., 2011). Potential utilizable forage, quantified by incorporating the estimates of refused and non-utilized biomass and relative forage quality were significantly greater under management-intensive rotational grazing when compared to the other treatments (Oates et al., 2011). However, Briske et al. (2008) concluded that continuous stocking resulted in similar or greater vegetative dry matter production, pounds of beef per animal and per unit area in the majority of native range stocking studies. They found that 87% of experiments yielded greater than or equal amounts of plant production in continuous systems when compared to rotational grazing systems. Briske et al. (2008) also indicated that ecological factors (i.e. precipitation and regrowth) constrain rangeland grazing strategies similarly and difference among grazing strategies are more dependent on management factors (i.e. fertilization and grazing parameters).

An alternative to the traditional continuous and rotational grazing methods is termed mob grazing. Mob grazing is similar to rotational grazing as it involves animals periodically grazing the same area of pasture during the growing season; however, mob grazing differs in terms of biomass that accumulates pre and post-grazing (Hay et al., 2012), the length of grazing, the duration of the rest period following a grazing event (Battini et al., 2007), and the stocking density which is the mass of animals per land area (Kidwell 2010). The Forage and Grazing Terminology Committee (1992), defined mob grazing as grazing by a relatively large number of animals at a high stocking density for a short period of time. The time period during which grazing can normally be practiced each year or portion of each year is termed a grazing season. Length of the grazing season is usually a function of the amount of available forage and climate (Forage and Grazing Terminology Committee, 1992). The high-intensity grazing in a mob system, results in a rapid reduction in biomass, to levels typically lower than rotational grazing. Producers claim that mob grazing increases soil organic matter because of the greater accumulation of litter (Kidwell 2012). Additionally, mob-grazed paddocks are grazed less frequently (i.e. one to two times over the entire grazing season) compared to management intensive rotational grazing systems.

Mob grazing has been utilized by scientists evaluating new cultivars and germplasms as forage crops to reduce the possibility of preferential grazing (Bittman and McCartney 1993). Limited research is available on the use of this grazing practice year-round on established pastures and its effects on forage quality, quantity, and pasture composition.

Depending on the growth stage of the forage and the species, pasture quality declines with time, as the plant matures (Owensby et al., 2008). Oates et al. (2011) found that results in their rotational system were influenced by the plant community remaining in a vegetative growth stage. During the reproductive stages of plant growth, carbohydrate reserves are shunted toward reproductive structures and to reserves below ground that will help the plant regrow following grazing. Repeated frequent grazing results in decreased root biomass and root nitrogen reserves (Schuman et al., 1999).

Smooth bromegrass is weakened by clipping at the initiation of stem elongation because the plants have low levels of root carbohydrates and few tiller buds (Walton 1980). Grazing when the plant has not been allowed to properly regrow, could result in ground cover changes. Thus, high-intensity grazing could potentially change the ground cover. McCartney and Bittman (1994) observed a negative impact on ground cover of seeded grasses as grazing intensities increased.

Palatability is defined as the selective intake or relative preference for forages by animals (Scheaffer et al., 2009). Forages with low palatability may have decreased animal selection even when nutritive value is high. The nutritive value of a given forage is a function of differences in the ratio of cell wall to cell contents and the degree of lignification (Lambert and Litherland, 2000). Thus leaves have a higher nutritive value than stems (Lambert and Litherland, 2000). Brundage and Petersen (1952) showed that immature, actively growing forages had higher nutritive value and less lignin than more mature pasture forages.

As a general principle, more available energy is contained in forages that have lower fiber content, especially the lignin component of fiber (Ball et al., 2007). Two measures that are used to determine forage quality are acid detergent fiber (ADF) and neutral detergent fiber (NDF). Acid detergent fiber is a measurement that quantifies cellulose, lignin, and ash, while NDF quantifies hemicellulose, cellulose, lignin, and ash in the forage. Lignin binds the primary and secondary cell walls together and is nearly indigestible (Lambert and Litherland, 2000). Protein is also an important factor in forage quality. Crude Protein (CP) is derived from true protein and non-protein nitrogen with plant protein being broken down by microbes into ammonia and amino acids in the rumen while remaining ammonia not digested in the rumen is absorbed into the bloodstream and converted to urea in the liver (Lambert and Litherand 2000).

Thus, knowing the NDF, ADF, and CP, of forages present in a grazing system, it is possible to determine the nutritive quality of the forage.

The botanical composition of a pasture contributes to the overall quality of available plant materials (Shakhane et al., 2013). High selective grazing pressure on desirable plant species can increase competitiveness of undesirable plant species. Overgrazing can result in increased numbers of undesirable species while under-grazing can lead to the exclusion of lower growing legumes (Radcliffe 1973; Dowling et al., 2006). Shakhane et al., (2013) reported an increased number of thistles (*Carthamus lanatus*) in research paddocks that carried lower stocking rates over relatively long grazing periods, suggesting that the sheep grazing these paddocks had a greater opportunity to repeatedly select species that suited their preference while avoiding species like thistle. Another study comparing the effects of continuous and rotational, time-control grazing on grassland components in southeastern Australia found that intensive, rotational grazing did not appear to have any notable benefits on perennial grass pasture components (Dowling et al., 2005). Grazing management decisions can influence changes in botanical composition, as well as many other factors.

Soil characteristics influence overall pasture quality. The health of grazing animals can also be influenced by the soil and can be linked to soil productivity and environmental quality (Dick et al., 1996). Plant material that is incorporated into the soil decomposes to form organic matter, with the decomposition facilitated by the soil biological community (e.g. earthworms, bacteria and fungi). Soil organic matter is composed of about 60% carbon and influences chemical, physical, and biological functions of soils (Bardgett, 2005). The success of any grazing system relies on adequate supply of nutrients from the soil to support aboveground plant growth. Organic matter aids in the absorption of nutrients, trace elements, and cations needed by the plant (Teague et al., 2011). It also prevents nutrient leaching and it generates organic acids that increase nutrient availability (Teague et al., 2011). Other benefits can also be derived from organic matter, including soil structural stability, increased cation exchange capacity (CEC), increased water holding capacity, and buffering of soil pH (Teague et al., 2011). Additionally, soil organic matter influences the microbial population responsible for the breakdown of organic material. Soil microorganisms regulate the transformation and storage of nutrients (Horwath and Paul, 1994). Therefore, because soil organic matter can modify the formation of the microbial community responsible for producing enzymes (Browman and Tabatabai 1978), management

practices that minimize the addition of organic matter into the soil may reduce the activities of enzymes produced by the microbial community and impact the ability of the soil ecosystem to supply nutrients needed to support plant growth (Ajwa et al., 1998). Enzymes produced by the microbial community are an essential component in catalyzing reactions that are necessary for organic matter decomposition and nutrient cycling in the soil (Ajwa et al., 1998). Enzyme activity in the soil changes more quickly than other soil properties, allowing for earlier indications of soil quality improvements or degradations (Dick et al., 1996). Dehydrogenase is an enzyme that can be used as a measure of soil microbial activity (Dick et al., 1996). Thus, soil plays an important role in any grazing system by supporting plant growth which is then consumed by the grazing animals.

At the initiation of the study three alternate hypotheses were outlined: 1) biomass production will be lower in the mob grazing treatments compared to the continuous and rotational grazing treatments because the plants will be grazed at a later growth stage thus limiting regrowth potential, 2) forage quality will be poorer in the mob grazing treatment compared to the rotational and continuous treatments due to the plants being grazed at a later growth stage, and 3) the increased trampling and defoliation of unutilized forage will result in an increase in soil enzyme activity and microbial biomass in the mob treatment compared to continuous and rotational treatments. Finally, our null hypothesis was that no impacts would exist from the different grazing treatments on forage production, forage quality, and soil properties. The objectives of this study were to determine the impact of continuous, rotational and mob grazing on forage biomass production and forage quality, of smooth bromegrass pastures and to determine the impact of the three grazing management practices on soil dissolved organic carbon, microbial biomass carbon, and dehydrogenase potential enzyme activity.

Methods and Materials

The trial design was a randomized complete block design with three treatments (continuous, mob, and rotation) and four replications of each treatment. Each mob and rotation treatment had a paddock area of 10 X 15 meters and the continuous paddock areas were 40 X 10 meters. Continuous paddocks were sized to support two sheep while the rotational paddocks supported seven sheep and the mob paddocks supported 25 sheep. Sheep were grazed for one to two days in the rotational paddocks and for 24 hours in the mob paddocks. Continuous paddocks

were grazed as long as sufficient forage was available. Mob paddocks were grazed no more than two times per year; while, the rotational and continuous paddocks were grazed an unlimited number of times as long as grazing parameters were met.

Grazing Parameters

Grazing parameters were determined based on the physiological state of sheep and potential dry matter intake (New Zealand Sheep Council 1994). Dry ewes were used and pasture condition was assumed to be average. Based on the number of animals present in each paddock, animal potential dry matter intake and assumed pasture condition, the grazing parameters were calculated for each paddock. Grazing for the continuous treatment began in the spring as soon as forage accumulation was at least 1500 kg DM ha^{-1}; and was terminated when forage biomass fell below 1500 kg DM ha^{-1}. Before grazing began, forage was allowed to accumulate to levels greater than 1500 kg DM ha^{-1} in order to maintain at least 1500 kg DM ha^{-1} during the study. A pre-grazing level of 4500 kg DM ha^{-1} and a post-grazing level of 1000 kg DM ha^{-1} were set for the mob treatments and a pre-grazing level of 2500 kg DM ha^{-1} and a post-grazing level of 1500 kg DM ha^{-1} were set for the rotation treatments.

Soil Measurements

Prior to grazing, soil samples were collected from each paddock. In 2012, 5 to 10 soil cores per paddock were collected from 0-5 and 5-10 cm (by 25 mm diameter) soil depths and homogenized. These samples were analyzed for soil pH, mehlich-III phosphorus, potassium, total carbon (TC), and total nitrogen (TN) and served as baseline measurements (Table 2.1). In 2013, soil samples were collected at a depth of 0-10 cm (by 25 mm diameter) at the initiation (spring) and conclusion (fall) of grazing. Sample analyses included dissolved organic carbon (DOC), microbial biomass carbon (MBC), and dehydrogenase enzyme potential activity.

Dissolved Organic Carbon Analysis

A single extraction approach was employed for the determination of DOC. Soil (8.0 ± 0.05 g moist) was extracted with 0.5 *M* K_2SO_4 at a ratio of 1:5 soil-to-solution (wt: vol). Samples were shaken for 1 hour on a reciprocating shaker and filtered through Whatman #42 filter paper (Jones and Willett, 2006). The concentration of DOC in the extracts was determined

by combustion in a Shimadzu TOC-L PC-controlled total organic carbon analyzer (Shimadzu, Columbia, MD).

Microbial Biomass Carbon Analysis

Microbial biomass carbon was determined by the chloroform-fumigation-extraction method. A second soil sample was weighed as described above and fumigated with ethanol-free chloroform (25 mL) for 24 hours in a vacuum desiccator lined with moist paper towels to maintain humidity. The desiccator was evacuated with a vacuum pump until the chloroform boiled vigorously for two minutes and was then sealed to maintain the vacuum. Following the incubation period, the residual chloroform and paper towels were removed. Remaining chloroform vapors were then removed by evacuating each desiccator 6 times for 3 minutes each, allowing air to pass back into the desiccator between each interval (Vance et al., 1987; Horwath and Paul, 1994). The fumigated soil was extracted and analyzed for DOC as previously described. Microbial biomass C was calculated as the difference in DOC between the fumigated and unfumigated extracts; no correction factor was applied.

Dehydrogenase Enzyme Potential Activity Analysis

Dehydrogenase enzyme activities were based on colorimetric determination of 2, 3, 5-triphenyl formazen (TPF) produced during the reduction of 2, 3, 5-triphenyltetrazolium chloride (TTC) by soil microorganisms. Soil (3.0 ± 0.05 g moist) was mixed with 3.0 mg of $CaCO_3$, 0.5 ml of 3% TTC solution, and 1.25 ml water, and incubated at 37°C for 24 hours. Following incubation, 5.0 mL of methanol was added, the soil solution vortexed for 1 minute, and filtered through Whatman #40 filter paper. All soil was quantitatively washed from the test tube and the filter paper rinsed with methanol until the reddish color was gone. Filtrate volume was adjusted to 50 mL and absorbance measured at 485 nm (Casida et al., 1964; Tabatabai, 1994).

Plant Measurements

Direct measurements:

Direct measurements of forage biomass were made by clipping three ~0.1 m^2 areas per paddock using motorized hand shears, drying the sample collected at 50˚C for 48 hours, and weighing the dried sample. Sample locations were randomly chosen along a line transect within each paddock. Sampling occurred in 2012 immediately before animals were turned out onto the

paddocks and again following animal removal from paddocks. The rotational and mob treatment paddocks were directly measured immediately before and after grazing to determine pasture mass. The sample period lasted from March through October 2012. A final season measurement was taken from each paddock on October 26, 2012, to determine the final biomass and quality components (i.e. ADF, NDF, and CP) for the first year. To measure pasture mass accumulation rate in the continuous treatment, exclusion cages were used. Exclusion cages stopped the sheep from grazing small areas of the paddock. A cage was placed over an area and the forage was allowed to regrow for a set period of time. After the regrowth period the herbage that had accumulated was cut back to the standard height and cut material was dried for 48 hours at 50^{o}C then weighed to determine the dry matter content of the material cut from under the cage.

In 2013, there was one pre-trial sampling of all the paddocks that occurred before grazing to assess forage biomass and quality components (i.e. ADF, NDF, and CP). Exclusion cages were also placed in the continuous treatment to measure pasture growth beginning on April 21, 2013. Sampling then followed a similar protocol to year one with forage biomass samples being collected pre- and post-grazing in each paddock. Additionally, there was one mid-season sample collection from all paddocks on May 7, 2013 to determine the pasture quality components (i.e. ADF, NDF, and CP), and growth within the exclusion cages. The sample period lasted from April through October of 2013. A final season measurement was taken from each paddock on October 10, 2013 to determine the final biomass and quality components (i.e. ADF, NDF, and CP) for the second year.

Indirect Measurements:

Indirect measurements were made using a Farmworks raising plate meter (RPM) model F200 (DairyNZ, Waikato, NZ). Every time pasture mass was measured directly by clipping a frame, a RPM reading was first taken to measure the pasture height of the clipped area. These pasture mass and height measurements were used to improve the accuracy of the existing default calibration equation of the RPM.

The RPM pasture height/mass measurements were used to make grazing management decisions for each treatment. All paddocks were measured every week using the RPM. Fifteen readings from within each paddock were taken and averaged to determine the RPM measurement for each paddock. These RPM measurements were used to determine when grazing should

commence for the rotational and mob paddocks. They were also used for continuous paddocks to determine the relationship of pasture mass to the targeted mass.

Forage disappearance was estimated using the pre- and post-grazing rising plate measurements. Disappearance in the continuous, mob, and rotational treatment paddocks was determined by: pre-grazing – post-grazing RPM for each grazing event and then summation of each of the treatment replications total after the pre-post calculation was taken. The summation total was then averaged across the 4 replications in each treatment to determine the forage disappearance in each treatment throughout the grazing season in kg DM ha^{-1}.

Forage Quality Measurements

Pasture quality differences between the treatments were determined by homogenizing pasture material from subsamples taken from 15 random locations in each paddock. These subsamples were collected by hand grabbing. Once samples were collected, they were placed in a dryer at 50ºC for 48 hours and then ground using a Wiley Mill through a 2 mm sieve. Samples were analyzed for acid detergent fiber (ADF), neutral detergent fiber (NDF), and crude protein (CP).

Acid detergent fiber and NDF contents were determined using an A200 Fiber Digester (Ankom Technology, Macedon, NY). Nitrogen concentrations of the smooth brome forage were determined by combustion using a Nitrogen Analyzer Model FP-2000 (LECO Corporation, St. Joseph, MI). The crude protein content of the samples was calculated as nitrogen (N) x 6.25 (FAO 2003).

Forage Class Composition Measurements

Samples collected for forage class compositions were cut at ground level from an area 7.62 x 45.72 cm along a line transect in each paddock. Three samples were collected from each paddock. Samples were collected three times each grazing season in May, June, and October. Samples were placed in labeled cloth bag at the time of collection and then stored at 5˚C to keep samples from decomposing. Forage class samples were broken into 3 classes: grass, forbs, and dead plant materials. Once sorted into forage classes, plant materials were placed in labeled paper bags, dried at 50ºC for 48 hours and weighed. The percent of total sample was determined for each class.

Grazing Events

In 2012, grazing events for all treatments were limited to a single grazing season that lasted from April through July. Five rotational and 1 mob grazing event occurred (Table 2.2). Continuous grazing occurred from April 2 to April 16 when sheep were removed due to insufficient forage. Grazing in the continuous treatments resumed May 1 and lasted until May 14 when again there was not enough forage present to support animal needs. The final continuous treatment grazing period lasted from June 29 to July 13, in 2012 (Table 2.2). More favorable conditions in 2013 allowed for two mob and five rotational grazing events (Table 2.2). Continuous paddocks were grazed beginning on April 21 but a snow storm and freezing conditions between April 23 and 24 necessitated that sheep be removed and delayed grazing until May 1. Grazing continued until June 25 with sheep being released again to graze in the fall on September 5 until October 10, 2013 (Table 2.2). Measurements were taken from March to October in 2012 and April to October in 2013.

Statistical Analysis

Data were analyzed as a random complete block design with 3 treatments and 4 replications per treatment using the PROC GLM procedure and least-squares difference (LSD) model fit for total biomass accumulation and forage disappearance analysis. The classes were treatment and rep with the model as total equals treatment. PROC MIXED procedure and the standard least-squares model fit (SAS Inst. Inc., Cary, NC) to test forage quality and forage class composition. The random effect was replication with class as date, treatment, and replication. An alpha level of $P< 0.05$ was used for significance in forage quality and forage class composition analysis. Weekly rising plate meter data was analyzed using PROC MIXED with the weekly data pooled by month (SAS Inst. Inc., Cary, NC). The classes were treatment, replication, year, and date and the random effects were year, replication (treatment x year), and date*replication (treatment x year). A significance level of $P<0.10$ was used to report tendencies in the data.

Results and Discussion

Weather

Temperature data from 2012 (Figure 2.1a) indicated that the maximum temperature was or exceeded 38°C on 26 days during the summer dormancy period. These high temperatures

limited the growth of the smooth brome given that growth of cool-season forage species stops when temperatures exceed 32°C (Smith 1962). Temperatures during the spring and early summer grazing season in 2012 were greater than temperatures during the spring grazing season of 2013. Precipitation data from 2012 indicated that the spring grazing season was drier than 2013, as precipitation totals from March to July were 24.5 and 33.8 cm for 2012 and 2013 respectively. Although more intense rainfall events occurred in 2012, the precipitation data for 2013 (Figure 2.1b) indicates that smaller, more frequent rainfall events occurred, leading to a wetter growing season. The lower temperatures and more rainfall in 2013 provided better growing conditions for the cool-season forage than conditions in 2012.

Available Forage

Total aboveground forage biomass was not different between the three treatments in both years throughout the grazing seasons of the trial. There were no differences between the three treatments at the conclusion of each year according to frame clippings taken in each treatment. The overall average readings of the weekly rising plate meter (RPM) measurements were also not different at $P<0.05$, indicating agreement between the frame clippings and the rising plate meter. A tendency indicated in the RPM data suggested that the accumulated aboveground available forage was higher in the mob treatment while the rotation and continuous treatments were not significantly different at the $P<0.1$ level (Table 2.3). At the time of grazing, the mob treatments provided a greater amount of forage readily available to the animals than the other two treatments. Although greater forage biomass was allowed to accumulate in the mob treatments, these treatments were also grazed to lower levels of remaining biomass, and based upon visual observations, required a longer time for forage regrowth. Repeated frequent defoliation was found to decrease root biomass and root nitrogen reserves, while carbon allocation to leaves was enhanced at the expense of the root biomass (Turner et al., 1993; Schuman et al., 1999). A multi-year study would need to be established to evaluate the overall impact of mob grazing on stand persistence in smooth bromegrass. Holland and Detling (1990) found that root production could be less affected by defoliation events if an adequate rest period is utilized.

Rotational and continuous treatments resulted in similar biomass accumulations when measured weekly using the RPM. Oates et al. (2011) found that management of the spatial

distribution of livestock and the timing of defoliation influenced biomass production and root biomass. Paine et al. (1999) also found that forage biomass was allowed to accumulate throughout the season in certain areas as cattle tended to return and repeatedly graze areas where new grass continually grew.

Forage disappearance in all treatments was not different in 2012 and 2013 at the $P < 0.05$ (Figure 2.2). Forage disappearance in the continuous, rotational and mob treatments was approximately 5000 kg DM ha^{-1}in 2012 and approximately 6000 kg DM ha^{-1} in 2013 (Figure 2.2). Although the stocking densities were not equivalent (Table 2.4 & 2.5), with the mob treatment carrying more kilograms of sheep per ha than the other treatments, there was no difference in the amount of forage disappearance. With the larger stocking density in the mob treatment, harvest efficiency could have increased as well as the total product kilograms per hectare compared to the other treatments. More total kilograms per hectare would result in more potential profits for producers. Paine et al. (1999) observed animals under continuous grazing management repeatedly returned to areas in the pastures where new grass was growing while avoiding other areas, as sheep select leaves over stems (Arnold 1960) and green material over non-green material (Arnold 1964; Hamilton et al., 1973. Teague and Dowhower (2003) indicated that low to moderate stocking rates allows for greater selectivity, than higher stocking rates. Another factor that could have affected the forage disappearance in each treatment is the biomass present as it is a function of plant growth and senescence each day. Forage biomass production is affected by environmental factors (i.e. precipitation and temperature), and the treatments in this study all had similar biomass accumulations when summed over the entire grazing season. The exclusion cages used to determine forage disappearance in the continuous treatment may not have adequately captured the forage production as animal selection and consumption could affect forage production rates.

Forage Quality

Analysis of CP, NDF, and ADF revealed date x treatment effects for spring and fall 2013 (Figure 2.3). An inverse relationship was present between CP and fiber components over time during spring 2012 and spring 2013. Results from this study supported our hypothesis that pasture quality declines in a mob grazing system, as ADF & NDF contents where higher and CP was lower at the time of grazing compared to the initiation of grazing in the rotational or

continuous treatments. In contrast, the forage quality in the continuous treatment compared to the rotational treatment was similar. The only difference in forage quality between the two treatments in this study were found at the time of spring grazing termination and fall grazing termination in 2013. Thus the continuous and rotational treatment paddocks in this study were found to have similar forage quality.

Lower quality in the mob treatments can be accounted for by the higher levels of fiber that were present as the plants matured throughout the growing season. The plants in the mob treatment were more mature and had greater ADF and NDF fiber components and less CP than the plants in the rotational treatment (Figure 2.3), which agreed with the findings of Brundage and Petersen (1952).

Soil Properties

No significant differences were present in dissolved organic carbon between treatments across the spring and fall sampling (Table 2.6). According to Jones and Willett (2006), the dissolved organic nutrients often are the more dominant elemental form in many soils compared to inorganic. Microbial mediated processes influence ecosystem functions that are related to nutrient cycling, soil fertility, and soil organic matter turnover; therefore, the size and activity of the microbial community is an important driver of nutrient fluxes that occur in both natural and managed ecosystems (Horwath and Paul 1994). No significant grazing treatment differences were observed for MBC or dehydrogenase in the spring or fall (Table 2.6). The spring sampling had significantly lower microbial biomass carbon and dehydrogenase than the fall sampling (Table 2.6). The greater microbial biomass and dehydrogenase in the fall could possibly be attributed to the larger amounts of observable plant litter that was available for incorporation into the soil in the fall versus the spring. This is speculation which is consistent with the observations of Garcia and Rice (1994) that MBC increases in response to aboveground litter accumulations and root biomass decay in the fall. Another possible explanation for the differences in MBC and dehydrogenase could be related to belowground root dynamics that were not measured in this study. Garcia and Rice (1994) indicated that short-term microbial biomass dynamics could be associated with root dynamics and the translocation of carbohydrates from aboveground to below ground plant parts. Temperature and moisture may have also influenced these measurements. Weather data from 2013 (Figure 2.1b) indicated that the fall sampling period had warmer soil

temperatures in the month of October, however, there was less precipitation that occurred during the fall sampling period. As microbial biomass and dehydrogenase activity are sensitive to temperature and moisture these factors could have contributed to the observed differences between the two sampling periods.

The MBC and dehydrogenase results supported the conclusion that, in the short term, the belowground soil community is more influenced by seasonal conditions i.e. temperature and moisture and historical management than by the introduction of new grazing management practices. While no changes were observed in response to the grazing treatment in this study, enzyme activities can be sensitive to changes in soil management (Dick 1994). Dehydrogenase is an enzyme that has been shown to be sensitive to soil management effects (Doran 1980; Dick et al., 1988; Martens et al., 1992). However, it is less suitable in projecting permanent changes in overall soil quality as it is unable to accumulate in complex forms within the soil; thus, it is more appropriately used as an indicator of the viable microbial population (Dick et al., 1996). The similar increase in MBC and dehydrogenase activity among treatments in the fall supports the conclusion that dehydrogenase is an indicator of the activity of the viable microbial population. Given sufficient time, grazing management practices that promote soil quality should support increased biological activity as indicated by greater enzyme production (Dick et al., 1996).

Forage Class Composition

Forbs increased significantly in the continuous treatment from the May to June sampling in 2012 (Figure 2.4a). This same trend was not observed in 2013 (Figure 2.5a) and in contrast to 2012 forbs where less than 20% of the pasture composition. Grasses as a percentage of the total composition decrease in the continuous treatment between the May and June sampling periods of 2013 (Figure 2.5 a). Forbs comprised 20% or less of the species composition in the rotational treatment in 2012 (Figure 2.4 c) and 2013 (Figure 2.5 c). Dead plant material increase from the May to June sampling in 2012 (Figure 2.4 c) and 2013 (Figure 2.5 c). In 2013 a significant increase was also measured from June to October (Figure 2.5 c) in rotation treatments. The proportion of grasses in the rotational treatment decreased significantly from May to June in both 2012 and 2013 and continued to decline from June to Oct in 2013. The proportion of grass in the mob treatment decreased from greater than 80% at the May sampling to less than 50% in the June sampling in 2012 (Figure 2.4 b) and 2013 (Figure 2.5 b). During this same time period dead

plant material increased from less than 20% to greater than 40% of the aboveground plant material. Forb comprised less than 30%, present of the pasture composition in both years.

The May sampling in 2012 and 2013 had higher proportions of grass than the June or October sampling dates (Figure 2.4 & Figure 2.5) in all treatments. This result is not unexpected given that smooth bromegrass is a cool-season forage. The majority of the total seasonal growth of cool-season grasses occurred in the spring with as much as 60% of the growth being attained by July (Riesterer et al., 2000). Others have also reported production peaks early in the growing season with production declining as the growing season progresses (Paine et al., 1999; Phillip et al., 2001; Popp et al., 1997).

Conclusions

The results of this study do not support our hypothesis that the mob treatment would have less biomass production because mob treatments produced the same amount of biomass as continuous and rotational treatments. However as trends in the data from this study would suggest, as biomass accumulation is very important in all production systems; thus, if a producer's goal is to amass usable forage, he or she could consider the mob grazing technique instead of using a conventional grazing technique like rotational or continuous grazing. However, if pasture quality is the main concern when developing a grazing management plan, mob grazing techniques are not as beneficial as a rotational or continuous grazing system. The results of this study did support our second hypothesis that mob grazing would have lower forage quality.

The results in this study indicate that belowground soil quality factors were influenced more by climate or by belowground root dynamics and not by grazing systems, which did not support the hypothesis that mob grazing trampling and defoliation effects would increase enzyme activity and microbial biomass. Soil quality parameters require a period of time before detectable change occurs. It is possible that the influences of this trial's two years of grazing has not been long enough to observe a measureable change in the size and activity of the soil microbial community.

Figures and Tables

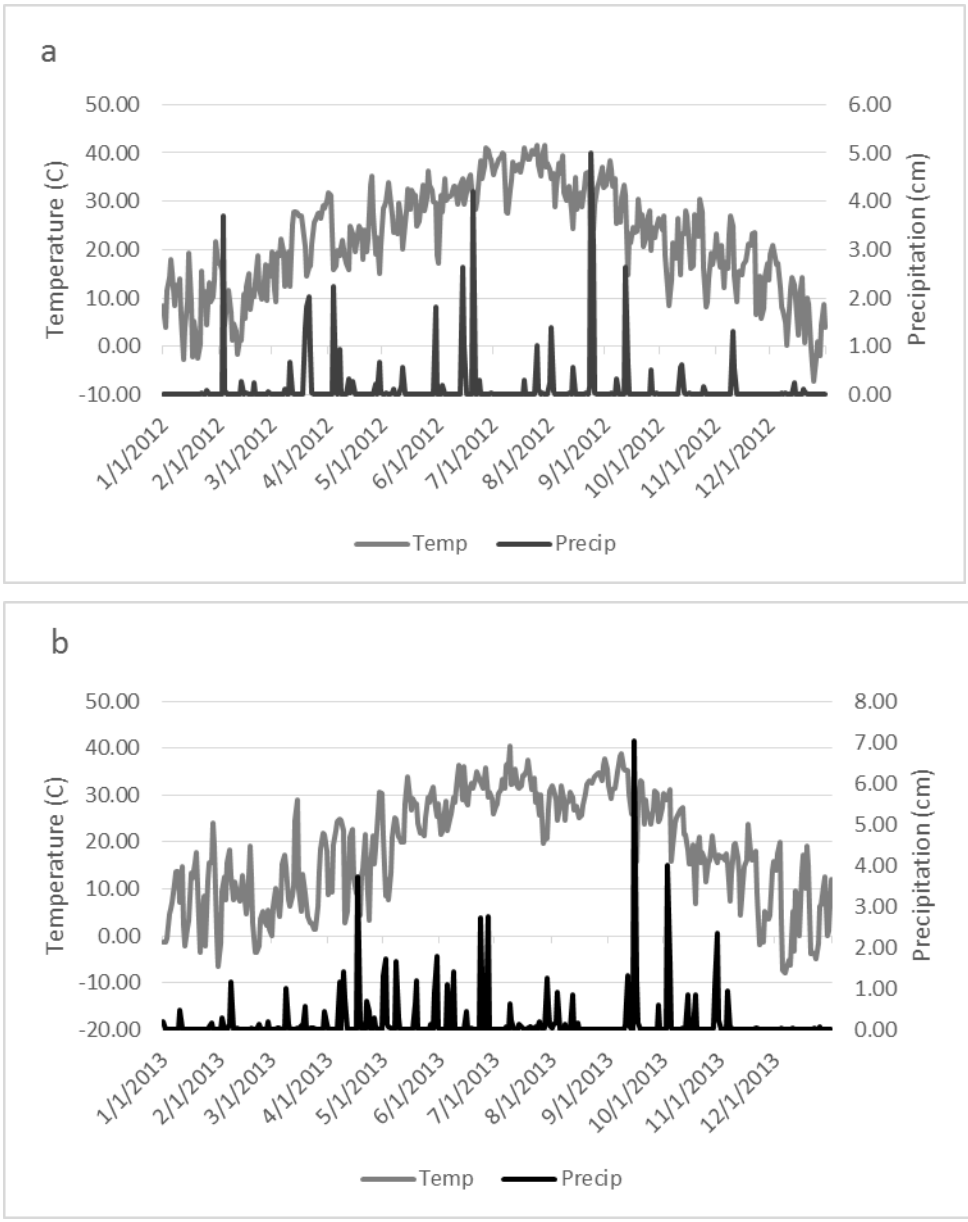

Figure 2.1. 2012(a) and 2013(b) temperature and precipitation data for Manhattan, KS, North Agronomy Farm.

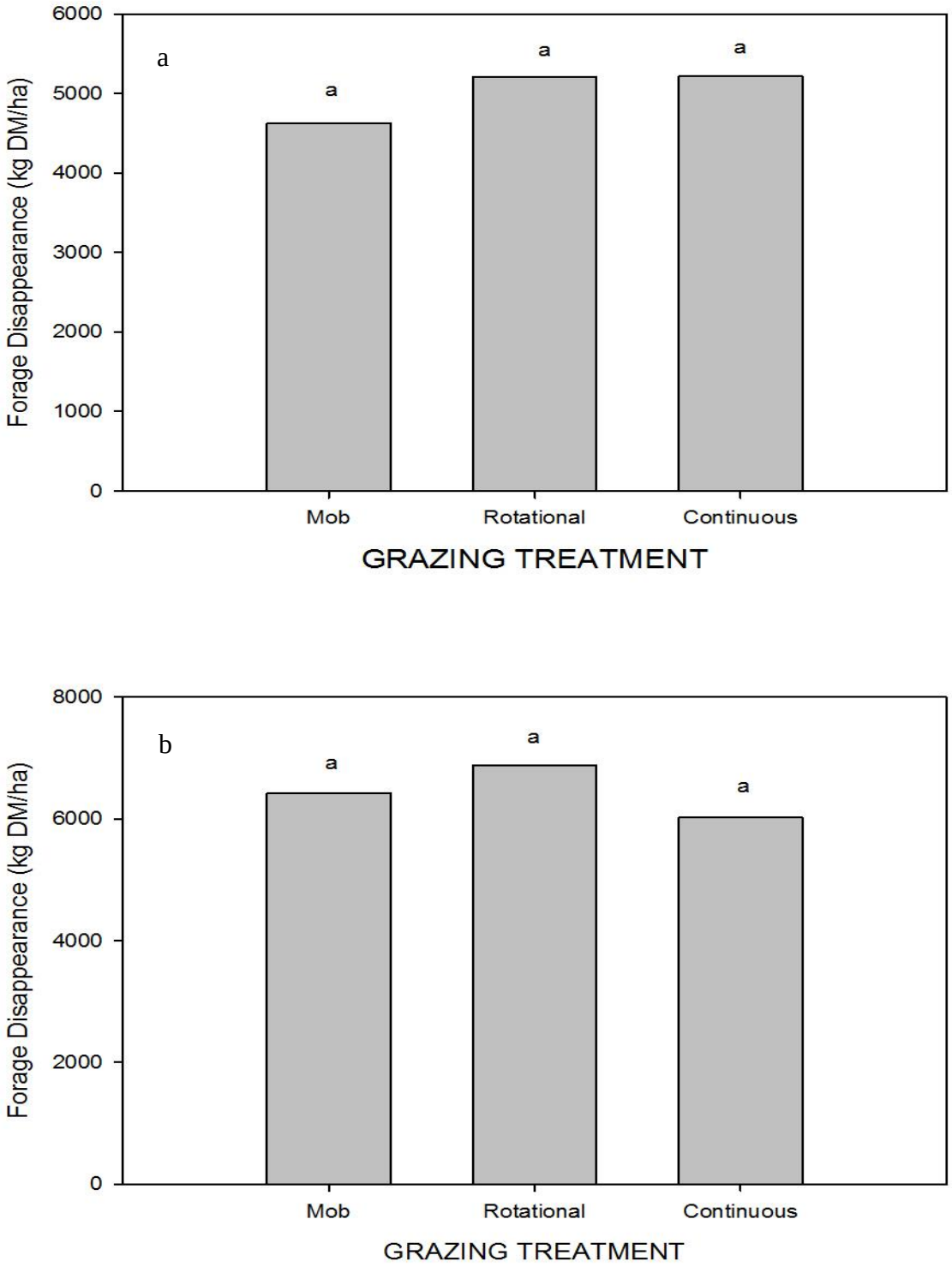

Figure 2.2 Forage Disappearance in kg DM/ha for all treatments in 2012(a) and 2013(b). Different letters indicate a significant difference at $p<0.05$.

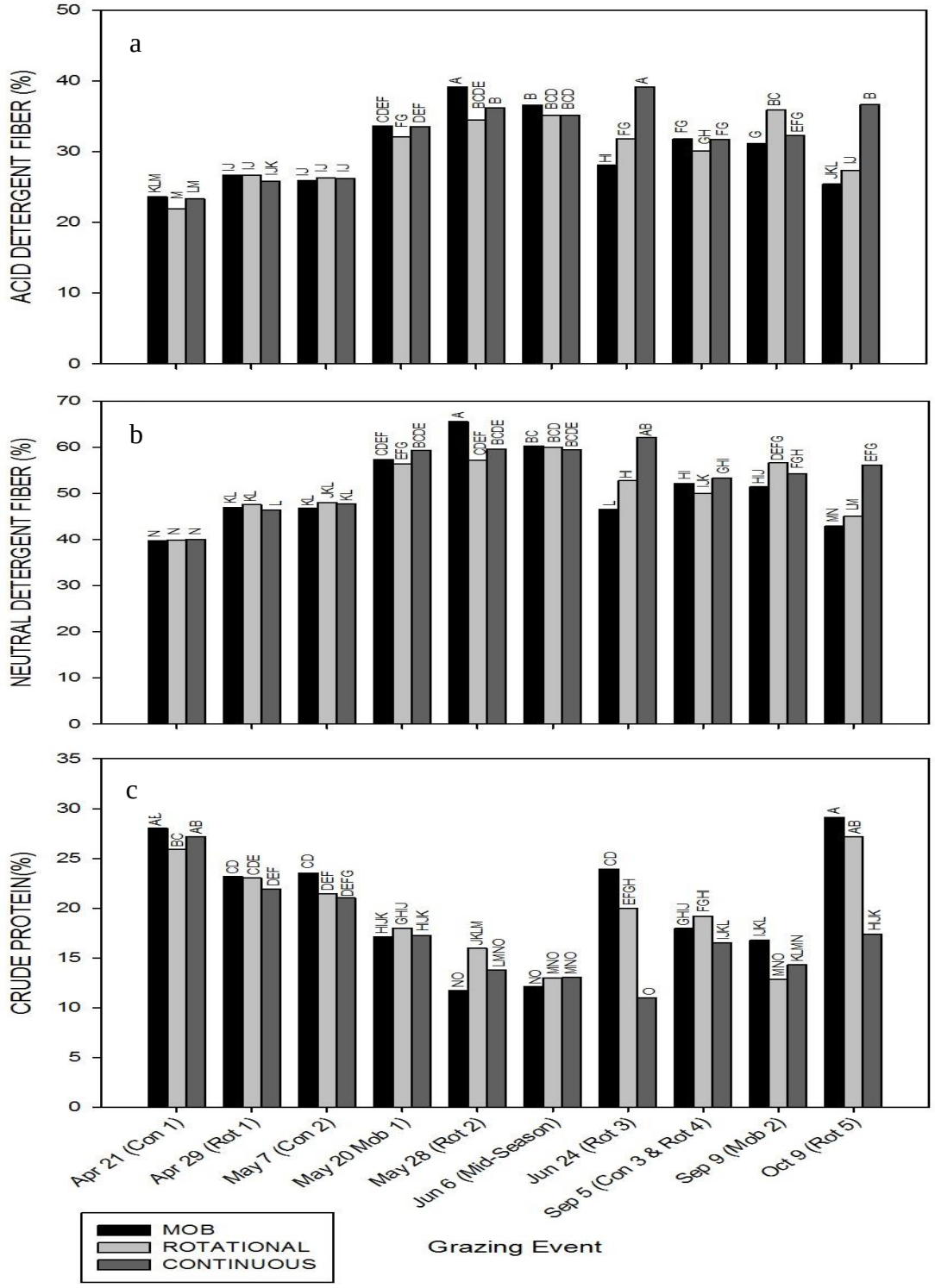

Figure 2.3 Acid detergent fiber (a), neutral detergent fiber (b), and crude protein (c) during the spring and fall 2013 grazing season. LSD to determine treatment by date significant differences are ADF 2.28, NDF 3.4, and CP 3.14 ($p<0.05$).

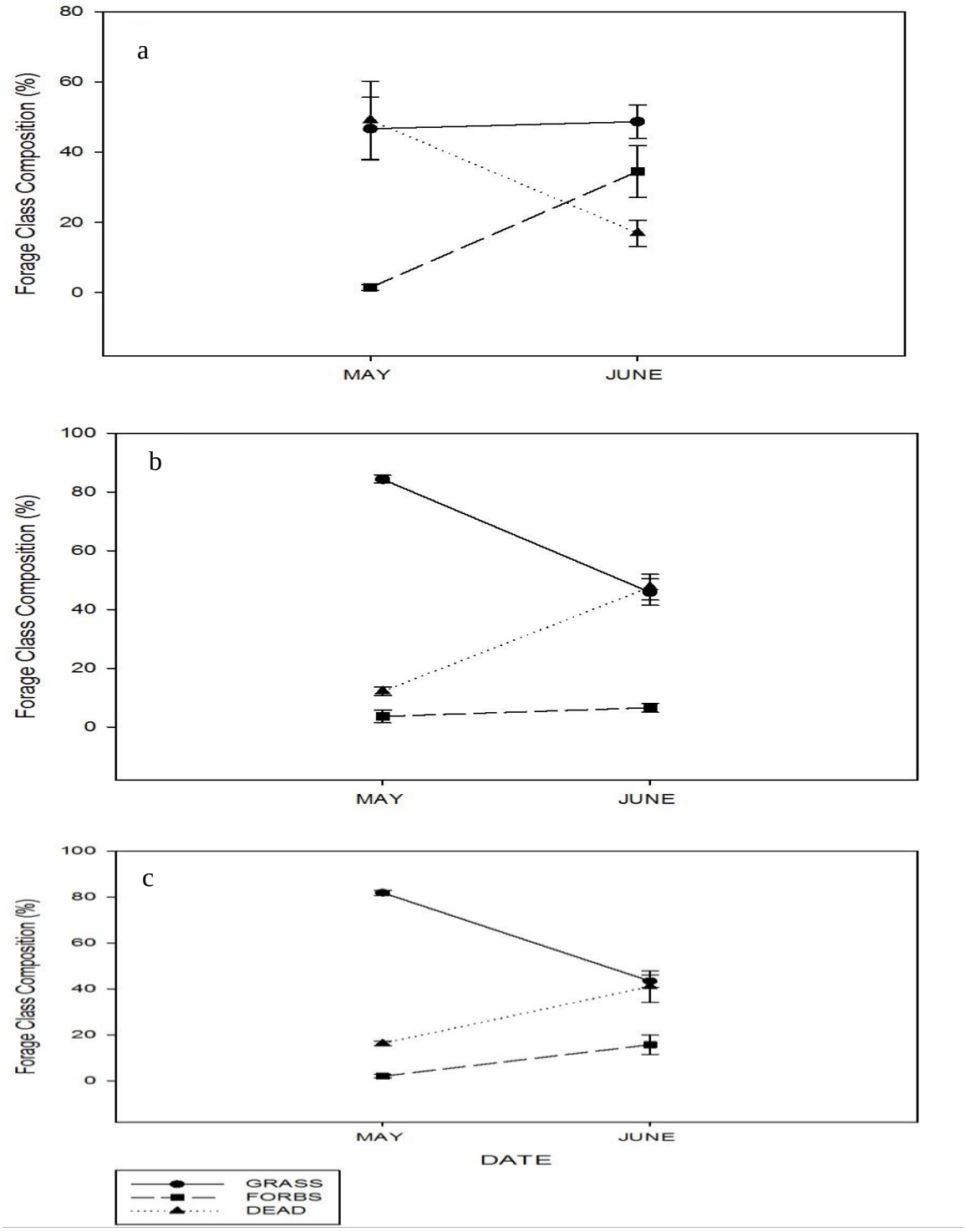

Figure 2.4 Forage class composition continuous (a), mob (b), and rotational (c) during the 2012 grazing season. LSD to determine significant differences are grass 12% forbs 11%, and dead 13% ($p<0.05$).

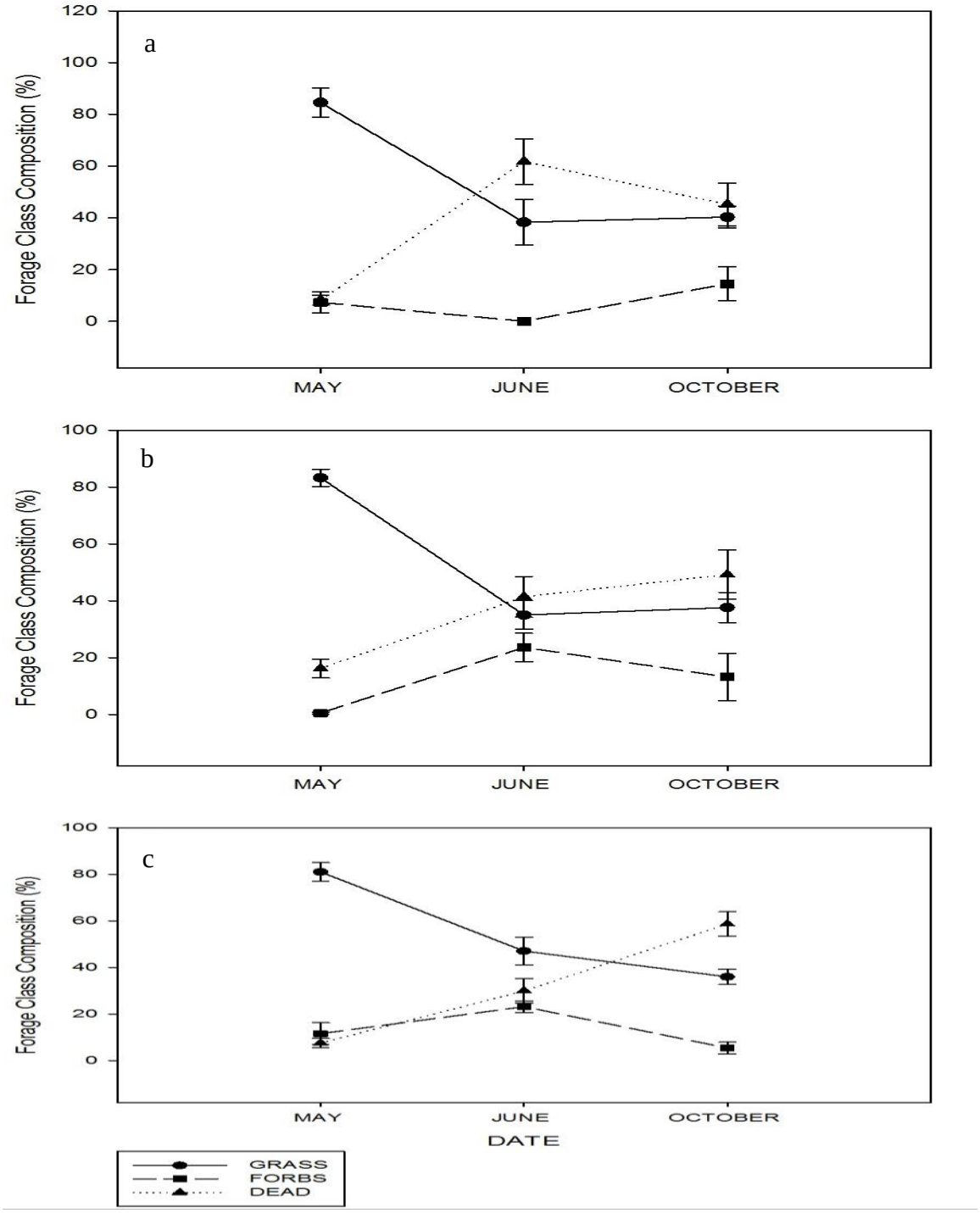

Figure 2.5 Forage class composition continuous (a), mob (b), and rotational (c) during the 2013 grazing season. LSD to determine significant differences are grass 12%, forbs 11%, and dead 13% ($p<0.05$).

Table 2.1 Soil pH and nutrients concentrations for the three treatments prior to the initiation of grazing in 2012.

Treatment[1]	pH	Mehlich-III P	K	Total N	Total C
		ppm	ppm	%	%
CONTINUOUS	7.09 a[2]	414 a	1305 a	0.42 a	4.46 a
ROTATIONAL	7.05 a	472 a	1453 a	0.43 a	4.65 a
MOB	6.94 a	373 a	1204 a	0.41 a	4.39 a

[1] Treatments represented are continuous grazing (CON), rotational grazing (ROT), and mob grazing (MOB).

[2] Different letters in the same column indicate a significant difference ($P \leq 0.05$)

Table 2.2 Grazing dates for both trial years of 2012 and 2013 for all treatment paddocks.

Grazing Dates										
	2012					2013				
CONTINUOUS[1]	4/2 to 4/16	5/1 to 5/16	6/29 to 7/13			4/21 to 4/30	5/1 to 6/25	9/5 to 10/10		
Mob[2]	4/25 to 4/26					5/20 to 5/21	9/9 to 9/10			
ROTATIONAL[3]	4/2 to 4/3	4/18 to 4/19	5/11 to 5/12	7/11 to 7/12	7/24 to 7/25	4/29 to 4/30	5/28 to 5/29	6/24 to 6/25	9/5 to 9/6	10/9 to 10/10

[1] (2 Sheep/Paddock/Grazing period)

[2] (25 Sheep/Paddock/Grazing period)

[3] (7 Sheep/Paddock/Grazing period)

Table 2.3 Aboveground forage available in each treatment as measured by the weekly rising plate measurement. Results are significant to the p<0.1 level.

	Forage Available
Continuous	2759 b
Mob	3019 a
Rotation	2699b

[1] Different letters in the same column indicate a significant difference (P≤0.1)

Table 2.4 Stocking rate and stocking density of each grazing treatment paddock in the 2012 grazing season.

	Stocking Rate		Stocking Density	Paddock size
	AU[1] Days/ trt ha	AUM[2] / ha	Kg[3] / ha	ha
Continuous	18	15	8000	0.04
Mob	5	11	266667	0.015
Rotation	7	15	74667	0.015

[1] AU is the abbreviation for animal unit.

[2] AUM is the abbreviation for animal unit months.

[3] The estimated weight for a dry ewe was 160 pounds or about 72.6 kilograms.

Table 2.5 Stocking rate and stocking density of each grazing treatment paddock in the 2013 grazing season.

	Stocking Rate		Stocking Density	Treatment Hectares
	AU[1] Days/ trt ha	AUM[2] / ha	Kg[3] / ha	trt ha
Continuous	41	34	8000	0.04
Mob	10	22	266667	0.015
Rotation	7	16	74667	0.015

[1] AU is the abbreviation for animal unit.

[2] AUM is the abbreviation for animal unit months.

[3] The estimated weight for a dry ewe was 160 pounds or about 72.6 kilograms.

Table 2.6 Soil analyses data from the spring and fall of 2013 at the p<0.05 level.

	Treatment	Dissolved Organic Carbon	Microbial Biomass Carbon	Dehydrogenase Enzyme Activity	Soil Gravimetric Water
		µg g^{-1}		µg TPF g^{-1} soil 24 hr^{-1}	g/g
Spring	Continuous	139.6 a[1]	266.5 b	179.4 b	0.30 a
	Mob	136.0 a	311.6 b	178.1 b	0.31 a
	Rotation	148.3 a	274.9 b	238.5 b	0.30 a
Fall	Continuous	130.8 a	749.4 a	934.1 a	0.38 a
	Mob	145.5 a	710.3 a	792.0 a	0.39 a
	Rotation	149.2 a	730.5 a	964.0 a	0.38 a

[1] Different letters in the same column indicate a significant difference (P≤0.05)

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Appendix A - Detailed Methods

Chloroform Fumigation Extraction (Microbial Biomass Carbon)

Background Information

Soil microbial biomass is a measure of the size of the microbial community in a given environment. Chloroform fumigation extraction, is one of several methods for determining the size of the microbial community. The chloroform vapors that the samples are exposed to kill the living organisms in the soil resulting in a flush of C, N and P as the microbial cells break apart. Thus by measuring the dissolved organic carbon in a fumigated and unfumigated sample it is possible to estimate the size of the microbial community (Vance et al 1987).

References

1. Vance, E.D., P.C. Brookes, & D.S. Jenkinson. (1987) An extraction method for measuring soil microbial biomass C. Soil Biology and Biochemistry 19,703-707.

Required Reagents:

1. 0.5 M K_2SO_4
   a. Bring to volume (2 L) with mili-Q water.
   b. Dissolve 174.26 g K_2SO_4 in ~1800 mL mili-Q water in 2 L volumetric flask
2. Ethanol-Free Chloroform (either stabilized with amylene, or distilled)

Required Equipment:

Oscillating shaker
Vacuum Dessicator
Fumehood
TOC Analyzer

Protocol

Extraction:

1. Setup Notebook
2. Label glass biomass jars
3. Prepare two sets of samples (One set for fumigated, one set for unfumigated)
4. Duplicate 10% of samples
5. Weigh 8 g of moist soil into jars
6. Add 40 mL 0.5 M K_2SO_4 into the unfumigated samples (1:5; soil: extractant)
7. Cap and shake for 30 min at slow speed in oscillating shaker
8. While the unfumigated extraction is shaking, begin chloroform fumigation.
9. Place 3 wet paper towels around the inside edge of the vacuum desiccator, and put biomass jars containing the soil inside.
10. Add a 100mL beaker containing ~4 boiling chips and about 25 mL chloroform.
11. Attach the vacuum desiccator to the vacuum pump and evacuate until the chloroform boils for 5 min.
12. Once the chloroform boils for 5 min, close the desiccator valve and disconnect from the pump.
13. Incubate in fumehood for 24 hours
14. Filter unfumigated through Whatman 42 filter paper (11 cm diameter) into 40 mL borosilicate vials.
15. Make sure all soil particles have been filtered out.
16. Store at 4˚C until ready to be analyzed for C
17. After 24 hours, release the vacuum and remove the chloroform and paper towels from the vacuum desiccator
18. Evacuate the vacuum desiccator for 3 min
19. Vent to the atmosphere
20. Repeat vacuum and release 6 times
21. Extract the fumigated soils as in the unfumigated (Steps 5, 6, 13, 14, 15)
22. Analyze samples for non-purgable organic carbon (NPOC) on a TOC analyzer
23. Determine MBC by ($Fumigated_C$ – $Unfumigated_C$)

Dehydrogenase

Background Information

Dehydrogenase enzymes are an indicator of microbial activity and soil health. This group of enzymes plays an important role in catalyzing reactions that are necessary for organic matter decomposition and nutrient cycling. 2, 3, 5-Triphenyltetrazolium chloride (TTC) is added to each sample and mixed thoroughly. Then the samples are allowed to incubate for a 24 hour period during which time the enzymes are breaking down the TTC to produce the end product triphenylformazan (TPF) that turns red when it reacts with methanol. The intensity of intensity of the red color is measured at 485nm wavelength using a spectrometer. Dehydrogenase can be used to indicate the activity of the viable microbial populations that are present within a soil (Casida et al 1964).

References

1. Casida, L.E., Jr., D.A. Klein, T. Santora. (1964) Soil dehydrogenase activity. Soil Science 98, 371-376.

Required Reagents:

1. 2, 3, 5-Triphenyltetrazolium chloride (TTC, 3%)
   a. Dissolve 3.0 g of TTC in ~80 mL mili-Q water
   b. Adjust volume to 100 mL with mili-Q water
2. Triphenyl formazan (TPF, 100µg/mL)
   a. Dissolve 10 mg (0.010 g) TPF in 80 mL of MeOH,
   b. Adjust volume to 100 mL with MeOH
3. Dehydrogenase Standards (make in 50 mL volumetric flasks):
   a. Standard 0: Add 0 mL standard solution to 50 mL MeOH
   b. Standard 250: Add 2.5 mL standard solution to 47.5 mL MeOH
   c. Standard 500: Add 5.0 mL standard solution to 45.0 mL MeOH
   d. Standard 750: Add 7.5 mL standard solution to 42.5 mL MeOH
   e. Standard 1000: Add 10.0 mL standard solution to 40.0 mL MeOH

4. Standard 1250: Add 12.5 mL standard solution to 37.5 mL Methanol (MeOH)

Required Equipment:

Vortex

Incubator

Spectrophotometer

Protocol

Calibration:

Spectrophotometer

Run standard 1 through the spectrophotometer at 485 nm and record absorbance.

Absorbance should be 0.000 or very close.

Continue by running the remaining standards through the spectrophotometer at 485 nm

Record absorbance value

Procedure:

1. Set up table in notebook (sample ID, test tube #, moist soil weight in grams)
2. Label flasks (labels for every sample should include ID, initials, treatment, rep, date, and what you are sampling for)
3. Weigh 3 g of moist soil in test tube
4. Add 30 mg Calcium Carbonate ($CaCO_3$)
5. Add 0.5 mL of TTC solution except to the blanks
6. Add 1.25 mL of MQH_2O
7. Vortex to mix contents
8. Place stopper in test tube
9. Incubate at 37˚C for 24 hours
10. Add 10 mL of MeOH
11. Vortex for 1 min
12. Add 0.5 mL TTC solution to blanks
13. Swirl to mix contents
14. Filter through Whatman 40 filter paper (11 cm diameter) into 50 mL volumetric flasks

15. Wash the test tube with MeOH and quantitatively transfer soil to the filter paper
16. Continue rinsing the paper with MeOH until just before the volumetric reaches 50 mL
17. Measure intensity of red color with spectrophotometer at 485 nm

Acid Detergent Fiber (ADF) Analysis

Background Information

Acid detergent fiber is the fibrous portion of forage or other feedstuffs that contains cellulose, lignin, and silica. ADF is indigestible for the animal and affects digestible energy of a forage or feedstuff. ADF is determined by boiling a sample in an acid detergent solution to remove the digestible components of the forage leaving the ADF portion behind. ADF is used to calculate digestibility as well as total digestible nutrients or net energy for lactation. (University of Georgia, n.d.).

References

1. ANKOM Technology. Acid Detergent Fiber in Feeds-Filter Bag Technique [Online]. Available at: http://www.ankom.com/media/documents/Method_5_ADF_Method_A200_RevE_11_15_13.pdf (accessed 10 November 3013; Verified 18 April 2014). Macedon, NY.
2. University of Georgia. College of Agricultural & Environmental Sciences. Common Terms Used in Animal Feeding and Nutrition [Online]. Available at: http://www.caes.uga.edu/commodities/fieldcrops/forages/glossary/A.html (accessed 10 November 2013; Verified 18 April 2014).

Required Reagents:

1. Acid Detergent Solution (AD Solution; Premixed solution is available from ANKOM.)
   a. Add 20 g cetyl trimethylammonium bromide (CTAB) to 1 L 1.00N H_2SO_4 previously standardized.
   b. Agitate and heat to aid solution.
2. Acetone

Required Equipment:

1. Analytical Balance – Capable of weighing down to 0.1 mg.
2. Oven – Capable of maintaining a temperature of 102 ± 2˚C.

3. Digestion Instrument – Capable of performing the digestion at 100 ±0.5 ˚C and maintaining a pressure of 10-25 psi. The instrument must be capable of creating a similar flow around each sample to ensure uniformity of extraction.
4. Filter Bags – Constructed from chemically inert and heat resistant filter media, capable of being heat sealed closed and able to retain 25 micron particles while permitting rapid solution penetration.
5. Heat Sealer – Sufficient for sealing the filter bags closed to ensure complete closure.
6. Dessicator Pouch – Collapsible sealable pouch with desiccant inside that enables the removal of air from around the filter bags.
7. Marking Pen- Solvent and acid resistant.

Protocol

Preparation of Sample:

Grind samples in a centrifugal mill with a 2 mm screen or cutter type (Wiley) mill with a 1 mm screen. Samples ground finer may have particle loss from the filter bags and result in low values.

Procedure:

1. Use a solvent resistant marker to label the filter bags. Weigh filter bag and zero balance (W_1).

   Note-Do not pre-dry filter bags as any moisture will be accounted for by the blank bag.
2. Weigh 0.45-0.55 grams of prepared sample directly in filter bag. Avoid placing the sample on the upper 4 mm of the bag (W_2).
3. Using a heat sealer, completely seal the upper edge of the filter bag within 4 mm of the top.

   Note-Use sufficient heat to completely seal the filter bag and allow enough cool time (2 sec) before removing the bag from the heat sealer.
4. Place a maximum of 24 bags into the bag suspender. All nine trays should be used regardless of the number of bags being processed. Place three bags per tray and then stack trays on center post with each level rotated 120 degrees. Insert bag suspender with

bags into the fiber analyzer vessel and place the bag suspender weight on top to keep it submerged.

Note-Prior to inserting the bag suspender, if the vessel temperature is warm from a previous run, add cold water and exhaust.

5. When processing 24 sample bags, add 1900-2000 mL of ambient temperature AD solution to the fiber analyzer vessel. If processing less than 20 bags, add 100 mL/bag of AD solution (use minimum of 1500 mL to ensure bag suspender is covered).
6. Turn agitate and heat on and confirm agitation. Set timer for 60 minutes and close lid.
7. At end of extraction, turn heat and agitate off. Open the drain valve (slowly at first) and exhaust hot solution before opening lid.

   Note-the solution in the vessel is under pressure. The exhaust valve needs to be opened to release the pressure and solution prior to opening the lid.
8. After the solution has been exhausted, close the exhaust valve and open the lid. Add 1900-2000 mL of (70-90˚C) rinse water. Turn agitate on and rinse for 5 minutes. The lid may be sealed with the heat on or left open with the heat off. Repeat 5 minute hot water rinses a total of three times or until water is neutral pH.
9. When rinsing process is complete remove the samples. Gently press out excess water from bags. Place bags in a 250 mL beaker and add enough acetone to cover bags and soak for 3-5 minutes.
10. Remove bags from acetone and place on a wire screen to air dry. Completely dry in oven at 102±2˚C (most ovens will complete drying within 2-4 hours).

    Note-Do not place bags in oven until acetone has completely evaporated.
11. Remove bags from oven, place directly into collapsible desiccant pouch and flatten to remove air. Cool to ambient temperature and weigh bags (W_3).

    Note-Do not use conventional desiccator container.

<u>Calculations</u>:

% ADF (as received basis) = $((W_3 - W_1)/ W_2)*100$

Where: W_1 = Bag tare weight

W_2 = Sample weight

W_3 = Dried weight of bag with fiber after extraction process.

Notes:

Caution: sulfuric acid is a strong acid and will cause severe burns. Protective clothing should be worn when working with this acid. Always add acid to water and not the reverse.

CTAB will irritate the mucous membranes. A dust mask and gloves should be worn when handling this chemical.

Acetone is extremely flammable. Avoid static electricity and use a fume hood when handling.

Neutral Detergent Fiber (NDF) Analysis

Background Information

One of the most common measurements of fiber in an animal feedstuff is neutral detergent fiber. Neutral detergent fiber measures the structural components of plant cells that animal feedstuffs contain. The structural components that make up NDF are lignin, hemicellulose, and cellulose. These components are not easily digestible for the animal. ANKOM technology uses a neutral detergent to breakdown the components of the diet that the animal can also digest leaving the fibrous parts behind allowing the NDF component of the feedstuff to be determined. The levels of NDF in an animal diet influence the amount of dry matter intake and the time of rumination (University of Georgia, n.d.).

References

1. ANKOM Technology. Acid Detergent Fiber in Feeds-Filter Bag Technique [Online]. Available at: http://www.ankom.com/media/documents/Method_5_ADF_Method_A200_RevE_11_15_13.pdf (accessed 10 November 3013; Verified 18 April 2014). Macedon, NY.
2. University of Georgia. College of Agricultural & Environmental Sciences. Common Terms Used in Animal Feeding and Nutrition [Online]. Available at: http://www.caes.uga.edu/commodities/fieldcrops/forages/glossary/A.html (accessed 10 November 2013; Verified 18 April 2014).

Required Reagents:

1. Neutral Detergent Solution (ND Solution)
2. Alpha-Amylase
3. Sodium Sulfite

Required Equipment:

1. Analytical Balance – Capable of weighing down to 0.1 mg.
2. Oven – Capable of maintaining a temperature of 102 ± 2˚C.

3. Digestion Instrument – Capable of performing the digestion at 100 ±0.5 ˚C and maintaining a pressure of 10-25 psi. The instrument must be capable of creating a similar flow around each sample to ensure uniformity of extraction.
4. Filter Bags – Constructed from chemically inert and heat resistant filter media, capable of being heat sealed closed and able to retain 25 micron particles while permitting rapid solution penetration.
5. Heat Sealer – Sufficient for sealing the filter bags closed to ensure complete closure.
6. Dessicator Pouch – Collapsible sealable pouch with desiccant inside that enables the removal of air from around the filter bags.
7. Marking Pen- Solvent and acid resistant.

Protocol

Preparation of Sample:

Grind samples in a centrifugal mill with a 2 mm screen or cutter type (Wiley) mill with a 1 mm screen. Samples ground finer may have particle loss from the filter bags and result in low values.

Procedure:

1. Use a solvent resistant marker to label the filter bags. Weigh filter bag and zero balance (W_1).

   Note-Do not pre-dry filter bags as any moisture will be accounted for by the blank bag.
2. Weigh 0.45-0.55 grams of prepared sample directly in filter bag. Avoid placing the sample on the upper 4 mm of the bag (W_2).
3. Using a heat sealer, completely seal the upper edge of the filter bag within 4 mm of the top.

   Note-Use sufficient heat to completely seal the filter bag and allow enough cool time (2 sec) before removing the bag from the heat sealer.
4. Place a maximum of 24 bags into the bag suspender. All nine trays should be used regardless of the number of bags being processed. Place three bags per tray and then stack trays on center post with each level rotated 120 degrees. Insert bag suspender with

bags into the fiber analyzer vessel and place the bag suspender weight on top to keep it submerged.

Note-Prior to inserting the bag suspender, if the vessel temperature is warm from a previous run, add cold water and exhaust.

5. When processing 24 sample bags, add 1900-2000 mL of ambient temperature ND solution to the fiber analyzer vessel. If processing less than 20 bags, add 100 mL/bag of ND solution (use minimum of 1500 mL to ensure bag suspender is covered). Add 20 g (0.5 g/50mL of ND solution) of sodium sulfite to the solution in the vessel. Add 4.0 mL of alpha-amylase to the solution in the vessel.
6. Turn agitate and heat on and confirm agitation. Set timer for 75 minutes and close lid.
7. At end of extraction, turn heat and agitate off. Open the drain valve (slowly at first) and exhaust hot solution before opening lid.

a. Note-the solution in the vessel is under pressure. The exhaust valve needs to be opened to release the pressure and solution prior to opening the lid.

8. After the solution has been exhausted, close the exhaust valve and open the lid. Add 1900-2000 mL of (70-90˚C) rinse water and 4.0 mL of alpha-amylase to the first and second rinses. Turn agitate on and rinse for 5 minutes. The lid may be sealed with the heat on or left open with the heat off. Repeat 5 minute hot water rinses a total of three times or until water is neutral pH.
9. When rinsing process is complete remove the samples. Gently press out excess water from bags. Place bags in a 250 mL beaker and add enough acetone to cover bags and soak for 3-5 minutes.
10. Remove bags from acetone and place on a wire screen to air dry. Completely dry in oven at 102±2˚C (most ovens will complete drying within 2-4 hours).

    Note-Do not place bags in oven until acetone has completely evaporated.

11. Remove bags from oven, place directly into collapsible desiccant pouch and flatten to remove air. Cool to ambient temperature and weigh bags (W_3).

    Note-Do not use conventional desiccator container.

Calculations:

% NDF (as received basis) = $((W_3 - W_1)/ W_2)*100$

Where: W_1 = Bag tare weight

W_2 = Sample weight

W_3 = Dried weight of bag with fiber after extraction process.

Notes:

Caution

Powdered chemicals will irritate the mucous membranes. A dust mask and gloves should be worn when handling this chemical.

Acetone is extremely flammable. Avoid static electricity and use a fume hood when handling.

Recipes for Required Solutions

Neutral Detergent Solution

Add 30.0 g sodium lauryl sulfate, USP; 18.61 g ethylenediaminetetraacetic disodium salt, dehydrate; 6.81 g sodium tetraborate decahydrate; 4.56 g sodium phosphate dibasic, anhydrous; and 10.0 mL triethylene glycol, in 1 L distilled h2O (premixed chemical solution available from ANKOM technology). Check pH range to 6.9 to 7.1. Agitate and heat to aid solution.

Alpha-amylase

Heat-stable bacterial alpha-amylase: activity = 17,400 Liquefon units / mL

Sodium sulfite –Na_2SO_3, anhydrous

Crude Protein (CP) Analysis

Background Information

Protein is the nutrient component in animal feed. Crude protein in derived by finding the total nitrogen of a plant sample and then multiplying the nitrogen by 6.25. One of the ways to determine total nitrogen is by combustion with either thermal conductivity/IR detection or gas chromatography/thermal conductivity detection. The method is based on the oxidation of the sample by "flash combustion" which converts all organic and inorganic substances into combustion gases (N_2, NO_x, CO_2, and H_2O). The method has a detection limit of approximately 0.02% for nitrogen and 0.1% for carbon. (University of California-Davis, n.d.).

References

1. LECO Corporation, St. Joseph, MI.
2. University of California-Davis, College of Agricultural and Environmental Sciences. Analytical Lab- 522 Total Nitrogen and Carbon-Combustion Method [Online]. Available at: http://anlab.ucdavis.edu/analyses/plant/sop522 (accessed 14 March 2014; 18 April 2014) Davis, CA.

Required Equipment:

Analytical balance

Nickel Foil

LECO Truspec CN

Protocol

Preparation of Sample:

Grind samples in a centrifugal mill with a 2 mm screen or cutter type (Wiley) mill with a 1 mm screen.

Procedure:

1. Weigh 0.15 g dried, ground plant material into a nickel foil
2. Place sample into combustion apparatus: LECO Truspec CN (St. Joseph, MI)

3. Combust for 4 minutes
4. Percent nitrogen was then multiplied by 6.25 to determine crude protein

Calculations:

% CP = Total N % x 6.25

Field Sampling - Frames

Background Information

Frame clippings are utilized to measure forage mass or dry matter. Frames are laid out over the area to be sampled and the area in the frame is clipped, dried and weighted. The resulting weigh is the portion of dry matter in the sample and the critical number that is of interest when determining if grazed forage has the appropriate amount of dry matter to meet to animal nutrition requirements.

Required Equipment:

Plastic Frame (~0.1 m^2)

Cloth Sample Bags

12V Battery

Hand Shears

Rising Plate Meter (RPM)

Protocol

1. Randomly select a place to sample within the paddock.

   Note-For continuous paddocks a sample area measuring the same size as the rotational and mob paddocks should be marked and readings should occur within the sample area.
2. Using the RPM, measure the selected sample site and record measurement in field book.
3. Place frame over area previously measured in paddock.
4. Using hand shears connected to 12V battery clip grass inside the frame.
5. Samples should be clipped to ground level.
6. Place clipped samples into cloth sample bags.
7. Mark each bag with treatment, rep, and clipping number.
8. Frame clippings should be repeated in each paddock a total of 3 times.
9. Frame clippings should be taken before and after each grazing event in all research paddocks.
10. Bags containing the clipped samples were then dried at 50˚C for 96 hours (4 days).

11. After drying period, bags were weighed and weights were recorded in field book.
12. Samples were then ground using a Wiley mill with a 2 mm screen and stored in specimen jars labeled with the treatment, rep, date, and sample type.

Field Sampling - Exclusion Cages

Background Information

Exclusion cages are used in field research when animals have access to an entire area. Exclusion cages prevent access to small areas in a paddock that is continuously stocked with animals allowing for researchers to measure forage growth or other features and compare the total grass production under the cage with the grass production outside of the cage. In this experiment, the cages are used for growth measurements and are moved throughout the trial to new locations.

Required Equipment:

3 Exclusion Cages
Stakes to Secure Cages
Rising Plate Meter (RPM)
Frame (~0.1 m^2)
Cloth Sample Bags
Hand Shears
12V Battery

Protocol

1. Using the RPM, randomly selected sites should be measured for a beginning growth reading in continuous paddocks only.

   Note -For continuous paddocks a sample area measuring the same size as the rotational and mob paddocks should be marked and readings should occur within the sample area.
2. Exclusion cage should be placed over the previously measured area.
3. After an extended regrowth period, cages were removed.
4. The area previously covered by cage was then measured again using the RPM.
5. Once measured for growth, the frame was placed over measured area.
6. Forage inside the frame was then clipped using the hand shears connected to the 12V battery.
7. Clipped samples were then placed in cloth sample bags.

8. Sample bags were then labeled with the treatment, rep, and cage ID.
9. Cages were then relocated in the paddock and placed using the same initial measurement technique with the RPM.
10. Cage frame clippings should be taken a total of 3 times per continuous paddock total.
11. Bags containing the clipped samples were then dried at 50˚C for 96 hours (4 days).
12. After drying period, bags were weighed and weights were recorded in field book.
13. Samples were then ground using a Wiley mill with a 2 mm screen and stored in specimen jars labeled with the treatment, rep, date, and sample type.

Forage Class Composition Field Samples

Background Information

Animals are selective grazers and will consume plant species that are more appetizing or appealing. Thus the repetitive grazing habits of animals on a paddock with different grazing techniques in place can be seen by the overall species composition of the paddock. Measurements of species composition can give you an idea of how damaging or beneficial the current grazing system in place can be on the overall plant species community. For example instances where weed species are becoming more prevalent may signal overgrazing whereas the same or similar plant community present throughout the growing season could signal an appropriate, grazing and rest period or stocking rate on the paddock.

Required Equipment:

Flags

Ruler or Tape Measuring (18 inches)

Hand Shears

12V Battery

Cloth Sample Bag

Protocol

1. Randomly select a site in each paddock.
2. Measure out 18 inches.
3. Flag the 18 inch section
4. Using hand shears connected to 12V battery, clip marked section.
5. Collect clipped sample and place in the cloth sample bag.
6. Mark bag with treatment, rep, and date.
7. Process should be repeated a total of three times.

   Note- All three clippings should be placed in the same collection bag.
8. Place clipped samples in bags in a cooler.
9. Homogenize the sample by mixing before sorting begins.
10. Take a large hand full of the mixed sample from bag and begin to sort sample clippings into four different piles: grass, weed, legume, and dead materials.
11. Place sorted piles into pre-weighed and marked brown paper bags.

Note- Paper bags should be weighed and have weights recorded in the notebook as well as labeled with treatment, rep, species type (grass, weed, etc.), and date.

12. Paper bags containing the samples are then placed in the dryer at 50˚C for 96 hours (4 days).
13. After drying period has expired, samples are then weighed, with weights recorded in notebook.
14. Empty bag weight is subtracted from a total sample weight (bag+sample) to determine sample weight.

Rising Plate Meter Weekly Measurements

Background Information

A rising plate is a device that used commonly in New Zealand. It is a weighted plate that slides over a shaft with an electronic device that performs a calculation for kilograms of dry matter per hectare based on the height readings the machine records. The RPM is placed on the forage sward and the plate slides down until the forage below the plate is adequate to support the plate weight. The distance between that shaft point on the ground and the plate is the height at this point and is recorded by a click. It is theorized that the forage mass or dry matter is proportional to the height of the forage. Locations for RPM readings should be randomly selected and many should occur in each paddock, 30 reading is suggested. Forage mass determination by the RPM can help to aide in determining grazing period initiation and termination (DairyNZ, Waikato, NZ).

References

1. DairyNZ. Farmfact [Online]. Available at: http://www.dairynz.co.nz/media/253639/1-15_Using_the_Rising_Plate_Meter.pdf (accessed 14 March 2014; Verified 18 April 2014) Waikato, NZ.

Required Equipment:

Rising Plate Meter (RPM)

Protocol

1. Using a calibrated RPM, walk diagonally across a paddock taking readings.
2. 15 readings should be taken while walking.
3. Machine averages the reading so record the final RPM and height measurement in field notebook at the end of 15 readings.
4. RPM readings should be taken once a week for duration of trial grazing season in each paddock.

    Note-For continuous paddocks a sample area measuring the same size as the rotational and mob paddocks should be marked and readings should occur within the sample area.

Calculations:

Compressed Height * 140 + 500 = kg DM/ha

Forage Disappearance Calculation

Pre Grazing RPM – Post Grazing RPM for each grazing event in treatment paddocks

Summation of all pre-grazing –post-grazing biomass

Forage Disappearance = Summation totals per treatment replication added together / 4 (number of replicates in each treatment)

Appendix B - Raw Data

Table B.1 Raw data files used to calculate forage disappearance in DM ha^{-1}.

	2012						Spring 2013			Fall 2013			
	DM[4] 1	DM 2	DM 3	DM 4	DM 5	Total	DM1	DM 2	DM 3	DM 4	DM 5	Total	
R[1] 1	1633	1255	1013	1137		5040	1447	1111	0	177	1792	4527	6877
R 2	1003	1302	2240	1661		6207	1283	1661	1395	709	2625	7674	
R 3	1363	1521	406	1643		4933	1386	1955	0	4354	1633	9329	
R 4	695	873	1680	1395		4643	2165	0	0	2469	1344	5978	
M[2] 1	4839					4839	3864			3103		6967	6422
M 2	4774					4774	5135			3178		8313	
M 3	4718					4718	3019			2473		5493	
M 4	4181					4181	3588			1325		4914	
C[3] 1	1197	1659	1064	672	427	5019	2753	2193	1092	1829		7868	6026
C 2	1288	2289	966	847	378	5768	2874	2408	0	1358		6640	
C 3	322	2072	1309	1316	175	5194	1171	1535	0	359		3066	
C 4	1365	1876	938	700	0	4879	2081	1591	1377	1479		6529	

[1]Rotational (R)
[2]Mob (M)
[3]Continuous (C)
[4]DM is the abbreviation for dry matter.

Table B.2 Forage class composition data as a percentage of the total sample.

Forage Class Composition					
Date	Trt	Rep	Grass %	Forbs %	Dead %
May-12	R[1]	1	84.2	1.3	14.5
May-12	R	2	79.8	0.9	19.3
May-12	R	3	83.1	1.4	15.5
May-12	R	4	80	4.3	15.7
May-12	C[2]	1	32.7	0	67.3
May-12	C	2	29.7	3.2	67.2
May-12	C	3	60	0	40
May-12	C	4	64.1	2.6	21.8
May-12	M[3]	1	86.7	2.9	10.4
May-12	M	2	85.8	1.5	12.7
May-12	M	3	84	0	16
May-12	M	4	80.6	10	9.4
Jun-12	R	1	35.4	3	61.6
Jun-12	R	2	46.5	19.4	34.1
Jun-12	R	3	46	19.4	34.7
Jun-12	R	4	45.5	20.9	33.6
Jun-12	C	1	40.5	38.5	21
Jun-12	C	2	60.2	17.5	22.3
Jun-12	C	3	41.6	52.4	6
Jun-12	C	4	52.3	29.4	18.4
Jun-12	M	1	33.5	6.6	59.9
Jun-12	M	2	49.3	3.5	47.3
Jun-12	M	3	54.7	5.4	39.9
Jun-12	M	4	46	10.8	43.2
Oct-12	R	1	70.7	8.3	20.9
Oct-12	R	2	58.3	22.1	19.7
Oct-12	R	3	67.1	2.3	30.7
Oct-12	R	4	58.8	8.4	32.8
Oct-12	C	1	64.6	9.3	26.1
Oct-12	C	2	62.8	12.3	25

Oct-12	C	3	60.4	16.2	23.4
Oct-12	C	4	71.2	9.1	19.7
Oct-12	M	1	59.2	1.2	39.7
Oct-12	M	2	64.4	0	35.6
Oct-12	M	3	71.7	0	28.3
Oct-12	M	4	67.9	2.3	29.8
May-13	R	1	73.1	15.5	11.5
May-13	R	2	85.6	6.5	8
May-13	R	3	89.8	1.7	8.5
May-13	R	4	75.4	22.6	2
May-13	C	1	72.4	17.6	10.1
May-13	C	2	95.6	0.4	4
May-13	C	3	77.4	10	12.6
May-13	C	4	92.7	1.2	6.1
May-13	M	1	90.6	0.9	8.5
May-13	M	2	80.1	0	19.9
May-13	M	3	76.8	0	23.2
May-13	M	4	85.4	1.4	13.2
Jun-13	R	1	62.6	22.1	15.4
Jun-13	R	2	41.3	18.7	40
Jun-13	R	3	34.9	30.2	34.9
Jun-13	R	4	49.3	21.4	29.3
Jun-13	C	1	42.3	0	57.8
Jun-13	C	2	14.7	0	85.3
Jun-13	C	3	38.9	0	61.1
Jun-13	C	4	57.3	0	42.7
Jun-13	M	1	33.3	17.2	49.5
Jun-13	M	2	47.9	19.1	33
Jun-13	M	3	23.5	19.5	57
Jun-13	M	4	35.4	38.5	26
Oct-13	R	1	31.8	0.6	67.6
Oct-13	R	2	31.8	1.7	66.5
Oct-13	R	3	45.8	8.8	45.4

Oct-13	R	4	34.4	10.6	55
Oct-13	C	1	28.3	18.3	53.3
Oct-13	C	2	40.4	0	59.6
Oct-13	C	3	47.7	30.6	21.8
Oct-13	C	4	44.8	9.2	46
Oct-13	M	1	26.7	18.3	55.1
Oct-13	M	2	32.9	0	67.1
Oct-13	M	3	51.4	0	48.6
Oct-13	M	4	39.5	34.5	26.1

[1] Rotational (R)

[2] Continuous (C)

[3] Mob (M)

Table B.3 MBC, DOC dehydrogenase and gravimetric water content as determined by laboratory analysis.

Soil Analysis Summary Table						
Date	Trt	Rep	Biomass C	DOC	Dehydrogenase	Grav H2O
Fall	C[1]	1	723.98	127.65	754.19	0.30
Fall	C	2	720.72	102.66	829.01	0.39
Fall	C	3	820.88	137.19	1182.53	0.41
Fall	C	4	732.05	155.49	970.45	0.41
Fall	M[3]	1	705.96	162.18	836.66	0.31
Fall	M	2	701.41	138.91	756.07	0.41
Fall	M	3	704.19	145.92	698.86	0.41
Fall	M	4	729.72	134.79	876.32	0.41
Fall	R[3]	1	664.95	133.45	673.92	0.29
Fall	R	2	818.69	143.00	819.55	0.41
Fall	R	3	769.32	152.21	1490.34	0.42
Fall	R	4	669.00	168.29	872.37	0.40
Spring	C	1	219.91	139.17	177.54	0.30
Spring	C	2	358.03	149.35	183.54	0.29
Spring	C	3	241.04	153.02	178.67	0.30
Spring	C	4	246.98	116.68	177.99	0.30
Spring	M	1	381.14	152.42	203.86	0.31
Spring	M	2	266.60	128.25	155.61	0.31
Spring	M	3	367.90	138.64	174.80	0.30
Spring	M	4	230.72	124.85	177.98	0.31
Spring	R	1	196.69	101.74	209.26	0.29
Spring	R	2	382.74	136.32	169.10	0.30
Spring	R	3	229.27	180.67	186.85	0.31
Spring	R	4	290.90	174.57	388.81	0.30

[1]Continuous (C)

[2]Mob (M)

[3]Rotational (R)

Table B.4 ADF, NDF, and CP percentages as determined by laboratory analysis.

Nutrient Analysis Summary Table					
Date	Trt	Rep	ADF	NDF	CP
4/3/12	M[1]	1	24.85	43.73	23.31
4/3/12	M	2	24.40	41.62	23.03
4/3/12	M	3	23.20	41.97	27.49
4/3/12	M	4	23.86	43.04	23.67
4/18/12	R[2]	1	28.09	47.71	21.58
4/18/12	R	2	26.69	47.34	23.8
4/18/12	R	3	25.70	44.40	26.26
4/18/12	R	4	28.17	48.30	25.19
4/25/12	M[3]	1	30.60	52.88	18.31
4/25/12	M	2	31.65	53.51	16.75
4/25/12	M	3	31.46	53.48	19.09
4/25/12	M	4	30.70	52.32	17.87
5/1/12	C	1	26.80	51.39	25.73
5/1/12	C	2	25.35	48.93	27.5
5/1/12	C	3	25.04	47.07	31.11
5/1/12	C	4	25.32	47.56	28.7
5/14/12	R	1	28.29	55.40	23.81
5/14/12	R	2	30.61	53.99	20.72
5/14/12	R	3	28.81	52.50	22.56
5/14/12	R	4	30.64	54.48	22.61
5/22/12	C	1	30.74	53.26	17.13
5/22/12	C	2	30.24	53.34	20.49
5/22/12	C	3	26.25	47.89	25.92
5/22/12	C	4	28.33	51.22	20.62
5/22/12	M	1	30.85	54.75	16.68
5/22/12	M	2	31.79	54.06	15.85
5/22/12	M	3	31.49	52.81	18.05
5/22/12	M	4	31.20	51.96	17.76
10/24/12	R	1	20.07	40.81	29.63
10/24/12	R	2	21.63	40.69	27.97

10/24/12	R	3	22.49	41.18	26.48
10/24/12	R	4	20.27	39.46	28.55
10/24/12	C	1	20.47	41.10	29.94
10/24/12	C	2	21.54	41.95	28.49
10/24/12	C	3	21.98	40.79	29.63
10/24/12	C	4	22.27	44.19	28.76
10/24/12	M	1	21.24	40.58	27.69
10/24/12	M	2	23.02	42.25	27.11
10/24/12	M	3	21.29	40.13	28.89
10/24/12	M	4	21.17	40.28	29.54
4/21/13	R	1	22.45	40.54	23.81
4/21/13	R	2	21.13	38.11	27.32
4/21/13	R	3	22.11	40.10	26.31
4/21/13	R	4	21.95	40.48	26.07
4/21/13	C	1	23.04	40.39	24.35
4/21/13	C	2	22.83	39.82	27.48
4/21/13	C	3	23.19	39.95	29.37
4/21/13	C	4	24.16	39.79	27.55
4/21/13	M	1	25.03	41.36	26.35
4/21/13	M	2	22.21	38.96	28.17
4/21/13	M	3	24.45	39.50	29.53
4/21/13	M	4	22.54	38.77	27.99
4/29/13	R	1	27.94	49.93	21.13
4/29/13	R	2	26.57	47.04	23.81
4/29/13	R	3	26.67	45.78	24.39
4/29/13	R	4	25.51	47.27	22.69
4/29/13	C	1	26.74	47.36	20.34
4/29/13	C	2	25.55	46.19	21.63
4/29/13	C	3	24.72	44.67	24.61
4/29/13	C	4	26.27	47.28	21.06
4/29/13	M	1	27.13	48.11	20.53
4/29/13	M	2	25.76	45.31	25.34

4/29/13	M	3	26.94	47.51	24.87
4/29/13	M	4	26.80	46.48	21.92
5/7/13	R	1	26.35	48.24	22.74
5/7/13	R	2	26.20	46.30	17.94
5/7/13	R	3	25.45	46.94	24.00
5/7/13	R	4	27.00	50.56	21.11
5/7/13	C	1	26.53	47.83	21.55
5/7/13	C	2	26.55	47.95	19.24
5/7/13	C	3	25.03	44.56	22.95
5/7/13	C	4	26.66	50.42	20.34
5/7/13	M	1	25.79	48.27	23.17
5/7/13	M	2	25.65	45.33	23.23
5/7/13	M	3	26.76	47.48	24.03
5/7/13	M	4	25.19	45.68	23.68
5/20/13	R	1	33.42	59.01	15.42
5/20/13	R	2	32.66	56.69	19.27
5/20/13	R	3	31.30	56.30	18.01
5/20/13	R	4	30.75	53.39	19.15
5/20/13	C	1	32.57	58.86	18.39
5/20/13	C	2	31.90	55.00	19.07
5/20/13	C	3	35.62	61.15	15.73
5/20/13	C	4	33.97	62.09	15.71
5/20/13	M	1	32.37	57.05	17.32
5/20/13	M	2	33.51	57.05	18.28
5/20/13	M	3	33.07	55.22	18.12
5/20/13	M	4	35.49	59.82	14.69
5/28/13	R	1	33.30	56.56	14.50
5/28/13	R	2	34.78	56.72	16.10
5/28/13	R	3	36.87	63.19	11.67
5/28/13	R	4	32.93	52.02	21.45
5/28/13	C	1	34.66	55.31	15.61
5/28/13	C	2	35.50	59.37	14.44
5/28/13	C	3	38.56	62.97	12.83

5/28/13	C	4	35.81	60.48	12.31
5/28/13	M	1	36.71	61.58	14.90
5/28/13	M	2	38.73	65.05	10.07
5/28/13	M	3	38.90	66.53	10.52
5/28/13	M	4	42.22	68.83	11.37
6/6/13	R	1	38.02	63.30	9.14
6/6/13	R	2	35.71	60.01	13.39
6/6/13	R	3	36.56	62.89	12.02
6/6/13	R	4	30.13	53.58	17.45
6/6/13	C	1	34.94	58.70	12.57
6/6/13	C	2	35.42	59.63	13.22
6/6/13	C	3	35.48	59.61	14.21
6/6/13	C	4	34.63	59.73	12.02
6/6/13	M	1	35.59	59.85	11.50
6/6/13	M	2	36.36	61.38	12.28
6/6/13	M	3	35.20	56.79	12.80
6/6/13	M	4	38.80	62.93	11.84
6/24/13	R	1	36.76	59.81	12.48
6/24/13	R	2	31.69	50.48	20.17
6/24/13	R	3	29.96	51.26	23.32
6/24/13	R	4	28.82	49.24	23.89
6/24/13	C	1	38.09	61.26	10.46
6/24/13	C	2	37.68	58.76	13.88
6/24/13	C	3	41.05	64.73	11.17
6/24/13	C	4	39.68	63.60	8.49
6/24/13	M	1	27.63	45.31	24.79
6/24/13	M	2	28.44	49.10	23.25
6/24/13	M	3	28.07	46.22	23.95
6/24/13	M	4	28.17	45.28	23.59
9/5/13	R	1	29.76	50.23	19.42
9/5/13	R	2	31.16	51.59	16.28
9/5/13	R	3	31.06	51.24	17.95
9/5/13	R	4	28.28	46.93	23.06

9/5/13	C	1	30.59	52.94	15.99
9/5/13	C	2	31.94	54.41	15.47
9/5/13	C	3	32.47	51.91	18.95
9/5/13	C	4	31.81	53.64	15.54
9/5/13	M	1	30.13	49.80	16.87
9/5/13	M	2	32.17	53.17	19.26
9/5/13	M	3	34.71	55.61	14.06
9/5/13	M	4	29.93	49.87	21.61
9/9/13	R	1	33.89	55.76	15.19
9/9/13	R	2	38.11	56.49	11.17
9/9/13	R	3	34.04	56.85	13.56
9/9/13	R	4	37.38	57.28	11.41
9/9/13	C	1	30.52	52.26	14.97
9/9/13	C	2	30.93	52.43	14.45
9/9/13	C	3	32.70	54.76	15.17
9/9/13	C	4	34.83	57.37	12.55
9/9/13	M	1	31.39	51.79	15.95
9/9/13	M	2	30.85	52.07	18.44
9/9/13	M	3	31.24	52.59	17.38
9/9/13	M	4	31.06	49.13	15.28
10/9/13	R	1	26.73	45.06	25.84
10/9/13	R	2	28.56	46.98	26.79
10/9/13	R	3	27.38	45.76	26.06
10/9/13	R	4	26.66	42.41	29.86
10/9/13	C	1	37.30	57.17	15.98
10/9/13	C	2	33.87	53.03	21.07
10/9/13	C	3	38.44	57.20	15.33
10/9/13	C	4	37.06	57.09	17.22
10/9/13	M	1	22.99	40.54	30.74
10/9/13	M	2	26.72	44.72	28.39
10/9/13	M	3	24.44	41.92	31.11
10/9/13	M	4	27.47	44.25	26.27

[1] Mob (M)

[2] Rotational (R)

[3] Continuous (C)

Table B.5 Rising plate meter data as a weekly average by treatment.

Rising Plate Meter			
Date	Continuous	Mob	Rotation
4/4/2013	3366.5	3310.5	2995.5
4/12/2013	3664	3835.5	3639.5
4/19/2013	4560	4553	4371
4/26/2013	5088.5	5130.5	5361.5
5/3/2013	4784	6366	4014
5/10/2013	5554	6670.5	5305.5
5/17/2013	5974	6194.5	5809.5
5/24/2013	5596	2579	5722
5/31/2013	4728	2358.5	3044.5
6/7/2013	4311.5	2460	2743.5
6/14/2013	3345.5	2537	2911.5
6/21/2013	3037.5	2649	2922
6/28/2013	2708.5	2488	2155.5
7/5/2013	3209	2967.5	2691
7/12/2013	3342	2820.5	2673.5
7/22/2013	3230	2813.5	2442.5
7/26/2013	2827.5	2810	2432
8/2/2013	3282.5	3450.5	3121.5
8/9/2013	4168	4542.5	4280
8/16/2013	4703.5	4875	4714
8/23/2013	5939	5298.5	5148
8/30/2013	5431.5	4322	4392
9/6/2013	4462	4220.5	2600
9/13/2013	3877.5	1585	2421.5
9/20/2013	3097	1833.5	2740
9/27/2013	2764.5	2183.5	3097
10/4/2013	2264	2589.5	3520.5

Table B.6 Available forage averaged across all grazing treatments by month as measured by the weekly rising plate measurement.

	Forage Available
March	3364
April	3371
May	3527
June	2611
July	2589
August	3229
September	2443
October	2165