WINTER RYE PASTURE PRODUCTION

PROGRAMS FOR GROWING

BEEF CATTLE

By

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NOMENCLATURE

ADF	acid detergent fiber
ADG	average daily gain
BW	body weight
cm	centimeters
CP	crude protein
CONV	conventional
d	day
DIP	degradable intake protein
DM	dry matter
gain/ha	gain per hectare
h	hour
ha	hectare
IVDMD	in vitro dry matter digestibility
IVOMD	in vitro organic matter digestibility
kg	kilograms
NDF	neutral detergent fiber
NRC	National Research Council
OM	organic matter
OPT	optimum
°C	degrees Celsius

CHAPTER I

REVIEW OF LITERATURE

Introduction

Annual cool-season grasses were initially used as forage resources for wild and domestic grazing livestock. Over time, these grasses were used to provide grain for humans. Resulting grain use afforded mankind the option of settling in one place and establishing a stable society (Phillips et al., 1996; Hodgson, 1976; Leonard and Martin, 1963). Forage is defined as feedstuffs that are composed of stems, leaves, and possibly grain and is fed as fresh material, hay, or silage (NRC, 2001). While small grain forages such as rye (Secale cereale L.), wheat (Triticum aestivum L.), oats (Avena sativa L.), and triticale (X Tritlcosecale Wittmack) are still used as high-quality feedstuffs for ruminants, sources of grain for human consumption have overshadowed their utility as forage (Phillips et al., 1996). These dual purpose forages are unique in their ability to satisfy nutrient requirements for both humans and livestock. Annual cool season forages comprise 35% of the cultivated land in the world. Of the cool season forages rye is the most geographically ubiquitous small grain in the United States (Phillips et al., 1996; Peterson et al., 1989).

Ruminants derive most nutrients from forage in typical production systems (Galloway et al., 1993). Small grains are frequently used in the southeastern United States as winter forage crops. These species produce high-quality forage during the cool-season months when perennial warm-season grasses are limited (Bruckner and Raymer, 1990; Horn et al., 2006; Horn et al., 2005). Small grains forages are an important part of complementary and synergistic livestock enterprises (Phillips et al., 1996), and wherever they can be grown, are a vital component of multi-forage livestock production systems (Barnes et al., 1995).

Small grains forage production occurs in two distinct phases, fall and spring. These plants also experience two types of growth, vegetative and reproductive. The vegetative phase primarily consists of leaf material. The later reproductive phase is characterized by rapid growth and an increased production of stem and inflorescence.

There are many other important economic and ecological considerations with regard to small grains forage such as grain production and their uses as companion crops, which are beyond the scope of this literature review and will not be discussed.

The plant-animal interface of grazing systems is difficult to ascertain. Animal performance is controlled by DM intake (Coleman et al., 1989; Fox, 1986; Martin, 1988; Vogel et al., 1987). DM intake is a function of bite size, bite rate, and grazing time (Hodgson, 1977; Forbes and Coleman, 1993). There is a dynamic interface between animal and forage. Canopy characteristics have an influence on diet composition, and consumption in turn alters the canopy (Hodgson, 1977). The resulting canopy causes animals to respond by altering their selection. Intake per bite is usually the major component affecting intake. This is strongly influenced by the forage mass available (Hodgson, 1977).

Differentiation of Forage Nutritive Value and Forage Quality

A short summary (Reid, 1994) was written to understand the significance of changes that have taken place in forage quality and utilization research since 1969.

Several forage evaluation methods have previously been defined. A schematic by Mott and Moore (1969) differentiated between forage nutritive value and forage quality. Forage nutritive value includes chemical compositions such as: crude protein (CP), crude fiber (CF), ether extract (EE), nitrogen free extract (NFE), vitamins and minerals. Forage quality is made up of two components, forage nutritive value and forage consumed. Therefore, forage nutritive value and forage quality are not synonymous, and in point of fact, forage nutritive value is a component of forage quality.

Traditional methods used to estimate forage nutritive value include measurements of cell wall and intracelluar contents, as well as crude protein. Cell wall content is generally regarded as the most important factor affecting forage intake because it is related to the filling effect and digestibility of forages. This can be attributed to the fact that it comprises the major fraction of dry matter (DM) and is highly correlated with intake and digestibility (Nelson and Moser, 1994). The cell wall components are made up of structural polysaccharides such as cellulose and hemicelluloses that are degraded by rumen microflora. The ability of the microflora to degrade and ferment cellulose and hemicellulose determine the amount of digestible energy (DE) obtained from the forage.

Forage Nutritive Value for Ruminants: Plant Considerations

Leaf:Stem Ratio

Changes with Maturity. Plant maturity is likely the greatest factor that affects morphology and thus forage quality. Forage quality declines with age and as a result there is a decrease in digestibility (Ugherughe, 1986). Digestibility is not the only plant attribute that can affect intake, the leaf:stem ratio heavily affects voluntary intake. Additionally, the flowering period of plants alters the morphological development in addition to the leaf:stem ratio because the production of new leaves is terminated. However, stem growth continues while leaf growth stops, and causes a continued reduction of the leaf:stem ratio. The stem then continues to increase and mature (Brown and Tanner, 1983). The overall result of the flowering period is a gradual reduction in the leaf:stem ratio, and while leaf production is gradually decreased, the leaves in the lower canopy senesce, and the stem increases in weight. This increase in stem weight as reported by Buxton and Casler (1993) rapidly decreases the quality of the forage, and is related to lignin which has low bioavailability to most species. Forage maturity has been shown to not only reduce intake (McCollum and Galyean, 1985), but digestibility as well (McCollum et al., 1992).

Leaf Digestibility. Leaf tissue is virtually always the highest quality component of forages (Hides et al., 1983). Leaf parts are classified as having a lamina (blade) and a sheath in grass species. Legume leaves consist of a lamina (leaflets) and a petiole or leaf stalk. Rates of cell wall digestion for leaf blades and leaf stems have been previously reported by Cherney and Marten (1982). Two cultivars of spring wheat, oats, triticale and barley were harvested over a wide range of maturity stages (Cherney and Marten, 1982). A progressive increase in inflorescence digestibility coupled with an increase in the proportion of inflorescence during grain filling was noted for all cultivars; however, this was somewhat offset by a decline in digestibility of the stem, leaf blade, and leaf sheath as the crops matured. The increased concentration of lignin in the stem was the major factor that accounted for a reduction in digestibility with increased maturity. It was concluded that sheaths should be considered as part of the stem when determining the quality of steam and leaf components. Additionally, Poppi et al. (1981) noted that cattle and sheep consumed 35 and 21% more leaf fraction than stem fraction of pangolagrass (Digiteria decumbans Stent.) and rhodesgrass (Chloris gayana Kunth). The extent of digestion was the same for both fractions; therefore, the increased intake was attributed to the shorter time the leaf fraction was retained in the rumen.

Hides et al. (1983) concluded that leaf fractions of Italian Ryegrass (Lolium multiflorum Lam.) remained similar in digestibility and crude protein with increasing maturity, which is counter-intuitive since previous work has shown a decrease in digestibility with increasing maturity (Griffin and Jung, 1983; Akin, 1989). Likewise, alfalfa leaves have also been reported to have similar in vitro dry matter digestibility (IVDMD) over a wide range of growth stages (Albrecht et al., 1987). The cell wall component in leaves has been shown (Albrecht et al., 1987) to increase by approximately 10% over the maturity range, so the decline in forage quality is due to a decrease in leaf:stem ratio and a decline in stem quality (Albrecht et al., 1987). Additional research comparing stem and leaf fractions of orchardgrass (Dactylis glomerata L.) by Lentz and Buxton (1992) showed 12% of the leaf fraction was indigestible and 49% of the stem and leaf sheath fractions were indigestible.

The digestibility of leaf blades, stems, and sheaths in switchgrass were studied by Twidwell (1988). The in-vitro dry matter digestibility (IVDMD) was highest for leaf blades, followed by sheaths and stems. Interestingly, leaf blades and sheaths both had similar nitrogen (N) concentrations. In legumes, leaves of alfalfa, red clover (Trifolium pretense L.), birdsfoot trefoil (Lotus corniculatus L.), and white clover (Trifolium repens L.) were studied by Wilman and Atimini, (1984). White clover and alfalfa had leaf blade cell wall components that were more digestible in vitro than red clover. In general, it was concluded that stem was less digestible than leaves; however, in white clover stem was more digestible than flower stalks. Minson (1990) reviewed many studies and concluded that leaf intake was higher than stem intake due to increased digestibility. Additionally, leaves have lower NDF concentrations, therefore they are more readily consumed than stems (Buxton et al., 1995).

Stem Digestibility. Laredo and Minson (1973) reported higher forage intakes of leaf fractions than stem portions, regardless of their digestibilities. Since stem usually has more tissues resistant to digestion than leaves, stem is generally lower in digestibility. This stem digestibility declines more rapidly with onset of plant maturity than does that of leaves. Bottom stems are more mature than top stems in most plants, hence lower in digestibility – this is especially noted in legumes. Leaf and stem digestibility are often similar in grasses and legumes, when the plants are young, but as tissues age, the leaf digestibility decreases at a much slower rate. This is attributed to the mesophyll cells in leaves, which makeup the major part of the leaf tissues (Akin, 1989). These mesophyll cells found in leaves are high in CP content, yet the fiber cells in stems build thick secondary cell walls (Akin, 1989). Subsequently, the stem tissue increases in lignin content as it matures. Immature grass stems are generally high in quality; however, they decrease in quality faster than leaves of most forage plants, especially when these plants are approaching maturity. The low digestibility of stems is due to their anatomy in that leaves are primarily comprised of many thin-walled mesophyll cells, whereby stems are comprised of highly lignified xylem cells, vascular bundles, and sclerenchyma cells. The lignification in grass and legume stems is for structural strength, and often the greatest limitation to the breakdown of stems in the rumen (Akin et al., 1990).

Proportion of Leaf and Stem Fractions. The proportion of leaf tissue in grasses such as big bluestem (A. Gerardii vitman) and switchgrass (Panicum virgatum L.) have been reported to decline with maturity (Griffin and Jung, 1983). Twidwell et al. (1988) reported that leaves accounted for nearly half (47%) of the yield of switchgrass found in early morphological development compared to only a quarter (26%) late in the season. Likewise, it has also been noted by Albrecht et al. (1987) that the leaf:stem ratio of alfalfa (Medicago sativa L.) decreased from 1.5 when in the vegetative stage to 0.5 at maturity. Similarly, stem fractions were increased from 18.5 to 50.7% of the yield, while, leaf fractions declined from 72.9 to 18.4% as alfalfa reached maturity (Nordkvist and Aman, 1986). The increase in percentage of stem tissue with maturation coupled with a rapid decline in nutrivive value of stems suggests that stem quantity is the critical determinant of whole plant nutritive value (Griffin and Jung, 1983).

Plant Environment in Relation to Forage Nutritive Value

Environmental effects on plants are integrated through physiological processes and reflected in forage growth rate, development rate, yield, and forage nutritive value. Inconsistencies in grazing animal performance are observed due to year-to-year, seasonal, and geographical variation in environments that alter forage growth, development, and forage quality even when forages are harvested at similar morphological stages.

The environment often exerts the greatest influence on forage quality by altering the leaf:stem ratios, yet it also causes other morphological modifications and alterations in chemical composition of forage parts. Temperature, water deficit, solar ration, and soil nutrient availability have the greatest effect on nutritive value of forages. The single greatest influence on forages is generally temperature.

Optimal Growth Temperatures

Cool season forage species reach optimal growth at temperatures near 20° C, while warm season forage species reach optimal growth near 30 to 35° C. When temperatures fall below the optimum for growth, soluble sugars accumulate due to the lower temperature sensitivity of photosynthesis compared with that of growth (Nelson et al., 1994; Buxton et al., 1995). In contrast, an increase in temperature increases the rate of plant development and reduces leaf:stem ratios and digestibility. An increase in temperature generally reduces forage nutritive value even when compared at the same morphological stage. Buxton et al. (1995) reported for every 1° C increase in temperature, a decrease in digestibility of 0.3 to 0.7 percentage units occurred. Yet, this increase in temperature has minor effects on crude protein concentration (Wilson and Minson, 1983; Wilson, 1993; Buxton et al., 1995). This phenomenon partially explains the high quality forages produced at northern latitudes or high elevations in the United States, where low temperatures dominate many seasons.

Effects of Drought

Drought generally inhibits tillering and branching of forages and speeds the death of established tillers. As a result, leaf area is reduced due to accelerated rate of senescence of older leaves. Nitrogen and soluble carbohydrates are mobilized and transported out of leaves as they die. Conversely, water stress slows development of forages. In the case of severe prolonged water stress, leaves are lost. In some perennial species the plants may go into dormancy, which causes most nutrients to be translocated from leaves to roots, which results in poor forage quality. Water stress, as researched in alfalfa, if sufficient to cause a large yield reduction, actually improved digestibility but not crude protein content. This is caused by the elevated crude protein concentration in stems and decreased concentration in leaves. Similar findings have been reported for other forages including perennial legumes and grasses (Peterson, et al., 1992; Shaeffer et al., 1992; Buxton et al., 1995).

Effects of Solar Radiation

Solar radiation also has an influence on forage quality through the change in photoperiod. An increase of 1 h in day length can improve digestibility by 0.2 % units. Subsequently, a lengthened photoperiod which occurs in spring and early summer has positive effects on forage quality, whereby shortening photoperiod during late summer and fall has negative effects. Nevertheless, cool temperatures in spring and fall contribute to high forage quality for cool season species. Cloudy weather may lower forage quality due to decreased photoperiod. Bright sunshine near harvest or grazing generally increases nonstructural carbohydrates in forage, thus increasing forage quality. Diurnal variation has been found in the concentration of nonstructural carbohydrates of forages, with the lowest values before sunrise and the highest values in late afternoon. Protein concentration exhibits diurnal fluctuations with highest concentrations also in late afternoon (Buxton et al., 1994; Buxton et al., 1995). Benefits in higher quality forage late in the day may be lost if forage is harvested for hay due to high respiration rates associated with these soluble plant fractions. Waiting until afternoon to cut forage for hay will increase the drying time.

Effects of Soil Nutrient Content

Soil nutrient content influences forage quality, yet these effects are small. Nitrogen fertilization has the greatest impact and usually increases crude protein concentration in forage. For grasses that are typically low in crude protein, nitrogen fertilization can improve digestibilities due to the increased nitrogen providing a better balance of available nitrogen and energy, and greater rumen microbial activity (Buxton et al., 1995).

Warm and Cool-Season Forages

Photosynthetic Pathways

In addition to a more active photosynthetic rate the forage mass of warm-season (C_4)grasses is much greater, but it is less densely packed in the canopy as are the cool-season (C_3) grasses, which helps facilitate grazing (Akin, 1986). C_3 plants are so named because the CO_2 is first incorporated into a 3-carbon compound, whereas the CO_2 in C4 plants are first incorporated into a 4-carbon compound. Photosynthetically, C_3 and C_4 grasses respond similarly at low levels of radiation. The most pronounced difference in photosynthesis is expressed at high levels of radiation. At higher radiation levels the conversion efficiency of solar radiation to fixed CO_2 for leaves in C_4 species is doubled over that of C_3 species (Nelson and Moser, 1994). Even with doubled rates of CO_2 fixation, the dry matter production of C_4 canopies is not 2-fold greater than C_3 canopies, due to the fact that most leaves in the lower canopy of plants are shaded. Subsequently, only a limited number of leaves at the top of the canopy can reach the photosynthetic potential of the C_4 species. These shaded leaves often operate at less radiation levels where the differences between C_3 and C_4 species are small. Even though the C_4 grasses are more efficient in light conversion, their paramount adaptation advantage over C_3 grasses is their increased water use efficiency, drought resistance, and heat tolerance (Nelson and Moser, 1994). These attributes are related to the photosynthetic pathway.

The C_4 pathway requires expenditure of additional energy. If temperatures are mild and water is abundant, the C_3 photosynthetic pathway is more efficient. However, under hot, dry conditions the C_4 photosynthetic plants are more efficient. Additionally, the ability of C_4 plants to avoid photorespiration offsets the additional energy costs of the photosynthetic pathway.

Digestibility

Cool-season grasses are more digestible than warm-season grasses. Warm-season grasses have greater proportions of stem caused by their ability to reach flowering more quickly than cool-season grasses. Mesophyll and phloem are degraded rapidly in both grasses, but digestion in warm-season grass is slower. The reason for this is uncertain, but possibly due to a greater concentration of phenolic compounds and tightly packed, radial tissue arrangement (Jung et al., 1993; Akin, 1989; Hanna et al., 1973).

Bacteria attach more easily to parenchyma bundle sheath cells and epidermis than to degraded tissues such as mesophyll (Akin, 1989). Not all highly lignified tissues are colonized, whereby less resistant tissues and peripheral areas are colonized and then partially digested. Lag time and digestion rates are slower for warm-season grasses than for cool-season grasses and legumes. Again, the reason for this is not fully understood, but possibly because time for hydration is longer for warm-season grasses (Mertens and Loften, 1980; Jung et al., 1993). Larger quantities of phenolic acid concentrations in warm-season grasses might restrict attachment in some areas, therefore leaving regions of warm-season grasses that are not colonized by microbes.

Forage Fiber

When forage intake is high, a slightly greater proportion of fiber digestion in the rumen with warm-season grasses than cool-season grasses is likely. This is attributed to the lower microbial protein synthesis, lower voluntary intake, and slower rate of digesta passage for warm-season grasses (Brake et al., 1989; Sun et al., 1992; Jung et al., 1993). Leibolz (1980) suggested greater microbial efficiency for cool-season grasses is because energy and nutrient supplies more closely harmonized potential rates of utilization by microbes located in the rumen. Additionally, ruminants require fiber provided by forages to stimulate the cardial region of the reticulum, which induces regurgitation, rumination, and rumen motility (Buxton et al., 1995).

Measures of Forage Fiber

Neutral Detergent Fiber. Crude fiber, acid detergent fiber, and neutral detergent fiber are the most frequent measures of fiber used in feed analysis; however, none of these fractions are chemically uniform. Neutral-detergent extraction is determined by boiling samples in a solution sodium laurel sulfate. The detergent extracts lipids, sugars, organic acids, and other water soluble material, and nonprotein nitrogen (NPN) compounds, soluble protein, and some silica and tannin. The non-soluble material is referred to as neutral detergent residue or, more commonly neutral detergent fiber (NDF). The NDF residue contains the major cell wall components such as cellulose, hemicellulose, and lignin. It can also contain minor cell wall components, including some protein, bound N, minerals, and cuticle. The soluble material has become synonymous with intracelluar contents and is highly digestible by all species, with the exception of pectins, silica and tannins. The NDF is only partially digestible by most species, but can be utilized to a greater extent by ruminants, due to microbial digestion.

Neutral detergent fiber best represents carbohydrates in plants, and NDF measures most of the chemical compounds considered to comprise the fiber fraction.

Acid Detergent Fiber. Acid detergent fiber (ADF) excludes hemicellulose and is comprised of components soluble in acid detergent and includes cellulose and lignin. ADF and lignin contents of feedstuffs are considered to be indicators of relative digestibility, whereas NDF content is more often considered to be an indicator of intake potential among or within forage species. Crude fiber is a method which does not quantitatively recover hemicellulose or lignin. NDF, ADF, and CF are highly correlated within a specific feedstuff. Nevertheless, in diets which contain different fiber sources, the correlations of fiber decrease. NDF is the superlative expression of fiber availability. ADF is also widely used, and crude fiber is considered obsolete.

Plant Fiber as an Energy Source for Ruminants

The energy from most plants is available predominantly in the form of carbohydrates, with only a small portion of the calories provided as fat. An exception to this would be oil-bearing seeds such as soybeans. The carbohydrates present in these plants are in the form of mono-, di-, and polysaccharides, including starch, and a variety of other complex carbohydrates, including cellulose and lignin, which are capable of resisting hydrolysis by enzymes elaborated by the host animal. In ruminants, large microbial populations in the rumen contain species capable of hydrolyzing cellulose present in plant cell wall structures. Van Soest (1982) classified dietary fibers by their type and source. Cellulose and hemicellulose are polymers of hexoses and pentoses. Lignin is a highly insoluble and a biologically unavailable mixture of polymers of phenolic acids and is often present in the outer bran layers of cereal grain seeds such as barley, in the stems of vegetative portions of grasses and legumes, and in the woody structure of trees and shrubs. It is interesting to note that termites elaborate enzymes capable of breaking down lignin. The structural components of plants also contain proteins including extensin which is usually of low bioavailability. Additional plant constituents that are considered plant fibers are the hemicelluloses: gums including pectins, and beta-glucans which are present in many cereal grains. The beta-glucans are present as cellular membranes and storage forms of energy in the plant. Tannins and tannin-protein complexes are present in the seed coats of some plants, notably in dark seeded cultivars of many grain sorghums. Tannins are completely unpalatable to animals and their presence possibly represents an adaptive mechanism for plants.

The fractional rate of passage from the rumen strongly regulates the extent of ruminal degradation of NDF. The rate of passage of soybean hulls (0.096/h) was greater than forage (0.054/h) in lactating cows averaging 23.7 kg/d of DMI (Erdman et al., 1987; Firkins, 1997). The probability that non-forage fiber sources (NFFS) have similar or faster passages rates than do forages, combined with the tendency of many NFFS to have rates of NDF digestibility that are similar to or slower than those of forages imply that a large proportion of potentially available non-forage NDF probably escapes ruminal fermentation in lactating dairy cows. Faster passage rate could decrease the ruminal digestibility of available NDF, which provides energy to support ruminal microbial protein synthesis. However, increased passage rate might also stimulate the efficiency of microbial protein synthesis through decreased energy used for maintenance.

Neutral Detergent Fiber Digestibility

Generally NDF is less digestible than nonfiber carbohydrates, thus the concentration of NDF in forage is negatively correlated with energy concentration. The proportions of cellulose, hemicellulose, and lignin affects the digestibility of NDF. As a result of this, forages with similar NDF concentrations will not necessarily have similar net energy concentrations. Similarly, diets or forages with high NDF concentrations may have more net energy than another diet or forage with lower concentrations of NDF.

Effects of Neutral Detergent Fiber on Ruminal Fermentation

The source of NDF has a major impact on cow response to NDF concentrations. Forage provided NDF is distinctly different form non-forage sources including soybean hulls, wheat midds, beet pulp, and corn gluten feed. Grain sources of NDF have a relatively large pool of potentially degradable NDF, small particle size, and relatively high specific gravity (Firkins, 1997). Moreover, the non-forage fiber sources have similar or faster passage rates than many forages; therefore, the rate of NDF digestion is slower or very similar to that of forages. A large proportion of potentially available NDF from non-forage sources may evade ruminal fermentation, which results in less acid production in the rumen (Firkins, 1997).

Concentrations of NDF are inversely related to ruminal pH. This is due to the fact that NDF generally ferments slower and is less digestible than non-fiber carbohydrates; therefore, less acid is produced within the rumen. Additionally, the majority of dietary NDF in forage diets has a physical structure that promotes chewing and saliva production, which then in turn influences the buffering capacity.

Forage Protein

True Protein and Non-Protein Nitrogen.

The nitrogen contained in forage can be divided into two fractions: true protein and nonprotein nitrogen (NPN). A majority of the NPN is in the form of nucleic acids, free amino acids, amides, and nitrate. Where sufficient carbohydrate or other sources of energy are available for microbial growth, NPN is converted to ammonia in the rumen and then used for microbial protein synthesis (Buxton et al., 1995). Forage nitrogen is comprised of 60 to 80% true protein. Upwards of 90% of all nitrogen in most forage is in cell solubles and readily digestible (Broderick, 1994). Crude protein concentrations can affect forage intake. Milford and Minson (1965) noted that forage intake by sheep declined exponentially when crude protein levels fell below 7%. Forage intake decreases when the nitrogen requirements of rumen microbial populations are not met (Van Soest, 1982).

Protein Digestion.

Protein digestion in ruminant animals is multi-faceted and includes degradation and loss of protein from the rumen, transformation of forage protein to microbial protein, and ultimately digestion and absorption of amino acids from microbes and forage that pass out of the rumen (Broderick, 1994; Fick et al., 1994; Buxton et al., 1995). The transformation of forage protein into microbial protein in the rumen is governed by the availability of energy for microbial growth. Thus, feeding an energy source such as grain, along with forage can improve the efficiency of utilization of protein nitrogen and NPN (Buxton et al., 1995). More than half (50 to 80%) of protein reaching the small intestine is synthesized by microbes. If energy availability is adequate, microbial protein can provide animals with enough protein for maintenance and for some increment of growth. If energy is limiting in forages, microbial protein may not be produced in large enough quantities for optimum performance during times of rapid animal growth, late gestation, or early lactation. In some instances, animal production is limited by excessive amounts of forage nitrogen that is lost from the rumen. The extent to which protein degradation is achieved by rumen microbes is controlled by the proteolytic rate and length of time in which plant residues are retained within the rumen. When proteins are degraded to amino acids and peptides, they can then be assimilated by microbes and used to synthesize microbial protein, or deaminated and metabolized for energy substrate. In the instance that amino acids are deaminated, ammonia is released into the rumen. When ammonia is absorbed through the rumen wall into the bloodstream, it is then detoxified in the liver by conversion to urea. However, a portion of the urea is recycled to the rumen through saliva and through the rumen wall, but the majority is excreted in the urine.

Maturity Effects on Degradable Intake Protein.

Maturity not only alters the leaf:stem ratio, but it affects the degradable intake protein (DIP) content of forages (Buxton et al. 1996). Not surprisingly, forage type affects the amount of DIP present. Cool-season grasses are usually higher in DIP than warm-season grasses (Moser and Hoveland, 1996). Moreover, the CP in smooth bromegrass (cool season) was comprised of 80% DIP, while switchgrass (warm season) CP was 50% DIP (Mullahey et. al, 1992). This is thought to be attributed to the lower extent of digestion of warm season vascular bundle sheath cells (Nelson and Moser, 1994; Akin, 1990).

Forage Intake

Forage intake is the primary determinant of level of production by ruminants grazing forage-based diets; nevertheless, it is one of the most challenging aspects of forage quality to determine. Forage intake often accounts for more than twice as much variation in animal performance as does forage digestibility (Mertens, 1994). Variation among animals has a large influence on intake of forages. Several intake-controlling mechanisms have been discussed by Baile (1975). These mechanisms included human factors, neural transmitters, chemical and hormonal mechanisms, digestibility, reticulo-rumen fill, and rate of passage. The difficulty in measuring forage intake is due to the variation among animals which has a pronounced influence on intake. In many situations, intake of energy and protein determine the level of animal performance. Intake of available energy is mainly a function of plant cell wall concentration. The cell walls limit intake and digestibility (Buxton, et al., 1995). A large portion of the complex carbohydrates in forages are located within the cell wall, which cannot be degraded by mammalian enzymes. Therefore, animals rely on microbial fermentation in the rumen to utilize the energy contained within cell walls (Buxton et al., 1995). Furthermore, cell contents yield different end products of digestion and require less metabolic and digestive processes than cell walls, thus resulting in greater digestibility and efficiency in metabolic processes. The most consequential division of dry matter into energy-providing components for ruminants is between cell walls and cell contents. Cell walls comprise approximately 40 to 80% of the organic matter in forages. Nevertheless, plant cell contents are nearly completely digestible. The availability of plant cell wall varies tremendously in regards to composition and structure (Moore et al., 1994).

Rumen Factors Controlling Forage Intake

Reticulo-Rumen Capacity and Rate of Disappearance. Control of forage intake in ruminants has been extensively reviewed. The fibrous and bulky features of forages lends emphasis to the physical effects of gut distention and the role it plays in voluntary intake. Previous research has concluded that in predominantly forage diets voluntary intake is limited by the reticulo-rumen capacity and the rate of disappearance of digesta from the organ (Balch and Campling, 1962; Ellis, 1978). Rate of disappearance is related to the rates of degradation and passage. Campling and Balch (1961) removed swallowed hay as it reached the reticulo-rumen, and found that hay accumulation had a detrimental effect on termination of eating. In contrast, the cows were coaxed into eating for longer than normal amounts of time by removing swallowed hay from the reticulo-rumen. Later, another study offered sheep coarsely ground roughage, sawdust, or polyvinyl chloride which were introduced into the rumen. Weston (1966) confirmed the ideas set forth by Campling and Balch (1961) that voluntary intake was limited by reticulo-rumen capacity and rate of disappearance from the organ.

Moreover, disappearance rate of digesta from the reticulo-rumen is regulated by the rate of digestion which in turn, depends on the chemical and physical properties of feedstuffs or forage consumed (Hungate, 1966). Readily fermentable carbohydrates in forage disappear from the reticulo-rumen quicker than structural components or cell wall fractions. Likewise, forages that take less time to be passed through the reticulo-rumen have been found to have greater voluntary intake than forages that take longer or are more coarse (Minson, 1963; Poppi et al., 1981). These conclusions support the notion that physical limitation on forage intake is imposed by limited size of the reticulo-omasal orifice (Allison, 1980).

Physical Fill. Previous research has shown that ruminants on forage diets eat to a constant rumen fill. Research with sheep offered poor, medium, and high quality hay was conducted by Blaxter et al. (1961). The sheep had similar amounts of DM contents in the digestive tract. Additional conformation was found later when a study evacuated and weighed digesta from the reticulo-rumen post feeding. The diets were comprised of hay and dried grass. Consumption ceased when the reticulo-rumen contained similar amounts of DM. Thus, quantity of the roughages consumed was highly correlated with the rate of disappearance from the reticulo-rumen.

A review by Buxton et al., (1995) concluded that physical fill limits intake of forages with high NDF concentration when fed to animals with high energy demands. For this reason, intake potential of forages is negatively related to NDF. Within the same plant species, intake is positively correlated with digestibility. This is attributed to digestibility being inversely related to NDF concentration (Buxton et al., 1995).

Rate of Digestion. Voluntary intake is also closely tied to forage digestibility. With rumen fill remaining constant, rate of passage through the reticulo-rumen has been demonstrated to increase as forage digestibility increases (Blaxter and Wilson, 1962). An additional study found little differences in voluntary forage intake when digestibility was expressed on a weight or volume basis (Dinius and Baumgardt, 1970). Observed differences in voluntary intake were noted by Minson (1971) where the differences were related to digestibility.

Furthermore, voluntary forage intake is limited by physical constraints within the gut, and more specifically the amount of digesta in the reticulo-rumen. A theory was that with certain forages, intake would be limited by rumen capacity and the speed at which undigested residues left the reticulo-rumen. Based on this theory, Thorton and Minson (1972) proposed that voluntary forage intake could be calculated from rumen fill and rumen content retention time. In addition, it was believed that if fill was constant, dry matter intake and retention time were inversely related. This hypothesis was tested using grasses and legumes fed to sheep (Thorton and Minson, 1973). The authors concluded that rumen fill with the wide range of forages tested was constant, and voluntary intake was primarily controlled by retention time of the fibrous fraction in the rumen. The greater consumption of leaf plant material as compared with stems in legumes and grasses was also related to a shorter retention time in the rumen (Thorton and Minson, 1973).

Plant Cell Wall. Cell wall concentrations of diets can reach up to 70% NDF before they begin to decrease intake and animal production in mature beef cows, and up to 20% NDF for fattening ruminants. Intermediate to the aforementioned levels, optimum NDF levels for dairy cows at peak lactation range from 27 to 30%. These NDF levels allow for adequate energy intake and provide adequate fiber in the diet (Mertens, 1994). As well as cell wall concentration, resulting rumen fill of forage is determined by the rate of disappearance of cell walls from the rumen via digestion and passage. Passage out of the rumen requires a decreased particle size and escape through the reticulo-omasal orifice of the rumen. The cell walls must be masticated and digested to reduce size before they can be passed through the small reticulo-omasal orifice opening.

Van Soest (1982) concluded that forage intake is dependent on structural volume, hence cell wall content. He suggested that the link between moisture content of forages and forage intake, may then be a function of structural volume if the plant moisture is trapped within the cell wall structure. Another suggestion was that addition of water to the rumen was absorbed and removed and had little effect on forage intake.

Nevertheless, Van Soest (1982) proposed that water retention by coarse structural components of ingested forage can have a sponge effect, and therefore have inhibitory effects on intake.

Animal Factors Controlling Voluntary Forage Intake

Body Size. In addition to many other factors, voluntary forage intake of grazing ruminants is correlated to body size (Holmes et al., 1961) and metabolic body size (Johnson et al., 1968). Energy demands have been shown to be proportional to the 0.75 power of body weight; and therefore, energy requirements per unit of weight for smaller animals are greater than for larger ones (Klieber, 1961). This resulted in the idea that intake should be reported in relation to metabolic body weight ($BW^{0.75}$). Younger animals have a relatively smaller rumen than adult animals. This causes an increased nutrient requirement and is often times met by an increased appetite and faster turnover rate of particles (Hungate, 1966). For instance, Horn et al. (1979) reported that calves selected forage with greater crude protein level and lower ADF and cellulose concentrations than did mature cows. When unlimited amounts of high quality forage are available, ad libitum intake of grazing ruminants is influenced solely by energy demand. Then grazing ruminant forage intake becomes dependent on liveweight, and energy demand (Corbett et al. 1963; Owen and Ingleton, 1963). Ad libitum intake by cattle is directly proportional to metabolic size; however, this varies with digestibility (Blaxter and Wilson, 1962).

Physiological Status. The physiological status of animals also influences forage intake. Alterations in physiological status can change intake greatly. Dry pregnant ewes within the same breed have been shown to have similar dry matter intakes, whereas lactating ewes of the same flock required 25 to 50% greater dry matter intake (Arnold and Dudzinski, 1967a,b). Variation in voluntary intake has also been noted for cattle during lactation and pregnancy. Rosiere et al. (1980) reported dry 2-year old heifers consumed only 67% as much forage as lactating heifers of the same age. Furthermore, Journet and Remond (1976) observed similar variation in voluntary intake of cattle.

Body Condition. Forage intake is not only related to body size and weight, but also body condition. Liveweight can be an inaccurate index of energy demand and intake due to the variation in liveweight over time, and also the variation of body condition among different individuals in the same herd (Arnold, 1970a). This is illustrated in work by Arnold et al. (1967b) where intake decreased with increasing body fat. Thus, intake and liveweight are negatively related. The idea of compensatory gain confounds the relationship between intake and liveweight. For example, Allden (1968) observed that thin sheep grazing pasture with fat sheep increased intake by at least 20% on a per unit of liveweight basis causing compensatory gain. Moreover, young sheep also compensated for previous periods of under nutrition by consuming more per unit liveweight than sheep that were previously meeting maintenance requirements.

Hormones and Metabolites. Hormones and metabolites also influence voluntary forage intake. Forbes (1980) described the effect of fatness on food intake, the first noted response was decreased abdominal capacity which is a result of increased mesenteric fat. Also, there is a decrease in the sensitivity of adipocytes to insulin as the animal becomes fatter, thus a decreased removal of glucose from the blood. With actual changes in size of adipocytes with fattening, the rate of "leakage" of fatty acids from adipose tissues increases. This increase is positively related to size, the fatter the animal the stronger the chemostatic regulation of negative feedback.

Seasonal Changes in Forage Intake

Seasonal changes in forage intake occur even when there are no visible changes in forage maturity. Corbett et al. (1963) concluded that lactating cows grazing temperate pastures consumed 10% less forage in fall than spring, even though organic matter (OM) digestibilities were similar. He then suggested that forage from the two seasons were in fact digested at different rates. Additionally, the lower intake in the spring forage was suggested to be attributed to the presence of excreta on the forage which was voided during the earlier grazing season, fungal infections such as rusts, soil contamination, and excess forage moisture. With regard to forage moisture, a study by Minson (1966) looked at the effects of moisture as a determinant of voluntary dry matter intake. It was concluded that feeding fresh, dried, or frozen forage to sheep had no significant effect of voluntary intake. Further seasonal differences in intake were also found for cattle grazing orchardgrass (Dactylis glomerta) and alfalfa and mixtures of the two species (Alder and Minson, 1963). The intake of fall forage was 9% less than the intake of summer forage, where the fall forage was slightly more digestible. Another study by Nichols et al. (1993) evaluated the effects of advancing maturity in cool and warm season grass species in Nebraska. Collectively in vitro organic matter digestibility (IVOMD) of these grasses decreased linearly from June to September. A curvilinear response was noted for crude protein concentration which decreased more rapidly from June to July than from July to September. These decreasing responses are typical seasonal changes observed in forage nutritive value.

Energy Supplementation of Grazing Ruminants

Importance of Energy Supplementation

Energy supplementation of cattle grazing small grain pasture is of importance for many reasons as addressed by Horn et al. (2005). Supplementation can provide a more balanced nutrient supply. Furthermore, supplement can be substituted for forage where it is desirable to increase stocking rate with regards to grazing management and marketing decisions. Lastly, supplementation can substitute supplement for forage in times of low forage standing crops. These supplements can extend the grazing season, and are often needed because of the low nutrient content of forage in relation to animal requirements. Energy supplements can also serve as a means of delivering feed additives such as ionophores or bloat preventive compounds (Horn et al., 2005). In contrast, Jung et al. (1993) has postulated that the amino acid supply in cool-season grasses is more limiting than energy. Highly digestible cool-season grasses contain protein which is rapidly and thoroughly degraded in the rumen, and may cause low efficiency. The supply of absorbed amino acids is not harmonized with the supply of energy. Supplements to increase the intestinal supply of protein can enhance the efficiency of acetate utilization. Such increased protein deposition concurrent with a decreased need for $NADPH_2$ in fat synthesis appear to be responsible, rather than increased $NADPH_2$ supplied by glucose precursors that arise from amino acid deamination (McRae et al., 1985; Jung et al., 1993).

Soybean Hulls as an Energy Supplement

Cattle Performance and Stocking Rate. Feeding modest amounts of an energy supplement to growing cattle on high-quality winter pasture can aid in increasing stability of the enterprise due to the variable forage supply throughout the season. Initial stocking rates can be markedly increased by having more cattle on hand to graze pasture after the initiation of spring growth. High-fiber by-product feeds have good potential for use in energy supplementation programs (Horn and McCollum, 1987). Ǿrskov and Fraser (1975) fed sheep whole or pelleted barley grain at a level of 85% of estimated maximum intake and evaluated ruminal pH in relation to forage intake. A ruminal pH of approximately 6.7 was observed for the whole barley, whereby the ruminal pH of the sheep fed pelleted barley changed diurnally and fell to less than 5.5 at 2 and 4 hours post feeding. Their conclusion was that the increased rate of fermentation resulted in pH conditions not conducive to celluloytic bacteria and was a major factor that depressed forage intake. It was later suggested by Mould et al. (1983) that depression of forage intake when grazing ruminants were supplemented with feeds high in readily fermentable carbohydrates such as barley or corn is of "composite nature" and due to a pH effect and a carbohydrate effect. Martin and Hibberd (1990) conducted a study to evaluate the effects of supplementation using soybean or cottonseed hulls on intake and utilization of low-quality native grass hay. They reported that total volatile fatty acid (VFA) concentrations increased linearly as the substitution of soybean hulls replaced cottonseed hulls in the diet. A rise in total VFA concentration in addition to decreased rumen pH (Martin and Hibberd, 1990; Hsu et al., 1987) supports the suggestion that soybean hulls provide a more fermentable substrate than prairie hay for ruminal microbes, and therefore soybean hulls are not digested at the expense of forage digestion. Additionally, Horn et al. (2005) reported that cattle seemed to prefer the high-fiber (soybean hull) supplement and consume it much more readily than the corn-based high-starch supplement. Supplements high in fiber and completely devoid of starch may actually enhance forage utilization (Martin and Hibberd, 1990). Several in vivo studies have noted that soybean hulls are approximately 75% digestible (Streeter and Horn, 1983; Hus et al., 1987). Martin and Hibberd (1990) fed twelve ruminally cannulated heifers supplements providing 0, 1, 2, or 3 kg/d of soybean hulls and included 440 g of protein/d in the form of cottonseed meal to determine the effects of supplementation on intake and utilization of low-quality native grass hay. Total diet OM digestibility was expected to increase as soybean hulls were increased in the diet; however, soybean hull supplementation did not alter total diet NDF digestibility and the effect on total diet OM digestibility increased linearly with added increments of soybean hulls. This indicated that the soybean hulls were more digestible than the native grass hay. Conversely, ADF digestibility increased. Comparable responses were observed in other cattle (MacGregor et al., 1976; Anderson et al., 1988a) and sheep studies (Sudweeks, 1977; and Anderson et al., 1988b). These data support the idea that soybean hulls are an acceptable energy supplement, and do not interfere with the celluloytic activity of rumen microbes (Highfill et al., 1987).

Many researchers have evaluated production characteristics and demonstrated improvements that resulted from energy supplementation regardless of energy source (Meijs, 1986; Anderson et al., 1988a; Grigsby et al., 1991; Vanzant and Cochran, 1994 Horn, 2006; Horn, 2005). Reported improvements include reduced weight loss, reduced body condition score loss, and increased gains. A supplement program to improve animal growth should complement forage deficiencies (Anderson et al., 1988). The effect of energy supplementation on performance of grazing cattle has been well noted throughout the literature. Utley et al. (1973) conducted a study in which cattle grazed oat or rye pasture (0.41 steer/hectare) and were fed corn silage to "appetite" daily, or grazed oat or rye pasture (0.27 steer/hectare) with no supplement. Daily gain was similar for both treatments, with stocking rate being dramatically increased when a supplement was offered. An additional study by Utley et al. (1976) placed cattle on rye pastures with or without a grain supplement at two stocking rates. The stocking rate was doubled for the cattle receiving supplement over the cattle that were not. Daily gain was greater for cattle being fed supplement while grazing rye pasture. Vogel et al. (1987) conducted a 3-year study with fall-weaned steers to test the effects of feeding silage to stocker cattle on wheat pasture, at increasing stocking densities on cattle performance. Steers received no supplement, and three additional treatments with an increase in stocking density and had ad libitum access to silage daily. Weight gain of steers on all treatments were similar. Often times daily gain of cattle where stocking rate is increased are similar when an energy supplement is fed. Even so, total gain/hectare is often increased by feeding the supplement. Vogel et al. (1987) found that total gain/hectare was 1.8-fold greater for steers on the heaviest stocked treatment over the control treatment, which were stocked lighter and received no supplement.

Soybean hulls are a by-product of soybean meal production. Soybean hulls have been studied extensively as an alternative energy source in ruminant diets (Johnson et al., 1962; Chase and Hibberd, 1986; Anderson et al., 1988a; Hsu et al., 1987). Similarities in daily gain and feed to gain have been shown by Brown et al. (1981) and Anderson et al. (1988a) for growing calves fed corn or soybean hull supplemented forage diets. Martin and Hibberd (1990) noted that low quality native grass hay OM intake (kg/d) peaked quadratically with 1 kg of soybean hull supplementation, further declining as additional soybean hulls were fed. Their theory was that soybean hulls swell very rapidly when exposed to water and could decrease hay intake via rumen fill. However, hay intake was decreased only 0.64 kg/d when 3 kg of soybean hulls were fed to mature ruminally cannulated cows. This indicated that ruminal distension caused by soybean hulls was not the primary factor limiting hay intake. Martin and Hibberd (1990) postulated that the small particle size of soybean hulls would allow them to enter the ruminal forage mat with little increase in total volume. Soybean hulls supplementation has been shown to increased total OM digestibility and intake (Martin and Hibberd, 1990). This supplementation increased total ruminal VFA concentrations that contained larger proportions of energetically efficient propionate. The resulting energy status of beef cattle grazing low quality forage was improved with soybean hull supplementation (Martin and Hibberd, 1990).

Researchers in Nebraska (Anderson et al., 1988 b) conducted four grazing trials using cattle on smooth brome grass evaluating different energy supplements. The first trial fed no supplement, whole untoasted soybean hulls, or corn at 1.36 kg DM• hd^{-1}•d^{-1} as an energy supplement. Energy supplementation tended to improve daily gain, but differences were not significant. The response to whole soybean hull supplementation and rolled corn supplementation was similar. The second trial grazed spayed heifers and steers on smooth brome pastures with four types of an energy supplement. No supplement, rolled corn, ground soybean hulls, or whole soybean hulls were fed at the same rate as the previous study. The energy supplements were found to increase daily gain over the grazing period. An increase of 25 kg of body weight per animal over un-supplemented animals was observed. Daily gain was similar among groups of cattle fed corn, and ground or whole soybean hulls as a supplement. The third trial deviated from the smooth brome pasture and used crossbred spayed heifers in a cornstalk grazing trial. The energy supplement regimens included no supplement, rolled corn, and whole soybean hulls. Moreover, trial four was designed to replicate trial 3. Heifers again were allocated to the same treatments. For both trials three and four heifers supplemented with corn whole soybean hulls had higher rates of gain than un-supplemented heifers. Similar to the first two trials, whole soybean hulls supported daily gains equivalent to that of corn. Pooled across four experiments, response to energy supplementation was found significant. Additionally, the researchers concluded that soybean hulls were similar in energy value to corn when used to supplement the grazing beef animal (Anderson et al., 1988a).

Supplement Conversion. A three-year study by Horn et. al., (1995) was conducted to determine the effects of high-starch or high-fiber energy supplements on performance of steer calves grazing wheat pasture. The high-starch supplement was corn based, and the high-fiber supplement was soybean hull/wheat middling based. The target level of supplement consumption was 0.75% of mean BW and stocking density was increased by 33% for two trials and 44% for the final trial. In a pooled analysis for the three year study, mean daily supplement consumption was 0.65% of BW. Cattle consumed the high-fiber supplement more readily than the high-starch supplement. Additionally, daily gain was increased by supplementation, and not influenced by type of supplement. Mean supplement conversions were 5.4 and 5.0 kilograms (kilograms as-fed•kilogram of increased gain^{-1}•hectare $^{-1}$) for high-starch and high-fiber supplements, respectively. It was concluded that energy supplementation allowed stocking density to be increased by one-third, and daily gain was increased by 0.15 kg. Vogel et al. (1987)

reported the use of silage to supplement stocker cattle on wheat pasture. The silage was fed ad libitum. Mean supplement consumption over a three year pooled analysis was 0.65% of BW and similar to Horn et al. (1995). Additional research (Goetsch et al., 1991) reported that when corn was supplemented at 0.50% of BW/d on a DM basis, ADG of steers was increased 0.3 kg while grazing bermudagrass pastures sod-seeded with rye, wheat, and annual ryegrass. Stocking density was 4.76 steers/ha and cattle also consumed fescue-bermudagrass hay at 1.4% of BW for nearly half of the study. Additional research where energy supplements were fed to cattle grazing small grains pastures has been reported in the literature (Grigsby et al., 1991; Branine and Galyean, 1990); however, these studies did not increase stocking density or report supplement conversion.

Effects of Processing on Digestion and Utilization. One steer and two lamb digestion trials were conducted (Anderson et al., 1988b) to evaluate the effects of extent of mechanical processing on the digestibility and utilization of soybean hulls. Whole toasted soybean hulls or corn replaced ensiled cornstalks in a digestion trial using seven ruminally fistulated steers. The soybean hulls and corn were fed at 0, 12.5, 25, or 50% (DM basis) of a corn stalk diet supplemented with soybean meal fed ad libitum. Dry matter intake increased with increasing energy level. Soybean hulls tended to be consumed at a higher level than corn, although no statistical differences were present. Dry matter digestibility was greater for steers consuming corn than for those consuming soybean hulls. Nevertheless, this difference was small being only 1 to 2 percentage units and agrees with Sudweeks (1976). The % digestibility of NDF decreased with corn, but increased with soybean hulls. No differences in rate of particulate passage in steers fed either corn or soybean hull diets were detected. The lamb digestion trial was conducted to determine pelleting effects on apparent digestibility of soybean hull dry matter and NDF. The trial used 24 crossbred sheep. Sheep grazing corn stalks had ad libitum access to cracked corn, whole, pelleted or ground soybean hulls followed by a phase of equal intake of the energy supplement. At equal intake levels, DM digestibility of the ground soybean hull diet was lower than the whole soybean hull diet. Rate of passage of ground (to pass through a 1.5-mm screen) soybean hulls was faster than that of un-ground soybean hulls. Even when the effect of intake was removed, rate of passage of the ground soybean hull diet was greater than for the whole soybean hull diet. Therefore, digestibility was decreased. The corn supplemented diet had lower NDF digestion than all other diets. There was a greater proportion of dietary NDF that came from ensiled cornstalks when corn was included in the diet. This is due to the fact that corn is much lower in NDF than soybean hulls (12 vs 70 to 82%). Lambs consuming whole soybean hull diets had greater NDF digestibilities than those fed ground soybean hull diets, which indicates an increased ruminal retention time of whole soybean hulls. When lambs were given ad libitum access to the energy supplements there was no difference in DM intake, DM digestibility, or NDF digestibility among the soybean hull diets. The second lamb digestion trial consisted of sixty-six crossbred wethers fed ad libitum brome hay. Treatments included whole soybean hulls ground through 4.8-mm, 3.2-mm screens, and pelleted soybean hulls through a 9.5-mm and 4.8-mm screen. These treatments were meant to simulate the situation in which a soybean processor would grind or pellet the soybean hulls prior to shipping. As screen size decreased, apparent particle size decreased. Furthermore, pelleting did not alter particle size of the ground material. It was also concluded that the soybean hull was somewhat resistant to processing. When the finest grind was used only 71.5% of the whole soybean hull was reduced to a size assumed to be small enough to exit the rumen. Minimal differences were observed, yet grinding tended to decrease the dry matter digestibility as screen size decreased. It was concluded that any differences in digestibility that resulted from smaller particle size due to processing procedures was small and did not merit consideration if the soybean hulls made up less than 50% of the dry matter intake.

Rate of Fiber Digestion. Anderson et al. (1988a) noted the rate of fiber digestion of soybean hulls is not extremely rapid (6%/h), yet the extent of digestion is high (93 to 95%), therefore increased digestion might result if soybean hulls had longer residence time in the rumen (Anderson et al., 1988a). Rate of passage from the rumen (%/h) was faster for ground than for whole soybean hulls. With similar rates of NDF digestibility for both whole and ground soybean hulls and greater rate of passage of ground hulls, ruminal dry matter digestibility (DMD) is decreased by feeding ground soybean hulls.

Effects of Stocking Rate on Cattle Performance

Carrying capacity of a pasture is defined as the number of animals of a specific type that can subsist on a unit of area and produce at a required rate over a specified time period (Cowlishaw, 1969). Maximum animal output is achieved when carrying capacity is known; however, this is not an easy thing to measure. Measuring the quantity (forage mass kg/ha) of forage available per unit of land, and the ability of the animal to utilize what is available must be achieved simultaneously. Grazing management involves subjective judgment and its effects are difficult to assess. Cowlishaw (1969) stated that the difficulties arise from an imbalance in forage nutrients required by animals and from poor sward structures from which animals are unable to obtain enough food. Moreover, Cowlishaw (1969) explained that optimum stocking rate allows grazing ruminants to produce at the most economic rate, which should not to be confused with the maximum rate. The economic rate may not be maximum, as the relationship between the value of pasture and the product play a role, along with costs associated with grazing management. Costs and values of input and output factors vary from time and place according to the laws of supply and demand, and therefore it is of great importance to producers to know how production per animal and production per hectare are affected by stocking rate. In general, gain per animal decreases linearly, while gain per hectare increases linearly as stocking rate is increased.

Gain/Animal

It is well know that production per animal and production per hectare are dependent on stocking rate (Petersen et al., 1965). If too few animals are used, forage is not fully utilized and maximum production per hectare is not achieved. When an excessive number of animals are used, production per hectare is also reduced due to a lack of forage. Petersen et al. (1965) also stated that both understocking and overstocking forage may result in negative changes to the botanical composition of the pasture. Previous data has shown the relationship between liveweight gain per animal and stocking rate to be linear (Riewe, 1961; Cowlishaw, 1962). Petersen et al. (1965) illustrated a point of discontinuity existed at the optimum or critical stocking rate, and at stocking rates below optimum forage intake remained constant. Thus, gain per head also remained constant. In contrast, as stocking rate was increased beyond the critical rate, a point is eventually reached where gain per animal is zero (Petersen et al., 1965). After this point animals are neither gaining of losing weight, and it may be thought of as a "maintenance" stocking rate. The theory proposed by Petersen et al. (1965) also stated that at stocking rates less than the critical rate, gain per head is maximum. This was in agreement with Cowlishaw (1969), where only two stocking rates were used on pasture. Gain per head was the same at both levels, indicating that available pasture was not fully utilized. Additionally, at stocking rates between the critical and the maintenance rate, gain per head is reciprocally related to stocking rate (Petersen, 1965). Finally, at stocking rates above the maintenance rate, all animals lose weight. Cowlishaw (1962) also demonstrated this discontinuity with yearling sheep at six stocking rates. With an increase in stocking rate, gain per animal started to decrease. This phenomenon has been called many names by researchers. It was described as a linear decline in daily gain with increasing stocking rate by Jones and Sandland, (1974). Earlier Mott (1969) described it as a curvilinear decline; whereas Hart et al. (1988) described it as a linear decline after a plateau at low stocking rates. These relationships were supported in a study by Ackerman et al. (2001), with heavy weight steers stocked at three increasing rates on Old World bluestem. As daily gain per animal decreased linearly stocking rate (kg/ha) increased. During subsequent years cattle grazing the same bluestem pastures also had a significant linear decrease in daily gain as stocking rate was increased. Decreasing daily gain due to increased stocking rate has been well established in the literature. Jones and Sandland (1975) fitted linear equations to data, the result also being that as stocking rate increased, gain per animal decreased. Hart et al. (1976) grazed steers on coastal bermudagrass pastures in three research trials. Similarly, as stocking rate was increased, daily steer gain decreased. Coleman and Forbes (1989) grazed Old World bluestem to maintain three different levels of forage mass in the summers of 1984 and 1985. Similar to previous research, there was a negative linear relationship between rate of gain and stocking rate. Coleman and Forbes (1998) also reported a decline in season-long gain of steers grazing Plains Old World Bluestem as the stocking rate increased. However, decreased gain of individual animals is often accompanied by increased gain/hectare as stocking rate is increased.

<u>Gain/Hectare</u>

Gain per hectare is an expression of stocking rate multiplied by gain per animal. Therefore, gain per hectare can be estimated from the estimated gain per animal and at any given stocking rate. Generally, maximum gain per hectare is achieved when animals have the opportunity for some selective grazing. Riewe et al. (1961) reported that any grazing study trying to measure or compare carrying capacity of pastures should utilize at least three stocking rates. Therefore, the rate that produces maximum gain/hectare can be identified. Previous research by Riewe (1961) and Cowlishaw (1962) have demonstrated the relationship between stocking rate and liveweight gain/ha to be curvilinear. In contrast, many studies have demonstrated that as stocking rate increases, gain/ha increases (Harlan, 1958; Phillips and Coleman, 1995, Coleman and Forbes, 1998). Ackerman et al. (2001) evaluated live weight gains of light and heavy steers grazing Plains Old World bluestem at three stocking rates. This research also provided evidence that gain/ha was increased as stocking rate increased.

Summary and Conclusions

In summary, small grains forages such as rye pasture are very important for growing cattle prior to feedlot entry in the southeastern United States. The aforementioned research has emphasized the effects of optimal stocking rate, while sensitive to forage characteristics including mass and nutritive value and animal factors such as forage intake. The optimal stocking rate can be altered by providing an energy supplement, which can provide a more balanced nutrient supply. Furthermore, supplement can be substituted for forage where it is desirable to increase stocking rate. Additionally, supplementation can substitute supplement for forage in times of low forage standing crops. Ultimately these supplements can extend the forage grazing season.

Literature Cited

Ackerman, C. J., H. T. Purvis, II, G. W. Horn, S. I. Paisley, R. R. Reuter, and T. N. Bodine. 2001. Performance of light vs heavy steers grazing Plains Old World bluestem at three stocking rates. J. Anim. Sci. 79:493-499.

Akin, D. E. 1989. Histological and physical factors affecting digestibility of forages. Agron. J. 81:17-25.

Akin, D. E. 1986. Interaction of ruminal bacteria and fungi with southern forages. J. Anim. Sci. 63:962-967.

Akin, D. E., L. L. Rigsby, C. E. Lyon, and W. R. Windham. 1990. Relationship of tissue digestion to textural strength in bermudagrass and alfalfa stems. Crop Sci. 30:990.

Albrecht, K. A., W. F. Wedin, and D. R. Buxton. 1987. Cell-wall composition and digestibility of alfalfa stems and leaves. Crop Sci. 27:735-741.

Alder F. E., and D. J. Minson. 1963. Seasonal effects of intake for cattle grazing orchardgrass. J. Agric. Sci. 60:359-367.

Allden, W. G. 1968. Under nutrition of the Merino sheep and it sequelae IV. Herbage consumption and utilization of feed for wool production following growth restrictions imposed at two stages of early post-natal life in a Mediterranean environment. Aust. J. Agr. Res. 19:977-1007.

Anderson, S. J., J. K. Merrill, M. L. McDonnell and T. J. Klopfenstein. 1988a. Digestibility and utilization of mechanically processed soybean hulls by lambs and steers. J. Anim. Sci. 66:2965-2979.

Anderson, S. J., J. K. Merrill, and T. J. Klopfenstein. 1988b. Soybean hulls as an energy supplement for the grazing ruminant. J. Anim. Sci. 66:2959-2964.

Arnold, G. W. and M. L. Dudzinski. 1967a. Comparison of fecal nitrogen regressions and in vitro estimates of diet digestibility for estimating the consumption of herbage by grazing animals. J. Agr. Sci. 68:213-219.

Arnold, G. W. and M. L. Dudzinski. 1967b. Studies on the diet of the grazing animal. The effect of physiological status in ewes and pasture availability on herbage intake. Aust. J. Agr. Res. 18:349-359.

Arnold, G. W. 1970. Herbage intake and grazing behavior in ewes of four breeds at different physiological states. Aust. J. Agr. Res. 26:1017-1024.

Baile, C. A. 1975. Control of feed intake in ruminants . In: Digestion and metabolism in the ruminant. Proc. IV Int. Symposium on Ruminant Physiology. The Univ. or New England Publishing Unit, Armidale, N. S. W. Australia.

Barnes, R. F., D. A. Miller, and C. J. Nelson. 1995. Forages. Volume I: An introduction to grassland agriculture. Iowa State University Press, Ames, IA. p.461-475.

Blach, C. C. and R. C. Campling. 1962. Regulation of voluntary intake in ruminants. Nutr. Abstr. And Rev. 32:669-686.

Blaxter, K. L., F. W. Wainman, and R. S. Wilson. 1961. The regulation of food intake by sheep. Anim. Prod. 3:51-61.

Blaxter, K. L. and R. S. Wilson. 1963. The assessment of a crop husbandry technique in terms of animal production. Anim. Prod. 6:27-42.

Blaxter, K. L. and R. S. Wilson. 1962. The voluntary intake of roughages by steers. Anim. Orod. 4:351-358.

Brake, A. C., A. L. Goetsch, L. A. Forster, Jr. and K. M. Landis. 1989. Feed intake, digestion and digesta characteristics of cattle fed bermudagrass or orchardgrass alone or with ground barley or corn. J. Anim. Sci. 67:3425-3436.

Branine, M. E., and M. L. Galyean. 1990. Influence of grain and monensin supplementation on ruminal fermentation, intake, digesta kinetics and incidence and severity of frothy bloat in steers grazing winter wheat pasture. J. Anim. Sci. 68:1139-1150.

Broderick, G. A. 1994. Quantifying forage protein quality. In Forage Quality, Evaluation, and Utilization. P. 200. G. C. Fahey, Jr., M. Collins, D. R. Mertens, and L. E. Moser (Eds.). American Society of Agronomy, Madison, WI.

Brown, P. W. and C. B. Tanner. 1983. Alfalfa stem and leaf growth during water stress. Agron. J. 75:799-805.

Brown, W. F., T. J. Klopfenstein, J. K. Merrill and M. L. McDonnell. 1981. Corn or soyhulls as energy supplements to crop residues. J. Anim. Sci. 53(Suppl. 1):112-123.

Bruckner, P. L., and P. L. Raymer. 1990. Factors influencing species and cultivar choice of small grains for winter forage. J. Prod. Agric. 3:349-356.

Buxton, D. R., D. R. Mertens, and K. J. Moore. 1995. Forage quality for ruminants:

plant and animal considerations. Prof. Anim. Sci. 11:121-131.

Buxton, D. R., J. S. Hornstein, W. F. Wedin, and G. C. Marten. 1985. Forage quality in stratified canopies of alfalfa, birdsfoot trefoil, and red clover. Crop Sci. 25:273-285.

Buxton, D. R. and M. D. Casler. 1993. Environmental and genetic effects on cell wall composition and digestibility. P. 685-714. In H. G. Jung, D. R. Buxton, R. D. Hatfield, and J. Ralph (Ed.). Forage cell wall structure and digestibility. ASA, Madison, WI.

Buxton, D. R. and S. L. Fales. 1994. Plant environment and quality. In Forage Quality, Evaluation, and Utilization. P. 155-199. G. C. Fahey, Jr., M. Collins, D. R. Mertens, and L. E. Moser (Eds.). American Society of Agronomy, Madison, WI.

Campling, R. C. and C. C. Balch. 1961. Factors affecting the voluntary intake of food by cows. I. Preliminary observations of the effect, on the voluntary intake of hay, of the changes in the amount of the reticulo-ruminal contents. Brit. J. Nutr. 16:523-530.

Chase, Jr., C. C. and C. A. Hibberd. 1986. Utilization of low-quality native grass hay by beef cows fed increasing quantities of corn grain. J. Anim. Sci. 65:557564.

Cherney, D. J. R., D. R. Mertens, and J. E. Moore. 1990. Intake and digestibility by wethers as influenced by forage morphology at three levels of forage offering. J. Anim. Sci. 1990. 68:4387-4399.

Cherney, J. H. and G. C. Marten. 1982. Small grain crop forage potential: I. Biological and chemical determinants of quality and yield. Crop Sci. 22:240-245.

Coleman, S. W. and T. D. A. Forbes. 1998. Herbage characteristics and performance of steers grazing old world bluestem. J. Range Manage. 51:399-407.

Coleman, S. W., T. D. A. Forbes, and J. W. Stuth. 1989. Measurements of the plant-animal interface in grazing research. P. 37-51. In G. C. Marten (Ed.) Grazing research: Design, methodology, and analyses. CSSA Spec. Publ. 16. ASA and CSSA, Madison, WI.

Corbett, J. L., J. P. Langlands, and G. W. Reid. 1963. Effects of season of growth and digestibility of herbage on intake by grazing dairy cows. Anim. Prod. 6:119-129.

Cowlishaw, S. J. 1969. The carrying capacity of pastures. J. Brit Grasslnd Soc. 24:207-214.

Cowlishaw, S. J. 1962. The effects of stocking density on the productivity of yearling female sheep. J. Br. Grassld Soc. 17:52-58.

Dinius, D. A., and B. R. Baumgardt. 1970/ Regulation of food intake in ruminants 6. Influence of caloric density of pelleted rations. J. Dairy Sci. 53:311-316.

Ellis, W. C. 1978. Determinants of grazed forage intake and digestibility. J. Dairy Sci. 61:1828-1840.

Erdman, R. A., J. H. Vandersall, R. E. Russek-Cohem, and G. Switalski. 1987. Simultaneous measures of rates of ruminal digestion and passage of feeds for prediction of ruminal nitrogen and dry matter digestion in lactating dairy cows. J. Anim. Sci. 64:565-665.

Fick, G. W., P. W. Wilkens, and J. H. Cherney. 1994. Modeling forage quality changes in the growing crop. In Forage Quality, Evaluation, and Utilization. P. 757. G. C. Fahey, Jr., M. Collins, D. R. Mertens, and L. E. Moser (Eds.). American Society of Agronomy, Madison, WI.

Firkins, J. L. 1997. Effects of feeding nonforage fiber sources on site of fiber digestion. J. Dairy Sci. 80:1426-1437.

Forbes, T. D. A. 1980. Hormones and metabolites in the control of food intake. *In:* Y. Ruckebusch and P. Thivend, Digestive Physiology and Metabolism in Ruminants. P. 145-160.

Forbes, T. D. A. and S. W. Coleman. 1993. Forage intake and ingestive behavior of cattle grazing old world bluestems. Agron. J. 85:808-816.

Fox, D. G. 1986. Physiological factors influencing voluntary intake by beef cattle. P. 193-207. In F. N. Owens (ed.) Symp. Proc. Feed Intake by Beef Cattle. 20-22. November. Oklahoma State University. MP-121. Oklahoma State University., Stillwater, OK.

Galloway, D. L., Sr., A. L., Goetsch, L. A. Forster, Jr., A. R. Patil, W. Sun, and Z. B. Johnson. Feed intake and digestibility by cattle consuming bermudagrass or orchardgrass hay supplemented with soybean hulls and(or) corn. J. Anim. Sci. 71:3087-3095.

Griffin, J. L. and G. A. Jung. 1983. Leaf and stem forage quality of big bluestem and switchgrass. Agron. J. 75:723-726.

Grigsby, K. N., F. M. Rouquette, Jr., W. C. Ellis, and D. P. Hutchenson. 1991. Use of self-limiting fishmeal and corn supplements for calves grazing rye-ryegrass pastures. J. Prod. Agric. 4:476-484.

Hanna, W. W., W. G. Monson, and G. W. Burton. 1973. Histological examination of fresh forage leaves after in vitro digestion. Crop Sci. 13:98-102.

Harlan, J. R. 1958. Generalized curves for gain per head and gain per acre in rates of grazing studies. J. Range Manage. 11:140-147.

Hart, R. H., J. W. Waggoner, Jr., T. G. Dunn, C. C. Kaltenbach, and L. D. Adams. 1988. Optimal stocking rate for cow-calf enterprises on native range and complementary improved pastures. J. Range Manage. 41:435-441.

Hart, R. H., W. H. Marchant, J. L. Butler, R. E. Hellwig, W. C. McCormick, B. L. Southwell, and G. W. Burton. 1976. Steer gains under six systems of coastal bermudagrass utilization. J. Range Manage. 29:372-325.

Hides, D. H., J. A. Lovatt, and M. V. Hayward. 1983. Influence of stage of maturity on the nutritive value of Italian ryegrasses. Grass Forage Sci: 38:33-38.

Highfill, B.D., D. L. Boggs, H. E. Amos, and J. G. Crickman. 1987. Effects of high fiber energy supplements on fermentation characteristics and in vivo and in situ digestibilities of low quality fescue hay. J. Anim. Sci. 65:224-229.

Hodgson, J. H. 1976. Forages, ruminant livestock and food. BioScience 26:625-630.

Hodgson, J. H. 1977. Factors limiting herbage intake by the grazing animal. P. 70-75. *In* B. Gilsenan (ed.) Proc. Int. meet. On Anim. Prod. From Temperate Grassl. An Soras Taluntais, Dublin, Ireland.

Holmes, J. C., J. G. W. Jones, and R. M. Drake-Brockman. 1961. The feed intake of grazing cattle. II. The influence of body size of animal on feed intake. Anim. Prod. 3:251-260.

Horn, F. P. J. P. Tellford, J. E. McCroskey, D. F. Stevens, J. V. Whiteman, and R. Totusek. 1979. Relationship of animal performance and dry matter intake to chemical constituents of grazed forage. J. Anim. Sci. 49:1051-1058.

Horn, G. W. 2006. Growing Cattle on Winter Wheat Pasture: Management and Herd Health Considerations. In The Veterinary Clinics of North America Food Animal Practice. M. F. Spire and R. A. Smith (Eds.). p. 335. W. B. Saunders Company, Philadelphia, PA.

Horn, G. W., F. T. McCollum. 1987. Energy supplementation of grazing ruminants. Proc. Grazing Livestock Nutrition Conference. July 1987. 24-36..

Horn, G.W., M. D. Cravey, F. T. McCollum, C. A. Strasia, E. G. Krenzer, Jr., and P. L. Claypool. 1995. Influence of high-starch vs high-fiber energy supplements on performance of stocker cattle grazing wheat pasture and subsequent feedlot performance. J. Anim. Sci. 73:45-54.

Horn, G. W., P. A. Beck, J. G. Andrae, and S. I. Paisley. 2005. Designing supplements for stocker cattle grazing wheat pasture. J. Anim. Sci. 83(E. Suppl.):E69-E78.

Hsu, J. T., D. B. Faulkner, K. A. Garleb, R. A. Barclay, G. C. Fahey, Jr. and L. L. Berger. 1987. Evaluation of corn fiber, cottonseed hulls, oat hulls and soybean hulls as roughage sources for ruminants. J. Anim. Sci. 65:244-255.

Hungate, R. E. 1966. The rumen and its microbes. P. 334-356. Academic Press, New York.

Johnson, R. R., E. W. Kosterman and H. W. Scott. 1962. Studies on feeding value of soybean flakes for ruminants. J. Anim. Sci. 21:406-410.

Johnson, W. L., W. A. Hardison, A. L. Ordoveza, and L. S. Castillo. 1968. The nutritive value of Panicum maximum (Guinea grass). III. Factors affecting voluntary intake by cattle and water buffalos. J. Agr. Sci. 71:67-71.

Jones, R. J. and R. L. Sandland. 1974. The relation between animal gain and stocking rate. J. Agric. Sci. 83:335-349.

Journet, M. and B. Remond. 1976. Physiological factors affecting the voluntary feed intake of feed by cows: A review. Livestock Prod. Sci. 3:129-146.

Jung, H. G., D. R. Buxton, R. D. Hatfield, and J. Ralph. 1993. Forage cell wall structure and digestibility. P. 33-71. G. A. Peterson, P. S. Baenziger, R. J. Luxmoore and S. H. Mickelson (Eds.). American Society of Agronomy Madison, WI.

Klieber, M. 1961. The fire of life. An introduction of animal energetics. P. 183-234. John Wiley and Sons, New York and London.

Laredo, M. A., and D. J. Minson. 1973. The voluntary intake, digestibility, and retention time by sheep of leaf and stem fractions of five grasses. Aust. J. Agr. Res. 24:875-888.

Leibholz, J. 1980. Urea and meat meal in the diets of ruminant calves – the sites of digestion and the nitrogen requirements for microbial protein synthesis. Aust. J. Agric. Res. 31:163-177.

Lentz, E. M. and D. R. Buxton. 1992. Crop quality and utilization. Digestion kinetics of orchardgrass as influenced by leaf morphology, finess of grind, and maturity group. Crop Sci. 32:482-486.

Leonard, W. H. and J. H. Martin. 1963. Wheat: Importance, history and adaptation. P. 227-287. In W. H. Leonard and J. H. Martin (ed.) Cereal crops. Macmillian Co., New York.

MacGregor, C. A., F. G. Owen, and L. D. McGill. 1976. Effect of increasing ration fiber with soybean mill run on digestibility and lactating performance. J. Dairy Sci. 59:682-684.

McRae, J. C., J. S. Smith, P. J. S. Dewey, A. C. Brewer, D. S. Brown, and A. Walker. 1985. The efficiency of utilization of metabolizable energy and apparent absorption of amino acids in sheep given spring- and autumn-harvested dried grass. Br. J. Nutr. 54:197-209.

Martin. G. C. 1988. Intensive grazing of cool season forages. P. 305-318. *In Proc*. Am. Forage Grassland Counc., Baton Rouge, LA.

Martin, S. L. and C. A. Hibberd. 1990. Intake and digestibility of low-quality native grass hay by beef cows fed graded levels of soybean hulls. J. Anim. Sci. 68:4319-4325.

McCollum, F. T. 1992. Chemical composition of cattle diets on tallgrass prairie. P. 25-26. In Range Research Highlights. Circular E-905. CES, Okla. State Univ.

McCollum, F. T. and M. L. Galyean. 1985. Cattle grazing blue grama rangeland II. Season forage intake and digesta kinetics. J. Range Mangt. 38(6):543-546.

Meijs, J. A. C. 1986. Concentrate supplementation of grazing dairy cows. 2. Effect of concentrate composition on herbage intake and milk production. Grass Forage Sci. 41:229-237.

Mertens, D. R. 1994. Regulation of forage intake. In Forage Quality, Evaluation, and Utilizations. P. 450-494. G. C. Fahey, Jr., M. Collins, D. R. Mertens, and L. E. Moser (Eds.). American Society of Agronomy, Madison, WI.

Mertens, D. R., and J. R. Loften. 1980. The effect of starch on forage fiber digestion kinetics in vitro. J. Dairy Sci. 63:1427-1446.

Milford, R., and D. J. Minson. 1965. The effect of crude protein concentration on forage intake by sheep. J. Br. Grassl. Soc. 20:177-179.

Minson, D. J. 1990. Forage in ruminant nutrition. Academic Press, Inc. New York.

Minson, D. J. 1966. The intake and nutritive value of fresh, frozen, and dried sorghum alum, Digitaria decumbens, and Panicum maximum. J. Brit. Grassl. Soc. 21:123.

Minson, D. J. 1963. The effect of pelleting and wafering on the feeding value of roughage: A review. J. Brti. Grassld. Soc. 18:39-44.

Minson, D. J. 1971. The digestibility and voluntary intake of six varieties of *Panicum*. Austr. J. Exp. Agr. Anim. Husb. 11:18-25.

Moore, K. J., R. D. Hatfield. 1994. Carbohydrates and forage quality. In Forage Quality, Evaluation, and Utilization. P. 22??G. C. Fahey, Jr., M. Collins, D. R. Mertens, and L. E. Moser (Eds.). American Society of Agronomy, Madison, WI.

Mott, G. O., and J. E. Moore. 1969. Forage evaluation techniques in perspective. P. L-1 to L-7. *In:* R. F. Barnes, D. C. Clanton, C. H. Gordon, T. J. Klopfenstein, and D. R. Waldo (ed.) Proc. Natl. Conf. Forage Quality Evaluation and Utilization, Nebraska Center Cont. Educ., Lincoln, NE.

Mott, G. O. 1984. Relationship of available forage and animal performance in tropical grazing systems. P. 373-377. *In Proc*. Am. Forage Grassl. Counc., Houston, TX. 23-26. January. Georgetown, TX.

Mould, F. L., E. R. Orskov and S. O. Mann. 1983b. Associative effects of mixed feeds. I. Effects of type and level of supplementation and the influence of the rumen fluid pH on celluloysis in vivo and dry matter digestion of various in vivo and dry matter digestion of various roughages. Anim. Feed. Sci. and Technol. 10:15.

Mullahey, J. J., S. S. Waller, K. J. Moore, L. E. Moser and T. J. Klopfenstein. 1992. In situ ruminal protein digestion of switchgrass and smooth bromegrass. Agron J. 84:183-188.

Nelson, C. J. and L. E. Moser. 1994. Plant factors affecting forage quality. In Forage Quality, Evaluation, and Utilization. P. 115-154. G. C. Fahey, Jr., M. Collins, D. R. Mertens, and L. E. Moser (Eds.). American Society of Agronomy, Madison, WI. .

Nelson, C. J., K. H. Asay, and D. A. Sleper. 1977. Mechanisms of canopy development of tall fescue genotypes. Crop Sci. 17:476-478.

Nichols, J. T., P. A. Duncan, and D. C. Clanton. 1993. Seasonal trends in forage quality of plants in subirrigated meadows of the Nebraska sandhills. Transactions of the Nebraska Academy of Sciences, p.25-32.

Nordkvist, E., and P. Aman. 1986. Changes during growth in anatomical and chemical composition and in vitro degradability of lucerne. J. Sci. Food Agric. 37:1-11.

NRC. 2001. Nutrient Requirements of dairy cattle. (7^{th} Ed.). National Academy Press, Washington, D. C.

Orskov, E. R. and C. Fraser. 1975. The effects of processing of barley-based supplements on rumen pH, rate of digestion and voluntary intake of dried grass in sheep. Br. J. Nutr. 34:493.

Owen, J. B. and J. W. Ingleton. 1963. A study of food intake and production in grazing ewes. II. The interrelationships between food intake and productive output. J. Agr. Sci. 61:329-340.

Petersen, R. G., H. L. Lucas, and G. O. Mott. 1965. Relationship between rate of stocking and per animal and per acre performance on pasture. Agron J. 57:27-41.

Peterson, C. M., B. Klepper, and R. W. Rickman. 1989. Seed reserves and seedling development in winter wheat. Agron. J. 74:781-784.

Peterson, P. R., C. C. Sheaffer, and M. H. Hall. 1992. Drought effects on perennial forage legume yield and quality. Agron. J. 84:415.

Phillips, W. A., S. C. Rao, R. L. Dalrymple, E. L. Klepper. 1996. Annual Cool-Season Grasses. P. 781-802. American Society of Agronomy. Madison, WI.

Phillips, W. A. and S. W. Coleman. 1995. Productivity and economic return of three warm season grass stocker systems for the southern great plans. J. Prod. Agric. 8:334-339.

Poppi, D. P., D. J. Minson, and J. H. Ternouth. 1981. Studies of cattle and sheep eating leaf and stem fractions of grasses. I. The voluntary intake, digestibility, and retention time in the reticulo-rumen. Aust. J. Agric. Res. 32:99-106.

Riewe, M. E. 1961. Use of the relationship of stocking rate to gain of cattle in an experimental design for grazing trials. Agron. J. 53:309-313.

Reid, R. L. 1994. Milestones in forage research (1969-1994). In Forage Quality, Evaluation, and Utilizations. P. 1-59. G. C. Fahey, Jr., M. Collins, D. R. Mertens, and L. E. Moser (Eds.). American Society of Agronomy, Madison, WI.

Rosiere, R. E., J. D. Wallace, and R. D. Pieper. 1980. Forage intake in two-year-old cows and heifers grazing blue grama summer ranges. J. Range Manage. 33:71-73.

Sheaffer, C. C., P. R. Peterson, M. H. Hall, and J. B. Stordahl. 1992. Drought effects on yield and quality of perennial grasses in the North Central States. J. Prod. Agric. 5:556-561.

Streeter, R. N. and G. W. Horn. 1983. Comparison of cottonseed hulls, rice mill feed, soybean hulls and beet pulp as roughages. Okla. Agric. Exp. Sta. Misc. Publ. MP-114:216.

Sudweeks, E. M. 1977. Digestibility by sheep of diets of citrus pulp, corn or soybean mill feed with three forages. J. Dairy Sci. 60:1410.

Sun, W., A. L. Goetsch, L. A. Forster, Jr., D. L. Galloway, Sr., and Z. B. Johnson. 1992. Feed intake and digestion by Holstein steers consuming warm or cool season grass hay and various supplements. Anim. Feed. Sci. Technol. 34:241-254.

Thorton, R. F. and D. J. Minson. 1972. The relationship between voluntary intake and apparent retention time in the rumen. Austr. J. Agr. Res. 28:871-877.

Thorton, R. F. and D. J. Minson. 1973. The relationship between apparent retention time in the rumen, voluntary intake, and apparent digestibility of legume and grass diets in sheep. Austr. J. Agr. Res. 24:889-898.

Twidwell, E. K., K. D. Johnson, J. H. Cherney, and J. J. Volence. 1988. Forage quality and digestion kinetics of switchgrass herbage and morphological components. Crop Sci. 28:778-782.

Ugherughe, P. O. 1986. Relationship between digestibility of *Bromus inermis* Plant Parts. J. Agronomy and Crop Sci. 157:136-143.

Utley, P. R., R. S. Lowrey, and W. C. McCormick. 1973. Corn silage and corn silage plus small grain pasture for finishing steers. J. Anim. Sci. 36:423-427.

Van Soest, P. J. 1982. nutritional ecology of the ruminant. O & B Books, inc., Corvallis, OR. p. 34-56.

Vanzant, E. S., R. C. Cochran. 1994. Performance and forage utilization by beef cattle receiving increasing amounts of alfalfa hay as a supplement to low-quality, tallgrass-prairie forage. J. Anim. Sci. 72:1059-1067.

Vogel, G. J., G. W. Horn, W. A. Phillips, and M. J. Ford. 1987. Influence of supplemental silage on performance and economics of growing cattle on wheat pasture. Prof. Anim. Sci. 3:50-55.

Wilman, D., and M. A. K. Atimimi. 1984. The in vitro digestibility and chemical composition of plant parts in white clover, red clover, and lucerne during primary growth. J. Sci. Food Agric. 35:133-138.

Wilson, J. R. 1993. Organization of forage plant tissues. In Forage Cell Wall Structure and Digestibility. P. 1. H. G. Jung, D. R. Buxton, R. D. Hatfield, and J. Ralph (Eds.). American Society of Agronomy, Madison, WI.

Wilson, J. R., and D. J. Minson. 1983. Influence of temperature on digestibility of the tropical legume *Macroptilium atropurpureum*. Grass Forage Sci. 38:39-47.

Weston, R. H. 1966. Factors limiting the intake of feed by sheep. I. The significance of palatability, the capacity of the alimentary tract to handle digesta, and the supply of glucogenic substrate. Aust. J. Agr. Res. 17:939-954.

CHAPTER II

Winter Rye Pasture Production Programs for Growing Beef Cattle

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Abstract

A two-year trial was conducted at the Noble Foundation Red River Demonstration and Research Farm near Burneyville, Oklahoma to determine the effect of different production programs on cattle performance while grazing winter rye pasture. Steers were allocated randomly, to one of five treatments replicated three times: conventional (CONV)**;** steers grazed rye pasture at an initial stocking rate of 2.5 steers/ha. Additional cattle were purchased and added to CONV to account for the rapid spring growth of the rye pasture. For treatments two, three, and four (SR1120, SR1400 and SR1680) steers grazed rye pasture at stocking rates of 4.7, 6.2, and 7.4 steers/ha, respectively, throughout the trial. Treatments SR1120, SR1400, and SR1680 had ad libitum access to soybean hulls. Cattle assigned to the optimum (OPT) treatment grazed rye pasture at an initial stocking rate of 1.6 steers/ha in year 1, and 3.7 steers/ha year 2, which was determined by measurements of forage mass prior to turnout to attempt to maintain a forage mass of no less than 840 kg/ha throughout the trial. In both trials, average daily gain and gain/steer were not different (P>0.57), whereas gain/ha increased linearly as stocking rate increased. The use of soybean hulls allowed stocking rates to be substantially increased over the CONV and OPT treatments without decreasing animal performance, and thus resulted in greater gain/ha.

Key Words: Growing beef cattle, Production programs, Rye pasture

Introduction

Winter small grains pasture is an important forage resource for growing cattle in the southeastern United States. These forage resources are utilized extensively during the winter to grow calves to heavier weights prior to feedlot finishing. Rate of weight gain is a key factor that affects the economic outcome of stocker cattle enterprises (Vogel et al., 1987). However, forage mass on small grains pasture varies tremendously over the grazing period, and often becomes limiting with respect to forage intake and average daily gain. There is a production risk involved with growing cattle on winter pasture due to indeterminate gains that result from sporadic weather conditions and limited forage supply (Coulibaly et al., 1996). Subsequently, energy supplementation of grazing ruminants is often necessary due to low forage availability at times in the grazing season (Horn and McCollum, 1987).

Horn et al. (1995) reported that high-fiber by-product feeds, including soybean hulls, offer alternatives to formulate energy supplements with high energy densities. Soybean hulls (SBH) are high in digestible fiber (Hsu et al., 1987). Feeds high in digestible fiber and low in starch have a more favorable effect on digestibility and intake of forage when compared with grain-based energy supplements (Anderson et al., 1987). The rapid rate of ruminal degradation of small grains forage (Zorrilla-Rios et al., 1985) and relatively low ruminal pH that rapid ruminal degradation promotes (Andersen and Horn, 1987) make SBH a logical choice for feeding growing cattle on high quality winter pasture. Previous studies have indicated that the use of energy supplements can enhance the profitability of a winter pasture stocker cattle enterprise (Horn, 2006; Horn et al., 2005; Vogel et al., 1987).

The availability of stocker cattle is highest in the fall because most calves are spring born (Peel, 2003). This enables cool-season forage systems, especially winter small grains, to play a unique role in stocker production. Producers have the opportunity to purchase cattle on seasonally low markets, thereby greatly reducing purchase cost. The objective of these trials was to determine the effect of different production programs on cattle performance while grazing winter rye pasture.

Materials and Methods

A two-year trial was conducted during the winters of 2004 to 2005 and 2005 to 2006 at the Noble Foundation Red River Demonstration and Research Farm near Burneyville, OK. Fifteen dryland pastures ranging between 4.05 and 6.07 ha were planted to cereal rye (Secale cereale L. variety Maton) on September 10, 2004 and ten pastures on October 4, 2005. For both trials, seeding rate was approximately 134 kg/ha and nitrogen (89 kg/ha) and phosphorus (67 kg/ha) were applied immediately prior to planting each year. An additional application of nitrogen (89 kg/ha) was applied after planting each year.

Grazing dates (days grazing) on rye were December 6 to April 12 (126 d) for year 1. In year 2 cattle grazed winter rye from December 13 to January 23. Due to low forage mass (kg DM/ha) caused by drought conditions in late summer and early fall, from January 24 to March 13 cattle were moved off rye pasture to a bermudagrass pasture where they were allowed ad libitum access to soybean hulls. Removal of cattle allowed rye pasture growth to accelerate. From March 13 to April 18 cattle grazed rye pasture again for a total of 77 grazing days for both phases. Weather and growing conditions for the cereal rye were very different each year. The spring and summer of 2004 were above average in rainfall, resulting in favorable rye planting conditions during late summer of that year. Conversely, extremely hot and dry conditions delayed planting in the fall of 2005 (Trial 2). Lack of rainfall resulted in drought stress in late January of 2006. Total annual precipitation at the study site for years 1 and 2 were 997.2 cm (39.3 inches), and 534.7 cm (21.05 inches), respectively.

Fall-weaned steer calves were used each year. In both years the cattle consisted primarily of Continental x British crossbred steers. Each year the cattle were processed on arrival and were fed rye hay (free-choice) and 1.81 kg •steer^{-1}•day^{-1} of supplement containing 90 g/ton chlortetracycline for approximately 40 d before being placed on rye pasture. The steers were vaccinated (Infectious Bovine Rhinotracheitis, Para-influenza 3, Bovine Virus Diarrhea, Bovine Respiratory Syncytial Virus, and a five-way Clostridial vaccine) and treated for internal and external parasites during processing. Steers were implanted with Synovex-S® (Syntex Laboratories, Palo Alto, CA) prior to placement on rye pasture.

In trial one, three hundred and ninety-seven steers (BW=212 kg ±5.04) and 15 pastures were used. Number of steers per pasture ranged from 8 to 31. The steers were allocated randomly, to one of five treatments replicated three times: conventional (CONV)**;** steers grazed rye pasture at an initial stocking rate of 2.5 steers/ha or 560 kg BW/ha. Later, in early March additional cattle were purchased to increase stocking rate to utilize the rapid spring growth of rye. The final stocking rate was 3.6 steers/ha. For treatments two, three, and four (SR1120, SR1400 and SR1680) steers grazed rye pasture at stocking rates of 4.7, 6.2, and 7.4 steers/ha throughout the trial, respectively, and initial stocking rates on rye pasture were 1120, 1400, and 1680 kg of BW/ha. The SR1120, SR1400, and SR1680 treatments also had ad libitum access to pelleted soybean hulls in a self-feeder with approximately 10 m of total bunk space. Optimum (OPT) steers grazed rye pasture at an initial stocking rate of 1.6 steers/ha or 348 kg of BW/ha, which was determined by taking forage mass measurements prior to turnout in an attempt to maintain a forage mass of no less than 840 kg/ha throughout the study. The final stocking rate after adding cattle in the spring was 2.5 steers/ha. All treatments were allowed access to rye hay during inclement weather. Additionally, hay was provided when any pasture of the three replicates dropped below a forage mass of 1120 kg DM/ha, if hay was not already present.

In trial two, three hundred steers (220 kg ± 4.89) and 10 pastures were used. Cattle per pasture ranged from 16 to 32 steers. Cattle were allocated to treatments the same as year 1, except the initial stocking rates for CONV and OPT treatments were 2.5 and 3.7 steers/ha, which resulted in 560 and 534 kg of BW/ha at initiation of grazing, respectively. Cattle were added to the CONV and OPT treatments at the onset of rapid spring growth of rye (i.e. February) resulting in final stocking rates of 3.8 and 5.5 steers/ha.

SBH consumption was measured by difference periodically weighing the self-feeders and adding additional SBH. Average daily consumption of supplement by cattle in each pasture was determined when the feeders were weighed and SBH were added and used to calculate daily consumption over the entire grazing period. Hay intake of the CONV and OPT treatments was estimated using bale weights and rate of disappearance. SBH conversion was calculated by dividing total soybean hull consumption for each pasture by the kg of additional gain/ha over that of the CONV treatment. Sweetlix®

(Sweetlix Livestock Supplement System, Mankato, MN) poloxalene medicated blocks were provided free-choice in each pasture for the prevention of bloat. Initial, intermediate, and final full weights of steers were measured on December 6, March 3, and April 12 in year 1; and December 13, March 13, and April 18 in year 2 and all weights were pencil shrunk 4%.

Forage mass was estimated by hand-clipping forage to ground level inside six 0.185m^2 quadrants along paced transects in each pasture. Clipping dates began before initiation of grazing and continued bi-monthly until mid-January then samples were taken weekly until termination of grazing. Samples were dried at 60°C to determine DM content, and then sent to a commercial testing laboratory to determine CP and ADF.

A completely randomized design was used for each trial and statistical analyses were performed using PROC MIXED (SAS Institute, Cary, NC). Pasture was the experimental unit. The data were analyzed using ordinary least squares. Non-orthogonal contrasts were conducted for treatments SR1120, SR1400, and SR1680 that included the effect of stocking rate which was partitioned into linear and quadratic effects. Contrasts also included a direct comparison of CONV and OPT treatments and the average of treatments SR1120, SR1400, SR1680 to the CONV treatment. Measurements of forage mass were analyzed using repeated measures methods and reported using generalized least squares. Means were separated using least significant difference. The model included treatment, month, and treatment by month interaction with pasture within treatment as a random effect. Appropriate covariance structures were modeled for each response variable and the fit statistics were used to choose the best structure.

Results and Discussion

Trial 1. ***Cattle Performance.*** Effects of feeding soybean hulls and increased initial stocking rates on performance of steers grazing rye pasture are summarized in Table 1. Ample rainfall during September, October, and November allowed for abundant forage at the beginning of this trial. Other factors such as soil moisture preserved by the no-till production system and fertilization all attributed to the adequate fall forage production. Soybean hull consumption ranged from 5.2 to 6.2 kg •steer^{-1}•day^{-1} for treatments SR1120, SR1400, and SR1680 and increased linearly ($P<0.01$) as stocking rate increased. Mean consumption of SBH was approximately 1.8, 2.1, and 2.2% of mean BW for treatments SR1120, SR1400, and SR1680, respectively. Supplement conversion was 8.80, 9.24, and 8.71 kg of supplement • kg of increased gain^{-1}•ha^{-1} for SR1120, SR1400, and SR1680 and had neither a linear nor quadratic effect ($P>0.88$) as stoking rate was increased.

Hay consumption ranged from 0.20 to 1.9 kg•steer^{-1}•day^{-1} across all treatments, and increased linearly ($P<0.01$) with increased stocking rate for treatments SR1120, SR1400, and SR1680. Steers of SR1680 consumed more hay than SR1120 and SR1400 this could be explained by less forage mass (kg DM/ha) throughout the grazing season as shown in figure 1. Average hay consumption of SR1120, SR1400, and SR1680 was greater ($P<0.01$) than CONV. Hay consumption differed ($P<0.01$) among CONV and OPT treatments, with CONV steers consuming more hay.

None of the planned contrasts or comparisons were significant for final BW off pasture, final backfat, daily gain, or gain/steer ($P>0.22$). Substantial increases in stocking rate and the feeding of SBH did not jeopardize daily gain or gain/steer ($P>0.90$). Thus, our data are in agreement with Vogel et al. (1987) whereby cattle grazed wheat pasture and received no supplement, and cattle grazed wheat pasture at three increased stocking rates over the control and had ad libitum access to silage that was fed daily. Likewise, Utley et al. (1973) noted similar results for daily gain where cattle grazed oat or rye pastures at 0.27 or 0.41 steers/ha with the latter being fed corn silage "to appetite" once daily. In contrast, declining ADG as a result of increased stocking rates has also been reported in the literature, though these studies did not feed an energy supplement (Coleman and Forbes, 1998; Hart et al., 1976; Jones and Sandland, 1974). Dissimilar to the current study, declines in season-long gains of steers grazing Plains Old World bluestem were reported as stocking rate increased (Coleman and Forbes, 1998). Gain/steer has often been shown (Harlan, 1958; Phillips and Coleman 1995) to decrease with an increase in stocking rate; however, this was not the case in the current study, where an energy supplement was provided. Petersen et al. (1964) suggested that gain per animal and gain/ha were similar as stocking rate was increased to a "critical" point, at which gain per animal becomes inversely related to stocking rate and gain/ha decreases linearly with further increases in stocking rate. In the current study gain/ha increased linearly ($P<0.01$) from 761 to 896 to 1077 kg/ha for treatments SR1120, SR1400, and SR1680, respectively, as the stocking rate increased. This resulted in gain/ha 1.9, 2.2, and 2.7-fold greater than the CONV treatment. Again, these findings agree with Vogel et al. (1987), in that total gain/ha was increased ($P<0.01$) by supplementing grazing cattle with silage and increased initial stocking rates. Classical responses of gain/ha to stocking rate were reported by Ackerman et al. (2001), but did not include effects of supplementation. Light and heavy weight steers at light (392 kg BW/ha), moderate (504 kg BW/ha), and heavy (840 kg BW/ha) stocking rates grazed Plains Old World bluestem, and gain/ha increased ($P<0.05$) as stocking rate increased. In our study, though differences ($P<0.01$) in the average of SR1120, SR1400, SR1680 and CONV were observed in gain/ha, no differences ($P=0.16$) in CONV and OPT treatments were observed. Incongruous with the current trial, Riewe (1961), and Cowlishaw (1962), noted the relationship between stocking rate and liveweight gain per hectare was curvilinear; though, supplement was not provided. The relationship between animal density and animal production is of great concern to producers. Jones and Sandland (1974) modeled an empirical response curve of animal production vs stocking density by pooling the results from a large number of grazing experiments. They reported a linear decrease in animal production as stocking density increased, which was not the case in the current research trial. Therefore, applying heavier initial stocking rates and feeding SBH has the potential to decreases the number of cattle that would have to be procured on seasonally high markets in the spring, permitting heavier stocking rates after the initiation of spring pasture growth

Forage Nutritive Value and Mass. The paramount importance of forage quality as a determinant of ruminant animal production is well established. Digestibility and fermentation of plant constituents, and voluntary intake by ruminants help quantify forage quality (Ulyatt, 1981). Chemical composition of forages changes enormously as plants mature from vegetative to flowering states (Ugherughe, 1985). Forage mass (kg DM/ha) was different ($P<0.03$) across months, yet similar across treatments as shown in figure 1. A decreasing pattern in total forage mass (kg DM/ha) was present in treatments SR1120, SR1400, and SR1680, implying that forage removal was greater than spring forage re-growth. This could have been caused by the increased stocking rate for treatments SR1120, SR1400 and SR1680. Forage height (figure 2) followed the same pattern as forage mass.

The CP and ADF concentrations are shown in figures 3 and 4. Both components were different ($P<0.01$) across months; however, CP was also different ($P<0.01$) among treatments, while ADF was not ($P=0.13$). The chemical composition changes that accompany maturity in plants are more rapid in stems than leaves (Minson, 1990), explaining why ADF begins to increase from December to January. The change is due to an increase in the amount of cell wall in relation to cell contents, and an increased volume of lignification of the cell wall (Ugherughe, 1985). This secondary thickening primarily occurs in cells associated with support and water transport (Albrecht et al., 1987). The lignification protects the polysaccharides contained within from fermentation by rumen microorganisms, thereby, introducing a physical barrier to the plant shielding it from mastication and ruminantion. A result of forage plant maturation is the increasing amount of cell wall, leading to lower digestibility by ruminants. This is shown in figure 4, by an increasing amount of ADF until February, then once spring re-growth initiation occurs ADF begins to trend down from February to March. Therefore, the nutritive value of forages is heavily affected by stage of growth and the amount of lignified tissue.

Trial 2. ***Cattle Performance.*** Effects of the energy supplements and increased initial stocking rate on performance of steers grazing rye pasture are summarized in Table 2. Lack of rainfall resulted in a later planting of rye in 2005 and delayed grazing initiation (table 2). Consequently, drought stress and elevated stocking rate (treatments SR1120, SR1400, and SR1680) resulted in two separate grazing phases. The first phase lasted 41 d and the second phase lasted 36 d. A third order polynomial response (P=0.03) was observed, as SBH consumption decreased from 4.2 to 3.9 and increased to 4.1 kg •steer^{-1}•day^{-1} for treatments SR1120, SR1400, and SR1690 as stocking rate increased. Mean consumption of SBH was 1.5, 1.4, and 1.4% of mean BW, for treatments SR1120, SR1400, and SR1680, respectively. This is less than in trial 1, and could be attributed to greater forage mass (kg DM/ha) throughout both grazing phases as cattle in trial 1 as shown in figures 1 and 5. This could imply that cattle prefer forage when given the choice between adequate high quality forage and SBH. Supplement conversions were 6.57, 4.19, and 4.50 kg of supplement • kg of increased gain^{-1}•ha^{-1} for the SR1120, SR1400, and SR1680 treatments and the response to stocking rate was quadratic (P<0.01). No hay was fed in this trial.

Final steer BW for the first and second pasture phases was not different (P>0.32) for any of the planned contrasts and comparisons. Final backfat was similar (P>0.15) for linear and quadratic responses with increased stocking rates, as well as similarities (P>0.15) for both direct comparisons. Daily gain is shown in table 2 for the first and second pasture phase, along with a combined daily gain for both phases. Combined daily gains were similar (P>0.16) for linear and quadratic effects of treatments SR1120, SR1400, and SR1680. There was no difference (P=0.13) in CONV and OPT treatments for combined daily gain, as well as, CONV and the average of SR1120, SR1400, and SR1680 (P=0.84).

None of the planned contrasts and comparisons were significant (P>0.13) for gain/steer. Similar to trial 1, gain/ha decreased linearly (P<0.01) coinciding with the increase in stocking rate. In trial 2, gain/ha was 1.9, 2.8, and 3.0-fold greater for treatments SR1120, SR1400, and SR1680 over CONV. The average SR1120, SR1400, and SR1680 and CONV were different (P<0.01); nevertheless, CONV and OPT were similar (P=0.19).

Forage Nutritive Value and Mass. Forage mass (kg DM/ha) and forage height are shown in figures 5 and 6, respectively. Forage mass across months was different (P<0.01) and did not differ (P=0.59) with treatment. This is analogous to forage mass in trial 1; however, the upward trend of growth from February to April indicates that forage re-growth was greater than removal by grazing, which is incongruous to trial 1. Forage height followed the same trend, where months were different (P<0.01), and treatments were similar (P=0.27).

Concentrations of CP and ADF are shown in figures 8 and 9, respectively. Crude protein was different (P<0.01) for all months, but the most dramatic change occurred from March to April, which can be explained by the maturing of the forage (Minson, 1990). Griffin et al. (1983), reported that averaged over grasses, rate of decline of stem CP was twice that of leaf CP. This could explain the rise in ADF (more stem) from February to April, and the opposite decline in CP from February to April. The most noted change in ADF occurred from March to April, which can also be explained by the increased amount of cellulose and lignin contained in the forage as it matures.

Implications

Providing free-choice soybean hulls in winter pasture production programs allows for the following advantages: 1) The leveraging of land resources where initial stocking rates can be greatly increased, thus decreasing the number of cattle that would have to be purchased on seasonally high spring markets to stock pastures heavier after the initiation of rapid spring forage growth, 2) a decrease in production risk and the addition of stability to an unstable forage supply throughout the grazing period, 3) a pronounced advantage in gain/ha (up to 3-fold greater) without a reduction in cattle performance.

Literature Cited

Ackerman, C. J., H. T. Purvis, II, G. W. Horn, S. I. Paisley, R. R. Reuter, and T. N. Bodine. 2001. Performance of light vs heavy steers grazing Plains Old World bluestem at three stocking rates. J. Anim. Sci. 79:493.

Albrecht, K. A., W. F. Wedin, and D. R. Buxton. 1987. Cell-wall composition and digestibility of alfalfa stems and leaves. Crop Sci. 27:735.

Andersen, M. A., and G. W. Horn. 1987. Effect of lasalocid on weight gains, ruminal fermentation and forage intake of stocker cattle grazing winter wheat pasture. J. Anim. Sci. 65:865.

Anderson, S.J., J. K. Merrill, M. L. McDonnell and T. J. Klopfenstein. 1987. Digestibility and utilization of mechanically processed soybean hulls. J. Anim. Sci. 66:2965.

Coleman, S. W., and T. D. A. Forbes. 1998. Herbage characteristics and performance of steers grazing old world bluestem. J. Range Manage. 51:399.

Coulibaly, N., D. J. Bernardo, and G. W. Horn. 1996. Energy supplementation strategies for wheat pasture stocker cattle under uncertain forage availability. J. App. Econ. 28:172.

Cowlishaw, S. J. 1962. The effects of stocking density on the productivity of yearling female sheep. J. Br. Grassland Soc. 11:140.

Griffin, J. L.and G. A. Jung. 1983. Leaf and stem forage quality of big bluestem and switchgrass. Agron. 75:723.

Harlan, J. R. 1958. Generalized curves for gain per head and gain per acre in rates of grazing studies. J. Range Manage. 11:140-147.

Hart, R. H., W. H. Marchant, J. L. Buler, R. E. Hellwig, W. C. McCormick, B. L. Southwell, and G. W. Burton. 1976. Steer gains under six systems of coastal bermudagrass utilization. J. Range Manage. 29:372.

Horn, G. W. 2006.Growing Cattle on Winter Wheat Pasture: Management and Herd Health Considerations. In The Veterinary Clinics of North America Food Animal Practice. M. F. Spire and R. A. Smith (Eds.). p. 335. W. B. Saunders Company, Philadelphia, PA.

Horn, G. W. and F. T. McCollum. 1987. Energy supplementation of grazing ruminants. In Proceedings of the Grazing Livestock Nutrition Conference. Laramie (WY): University of Wyoming; p. 125.

Horn, G.W., M. D. Cravey, F. T. McCollum, C. A. Strasia, E. G. Krenzer, Jr., and P. L. Claypool. 1995. Influence of high-starch vs high-fiber energy supplements on performance of stocker cattle grazing wheat pasture and subsequent feedlot performance. J. Anim. Sci. 73:45.

Horn, G. W., P. A. Beck, J. G. Andrae, and S. I. Paisley. 2005. Designing supplements for stocker cattle grazing wheat pasture**.** J. Anim. Sci. 83: E69.

Hsu, J. T., D. B. Faulkner, K. A. Garleb, R. A. Barclay, G. C. Fahey, Jr., and L. L. Berger. 1987. Evaluation of corn fiber, cottonseed hulls, oat hulls, and soybean hulls as a roughage source for ruminants. J. Anim. Sci. 65:244.

Jones, R. J. and R. L. Sandland. 1974. The relation between animal gain and stocking rate. J. Agric. Sci. 83:335.

Minson, D. J. 1990. Digestible energy of forage. In Forage in Ruminant Nutrition. T. J. Cunha (Ed.). Academic Press. San Diego, CA. p. 85.

Nelson, C. J. and L. E. Moser. Plant factors affecting forage quality. 1994. Forage quality, evaluation and utilization. G. C. Fahey, Jr., M. Collins, D. R. Mertens, and L. E. Moser, ed. Am. Soc. Of Agronomy. Madison, WI. p. 111.

Peel, D.S. 2003. Beef cattle growing and backgrounding programs. In The Veterinary Clinics of North America Food Animal Practice. S. R. Koontz (Ed.). p. 364. W. B. Saunders Company, Philadelphia, PA.

Petersen, R. G., H. L. Lucas, and G. O. Mott. 1965. Relationship between rate of stocking and per animal and per acre performance on pasture. Agron J. 57:27.

Phillips, W. A. and S. W. Coleman. 1995. Productivity and economic return of three warm season grass stocker systems for the southern great plains. J. Prod. Agric. 8:334.

Riewe, M. E. 1961. Use of the relationship of stocking rate to gain of cattle in an experimental design for grazing trials. Agron J. 55:309.

Vogel G. J., G. W. Horn, W. A. Phillips and M. J. Ford. 1987. Influence of supplemental silage on performance and economics of growing cattle on wheat pasture. Prof. Anim. Sci. 3:50.

Ugherughe, P. O. 1986. Relationship between digestibility of *Bromus inermis* Plant Parts. J. Agronomy and Crop Sci. 157:136.

Ulyatt, M. J. 1981. The feeding value of herbage: can it be improved? N. Z. Agric. Sci. 15:200.

Utley, P. R., R. S. Lowrey, and W. C. McCormick. 1973. Corn silage and corn silage plus small grain pasture for finishing steers. J. Anim. Sci. 36:423.

Zorrilla-Rios, J., G. W. Horn, M. J. Ford, R. W. McNew, and K. B. Poling. 1985. In situ disappearance of dry matter and nitrogen of wheat forage, corn gluten meal, and cottonseed meal and soybean meal in steers grazing wheat forage at two stages of maturity. Oklahoma Agric. Exp. Sta. Res. Rep. MP-117.

Table 1. Least squares means for effects of feeding soybean hulls and increased initial stocking rate on performance of steers grazing rye pasture for trial 1.

Item	CONV[a]	SR1120[b]	SR1400[b]	SR1680[b]	OPT[c]	SEM	Contrast, P-value			
							CONV VS Linear[d]	SBH[e] VS Quad[d]	OPT	CONV
No. of steers	45	87	90	89	29	-	-	-	-	-
Initial forage mass kg DM/ha	1226	1662	1526	1211	1262	-	-	-	-	-
Stocking rate, steers/ha										
Initial	2.5	-	-	-	1.6	-	-	-	-	-
Final	3.6	-	-	-	2.5	-	-	-	-	-
Weighted avg	2.7	4.7	6.2	7.4	2.6	-	-	-	-	-
Initial BW, kg/ha	560	1120	1400	1680	348	-	-	-	-	-
SBH consumption, kg as-fed/d[f]	-	5.2	5.8	6.2	-	0.20	<0.01	0.78	-	-
Hay consumption, kg as-fed/d[g]	1.5	0.20	0.20	1.90	0.70	0.13	<0.01	<0.01	<0.01	<0.01
Initial wt, kg	218	209	205	211	219	5.40	-	-	-	-
Final wt, kg	366	368	350	357	359	7.80	0.33	0.22	0.53	0.40
Daily gain, kg	1.18	1.27	1.15	1.15	1.11	0.08	0.36	0.57	0.60	0.90
Gain/steer, kg	148	159	145	145	140	10.6	0.36	0.57	0.60	0.90
Gain/ha, kg	404	761	896	1077	343	31.15	<0.01	0.42	0.16	<0.01
Supplement conversion[h]	-	8.80	9.24	8.71	-	0.48	0.88	0.42	-	-

Final backfat, cm	1.30	1.49	1.30	1.45	1.23	0.135	0.84	0.33	0.72	0.47

[a]Steers grazed rye pasture and had access to rye hay when pasture forage mass fell below 1120 kg DM/ha.

[b]Steers grazed rye pasture and had ad libitum access to SBH in self feeder with approximately 10 m of bunk space.

[c]Steers grazed rye pasture at stocking rates determined by taking forage mass measurements prior to turnout in an attempt to maintain a forage mass of no less than 840 kg/ha throughout the study.

[d]Contrast effects only on treatments SR1120, SR1400, SR1680.

[e]Average of SR1120, SR1400, SR1680 vs CONV.

[f]Kilograms of soybean hulls (as-fed)•steer^{-1}•day^{-1}.

[g]Kilograms of hay (as-fed)•steer^{-1}•day^{-1}.

[h]Kilograms of soybean hulls (as-fed) per kg of increased gain^{-1}•hectare^{-1} over CONV.

Table 2. Least squares means for effects of feeding soybean hulls and increased initial stocking rate on performance of steers grazing rye pasture for trial 2.

Item	CONV[a]	SR1120[b]	SR1400[b]	SR1680[b]	OPT[c]	SEM	Contrast, P-value CONV VS Linear[d]	SBH[e] VS Quad[d]	OPT	CONV
No. of steers	31	62	64	62	45	-	-	-	-	-
Initial forage mass kg DM/ha	2184	2278	2211	2325	2325	-	-	-	-	-
Stocking rate, steers/ha										
Initial	2.5	-	-	-	3.7	-	-	-	-	-
Final	3.8	-	-	-	5.5	-	-	-	-	-
Weighted avg	3.1	5.0	6.6	7.6	4.6	-	-	-	-	-
Initial BW, kg/ha	560	1120	1400	1680	534	-	-	-	-	-
SBH consumption, kg as-fed/d[f]	-	4.2	3.9	4.1	-	0.06	0.83	0.03	-	-
First grazing phase										
Initial wt, kg (12/13)	220	224	213	220	217	4.89	-	-	-	-
Final wt, kg (1/23)	278	273	268	272	279	6.30	0.96	0.58	0.43	0.41
Daily gain, kg	1.41	1.19	1.33	1.29	1.30	0.08	0.41	0.39	0.40	0.20
Second grazing phase										
Initial wt, kg (3/13)	306	305	292	299	301	7.22	0.63	0.29	0.63	0.40
Final wt, kg (4/18)	355	342	357	350	353	4.02	0.70	0.62	0.32	0.91
Daily gain, kg	1.34	1.46	1.62	1.29	1.14	0.08	0.21	0.06	0.15	0.29
Combined (phases 1 & 2)										

Daily gain, kg	1.38	1.32	1.47	1.38	1.23	0.05	0.52	0.16	0.13	0.84
Combined (phases 1 & 2)										
Gain/steer, kg	106	102	113	106	95	4.42	0.52	0.16	0.13	0.84
Gain/ha, kg	270	520	744	813	354	39.5	<0.01	0.17	0.19	<0.01
Supplement										
Conversion[g]	-	6.57	4.19	4.50	-	0.23	0.76	<0.01	-	-
Final backfat, cm	1.06	0.98	1.10	1.19	1.04	0.05	0.47	0.15	0.32	0.47

[a]Steers grazed rye pasture and had access to rye hay when pasture forage mass fell below 1120 kg DM/ha.

[b]Steers grazed rye pasture and had ad libitum access to SBH in self feeder with approximately 10 m of bunk space.

[c]Steers grazed rye pasture at stocking rates determined by taking forage mass measurements prior to turnout in an attempt to maintain a forage mass of no less than 840 kg/ha throughout the study.

[d]Contrast effects only on treatments SR1120, SR1400, SR1680.

[e]Average of SR1120, SR1400, SR1680 vs CONV.

[f]Kilograms of soybean hulls (as-fed)•steer^{-1}•day^{-1}.

.[g]Kilograms of soybean hulls (as-fed) per kg of increased gain^{-1}•hectare^{-1} over CONV.

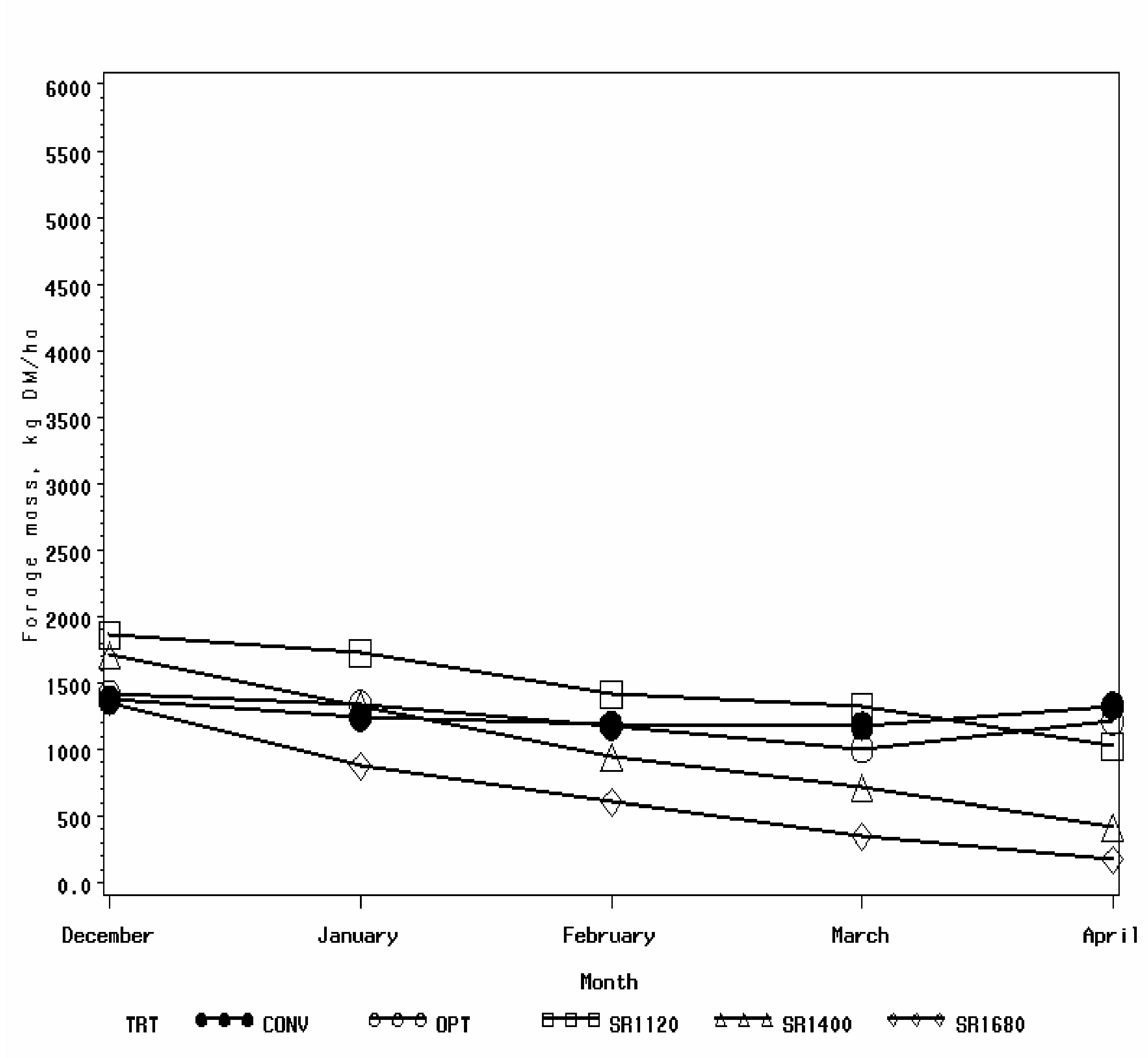

Figure 1. Least squares means of forage mass (kg DM/ha) of samples from rye pastures grazed by steers throughout the grazing period. Trial 1.

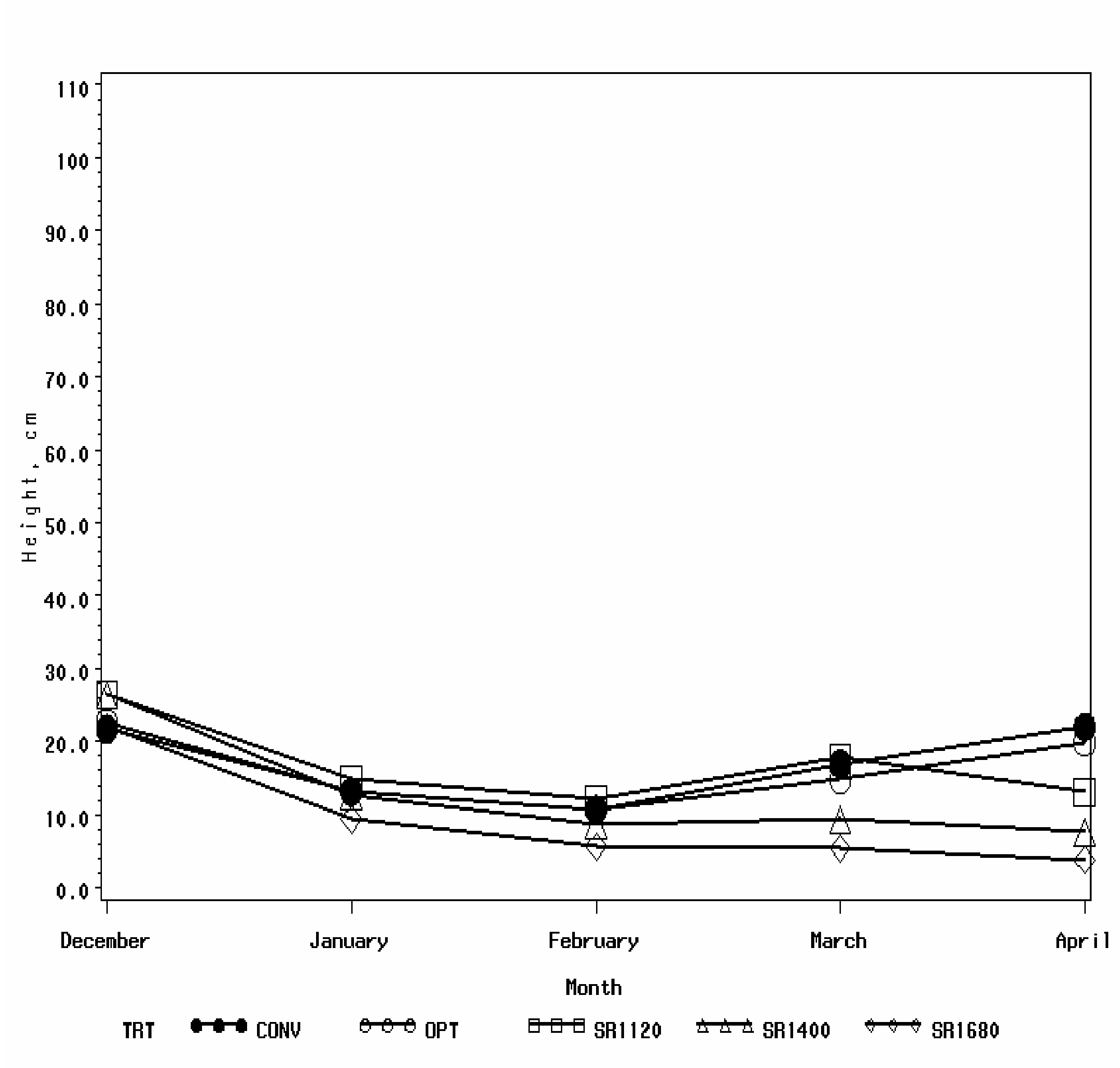

Figure 2. Least squares means of forage height (cm) of samples from rye pastures grazed by steers throughout the grazing period. Trial 1.

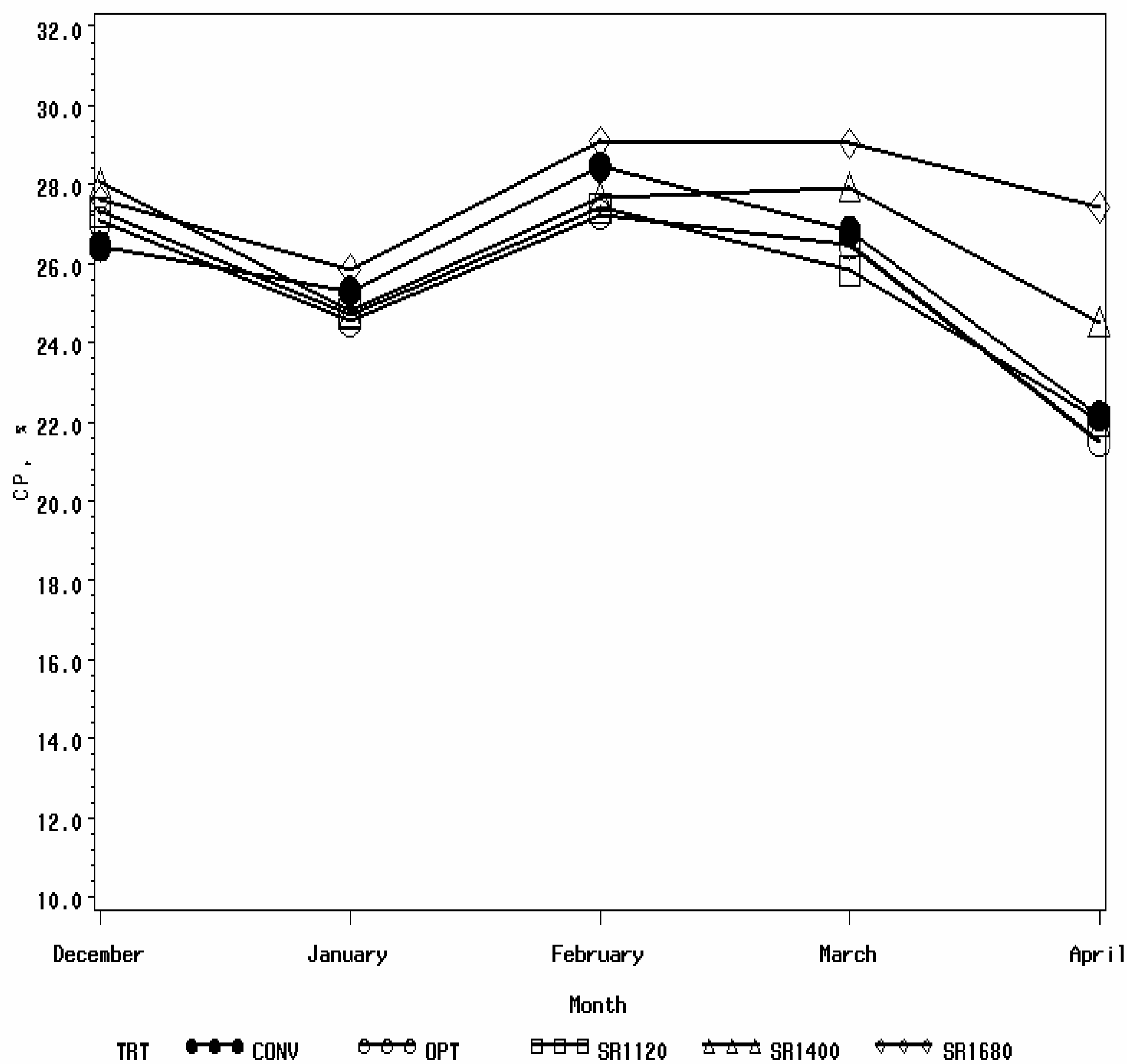

Figure 3. Least squares means of CP concentrations of samples from rye pastures grazed by steers throughout the grazing period. Trial 1.

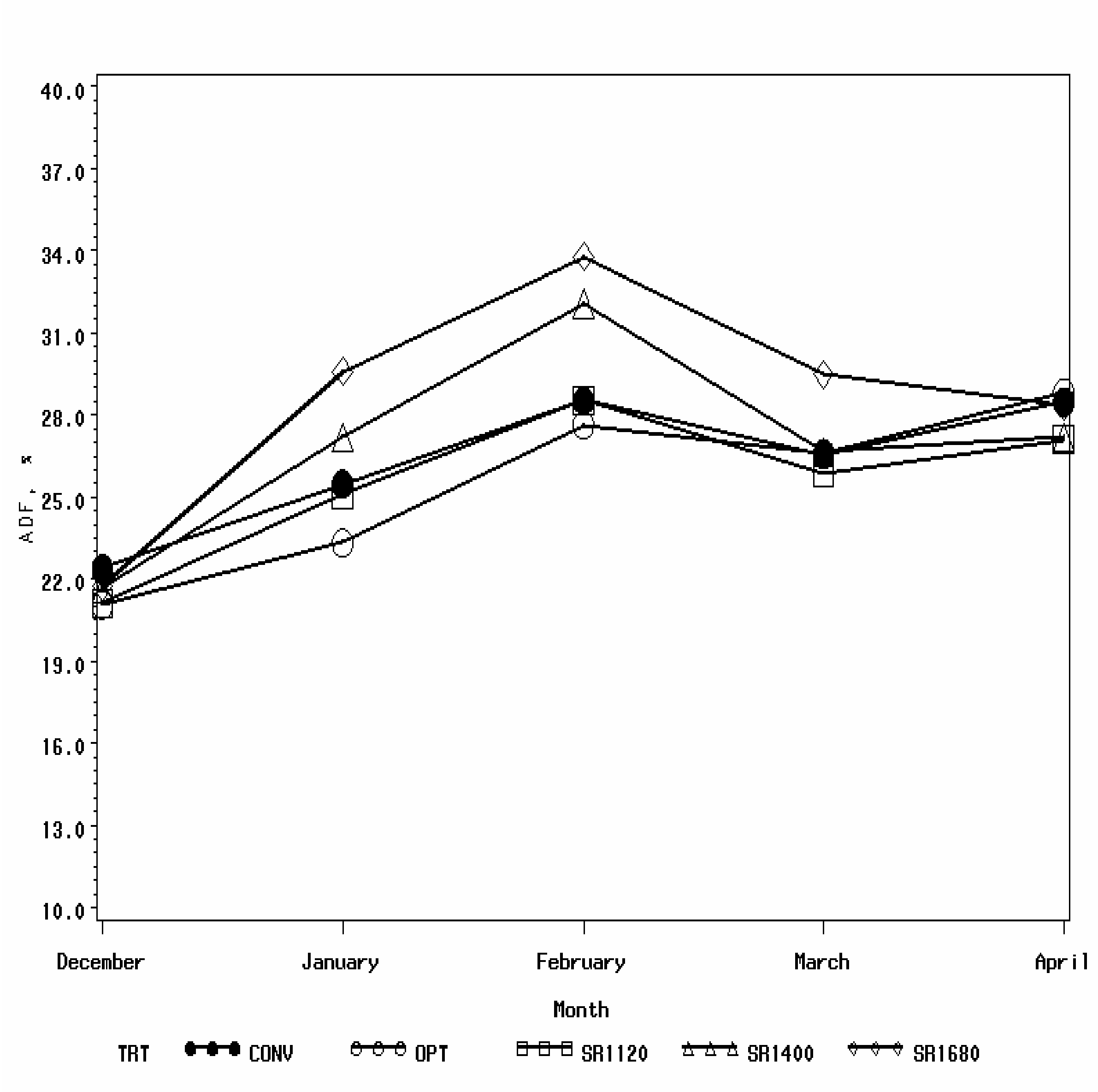

Figure 4. Least squares means of ADF concentration of samples from rye pastures grazed by steers throughout the grazing period. Trial 1.

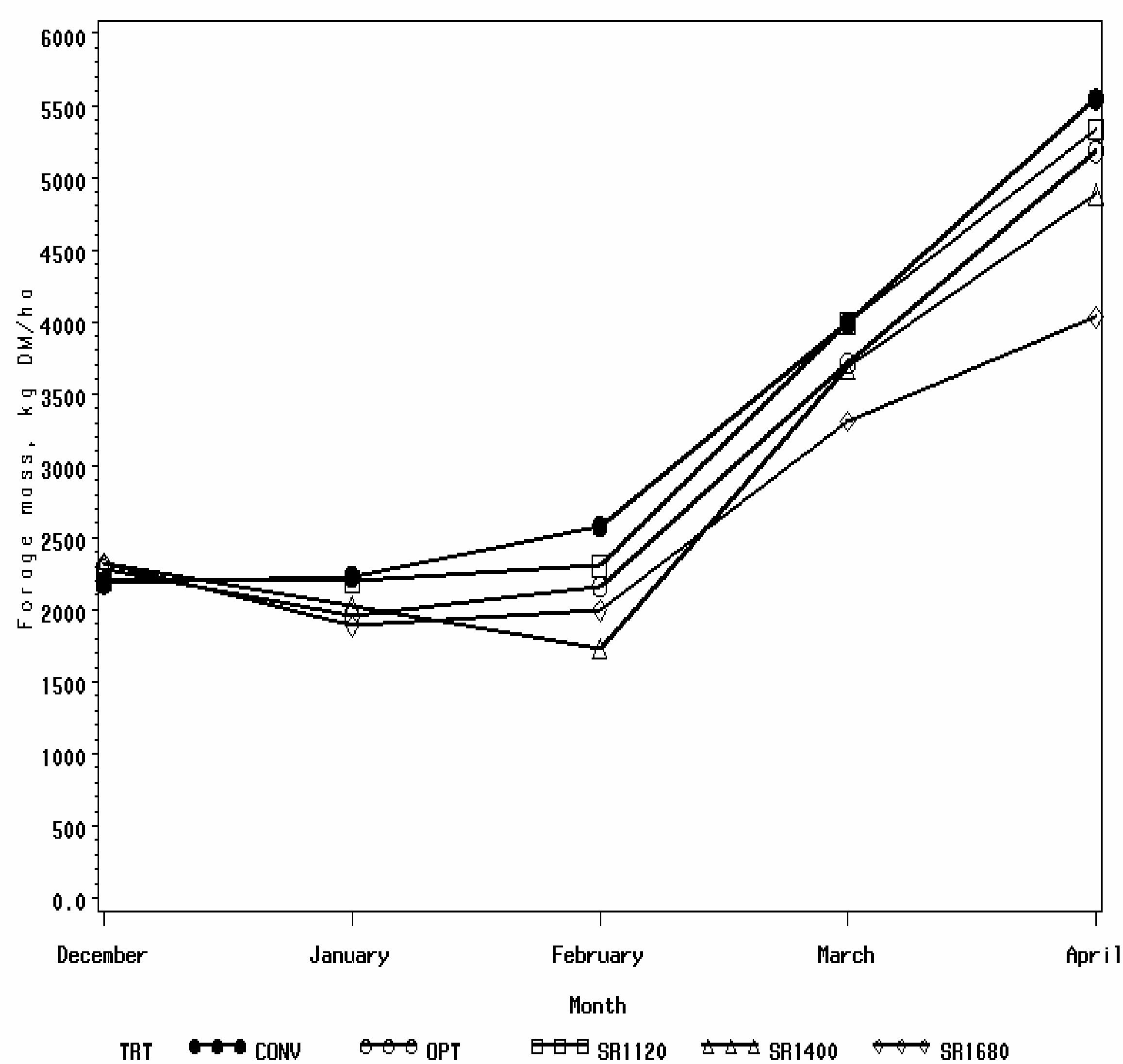

Figure 5. Least squares means of forage mass (kg DM/ha) of samples from rye pastures grazed by steers throughout the grazing period. Trial 2.

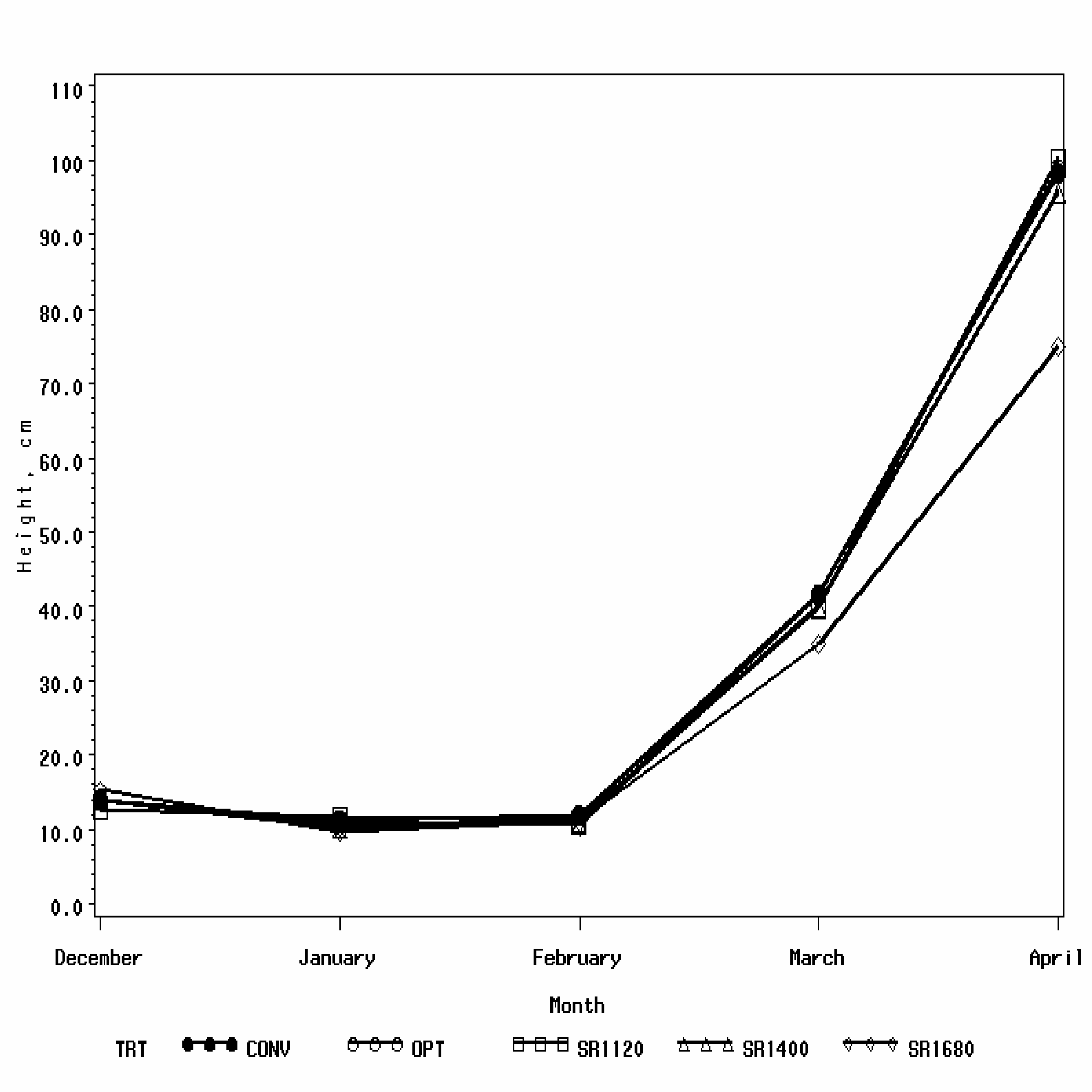

Figure 6. Least squares means of forage height (cm) of samples from rye pastures grazed by steers throughout the grazing period. Trial 2.

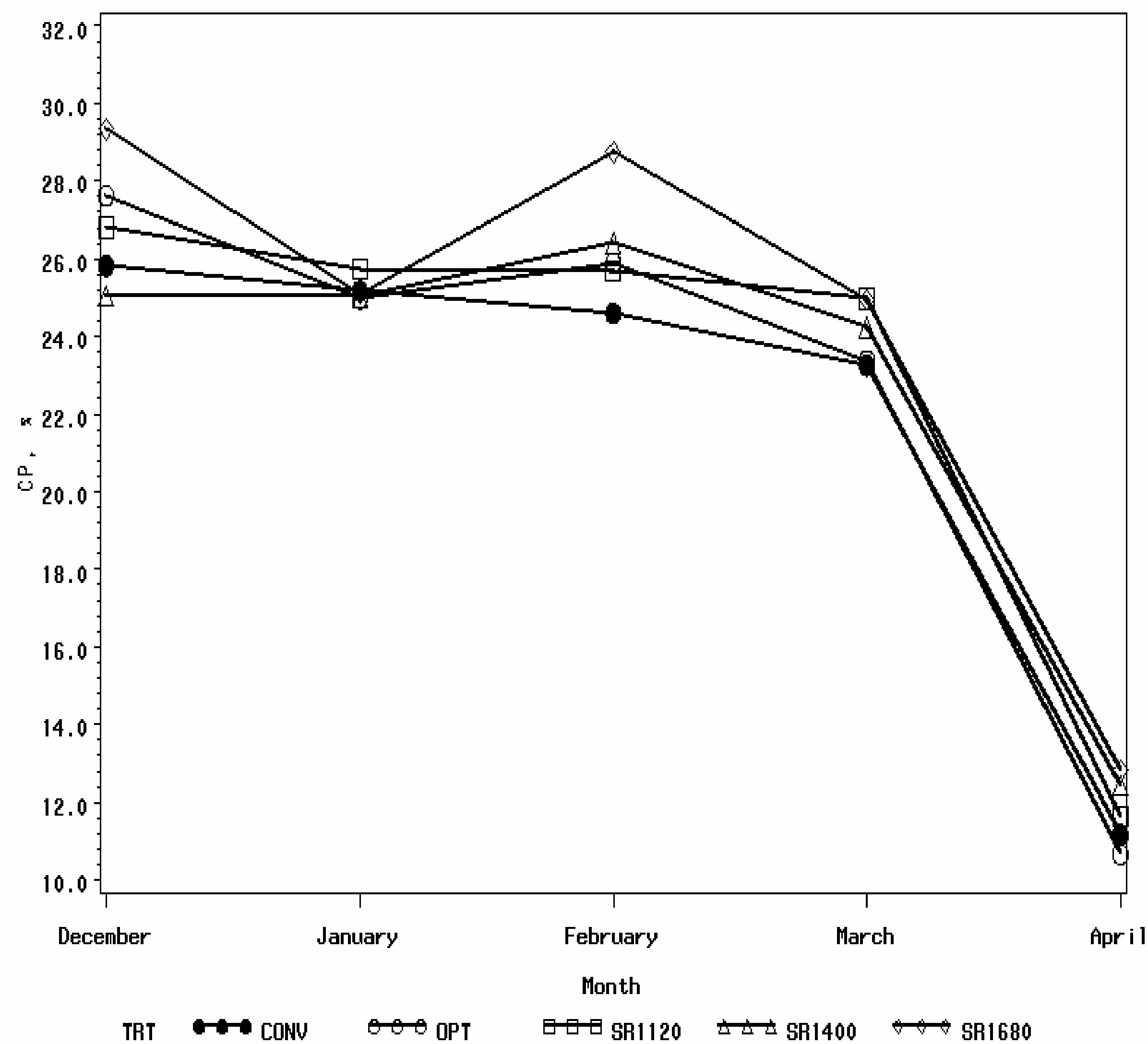

Figure 7. Least squares means of CP concentration of samples from rye pastures grazed by steers throughout the grazing period. Trial 2.

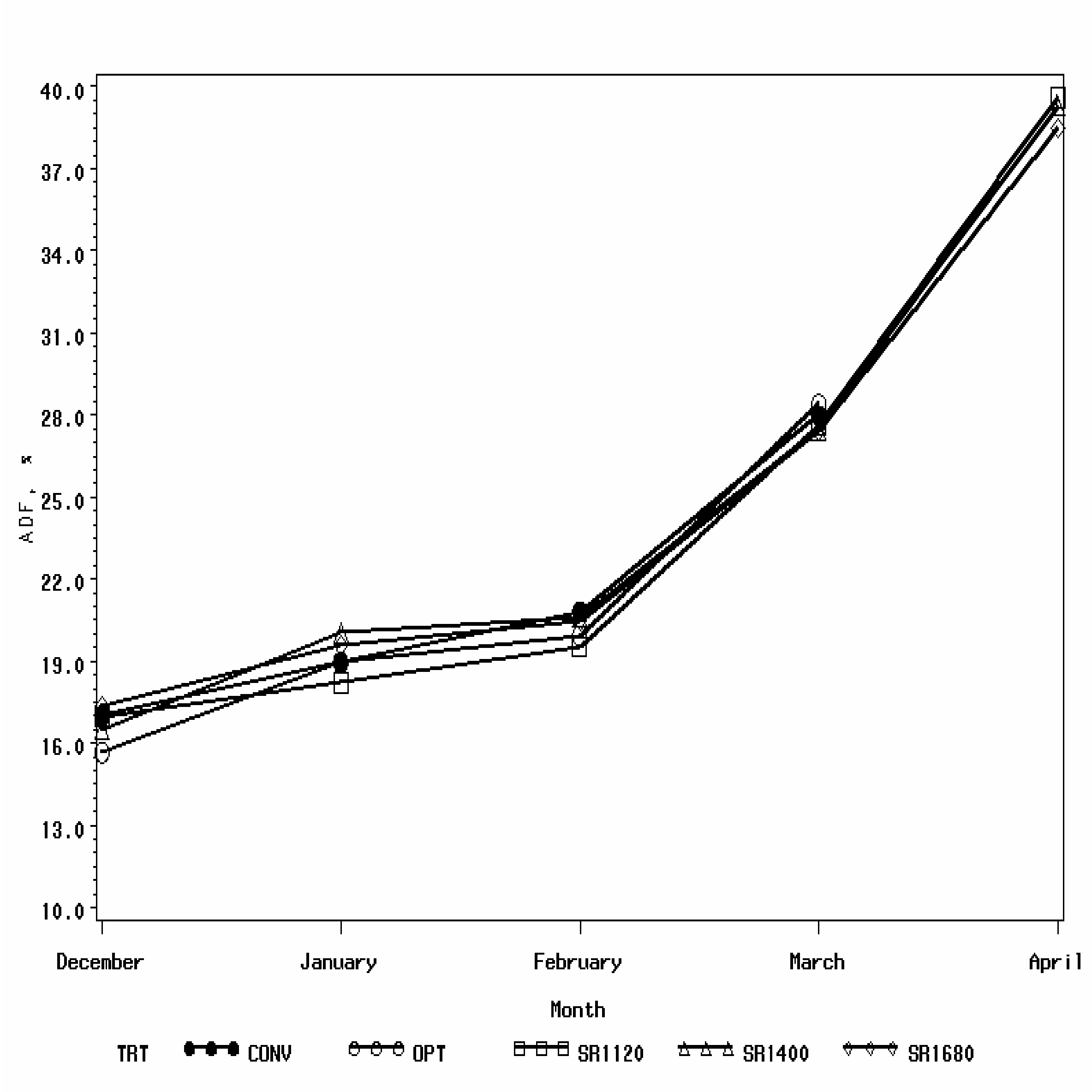

Figure 8. Least squares means of ADF concentration of samples from rye pastures grazed by steers throughout the grazing period. Trial 2.

CHAPTER III

ECONOMIC ANALYSIS OF WINTER RYE PASTURE PRODUCTION PROGRAMS FOR GROWING BEEF CATTLE

Abstract

A two-year trial was conducted at the Noble Foundation Red River Demonstration and Research Farm near Burneyville, Oklahoma to determine the effect of different production programs on cattle performance while grazing winter rye pasture. Steers were allocated randomly, to one of five treatments replicated three times: conventional (CONV)**;** steers grazed rye pasture at an initial stocking rate of 2.5 steers/ha. Additional cattle were purchased and added to CONV to account for the rapid spring growth of the rye pasture. For treatments two, three, and four (SR1120, SR1400 and SR1680) steers grazed rye pasture at stocking rates of 4.7, 6.2, and 7.4 steers/ha, respectively, throughout the trial. Treatments SR1120, SR1400, and SR1680 had ad libitum access to soybean hulls. Optimum (OPT) steers grazed rye pasture at an initial stocking rate of 1.6 steers/ha in year 1, and 3.7 steers/ha year 2, which was determined by measurements of forage mass prior to turnout to attempt to maintain a forage mass of no less than 840 kg/ha throughout the trial. In both trials, return to land, labor, and management ($/ha) was greater ($P<0.05$) for the average of treatments SR1120, SR1400, and SR1680 than CONV. Thus, there was a pronounced advantage in returns ($/ha) to land, labor, and management by feeding soybean hulls to increase initial stocking rates on winter rye pasture.

Introduction

The stocker cattle industry is one of the many diverse production and marketing activities that comprise the United States beef industry. Stocker production is a margin business, and profit potential is primarily determined by the gross margin between the initial purchase cost of the animal and the final sale value of the animal (Peel, 2003). Peel (2003) reported that this margin is determined by the relationship between feeder and stocker cattle price and weight. Due to the seasonality of cattle prices producers have the opportunity to purchase cattle in the fall on seasonally low markets, thereby greatly reducing purchase cost. Furthermore, increasing initial stocking rate and having more cattle on hand for spring grazing can be particularly important to the economics of growing cattle on winter pasture. Feeding moderate amounts of an energy supplement to cattle on winter pasture has been reported (Horn, 2006) as a means of adding stability to an unstable forage supply, therefore decreasing production risk and as a means of having more cattle for the spring grazing period. Additionally, energy supplementation of wheat pasture cattle has been reported to decrease production risk (Coulibaly et al., 1996).

Materials and Methods

A two-year study was conducted during the 2004 to 2005 and 2005 to 2006 winter pasture years at the Noble Foundation Red River Demonstration and Research Farm near Burneyville, OK. Fifteen dryland pastures ranging between 4.05 and 6.07 ha were planted to cereal rye (Secale cereale L. variety Maton) on September 10, 2004 and ten pastures on October 4, 2005. For both trials, seeding rate was approximately 134 kg/ha and anhydrous ammonia (89 kg/ha) and phosphorus (67 kg/ha) were applied immediately prior to planting each year. An additional application of anhydrous ammonia (89 kg/ha) was applied after planting each year.

Grazing dates (days grazing) on rye were December 6 to April 12 (126 d), and December 13 to January 23 plus March 13 to April 18 (77 d) for years 1 and 2, respectively. Weather and growing conditions for the cereal rye were very different each year. The spring and summer of 2004 were above average in rainfall, resulting in favorable rye planting conditions during late summer of that year. Conversely, extremely hot and dry conditions delayed planting in the fall of 2005 (Trial 2). Lack of rainfall resulted in drought stress in late January of 2006. Total annual precipitation at the study site for years 1 and 2 were 997.2 cm (39.3 inches), and 534.7 cm (21.05 inches), respectively.

Fall-weaned steer calves were used each year. In both years the cattle consisted primarily of Continental x British crossbred steers. Each year the cattle were processed on arrival and were fed rye hay (free-choice) and 1.81 kg •$steer^{-1}$•day^{-1} of supplement containing 90 g/ton chlortetracycline for approximately 40 d before being placed on rye pasture. The steers were vaccinated (Infectious Bovine Rhinotracheitis, Para-influenza 3, Bovine Virus Diarrhea, Bovine Respiratory Syncytial Virus, and a five-way Clostridial vaccine) and treated for internal and external parasites during processing. Steers were implanted with Synovex-S® (Syntex Laboratories, Palo Alto, CA) prior to placement on rye pasture.

In trial one, three hundred and ninety-seven steers and 15 pastures were used. Number of steers per pasture ranged from 8 to 31. The steers were allocated randomly, to one of five treatments replicated three times: conventional (CONV); steers grazed rye pasture at an initial stocking rate of 2.5 steers/ha or 560 kg BW/ha. Later, in early March additional cattle were purchased to increase stocking rate to utilize the rapid spring growth of rye. The final stocking rate was 3.6 steers/ha. For treatments two, three, and four (SR1120, SR1400 and SR1680) steers grazed rye pasture at stocking rates of 4.7, 6.2, and 7.4 steers/ha throughout the trial, respectively, and initial stocking rates on rye pasture were 1120, 1400, and 1680 kg of BW/ha. The SR1120, SR1400, and SR1680 treatments also had ad libitum access to pelleted soybean hulls in a self-feeder with approximately 10 m of total bunk space. Optimum (OPT) steers grazed rye pasture at an initial stocking rate of 1.6 steers/ha or 348 kg of BW/ha, which was determined by taking forage mass measurements prior to turnout in an attempt to maintain a forage mass of no less than 840 kg/ha throughout the study. The final stocking rate after adding cattle in the spring was 2.5 steers/ha. All treatments were allowed access to rye hay during inclement weather. Additionally, hay was provided when any pasture of the three replicates dropped below a forage mass of 1120 kg DM/ha, if hay was not already present.

In trial two, three hundred steers and 10 pastures were used. Cattle per pasture ranged from 16 to 32 steers. Cattle were allocated to treatments the same as year 1, except the initial stocking rates for CONV and OPT treatments were 2.5 and 3.7 steers/ha, which resulted in 560 and 534 kg of BW/ha at initiation of grazing, respectively. Cattle were added to the CONV and OPT treatments at the onset of rapid spring growth of rye (i.e. February) resulting in final stocking rates of 3.8 and 5.5 steers/ha.

SBH consumption was measured by difference periodically weighing the self-feeders and adding additional SBH. Average daily consumption of supplement by cattle in each pasture was determined when the feeders were weighed and SBH were added and used to calculate daily consumption over the entire grazing period. Hay intake of the CONV and OPT treatments was estimated using bale weights and rate of disappearance. SBH conversion was calculated by dividing total soybean hull consumption for each pasture by the kg of additional gain/ha over that of the CONV treatment. Sweetlix® (Sweetlix Livestock Supplement System, Mankato, MN) poloxalene medicated blocks were provided free-choice in each pasture for the prevention of bloat. Initial, intermediate, and final full weights of steers were measured on December 6, March 3, and April 12 in year 1; and December 13, March 13, and April 18 in year 2 and all weights were pencil shrunk 4%.

An economic analysis was conducted to assess the profitability of the different production programs. Pasture cost included the cost of chemical, seed, fertilizer, no-till planting cost, and interest at 7%. Supplement included the cost of bloat blocks ($10.47/block), hay ($60.00/ton) and soybean hulls ($103.40/ton). Total pasture cost for both trials 1 and 2 were $248.37/ha. In addition to determining total pasture cost, cost per kg of gain on pasture was calculated by dividing the total pasture cost by the kg gained per pasture and then averaged by treatment. Return to land, labor, and management was calculated as gross return, $/steer, and $/ha. Return to land, labor, and management for year 1 was calculated by multiplying the market value of gain ($1.65/kg) by total weight gained minus the total cost. Return to land, labor, and management for year 2 was calculated by multiplying the market value of gain ($0.81/kg) by total weight gain minus the total cost. Return to land, labor, and management on a $/steer basis, was calculated by dividing the gross return to land, labor, and management by the weighted average head count per pasture. Return to land, labor, and management ($/ha) was figured by multiplying the return ($/steer) by stocking rate.

A completely randomized design was used for each trial and statistical analyses were performed using PROC MIXED (SAS Institute, Cary, NC). Experimental units were pastures. The data were analyzed on a pasture basis using ordinary least squares. Non-orthogonal contrasts were conducted for treatments SR1120, SR1400, and SR1680 that included the effect of stocking rate which was partitioned into linear and quadratic effects. There was a direct comparison of CONV and OPT treatments and the average of treatments SR1120, SR1400, SR1680 to the CONV treatment. Measurements of forage mass were analyzed using repeated measures methods and reported using generalized least squares. Means were separated using least significant difference. The model included treatment, month, and treatment by month interaction with pasture within treatment as a random effect. Appropriate covariance structures were modeled for each response variable and the fit statistics were used to choose the best structure.

Results and Discussion

Trial 1

Supplement cost ($/ha) increased linearly ($P<0.01$) from $400.27 (SR1120) to $565.89 (SR1400) to $810.01 (SR1680) for treatments that had free-choice access to soybean hulls. This increase in supplement cost ($/ha) corresponds with the linear increase in soybean hull consumption as stocking rate was increased. Supplement cost ($/ha) was similar ($P=0.25$) for the CONV and OPT treatments, while the average of SR1120, SR1400, and SR1680 was greater ($P<0.01$) than CONV, which was attributed to the cost of soybean hulls for treatments SR1120, SR1400, and SR1680. Furthermore, the cost of gain ($/kg) mirrors the supplement cost ($/ha) in that it increased linearly (P<0.05) for treatments SR1120, SR1400, and SR1680. Cost of gain ($/kg) was not different (P=0.39) for CONV and OPT treatments, yet the average of SR1120, SR1400, and SR1680 was greater (P<0.01) than CONV. A higher cost of gain ($/kg) for treatments receiving soybean hulls is because average supplement cost ($592.06/ha) was greater than the supplement cost of CONV ($56.94/ha), yet gain/steer and rate of weight gain was similar as reported in chapter II.

Reported returns excluded the cost of land, labor, and management. There was a linear decrease (P<0.01) in return to land, labor, and management ($/steer) as stocking rate was increased for treatments SR1120, SR1400, and SR1680. This linear decrease is a direct result of the increased stocking rate and increased soybean hull consumption. CONV and OPT treatments were similar (P=0.49), while the average of treatments SR1120, SR1400, and SR1680 and CONV were different (P<0.01) with CONV being greater. Return to land, labor, and management ($/ha) was similar (P>0.26) for the SR1120, SR1400, and SR1680 treatments. These data are in contrast to Izac et al. (1990) where biological optimum corresponded to the highest stocking rate and the economic optimum did not. The biological optimum was defined as maximum gain/ha and the economic optimum was defined as maximum return to fixed resources ($/ha). In the current study, neither the biological nor the economical optimum was observed. This is because as stocking rate increased gain/ha increased linearly (P<0.01) as reported in chapter II, and there was no differences in return to land, labor, and management ($/ha) among treatments SR1120, SR1400, and SR1680. Conversely, Wachenheim et al. (2000) reported that net return to fixed resources varied as forage mass and stocking rate varied.

The stocking rate that had the greatest return to fixed resources was less than the stocking rate that supported the greatest gain/ha. This is in contrast to the current study where SR1680 provided the biological, as well as economical optimum. The inconsistencies were attributed to the fact that additional variable costs associated with acquiring, maintaining, and selling additional steers outweighed the revenue received from the additional weight sold (Wachenheim et al., 2000). Incongruous to that idea, Kaitbie et al. (2003) suggested that the cost of understocking is relatively more expensive than overstocking. Unlike perennial pastures, overstocking of winter pasture is not expected to have negative consequences since it is grazed out or harvested for grain. Hence, over a range of stocking densities, having too few cattle and permitting forage to go unused is relatively more costly than having too many cattle. Ultimately Kaitbie et al. (2003) suggested that producers should sufficiently stock pastures with cattle to ensure the maximum amount forage is consumed. In the current study, return to land, labor, and management ($/ha) was not different (P=0.16) for CONV and OPT treatments. Nevertheless, the average of treatments SR1120, SR1400, and SR1680 was greater (P<0.01) than the CONV treatment.

Trial 2

Supplement cost ($/ha) increased linearly (P<0.01) for treatments SR1120 ($207.15), SR1400 ($262.20), and SR1680 ($316.72), as stocking rate was increased. Even though the linear increase is similar to trial 1, the actual cost ($/ha) was less than half that of trial 1. This could have potentially been due to the increased amounts of forage mass (kg/ha) present throughout trial 2, which was in much greater quantity than trial 1, as shown in chapter II. Likewise, CONV and OPT treatments were similar (P=0.35), because all treatments consumed similar amounts of bloat blocks which was the only supplement cost for CONV and OPT. Conversely, supplement cost ($/ha) was greater (P<0.01) for the average of SR1120, SR1400, and SR1680 than CONV. This is related to the consumption and cost associated with the soybean hulls for treatments SR1120, SR1400, and SR1680. Cost of gain ($/kg) was similar (P>0.26) among treatments consuming soybean hulls, even though supplement cost ($/ha) increased linearly. An explanation is that as stocking rate was increased there was more total kg of BW to dilute the total fixed costs (pasture cost), arriving at similar cost of gain. Moreover, the cost of gain ($/kg) of CONV and OPT was not different (P=0.16), because of similar supplement cost. Conversely, the average of treatments SR1120, SR1400, and SR1680 and CONV was different (P=0.05) with CONV having a higher cost of gain ($/kg). Again this is due to the fact that CONV was stocked lighter (kg/ha) than treatments SR1120, SR1400, and SR1680, therefore there was less kg of BW to dilute the total costs.

Return to land, labor, and management ($/steer) tended to increase linearly (P=0.09) from ($8.67) to $11.85 to $10.18. This is incongruous to the results of trial 1 where return to land, labor, and management ($/steer) decreased linearly as stocking rate was increased. In addition, return to land, labor, and management ($/ha) increased linearly (P=0.04) for treatments SR1120, SR1400, and SR1680. CONV and OPT treatments were similar (P=0.21), and the average for return to land, labor, and management ($/ha) of SR1120, SR1400, and SR1680 was greater. This implies that purchasing additional cattle in the fall on a seasonally low market and increasing initial stocking rates on winter pasture produces greater returns ($/ha) than does traditional stocking rates such as the CONV treatment.

Implications

Due to the seasonality of cattle prices and dynamics of breakeven selling prices, having additional cattle on hand for spring grazing is important for the economics of growing cattle on winter pasture. Providing an energy supplement to growing cattle on winter pasture allowed initial stocking rates to be increased. From this research we conclude that there was a pronounced advantage in returns ($/ha) to land, labor, and management by feeding soybean hulls to increase initial stocking rate on winter rye pasture.

Literature Cited

Coulibaly, N., D. J. Bernardo, and G. W. Horn. 1996. Energy supplementation strategies for wheat pasture stocker cattle under uncertain forage availability. J. App. Econ. 28:172.

Horn, G. W. 2006. Growing Cattle on Winter Wheat Pasture: Management and Herd Health Considerations. In The Veterinary Clinics of North America Food Animal Practice. M. F. Spire and R. A. Smith (Eds.). p. 335. W. B. Saunders Company, Philadelphia, PA.

Izac, A. M. N., K. A. Anaman, and J. W. Jones. 1990. Biological and economic optima in a tropical grazing ecosystem in Australian Agricultural Ecosystems. Environ. 30:265-279.

Kaitbie, S., F. M. Epplin, B. W. Brorsen, G. W. Horn. 2003. Optimal stocking density for dual-purpose winter wheat production. J. Agric. Appl. Econ. 35:29-38

Peel, D.S. 2003. Beef cattle growing and backgrounding programs. In The Veterinary Clinics of North America Food Animal Practice. S. R. Koontz (Ed.). p. 364. W. B. Saunders Company, Philadelphia, PA.

Wachenheim, C. J., J. R. Black, M. L. Schlegel, and S. R. Rust. 2000. Grazing methods and stocking rates for direct-seeded alfalfa pastures: III. Economics of alternative stocking rates for alfalfa pastures. J. Anim. Sci. 8:2209-2214.

Table 3. Least squares means for effects of energy supplement and increased initial stocking rate on the economics of steers grazing rye pasture.

Item	CONV[a]	SR1120[b]	SR1400[b]	SR1680[b]	OPT[c]	SEM	Contrast P-Value: Linear[d]	Quad[d]	CONV vs OPT	SBH[e] vs CONV
Trial 1										
Supplement Cost, $/ha	$56.94	$400.27	$565.89	$810.01	$30.39	15.37	<0.01	0.06	0.25	<0.01
Cost of Gain, $/kg	$0.76	$0.85	$0.91	$0.98	$0.81	0.04	0.05	0.92	0.39	0.01
Return to Land, Labor, and Management										
$/steer	$132.50	$127.66	$99.56	$86.78	$124.92	7.92	0.01	0.51	0.49	0.01
$/ha	$361.66	$596.51	$616.66	$641.22	$305.61	28.02	0.26	0.94	0.16	<0.01
Trial 2										
Supplement Cost, $/ha	$18.96	$207.15	$262.20	$316.72	$22.40	2.35	<0.01	0.93	0.35	<0.01
Cost of Gain, $/kg	$0.99	$0.88	$0.69	$0.70	$0.80	0.08	0.17	0.35	0.16	0.05
Return to Land, Labor,										

and Management										
$/steer	($17.18)	($8.67)	$11.85	$10.18	($0.12)	6.40	0.09	0.22	0.12	0.03
$/ha	($53.73)	($44.26)	$78.01	$77.92	(9.04)	31.14	0.04	0.17	0.21	0.05

[a]Steers grazed rye pasture and had access to rye hay when pasture forage mass fell below 1120 kg DM/ha.

[b]Steers grazed rye pasture and had ad libitum access to SBH in self feeder with approximately 10 m of bunk space.

[c]Steers grazed rye pasture at stocking rates determined by taking forage mass measurements prior to turnout in an attempt to maintain a forage mass of no less than 840 kg/ha throughout the study.

[d]Contrast effects only on treatments SR1120, SR1400, SR1680.

[e]Average of SR1120, SR1400, SR1680 vs CONV.

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