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**Influence of Sward Height, Daily Timing of Concentrate
Supplementation and Grazing Time Management on
Pasture Utilization of Lactating Beef Cows**

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Dissertation submitted to the
Davis College of Agriculture, Forestry and Consumer Sciences
West Virginia University
In partial fulfillment of the requirements
For the degree of

**Doctor of Philosophy
In
Animal and Food Sciences**

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Intake, Digestibility

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ABSTRACT

Influence of Sward Height, Daily Timing of Concentrate Supplementation and Grazing Time Management on Pasture Utilization of Lactating Beef Cows

Ondieki J. Gekara

To establish the effect of sward height, concentrate feeding time and grazing time management on performance of grazing cattle, thirty-two cross-bred beef (24 Angus and 8 Hereford) cows (632 kg BW) and calves (104 kg BW) were grouped by weight and calving date. They were randomly assigned to two sward height (SH) treatments (4 to 8 or 8 to 12 cm), replicated four times. The cows were fed a concentrate supplement ($4.1 \text{ kg DM}\cdot\text{cow}^{-1}\cdot\text{d}^{-1}$) in the AM at 0700 h or PM at 1800 h (T), and either restricted to 12 h/d grazing (0700 to 1900 h) or unrestricted to 24 h/d grazing (MGT). The experiment was repeated over three 15-d periods in May, June/July and August 2000. The herbage on high SH pasture was higher ($P < .05$) in fiber and lower ($P < .01$) in crude protein compared to low SH herbage. For cows on restricted grazing, supplementing in the AM as opposed to PM resulted in greater ($P < .05$) forage DMI (8.6 vs. 8.1 kg/d) while unrestricted cows had greater forage DMI (8.4 vs. 8.2 kg/d) when supplemented in the PM as opposed to AM. Supplementing in the PM as opposed to AM resulted in greater ($P < .05$) herbage DMD (67.7 vs. 65.4%) for cows on high SH; cows on low SH had greater herbage DMD (66.3 vs. 64.5%) when supplemented in the AM. An interaction between T and MGT ($P < .10$) for digestible DMI (DDMI) was apparent. For cows restricted to 12 h/d grazing, supplementing in the AM as opposed to PM resulted in greater DDMI (5.0 vs. 4.7 kg/d) while unrestricted cows had greater DDMI (4.9 vs. 4.6 kg/d) when supplemented in the PM as opposed to AM. Supplementing in the PM as opposed to AM, increased the time spent grazing ($P < .10$) to a greater extent for restricted compared to unrestricted cows. When forage availability or grazing time is limiting, supplementing in the AM may result in greater forage utilization because of increased forage DMD and DDMI.

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CHAPTER 1: INTRODUCTION

In the US, lactating dairy and finishing beef cattle are fed high levels of concentrates such as corn and soybean meal because of the desire for greater levels of productivity. When cattle consume forages as their only feed source, intake of available energy may not be adequate to meet desired rates of performance (gestation, lactation, and gain). Supplementation with concentrate feeds has the potential to increase the production level of cattle on pasture. However, supplementation of grazing cattle with concentrates has not always been a viable option to increase animal performance.

Previous work (Gekara et al., 2001) has shown that forage utilization decreased as level of supplement increased (to greater than 60% of total DMI) and season progressed (spring to late summer). The decrease in forage utilization could be attributed to forage conditions, associative animal factors and/or rumen environment. Forage factors influencing forage utilization include botanical and chemical composition (Minson, 1990), physiological maturity (Hodgson, 1990), cell wall characteristics (Akin, 1989; Jung, 1989), forage allowance (Hodgson, 1975, 1984), and forage height and density (Jamieson and Hodgson, 1979). Animal factors such as bite size, biting rate, grazing time and selectivity (Hodgson, 1990; Rook et al., 1994a) also exert great influence on forage utilization. To increase forage utilization further, an optimum environment has to be maintained in the rumen (Hoover, 1986; Mould and

Ørskov, 1984). For efficient nutrient utilization, grazing management should minimize animal and forage factors that negatively influence animal performance and forage productivity.

CHAPTER 2: LITERATURE REVIEW

Factors influencing forage utilization by grazing animals

Grazing ruminants derive most of their energy from forage fermented in the rumen. Forage fermentation is the work of a diverse population of anaerobic microorganisms (bacteria, protozoa and fungi) resident in the rumen (Hungate, 1966). Microbial fermentation of plant constituents (structural and non-structural carbohydrates) yields volatile fatty acids (VFA) that provide energy to ruminants. A combination of animal and plant factors interact to affect physical degradation of forages, promoting passage of plant residues through the intestinal tract, thus, influencing forage intake and consequent utilization (Akin, 1989). Protein available for digestion in the small intestine is from undigested protein and microbial protein synthesized in the rumen (Akin, 1989; Van Soest, 1994). To increase forage utilization an optimum environment in the rumen has to be maintained (Hoover, 1986).

I. Forage factors

Supply of adequate high quality forage throughout the grazing season and year round is a major challenge for cattle producers worldwide. Forage quality refers to the nutrient content of forage (non-structural carbohydrates, crude protein, neutral detergent fiber, acid detergent fiber, lipids, vitamins and minerals) in regard to digestibility and availability of these nutrients to the host

animal. Forage quality is influenced by its botanical and chemical composition, and physiological maturity (Minson, 1990) while quantity of grazed forage (mass) is determined by its height and density (Jamieson and Hodgson, 1979). Forage quality and quantity influence forage intake and digestibility and subsequently productivity of grazing animals (Minson, 1990). Forage allowance (forage mass per unit area of pasture available to a population of grazing animals) also influences forage utilization (Hodgson, 1975).

A. Botanical and chemical composition

Both botanical composition (proportion of grass, legume, weeds and dead material) and chemical composition or nutrient content (dry matter, crude protein, fiber, lignin and ash) can influence forage utilization by grazing ruminants (Minson, 1990).

Botanical composition

Voluntary intake of legumes has been observed to be 28% greater than equally digestible grasses (Minson, 1971). The higher intake of alfalfa compared with grasses appears to be due to an increased rate of digestion and rate of passage from the rumen of the neutral detergent fiber (NDF) fraction of legumes (Hacker and Minson, 1981; Poppi et al., 1981). Greater intake of legume than grass is partially responsible for the superior performance of ruminants fed legumes (Reid et al., 1990). Ruminant digesta fill is usually less for legume than for grass (Thornton and Minson, 1973) probably due to differences in cell wall composition (Minson, 1990). Effects of legume on intake and animal

performance is related to enhanced propionate production, increased rate of ruminal outflow of undigested forage (Moseley and Jones, 1979, 1984), elevated ruminal organic matter (OM) digestion rate, and postruminal digestion of protein (Beever et al., 1986a,b). To achieve the same metabolizable energy (ME) utilization, grass must be at least ten percentage units more digestible than legume (Freer and Jones, 1985). Legumes also have a lower water-soluble carbohydrate content and greater buffering capacity, which restricts rapid decline in rumen pH, thus, stabilizing the rumen environment (Minson, 1990).

Moseley and Dellow (1985) reported that the efficiency of use of ME for maintenance or gain is typically greater for legume than grass based diets. Greater concentration of ME in legumes and less energy expended for ingesting and ruminating legumes than grasses are thought to be the reasons. High propionate production may be a major contributor to greater efficiency for legumes than for grasses (Waldo et al., 1990); a high propionate supply minimizes tissue catabolism for gluconeogenesis (Abdul-Razzaq and Bickerstaffe, 1989). Martz et al. (1999) reported that the content of crude protein (CP), net energy for lactation and in situ dry matter (DM) digestibility of cool season pasture increased for dairy cattle during the grazing season. Further, the content of NDF decreased and acid detergent fiber (ADF) tended to remain constant or decreased during the grazing season, probably because of increased legume and decreased amount of dead material in the sward in late summer.

Chemical composition

Neutral detergent fiber (hemicellulose, cellulose, lignin, and some ash) is the most consistent fiber component associated with intake (Van Soest, 1994). The negative association of NDF with intake has usually been interpreted as a fill effect (Van Soest, 1994). Similarly, acid detergent fiber (cellulose, lignin, and some Ash) component is negatively associated ($r = -.79$) with digestibility (Minson, 1990). In addition, acid detergent lignin (lignin and some ash) of forage is negatively correlated with DM and OM digestibility (Van Soest, 1994). When animals consume low quality roughages, protein (<5% CP) not only becomes deficient relative to requirements of the host animal, but also limits the supply of degradable proteins for microbial growth and fermentation. Consequently, the rate of cell wall digestion drops dramatically and passage rate decreases as well as forage intake (Hodgson and Illius, 1996). Thus, protein deficiencies are a major limitation to intake and utilization of forages. In well-managed temperate grass-legume pastures animal production is rarely limited by digestible proteins, thus, output per animal can be substantially improved by supplementing with high-energy grains (Blaser et al., 1969).

B. Cell wall characteristics

Plant cell walls are the major sources of dietary fiber for animals. Energy availability from forages is limited by fiber concentration (accounts for 30-80% of OM in forages) because fiber is slowly and incompletely digested whereas cell solubles are almost completely digested (Buxton and Brasche, 1991; Buxton,

1996). Mammalian enzymes cannot degrade cell wall polysaccharides; instead, herbivores depend on microbial fermentation to degrade these polysaccharides (Buxton and Brasche, 1991). In the grazing ruminant, intake control is usually dominated by the effect of plant cell wall material in the digestive tract, especially the rate at which digesta can leave the rumen (Kennedy, 1990). The relative effects of mastication, rumination, ease of microbial colonization and rate of enzymatic digestion on particle outflow are mainly influenced by the cell wall characteristics which affect the rate of digesta disappearance from the rumen (Hodgson and Illius, 1996).

Rate and possibly extent of rumen microbial degradation of cell wall carbohydrates (CHO) may vary due to degree of H-bonding, branching patterns, and association of individual CHO with other cell wall constituents, mainly lignin (Hatfield, 1989). As forage plants mature, increased crystallization of cellulose and bonding between cell wall polysaccharides (cellulose and hemicellulose) and lignin, present a major problem to the ruminant (Akin, 1989). Physical resistance of mature forage to chewing and rumination increases while susceptibility to microbial colonization and digestion is reduced (Dove, 1996). Increasing stem to leaf ratio compounds the effect of maturation in that microbial access during digestion is restricted, since stem usually contains more lignin (Wilson, 1994).

Grass fiber is more digestible than that of legumes (ruminants digest 60-70% of grass fiber and 40-50% of legume fiber), but legume fiber digests at a

faster rate (Buxton and Brasche, 1991). The generally greater rate of cell wall degradation for legume than grass is thought to be a function of more restricted or localized deposition of lignin and greater proportion of core (localized) lignin than non-core (free) lignin (Jung, 1989). Further, a lower proportion of non-core (free) lignin in legume than in grass might be associated with less inhibitory effects of free phenolic (lignin) monomers on microbial activity (Fukushima et al., 1991). Consequently, increased lignification of legume leaves with maturation depresses CHO digestibility less than lignification of grass leaves, in part because there is less free lignin in legume to bind with non-cellulosic polysaccharides. These factors presumably contribute to a smaller change in legume digestibility with increasing maturity compared to grass (Sharma et al., 1988; Galyean and Goetsh, 1993).

Moseley and Dellow (1985) reported that ruminants spent 40% more time eating and 90% more time ruminating grass than legume because of greater particle breakdown by mastication of legume than grass. Lower cell wall content and cubical nature of legume particles compared to long and slender grass particles (Minson, 1990), less lignin-CHO bonding, and the localization of lignification to certain cell compartments in legume compared to grass, enhances legume susceptibility to microbial attack compared to grass (Akin, 1989).

C. Diurnal variation in nutrient content

Seasonal and diurnal variations in nutrient content (mainly carbohydrate and N) in forage crops are important considerations for making grazing management decisions (Wilkinson et al., 1994). Holt and Hilst (1969) reported that water soluble carbohydrate (glucose, fructose, sucrose) content in Kentucky bluegrass (*Poa pratensis* L.), bromegrass (*Bromus inermis* L.) and tall fescue (*Festuca arundinacea* L.) increased linearly from 0600 h to 1800 h. The water soluble carbohydrate content in alfalfa followed a curvilinear diurnal trend from low at 0600 h to maximum levels at 1200 h and decreased slightly by 1800 h. Nonstructural polysaccharide (mainly starch) content followed a nonlinear daily trend peaking in the afternoon.

The concentration of various carbohydrates and N in plants varies diurnally, presumably in response to changes in light intensity, temperature, and other environmental factors (Youngberg et al., 1972). Light has a direct role in carbohydrate synthesis, temperature in carbohydrate assimilation, and moisture in carbohydrate translocation (Lechtenberg et al., 1971). Lechtenberg et al. (1971) further reported that leaf starch of alfalfa increased from 10.2 to 20.3% of the DM during daylight hours, most of the increase occurring between 0900 h and 1500 h. In vitro DM digestibility averaged 1.6% higher at 1800 h than at 0600 h. Thus, farmers may take advantage of the diurnal variation in forage quantity, constituency and digestibility by harvesting or grazing late in the

afternoon or evening when DM and water soluble carbohydrates are highest (Mayland et al., 1998; Orr et al., 1997).

D. Forage type

Cool season grasses are more digestible than warm season grasses because the proportion and arrangement of tissues differ as a result of differences in photosynthetic pathways and optimal growing temperatures (Akin, 1989). The C_3 plants (cool season grasses and legumes) fix CO_2 by the reductive pentose phosphate pathway whereas C_4 plants (warm season grasses) fix CO_2 by the C_4 dicarboxylic acid pathway (Voet and Voet, 1995).

The main advantage of C_3 over C_4 grasses is that C_3 plants have greater proportion of highly degradable mesophyll tissue and that this tissue appears to be more loosely arranged than that in C_4 plants, allowing easier microbial attack (Hanna et al., 1973). Also, the proportion of parenchyma bundle sheath is greater in C_4 than C_3 species, and this tissue is generally slowly or only partially degraded and contributes to more rigid residue (Akin, 1982, 1986). In contrast, the parenchyma bundle sheath of C_3 grasses is rapidly and extensively degraded, probably because phenolic compounds (lignin) do not limit degradation as in C_4 grasses (Akin, 1982). Thus, warm season grasses have a greater proportion of the less digestible stem and reach flowering more quickly than cool season grasses (Galyean and Goetsch, 1993). In addition, lag time of ruminal cell wall digestion is longer and digestion rate slower for warm season grasses than for cool season grasses and legumes, perhaps because adherence time of bacteria

to particles is longer and concentration of phenolic acids (lignin) is greater for warm season grasses than for cool season grasses (Mertens and Loften, 1980; Akin, 1986).

Minson and McLeod (1970) reported that temperate grasses were 12.8% more digestible than tropical grasses cut at any stage of growth mainly due to the influence of ambient temperature (accounts for about 60% of the difference) and anatomical structure differences (accounts for the remainder). High temperature reduces DM digestibility by increasing the amount of cell wall and its lignification as well as promoting stem development. Differences between tropical and temperate legumes were small since both plants are C₃ species and their leaves have similar anatomical structure (Minson and McLeod, 1970).

E. Physiological maturity

Marked physiological changes take place as forage matures. The ratio of cell walls to cell contents and degree of lignification of cell walls increase (Hodgson, 1990), and stem to leaf ratio rapidly increases (Ulyatt, 1981; Wilman et al., 1976). Leaves lose cell contents steadily with advancing senescence, thus, digestibility of dead leaf tissue declines to 40-50% (Hodgson, 1990). The N content of the DM of young herbage, typically in the range of 3-4%, declines to as low as 1% in very mature forage. In addition, structural carbohydrates (digested slowly) and lignin (indigestible) increase rapidly in stems and slowly in the leaves, contributing to the decline in digestibility in mature forage (Ulyatt, 1981).

A rapid turnover of tissue takes place as new leaves are continually produced and old ones die (Hunt, 1965). In perennial ryegrass a new leaf appears on each tiller on average every 11 days (April to September), but as only three live leaves per tiller are maintained, average longevity of leaves is just 33 days (Davies, 1977). Thus, optimum utilization of ryegrass may require more frequent defoliation to minimize the effects of old or dead material. As forage matures digestibility declines because N decreases, and fiber and lignin contents increase; these changes may be accompanied by decreased forage intake, ruminal NH_3 concentrations, total volatile fatty acid (VFA) concentrations and increased acetate to propionate ratio (Van Soest, 1994).

Funk et al. (1987) reported that in vitro OM digestibility and dietary N decreased and fiber content increased ($P < 0.05$) as forage (mainly blue grama rangeland) matured through the growing season. Park et al. (1994) reported that total masticate N, in vitro OM disappearance and OM intake of intermediate wheatgrass decreased while bound N increased ($P < 0.05$) with each sampling date (April through December). Cherney et al. (1993) reported that NDF increased from 40.0 to 62.7%, indigestible fiber increased from 6.0 to 25.5%, lignin increased from 1.7 to 5.3% whereas digestibility of fiber decreased from 79.9 to 44.2% as maturity of cool season perennial grasses increased from May to mid June. The authors also found a strong negative correlation ($r = -.78$) between lignin and fiber digestibility as forage matured, generally agreeing with other literature (Akin, 1989; Van Soest, 1994).

The decline in nutritive value of forages is considered to be linear with physiological maturity (Blaser et al., 1986) and has implications on forage utilization (Burns, 1981). Burns et al. (1997) reported that OM and NDF digestibility of switchgrass (*Panicum virgatum* L.) decreased ($P < 0.05$) while NDF, ADF, acid detergent insoluble CP, and undegradable intake CP increased linearly ($P < 0.01$) with advancing season when fed to steers. Steer responses were indicative of increasingly mature forage. Cherney et al. (1993) and Johnson et al. (1998) reported similar results.

Elizalde et al. (1999) reported that the extent of ruminal DM and CP degradation by steers decreased with maturity of alfalfa and tall fescue, due to increased proportion of rumen undegradable CP as a percentage of CP. Further, a decrease in intake as forage matured could be attributed to chemical (mainly nutrient content) and physical (leaf to stem ratio and particle size) changes (Weston and Poppi, 1987). Seasonal changes in forage intake and ruminal fermentation of cool season forages suggest that animal performance might be increased if supplemental energy is provided early in the growing season; however, supplemental protein would likely be needed as these forages mature (Cherney et al., 1993).

F. Forage height and density

Forage height or sward height (SH) is an important variable that can be used to estimate forage mass (kg/ha) and, when measured on a regular basis, forage growth rate (kg/unit time). Sward height can be estimated using the Hill

Farming Research Organization (HFRO) sward stick, rising plate meter or a graduated measuring stick. Bransby et al. (1977) reported a positive correlation between forage height and DM yield; as sward height increased, forage mass also increased. Wright et al. (1990) reported that cows on high (7-8 cm) sward surface height (SSH) consumed more forage (10.8 vs 8.9 kg OM/d) compared to those on low (4-5 cm) SSH. Similarly, calves on high SSH gained more (1.40 vs 0.63 kg/d) compared to those on low SSH.

Forage height has an inverse relationship with quality (Minson, 1990). Consequently, forage DM intake is affected by grazing behavior (small bite size and insufficient grazing time) of animals in response to low forage height. In such circumstances, quantity of forage and not quality, should be limiting animal productivity. Reports by Mayne et al. (1987) concluded that a reasonable compromise between sward utilization (mainly perennial ryegrass) and animal performance can be achieved by grazing cows to a residual sward height of 6 cm (SSH of 8 cm) as assessed by the rising-plate sward stick. Cool season pastures maintained at 8-10 cm provide the best compromise between forage quality and intake of grazing beef (Prigge et al., 1997) and dairy (Rook et al., 1994a) cattle.

In temperate grass swards, SH is the dominant variable influencing short-term forage intake in grazing animals (Hodgson, 1981; Jamieson and Hodgson, 1979a, b). The dominant influence on intake of warm-season grasses is leaf density and leaf to stem ratio (Forbes, 1988). In swards with short or no flower horizons, such as Bermuda grass, bite size increases steadily with increasing

sward height. However, in swards with tall flower canopy, such as brome grass, bite size declines markedly with the appearance of flower horizons (Forbes, 1988). Reduction in bite size after appearance of flower heads presumably occurs because animals become more selective and because the leaf density of the surface horizon is reduced greatly. In situations where forage intake is increasingly limited by bite size, the need for supplementation with concentrates becomes more appropriate.

G. Forage allowance

Forage allowance refers to forage mass (kg DM) available to an animal per day. It is usually expressed as $\text{kg DM}\cdot\text{animal}^{-1}\cdot\text{d}^{-1}$ or $\text{g DM}\cdot\text{kg BW}^{-1}\cdot\text{d}^{-1}$, the latter accounts for differences in animal BW. Forage allowance is a component of grazing ecosystems that lends itself most readily to manipulation by grazing management (Hodgson, 1984). The relation between intake and forage allowance is generally curvilinear, once the allowance of desired forage is less than twice the maximum intake, there is progressive fall in quantity of forage consumed (Combellas and Hodgson, 1979). Hodgson (1975) suggested that herbage intake and milk production of the grazing dairy cow are maximized when the daily herbage allowance is equivalent to four times the amount consumed. Mayne et al. (1987) reported that in a rotationally grazed perennial ryegrass-clover pasture, average milk yields of dairy cows maintained at low, medium and high herbage allowance (36, 53 and 63 g OM/kg BW, respectively) was 11.8, 14.6 and 14.5 kg/d, respectively, generally agreeing with Hodgson

(1975). Redmon et al. (1995) reported that forage intake, OM disappearance (OMD), and estimated daily gain of steers grazing winter wheat pasture (*Triticum aestivum* var. Chisholm) were related to forage allowance. As herbage allowance increased, intake, OM digestibility and estimated daily gain improved; forage intake and estimated ADG declined severely when herbage allowance fell below $0.24 \text{ kg DM} \cdot \text{kg BW}^{-1} \cdot \text{day}^{-1}$.

Under ideal conditions, herbage removal by grazing should match herbage growth and herbage allowance will be considered constant (Hodgson, 1990). However, in many grazing situations, rate of sward depletion by grazing exceeds the rate of sward growth and the animal is offered gradually diminishing herbage allowance as the grazing season advances. Response to concentrate input seems to be higher when herbage allowance is low (Wilkins et al., 1995; Jennings and Holmes, 1984), or when the stocking rate is very high (Hoden et al., 1991). Reports by Meijs and Hoekstra (1984) concluded that at a low daily herbage allowance (16 kg OM/cow), approximately 4 cm cutting height, mean substitution rate of herbage by concentrate was 0.1; at a high daily herbage allowance (24 kg OM/cow), substitution rate increased to 0.5. Substitution rate refers to the amount of forage DM that is replaced for each kg DM of concentrate consumed. In general, substitution rate varies between 0.5 and 0.9 kg forage DMI for each kg of grain fed (Kellaway and Porta, 1993), depending on gut fill, supply of energy, CP, ruminally degradable protein, stage of lactation, and pasture availability.

Reduction in herbage intake resulting from supplementation is manifested mainly through a reduction in grazing time. Meijs and Hoekstra (1984) reported a reduction of in grazing time of 3-20 minutes/kg DM concentrate fed with little effect on rate of biting or bite size. To obtain an increase in milk yield similar to that obtained with 1 kg DM/d of concentrate, it is necessary to increase the herbage allowance by 5 kg DM/d (Hoden et al., 1991).

II. Supplementation

The objective of feeding supplements to cattle is to increase or maintain their productive performance (growth, reproduction and lactation). Concentrate supplements, mainly energy and CP, are fed to grazing animals to supply deficient energy and protein (NRC, 1989). Energy supply to the rumen may be most effective when there is a rapid NH_3 production and loss of protein. The supplemental energy will allow for the capture of $\text{NH}_3\text{-N}$ by the rumen microbes in the form of microbial protein. Rapid ruminal $\text{NH}_3\text{-N}$ production occurs with temperate pastures especially in spring, some of the tropical legumes, and most probably with tropical grasses immediately following rain (Poppi and McLennan, 1995). To be effective, there must be synchrony between energy and NH_3 release in the rumen (Galyean and Owens, 1991). However, grain supplements may decrease forage intake and utilization (Horn and McCollum, 1987), the effect depending on level and type of grain fed. Animal response to supplements may depend on type, amount and time of feeding.

A. Energy supplements

High-energy feeds can be grouped into two main subclasses, cereal grains and by-product feeds. Cereal grains (e.g. corn, wheat, barley, and oats) contain high amounts of starch and are low in fiber whereas most by-product feeds (e.g. wheat midds, seed hulls, sugar beet pulp) are also high in fiber.

Cereal grains

Depending on quality of forage on offer, energy supplements generally increase animal performance. Elizalde et al. (1998) reported that supplemented steers grazing endophyte-infected tall fescue had higher ADG than unsupplemented steers (0.74 vs. 0.64 kg/d); however, total OM intake and OM digestibility did not differ ($P > 0.10$) among treatments, suggesting that supplemented animals utilized metabolizable energy more efficiently than the unsupplemented group. In this study, steers were fed either ground or whole corn with hay or 4 h after hay was fed. The authors concluded that starch utilization was highest for the ground corn as opposed to the whole corn treatment, regardless of time that the concentrate was fed.

Grain processing could influence animal performance. Wu et al. (2001) reported higher milk yield and milk protein, and lower milk fat for cows fed supplemental ground high moisture shelled corn (HMC) compared to dry cracked shelled corn (22.9 vs 20.5 kg/d, 3.26 vs 3.15%, and 3.28 vs 3.67%, respectively). The cows (in late lactation) were grazing high quality (17.7% CP) pasture. The greater effect of ground HMC over cracked dry corn was likely due

to greater ruminal fermentation and digestion of starch in the HMC, increasing the supply of protein and ME. Reports by Reis and Combs (2000) indicated that total DMI, DM digestibility and milk yield increased as grain supplementation increased. Ruminal pH and total VFA concentration were not affected by supplementation, but ruminal NH₃ concentration was reduced, probably because of a decrease in N intake and greater use of NH₃-N for ruminal microbial synthesis. In contrast, Soriano et al. (2000) showed no differences in milk yield (30.3 kg/d), milk protein (2.97%), and milk urea N (14.7 mg/dl) of Holstein cows (107 days in milk) grazing high quality pasture (>19% CP) fed supplemental HMC, coarsely ground or finely ground corn.

Cereal grains differ in their rates and extent of fermentation. Barley and wheat are fermented more rapidly by ruminal microbes than corn and sorghum (Nordin and Campling, 1976; Cone et al., 1989). Compared to corn, barley starch is generally more rapidly fermented in the rumen and has greater concentration of rumen degradable protein (Herrera-Saldana et al., 1990b). Feeding a highly fermentable grain such as barley may have a greater detrimental effect on ruminal fiber digestion than a less fermentable grain (Ørskov and Fraser, 1975). For most grains, 90% or more of starch is normally fermented in the rumen, however, for others such as corn and milo, up to 30% or more could escape ruminal fermentation (Ørskov, 1986).

Herrera-Saldana et al. (1990b) reported that assuming a passage rate of 6%/h, the calculated ruminal availability of starch from oats, wheat, barley, corn,

and milo was 98, 95, 90, 62, and 49%, respectively. The low ruminal availability of milo is probably due to the protein matrix associated with starch granules, type and proportion of protein found in the endosperm and proportion of the endosperm. However, when rapidly degradable carbohydrates such as oats, wheat, and barley are fed in large quantities, fiber digestion may be disrupted limiting their inclusion in diets for grazing ruminants. Effect of various grain sources on intake and digestive processes in ruminants depends on forage type, level and type of supplement. Brake et al. (1989) reported that total DMI and OM digestibility of Holstein steers supplemented with barley or corn was higher for orchardgrass than bermudagrass and higher for barley than corn.

Casper et al. (1999) reported greater milk production for cows fed corn-based diets compared to cows fed barley-based diets (26.3 vs 23.7 kg/d) although DMI was similar for both groups. The slightly greater starch content of corn diets that is less rapidly degraded and greater proportion escaping ruminal fermentation may have contributed to greater milk production for cows fed corn compared to barley. Ruminal $\text{NH}_3\text{-N}$ and rumen VFA concentrations were greater for cows fed corn than those fed barley (15.0 vs 9.0 mg/dl and 133 vs 121 $\mu\text{mol/ml}$, respectively). However, fractional passage rates of solids from the rumen were greater for cows fed barley than those fed corn (4.2 vs 3.4%/h). Results of this study are consistent with earlier work (Casper and Schingoethe, 1989; Casper et al., 1990) which concluded that non structural carbohydrate

solubility, but not degradability, influences milk production when lactating cows are fed diets based on corn or barley.

Contrary to previous studies, Feng et al. (1995) reported that various corn/barley mixtures provided at 30% or 35.5% of diet DM had no effect ($P > 0.10$) on DMI, ruminal particulate passage rate, and total tract NDF digestibility of ruminally cannulated steers fed low quality grass hay-based diets (8.2% CP). Ruminal and total tract DM, and starch digestibility were greater ($P < 0.01$ and $P < 0.10$, respectively) for barley than corn containing diets. The authors concluded that ruminal and total tract digestibility, and protein flow to the small intestines could be increased more with barley than corn as energy supplement to grass hay-based diets. Vanzant et al. (1990) did not find differences in forage intake and utilization between supplemented rolled sorghum grain (upto 0.66% of BW, as fed) and unsupplemented yearling steers grazing big bluestem pastures (6.1% CP) in the spring and early summer. In this study, amount of supplements fed was less than amount suggested by Horn and McCollum (1987) (0.7% of BW) to affect forage fermentation and consequent forage intake and may explain the lack of supplement effect.

Berzaghi et al. (1996) did not find differences in total OM intake between diets of pasture only or pasture plus 6.4 kg/d cracked corn and mineral mix, however, forage OM intake was lower for cows fed corn supplement. Apparent ruminal and total tract digestibility of OM and NDF were lower for supplemented than for unsupplemented cows. Milk yield increased for supplemented cows

over the unsupplemented group (23.7 vs 19.5 kg/d), probably because supplemental corn increased energy intake, reduced ruminal $\text{NH}_3\text{-N}$ concentration and increased recovery of intake N at the duodenum.

In a review, Moore et al. (1999) found little relationship between changes in voluntary forage intake and sources of supplemental energy and CP. The authors concluded that the lowest increases in ADG were with native forages supplemented with molasses alone or low molasses containing high levels of NPN; whereas the greatest increases in gain were with improved forages, supplements with greater than 60% TDN, and supplemented CP intake greater than 0.05% of BW. Supplements decreased voluntary forage intake when supplemental TDN intake was greater than 0.7% of BW, or forage TDN to CP ratio was less than 7 (adequate N), or when fed alone, forage intake was more than 1.75% of BW (high quality forage).

Feeding supplemental diets high in energy or protein before and after calving could influence cow weight and condition, reproductive performance, and calf weight gain. Marston et al. (1995a,b) reported that cows fed energy-based diet (2.44 kg/d, 20% CP) before and after gestation had greater bodyweight gain at calving ($P < 0.01$) and greater pregnancy rate ($P < 0.01$) than cows fed a protein-based diet (1.22 kg/d, 40% CP). Cow performance postpartum and calf-weaning weight, were not affected by supplementation ($P > 0.10$). The authors concluded that conception rates were significantly improved by feeding higher levels of supplemental energy prepartum but not postpartum.

Supplemental energy fed to yearling cattle on pasture usually results in increased rates of gain. However, rate of gain and efficiency during subsequent finishing in the feedlot (for steers previously supplemented) have been reported (Denham, 1977) to decrease because of compensatory gains by non-supplemented animals. Perry et al. (1971) reported daily gains greater than 0.3 kg/d for supplemented yearling cattle on pasture; however, feedlot gains during the finishing phase were negatively correlated with pasture gains. Similarly, Coleman et al. (1976) reported that yearling cattle on pasture fed an energy supplement gained more (0.67 vs 0.38 kg/d) than the unsupplemented group. Feedlot gains (0.99 kg/d for all groups), carcass quality grade and estimated % yield were not affected; however, dressing percentage and back fat thickness of supplemented cattle was greater than for the unsupplemented group.

By-product feeds

To prevent adverse effects of starch on ruminal fiber digestion (Gekara et al., 2001), high-fiber by product feeds (e.g. wheat midds, soybean hulls, and corn gluten feed) and lipids (mainly vegetable oils e.g. soybean oil, canola oil) offer alternatives to grain for formulating high-energy supplements. Anderson et al. (1988) reported that soy hulls and corn elicited a similar animal response; they both increased ($P<0.05$) ADG of growing beef calves by 0.17 kg/d over the unsupplemented group. Soy hulls have an advantage over corn in that they contain high amounts of digestible fiber (NDF and ADF) rather than starch and,

therefore, supply supplemental energy while minimizing changes in ruminal fermentation.

Horn et al. (1995) reported that steer calves raised for feedlot finishing and fed supplemental corn-based high-starch or soybean hull/wheat midds-based high-fiber diets (0.65% of BW) had similar ADG (1.07 kg/d). However, supplemented steers gained more (1.07 vs 0.92 kg/d) than the unsupplemented group. The authors suggested that ADG and increased stocking density should be considered, along with costs, in selecting an energy supplement for growing cattle grazing a wheat pasture. Forster et al. (1993) suggested that rice bran supplemented at 0.38% of BW either separately or mixed with corn at 0.25% of BW, may be as great in value as corn given separately in respect to gain of Holstein steer calves grazing forage of moderate to high quality (greater than 12% CP).

Lipid sources can be added to grain supplements to increase energy density of the supplement without increasing the level of grain feeding. Brokow et al. (2001) reported that soybean oil (12.5% of supplemental DM, replaced corn on a TDN basis) inclusion in the diet had no adverse effects on animal performance; however, flow of microbial N was more depressed for soybean oil than for the corn treatment. The authors suggested that feeding low levels of supplemental grain with soybean oil (0.30% of BW) or without (0.35% of BW), is an effective strategy of increasing dietary energy for cattle grazing high quality forages (19% CP).

B. High CP supplements

A goal in the protein formulation of diets is to provide adequate amounts of amino acids to the animal for optimal efficiency and desired animal productivity with minimum amounts of dietary CP (NRC, 2001). Dietary CP can be classified as either ruminally degradable or ruminally by-pass fraction. The terms ruminally degradable CP (RDP) and degradable intake CP (DIP) refer to that portion of protein that is degraded by rumen microorganisms in the rumen. Ruminally undegradable CP (RUP) and undegradable intake CP (UIP) refer to that portion of CP that by-pass ruminal degradation. Efficient use of dietary CP requires selection of feed and supplement N that will provide adequate RDP for maximal synthesis of microbial CP and RUP that will optimize the profile and amounts of absorbed amino acids (NRC, 2001). Presumably, RDP could be complemented by supplementation (NRC, 2001) with readily available forms of energy or RUP.

For growing cattle, protein nutrition is critical because a deficiency of 1 g of protein per day can reduce gain by 10 g/d (NRC, 1984). Moreover, animal responses to supplemental protein usually are observed when the CP content of forages is less than 6 to 8% (Campling, 1970). Supplemental proteins high in RDP include soybean meal (SBM), linseed meal, sunflower meal; high RUP proteins include heated/chemically treated SBM, distillers' grains, brewers' grains, blood meal, corn gluten meal (CGM), meat and bone meal, or blends of these sources (NRC, 2001; Santos et al., 1998a). Immature forages often contain an

excess of RDP. However, as forages mature CP, particularly RDP may become limiting; consequently, supplements containing appreciable quantities of RDP can stimulate microbial fermentation and forage utilization (Drouillard and Kuhl, 1999).

Ruminally degradable CP

Protein supply to the intestinal tract for absorption in ruminants is influenced by ruminal degradability of dietary CP and production of microbial protein. Supplemental RDP fed to beef cattle consuming low quality forages (6.1% CP) increased forage DMI and digestibility (McCollum and Galyean, 1985) and improved cow BW and condition (DelCurto et al., 1990). In grazing systems utilizing low-quality winter forages, RDP is often deficient and does not meet the metabolizable protein requirements of cows. Jordon et al. (2002) suggested that feeding dried poultry waste as a cheap source of supplemental RDP could provide a more favorable rumen NH_3 production, increasing efficient N utilization, and, may replace SBM for cows grazing low-quality winter forages.

Garrett et al. (1987) reported that the flow of bacterial non-ammonia N to the duodenum was highest when steers were fed SBM or linseed meal, intermediate for urea and lowest ($P < 0.05$) for CGM (86.8, 86.1, 76.3, and 65.9 g/d, respectively). Ruminal digestion of dietary CP was greater in steers fed urea than those fed CGM, but intermediate for steers fed SBM and linseed meal (58.4, 48.8, 53.1, and 53.9%, respectively). Thus, when CP sources high in

RUP are fed, inclusion of sources high in RDP should be considered to maximize microbial efficiency of energy and N utilization.

Reports by Bodine et al. (2000) indicated that intake of hay (6% CP) and total OM increased quadratically ($P < 0.01$) in response to added DIP with or without supplemental corn. The authors concluded that providing adequate supplemental RDP seemed to overcome negative associative effects typically seen when supplementing low-quality forages with large quantities of low-protein, high-starch feeds. In a related study, Bodine et al. (2001) reported that feeding high-grain vs high-fiber pelleted energy supplements formulated to provide adequate RDP did not alter forage intake or OM digestibility. In this study, an adequate RDP to TDN balance decreased the negative associative effects often observed when large quantities of high-starch supplements are fed with low-quality hay. McCollum and Galyean (1985) reported that intake of low quality prairie hay (6.1% CP) increased ($P < 0.01$) and digesta passage rate was faster ($P < 0.01$; 4.5 vs 2.9%/h) when beef steers were supplemented with CSM at the rate of 800 g/d. It is not clear from this study whether the increased passage rate is a function of increased intake because of metabolic responses to protein supplementation, or to increased rate of fermentation of DM in the rumen.

In some studies, CP supplements have either elicited minimal or no response at all. McCormick et al. (2001) reported that type of CP supplement (SBM or CGM), had no effect ($P > 0.10$) on forage DMI (12.7 ± 1.0 kg/d), total

DMI (23.9 ± 1.2 kg/d) or milk yield (30.3 vs 28.9 kg/d) of grazing dairy cows. In grazing systems utilizing high quality forage (25.6% CP), CP is rapidly degraded in the rumen (Hongerholt and Muller, 1998) and $\text{NH}_3\text{-N}$ surplus and extensive ruminal N losses may occur (Beever and Siddons, 1986). The lack of response to supplemental RDP when dairy cows are grazing pastures containing more than 15% CP may be due to high N losses in the rumen (Hamilton et al., 1992). In such cases, supplemental CP high in RUP can elicit the desired animal response. In addition, diets high in RDP (in excess of NRC recommendations) have been shown to be detrimental to cow reproductive performance (Canfield et al., 1990; Blanchard et al., 1990).

Ruminally undegradable CP

Studies from the 1960s (Virtanen, 1966) showed that the rumen is capable of supplying the required protein of cows producing up to 4500 kg/cow per lactation. However, milk yield per cow in the US has more than doubled during the last 30 years, approaching 14000 kg per lactation. Thus, microbial protein synthesis increasingly cannot meet the high protein requirements, and significant amounts of dietary protein must escape ruminal degradation (Santos et al., 1998) to supply these needs.

In a review, Santos et al. (1998b) concluded that increasing RUP per se in dairy cow diets, which often results in decreased RDP and change in absorbed amino acid (AA) profiles, does not consistently improve lactation performance. Possible reasons for lack of response include decreased microbial synthesis in the

rumen, RUP source with a poor essential AA profile, RUP source with low digestibility in the small intestine (Schingoethe, 1991), and control diets already sufficiently high in RUP (NRC, 2001).

Feeding proteins that are resistant to microbial degradation in the rumen has been proposed to increase the amount of dietary protein reaching the small intestine (Stern et al., 1983). For a RUP source to elicit a positive response, the AA profile (mainly Lys and Met, first and second limiting AA, respectively) should complement that of microbial protein (Schingoethe, 1991; Clark et al., 1992). Schwab (1994) suggested that the amount of Lys and Met in duodenal digesta for maximizing milk and milk protein yields should be 15 and 5% of total essential AA, respectively. Hence, RUP sources low in Lys and Met might result in no increase or a decrease in milk yield and composition.

Shroeder and Gagliostro (2000) reported that milk and milk protein yields were increased by fishmeal compared to sunflower meal (26.8 vs 25.6, and 0.90 vs 0.81 kg/d, respectively). The authors attributed the higher milk yield observed to the quality of absorbed protein and higher glucose availability to the mammary gland because fishmeal has a higher concentration of RUP. Schor and Gagliostro (2001) reported that early-lactation dairy cows grazing moderate quality pastures (13.7% CP) supplemented with fishmeal consumed more forage DM (17.2 vs 13.2 kg/d), produced more milk (29.3 vs 24.9 kg/d) and reduced ruminal NH₃-N levels compared to the SBM-supplemented group. The authors

attributed the higher milk yield to increased DMI rather than enhanced body lipid mobilization.

In contrast, replacing a RDP source for RUP source resulted in no effect on DMI and N intake in several studies (Armentano et al., 1986; Chan et al., 1997; Mabjeesh et al., 1996). Microbial N flow to the small intestine was decreased ($P < .05$) by high RUP sources (275 vs 240 g/d), suggesting that when high RUP sources replaced SBM, a RDP shortage probably limited microbial synthesis. Reports of Bargo et al. (2001) indicated that level and source of supplemental protein (low/high sunflower meal or high protein feather meal) did not affect forage DMI (13.2 kg/d), total DMI (19.6 kg/d) and milk yield (20.5 kg/d) of cows grazing oats (*Avena sativa* L.) in the winter. The authors concluded that higher RUP intake (feather meal) did not increase animal performance, suggesting that RUP was not limiting for cows on pasture producing less than 22 kg of milk/d. Hongerholt and Muller (1998) reported that supplemental grain mixture (high in RUP) content did not alter DMI or milk yield of high yielding cows rotationally grazing high quality pasture (25% CP), however, milk protein tended to be higher for cows on RUP supplement. McCormick et al. (2001) made similar observations for Holstein cows grazing immature winter annual pastures (25% CP), indicating that energy, and not protein, may have been the major nutritional constraint limiting milk yield.

Supplements high in RUP have been shown to improve reproduction when fed in excess of NRC recommendations (Wiley et al., 1991). However, feeding

excess CP has also been reported to increase days to first ovulation (Carroll et al., 1988) or lower fertility (Jordan and Swanson, 1979). Although the exact mechanism on how excess CP affects reproduction is not known, high protein diets probably elevate plasma urea N (Carroll et al., 1988) and urea is thought to decrease bovine sperm viability (Duby and Trischler, II, 1986).

Crude protein content

Animal responses (intake and digestibility) to supplements may depend on the CP level of the supplement and forage offered. Marston and Lusby (1995) reported that gestating and lactating beef cows fed SBM-based protein diet (40% CP) consumed 1 kg DM/d more prairie hay (<5% CP) and hay digestibility was greater ($P < 0.001$) than for cows fed soybean hull-based energy diet (20% CP). However, total metabolizable energy intake was similar ($P = 0.35$) for both treatments. The authors concluded that increasing total energy intake of cows consuming low-quality forage by feeding energy supplements is difficult after meeting protein requirements. Reports of DelCurto et al. (1990) concluded that beef cow body condition and bodyweight losses during winter grazing period were minimized with increasing supplemental CP concentration (13, 25 and 39% CP). However, intake and utilization of dormant forage (8.7% CP), mainly bluestem (*Andropogon gerardii* L.), by steers were improved with moderate (25% CP) levels of supplemental protein.

In contrast, Karges et al. (1992) reported that steers grazing summer native range grass species (<14% CP) and fed supplemental RDP or RUP

showed no response to RDP supplement; however, a linear gain response ($P < 0.01$) was observed in steers fed RUP. Results of this study suggested that microbial protein synthesis may be insufficient to satisfy the metabolizable protein requirement, probably limiting steer gains. Wheeler et al. (2001) reported that supplemental protein concentration did not alter forage DMI, total OMI, apparent digestibility of OM or NDF, cumulative cow weight change or cumulative body condition score. However, protein supplemented cows (at 0.2, 0.4 and 0.6 g of supplemental protein/kg of BW) lost less weight and condition compared to unsupplemented animals.

C. Time of supplementation

For supplements to be effectively utilized on pasture there should be synchronous availability of carbohydrate (CHO) and NH_3 release in the rumen to maximize microbial protein synthesis and minimize the negative effects of carbohydrate fermentation on fiber digestion. Thus, the time of day when supplemental energy or protein is fed is critical and could influence the synchronous availability of CHO and NH_3 . Providing a more stable ruminal NH_3 -N concentration through synchronous availability of NH_3 and CHO usually increases fiber utilization (Hoover, 1986; Mould and Ørskov, 1984).

Grazing behavior (Adams, 1985) and ruminal effects (Judkins et al., 1991) of frequency and time that supplements are fed have been evaluated with a limited number of forage types. Adams (1985) reported that yearling steers supplemented in the PM (1330 h) had greater digestible energy intake ($P < 0.10$)

and ADG ($P < 0.01$) than the AM-supplemented (0730 h) group. The steers were grazing Russian wild ryegrass (*Elymus junceus* L.) only (6.6% CP) or supplemented with corn (0.3% of BW) either in the AM or PM. Although supplemented steers did not graze for two to four h after supplementation, animal performance was not affected. Leonard et al. (1989) reported that form ($P < 0.08$) and not time ($P > 0.10$) of feeding corn grain influenced animal performance, ADG and passage characteristics of beef steers offered fescue hay.

Wiley et al. (1991) reported that in situ NDF disappearance rates of supplements containing DL-methionine fed to cows at 1200 or 1500 h were greater ($P < 0.01$) than those supplemented at 0800 h. In this study, cows were fed hay only (8.6% CP) or supplemented with DL-methionine at 0800, 1200, or 1500 h. The increased rate and extent of DM and NDF disappearance occurred possibly through increased microbial fermentation because of the synchronous availability of N and CHO for rumen microbes at 1200 or 1500 h, as opposed to 0800 h. The authors concluded that the favorable ruminal responses to supplemental DL-methionine depended on time of supplementation. In contrast, McCracken et al. (1993) reported that daily supplemental methionine (11.4 g/steer) increased ($P < 0.05$) the rate of NDF digestion of steers grazing low quality fescue (*Festuca arundinacea* L.) fed at 0700 h but not at 1200 h. However, forage intake and ruminal fermentation kinetics were not altered ($P > 0.10$) by time of supplementation. The disparity in results between this study and that of Wiley et al. (1991) may be that carbohydrates were more readily

available with the actively growing forage compared to the low quality hay used in the study of Wiley et al. (1991).

Robinson et al. (1997) reported that lactating dairy cows fed a protein supplement (47.4% CP) during the night (0030 h, 7.5 h after the evening meal) had greater apparent fore-stomach digestion ($P < 0.05$) of OM (42.5 vs 36.6%) and CP (11.8 vs -2.3%) than cows fed the supplement during the day (0830 h, 0.5 h after the morning meal). The meal was a mixture alfalfa silage, whole crop oat silage, and concentrate consisting of primarily barley grain (12.8% CP). Volatile fatty acid (except isobutyrate) concentration was greater whereas flow of nonbacterial NAN (as a proportion of N intake) to the duodenum was lower ($P < 0.05$) for cows fed protein supplement during the night compared to cows fed the supplement during the day. These results support the view (Robinson et al., 1987; Ulyatt et al., 1984) that protein fed during the night stimulates ruminal fermentation (at night), resulting in greater fore-stomach OM digestion and less escape of dietary protein from the fore stomach. Shabi et al. (1998) reported that mean daily ruminal $\text{NH}_3\text{-N}$ concentration was reduced by high ruminally degradable OM, low ruminally degradable CP, and twice daily feeding (at 0600 and 1800 h). In addition, a high concentration of ruminally degradable OM at a high feeding frequency (four times daily at 0600, 1200, 1800, and 2400 h) resulted in lower fluctuation of ruminal $\text{NH}_3\text{-N}$.

In contrast, several reports indicate either minimal or no animal response to time of energy or CP supplementation. Reports of Barton et al. (1992) found

minimal differences in intake and digestibility between steers supplemented with cottonseed meal (CSM) at the rate of 0.25% of BW at 0600 or 1200 h; however, supplementation enhanced intake and digestibility of dormant intermediate wheat grass. The authors concluded that morning supplementation created greater spikes of ruminal NH₃ concentration than afternoon supplementation did, albeit with little influence on ruminal fermentation. Judkins et al. (1991) reported similar observations in that forage DMI, bacterial synthesis, ruminal kinetics and ADG were not influenced ($P > 0.05$) by time of protein supplementation. In this study, four ruminally cannulated steers were fed low quality fescue hay (6.1% CP) only or hay supplemented with CSM at 1.6 g/kg BW once daily at 0600, 1000 or 1400 h. However, steers supplemented with CSM had greater ADG ($P < 0.05$) over the unsupplemented group.

Hunt et al. (1989) reported that DM and NDF intake of low-quality grass hay (6.6% CP), NDF and ADF in situ disappearance and ruminal VFA concentrations were greater ($P < 0.05$) when CSM was fed as opposed to control (no CSM); however, time of feeding CSM (at 12 h, 24 h or 48 h) did not affect ($P > 0.10$) these variables. Cottonseed meal was fed to provide 3 g CP/kg BW^{0.75} daily. The authors suggested that the time interval of feeding supplemental protein is not critical for steers consuming forage high in DIP. It appears that the time of feeding a protein supplement has minimal associative effects compared to type and quantity of supplement.

D. Synchronization of ruminal energy and N

Synchronization refers to the combination of carbohydrate and CP sources with similar ruminal degradation resulting in a more efficient utilization of energy and N in ruminant diets. Synchronous supply of N and energy substrates is one way to achieve a stable ruminal environment (Sinclair et al., 1993). Microbial growth and protein synthesis can be stimulated by stable ruminal kinetics (Khorasani et al., 1994; Sniffen and Robinson, 1987) and by reducing feed-related associative effects in the rumen (Robinson, 1989).

Synchronization of the rate of carbohydrate fermentation and protein degradation has been suggested as a means to optimize microbial growth in the rumen (Hoover and Stokes, 1991) and improve the capture of rumen degradable CP (Johnson, 1976; Nocek and Russell, 1988). Despite the efficient synthesis of microbial protein from diets consisting of high quality pasture, pre-duodenal losses of N can account for up to 30% of ingested N (Beever and Siddons, 1986). This loss of N occurs when concentrations of ruminal NH_3 are high because of the rapid and extensive ruminal degradation of pasture N (Beever and Siddons, 1986; van Vuuren et al., 1991). Rook et al. (1994a) attributed increased N loss observed to inconsistent diurnal pattern of DMI by intensively grazed dairy cows. Van Vuuren et al. (1990) suggested that, for optimal utilization of pasture N, supplemental carbohydrate should theoretically have a degradation rate similar to that of pasture N (8 to 14%/h) or ratio of 25 g of N/kg of OM fermented.

Sinclair et al. (1993; 1995) reported improved efficiency of ruminal microbial synthesis by maintaining proper hourly amounts and ratios of the available carbohydrate and N supplies in the rumen. When dietary concentrations of ruminally degradable carbohydrate and protein were matched, concentration of ruminal metabolites (Stokes et al., 1991) or milk yield and composition (Aldrich et al., 1993; Casper and Shingoethe, 1989; Herrera-Saldana et al., 1990a) were altered. Synchronous ruminal release of supplemental carbohydrate with pasture N appeared to improve the capture of ruminal N (Kolver et al., 1998). However, N retained for milk production and growth, milk yield, composition or efficiency, was not influenced by treatment. Increased capture of excess N may have other physiological effects. The energy cost associated with metabolic disposal of excess N has been proposed to be 0.2 Mcal of net energy for lactation per 100g of CP consumed (Twiggs and Gils, 1998). In addition, adverse effects of excess N on reproductive performance (decreased fertility, increased embryonic mortality and increased number of days open) are well documented (NRC, 2001).

In other reports, attempts to synchronize ruminal nonstructural carbohydrates and CP degradability have produced minimal benefits for dairy cows in mid lactation. Henning et al. (1993) reported that the degree of energy and N synchronization affected neither microbial flow nor efficiency of growth, thus suggesting that merely improving degree of synchronization between energy and N release rates in the rumen does not always increase microbial

yield. Robinson and McQueen (1994) reported that synchronization of ruminal fermentation of dietary carbohydrate and N had no effect on ruminal VFA concentration or overall milk yield of dairy cows. Despite synchronized availability of OM and CP, Robinson (1989) observed large fluctuations in ruminal metabolite concentrations when large amounts of rapidly fermentable supplements were fed, resulting in a lower ruminal pH and reduced microbial synthesis. Dietary manipulation priority should aim to obtain an even ruminal energy supply and provide the appropriate amount of ruminally available N (NRC, 2001). An even ruminal N supply, avoiding too rapid a ruminal N release, should also be considered in the formulation of supplements.

III. Grazing behavior

The grazing process is a complex set of events initiated by the grazing animal in response to hunger (Forbes, 1988). The animal responds to hunger by searching an appropriate feeding station and allocating time to the ingestion process (prehension, biting, manipulation/chewing and swallowing). This process is repeated over in several bouts until the animal receives a satiety signal to stop eating or fatigue limits further grazing activity (Forbes, 1988; Hodgson, 1990; Stobbs, 1973). Other activities associated with grazing include rumination process (regurgitation, re-chewing, and swallowing of feed bolus) and idling/resting. The behavior of grazing animals on pasture is generally responsive to forage conditions, mainly allowance and quality (Hodgson, 1990).

A. Behavior characteristics

Bite size, biting rate, grazing time and rumination time generally characterize grazing behavior. According to Hodgson (1990), bite size is the dominant animal variable affecting forage intake. A small bite size is indicative of limiting forage conditions. Bite size rapidly declines once sward height falls below certain threshold height, 4 cm for cattle (Rook et al., 1994a) and 3 cm for sheep (Hodgson, 1990). Bite size varies widely with type and stage of growth of the forage being grazed. For temperate grasses, bite size linearly increases with sward height until leaf density begins to decline as flower horizons appear (Forbes, 1988). Stobbs (1973) suggested that forage intake by cows grazing tropical grass swards might be restricted if mean bite size fell below 0.30 g OM. Leaver (1986) reported that at a bite size of 0.65, 0.45 and 0.25 g DM, depression from maximum herbage DM intake decreased by 0.8, 3.4 and 8.1 kg DM/d, respectively. On average, most cows take 36,000-40,000 bites/d and 35-75 bites/minute (Chacon et al., 1978), depending on height and density of pasture.

Animals generally tend to compensate for reduced bite size by increasing the biting rate or grazing time (Chacon et al., 1978; Henricksen and Minson, 1980; Forbes and Coleman, 1987) or both (Philips and Leaver, 1985). However, fatigue on the part of the grazing animal may limit the extent to which biting rate and/or grazing time can be increased (Rook et al., 1994a). Grazing time is one of the limiting factors controlling intake when forage availability is low (Rook et

al., 1994a). An animal that needs less forage to meet its energy requirements will require less time to consume its desired level of DM from pasture. Consequently, the forage height necessary to maximize performance would be lower for concentrate-supplemented cows than for unsupplemented cows (Gekara et al., 2001).

Philips and Leaver (1985) reported that rumination time tended to be lower in early spring and late summer (6.5 h/d) compared to mid summer (7.8 h/d), indicative of seasonal variation in forage fiber content. The authors suggested that low forage fiber content and low herbage intake may have contributed to the rumination times observed for early spring and late summer, and mid summer, respectively. The authors further reported that rumination activity was concentrated in the night hours and also interspersed between the major grazing bouts in the daytime.

B. Selective grazing

Ruminants are selective grazers, thus, the nutrient content of the pasture consumed is usually greater than that of the pasture offered (Minson, 1990). Selective grazing strategy is employed by animals to discriminate against forage parts or plants deemed unsavory, dead, mature or poor in quality. Leaves and leafy stems devoid of dead material are selected over mature and flowery stems as well as legume over grass (Minson, 1990). However, animals grazing more selectively travel longer distances as they spend more time search grazing (Krysl and Hess, 1993). In addition, animals grazing selectively generally allocate

more time to grazing activity at the expense of other productive activities such as rumination and resting (Rook et al., 1994a).

Depending on animal species, differences in grazing behavior and diet selection can influence the structure of a sward. The composition and structure of a grazed sward is a result of the competitive interactions between the plant species (for light and nutrients) and degree of defoliation. Thus, forage composition and structure is determined by the degree of animal selectivity and grazing pressure (Schwinning and Parsons, 1996). Higher white clover content tended to develop in grass/white clover swards when grazed by cattle compared with sheep (Briseño de la Hoz and Wilman, 1981), or goats compared with sheep (Penning et al., 1996). The observed response was probably a function of the mechanics of animal grazing behavior in relation to sward canopy structure. Active selection may have played a role in reducing the proportion of clover in pastures grazed by sheep as opposed to cattle. Studies of Milne et al. (1982) showed a higher proportion of clover in the diet selected by sheep compared with cattle and goats. Wright et al. (2001) reported that grazing grass/clover swards by cattle followed by sheep resulted in a higher proportion of white clover in the diet of both species, thus, herbage intake for both species tended to be higher.

IV. Grazing management

Seasonal variation in pasture conditions, mainly quality and quantity, is an important consideration for undertaking a system of managing pastures and grazing animals to ensure animals have access to an ample supply of good quality forage year round.

A. Grazing system

Rotational and continuous stocking are common management systems for grazing dairy and beef cattle. In rotational grazing, animals are rotated between grazing and resting of pastures, subdivided into at least two paddocks. In continuous stocking, animals remain on the same pasture throughout the grazing season. Williams and Hammond (1999) reported that animal performance as determined by ADG, body condition score, pregnancy rate, and adjusted 205-d weaning weight of calves, was not affected when continuous or rotational grazing management were compared. For both systems, herbage mass and quality of forage (in vitro OM digestibility and CP concentrations) did not change ($P > 0.10$). The authors concluded that the main advantages of continuous over rotational grazing management are less labor and fencing costs, and reserving an area for production of winter feeds.

In either rotational or continuous grazing systems, optimal stocking rate (number of animals per unit area of pasture) is important from the standpoint of animal and pasture production (Hodgson, 1990). Baker et al. (1981) reported that milk yield and ADG of cow/calf units was affected by the severity of grazing

induced in set-stocking pastures. Increasing the stocking rate from low (3.33/ha) to medium (3.81/ha) reduced daily milk yield, cow and calf gain by 1.1, 0.14 and 0.09 kg/d, respectively, and from medium to high (4.44/ha) by 1.3, 0.24 and 0.03 kg/d. The authors concluded that pasture management decisions should be based on the cow rather than calf performance since the calf is buffered against the effects of herbage allowance by cow milk.

Frame and Dickson (1985) reported that herbage digestibility increased and dilution of re-growths by residual aging herbage was reduced as stocking rate increased. However, the benefits that farmers can expect from more intensive grazing management are more evident in a year of good pasture growth (Bryan et al., 2000).

B. Sward management

The primary goal of a producer in forage management is to maintain forage quality at a level that will support desired levels of gain or milk production. Thus, sward management should aim to optimize herbage utilization and at the same time provide a sward able to withstand repeated defoliation throughout the season. Sward management such as rest-period interval, stubble height, and other factors that affect forage quality may depend on type of forage. Jones (1985) reported that warm season grasses are generally lower in quality (CP and digestibility) than temperate genera due to a relatively low leaf to stem ratio, rapid rates of maturation, and chemical and physical characteristics associated with C₄ photosynthetic pathway.

Re-growth of a sward following defoliation may depend on frequency, intensity, and timing of defoliation. Two aspects of defoliation management that can be readily varied in a rotational stocking system are frequency and intensity, and both can have an effect on pasture production (Bryan et al., 2000). Frequency refers to time intervals between successive defoliations while intensity refers to the severity of defoliation. Frequency of defoliation could be considered in relation to developmental phases of plants and season of the year (Harris, 1978). Severe defoliation which may involve removal of growing points and treading of a sward requires a longer recovery period especially late in the grazing season when growth rate is slow (Harris, 1978). Re-growth period may also depend on the growth habit of the sward (Pearson and Ison, 1997). For instance, stoloniferous plants could require longer recovery periods following defoliation since their growing points are more prone to the effects of treading (Harris, 1978).

Time required for re-growth to attain a sward height that provides optimal herbage mass, quality, and animal performance, varies. Prevailing weather conditions, canopy tissue demography (leaf, stem, and senescence tissue), nutrient availability, residual height after defoliation, and developmental stage may influence recovery from defoliation (Belesky and Fedders, 1994). Mayne et al. (1987) showed that grazing intensely early in the season (to 6 cm sward height) resulted in better sward structure late in the season and improved grassland utilization. The authors concluded that in a rotational grazing system,

a reasonable compromise between sward utilization and animal performance could be achieved by grazing spring-calving dairy cows to a residual sward height of 6 cm. Bryan and Mills (1988) reported that more herbage was produced from a Kentucky bluegrass/white clover sward cut to simulate rotational re-growth (4-wk re-growth interval) than from a sward managed for hay. Repeated defoliation (50% and 70% removal) of orchardgrass (*Dactylis glomerata* L.), tall fescue (*Festuca arundinacea* L.) x perennial ryegrass hybrid and prairie grass (*Bromus unioloides* L.) resulted in more stable distribution of herbage within a season although herbage mass was smaller compared with canopies managed as hay (Belesky and Fedders, 1994). Grazing management strategies including optimal stocking rate and sward management are crucial if optimum animal and pasture productivity is to be achieved.

Agronomic practices such as grazing management, application of fertilizer and improvement of pastures are a prelude to an ample supply of high quality forage (Pearson and Ison, 1997). Use of fertilizer, mainly N, P and K, is a management practice often used to increase forage productivity (quality and quantity) particularly when soils are deficient in these essential nutrients (Pearson and Ison, 1997). Nitrogenous fertilizer can improve the CP content of some forages resulting in increased intake of up to 70%, however, this effect may be related to stage of forage maturity (Minson, 1990). Similarly, grass/legume mixtures can increase the N content of forage (Marshall et al.,

1998) because legumes fix atmospheric N that grasses readily utilize, enhancing their N content.

CHAPTER 3: INTRODUCTION

When cattle consume forages as their only energy source, intake of available energy may be inadequate to meet desired production demands. To increase milk production, supplementation (with concentrates) of lactating dairy cows under grazing situations is a viable option (Kolver and Muller, 1998). Gekara et al. (2001) reported that concentrate supplementation of cows grazing lower sward height (6.6 cm) pasture resulted in greater forage DMI compared to cows on higher sward height (8.8 cm) pasture. This suggests that pasture management could be an important variable influencing the effectiveness of supplementation.

Gekara et al. (2001) further reported that forage intake and digestibility of grazing cows decreased as the level of supplement increased from 0 to 1.2% of BW. Declining forage intake and digestibility could be attributed to disruption of the rumen environment via fluctuations in pH, microbial types and/or population (Hoover, 1986; Mould and Ørskov, 1984). Moreover, the grazing intensity of cattle varies throughout the day partly in response to environmental temperature, demand for other activities such as rumination and resting (Rook et al., 1994a) or to diurnal changes in nutrient composition of pasture (Orr et al., 1997) and/or rumen metabolites (Van Vuuren et al., 1986). Because of diurnal changes in the ruminal environment brought about by the grazing pattern of cattle, the effectiveness of concentrate supplements on pasture could be influenced by time of concentrate feeding via effecting fiber digestion and other

variables associated with ruminal fermentation. Consequently, the objective of this study was to determine the effect of sward height, timing of concentrate supplementation and grazing time management on pasture utilization of lactating beef cows as a model for dairy cattle.

CHAPTER 4: MATERIALS AND METHODS

Experimental Design

The experiment was conducted at the West Virginia University Animal Science Farm, Morgantown, during the 2000 grazing season on naturalized cool-season grass pastures. The experimental area has a slope of 15-20% and soil types were: Clarksburg (fine-loamy, mixed, mesic Typic Fragiudalfs); Dormont (fine-loamy, mixed, mesic ultic Hapludalfs) and Holly (fine-loamy, mixed, non acid, mesic Typic Fluvaquents). No lime or fertilizer was applied. Thirty-two multiparous crossbred (24 Angus and 8 Hereford) beef cows (632 ± 14 kg BW) calving between February 1 and April 1 and their calves (104 ± 4 kg BW) were grouped according to calving date and body weight. They were randomly assigned two sward height (**SH**) treatments (4 to 8 or 8 to 12 cm), replicated four times. Each cow received a concentrate supplement (4.1 kg DM/d) fed at one of two different times (**T**), either at 0700 h (AM) or 1800 h (PM), and either restricted (R) to grazing 12 h/d (0700 to 1900 h) or unrestricted (U) to 24 h/d grazing management (**MGT**). The R grazing management was incorporated to simulate a dairy system where cows would be allowed to graze one period daily between milking. The experiment was conducted over three periods, each lasting 15 days: May 5 – May 26 (period 1), June 29 – July 13 (period 2) and August 15 – August 29 (period 3). The experimental cow/calf units grazed on the same plots during all three experimental periods, but were re-randomized within the T or grazing management treatments during each period.

Animals and Diet

Before the start of period 1, all animals were fitted with fly control ear tags (Cutter blue, Bayer Corp., Shawnee, KS) and treated for internal parasites using Safe-Guard (Hoechst Roussel Vet, Summersville, NJ). Protocol approved by the University Animal Care and Use Committee was applied in the management of animals and experimental procedures. Animals were weighed at the beginning and end of each experimental period. Cows were fed the supplements individually in 2.5 m x 0.8 m stalls located within each plot. Stalls were also used for placement and removal of vibracorders, feeding of a fecal output marker and collection of fecal samples. Animals were usually in the stalls for less than fifteen minutes twice daily for these procedures.

The concentrate supplement was offered in one portion at the prescribed feeding time throughout the 15-d experimental period. To ensure uniform distribution of the marker (Yb) in the feces, Yb-labeled oats were fed twice daily. The labeled oats were mixed with the supplement at the prescribed supplementation time or mixed with a portion of the supplement (100 g) and fed to cows not receiving supplement at that particular time to encourage consumption. The supplement was comprised of mainly corn and soybean meal, and its composition and nutritive value are reported in (Table 1). All animals were allowed free access to a trace mineralized salt block¹ (Morton International, Inc. Chicago, IL) and water.

¹95-98% NaCl, 0.35% Zn, 0.28% Mn, 0.175% Fe, 0.035% Cu, and 0.007% Co

Cattle on restricted grazing management were removed from the plots at 1900 h and confined in nearby holding pens (supplied with drinking water only) where they remained overnight and were returned to their specific plots for grazing at 0700 h.

The naturalized pasture was comprised of grasses, predominantly Kentucky bluegrass (*Poa pratensis* L.) and some orchardgrass (*Dactylis glomerata* L.); legumes, predominantly white clover (*Trifolium repens* L.) and some red clover (*Trifolium pratense* L.); weeds were mainly broad-leaved. Non-experimental yearling cattle of similar breeding as the cows were used on a put and take basis throughout the grazing season to maintain the swards at the desired heights. Appropriate adjustments in yearling cattle numbers were made weekly. Between periods, the experimental cow-calf units were moved to non-experimental pastures of similar type.

Sampling Procedure

Pasture conditions were monitored weekly throughout the grazing season by taking sward height (SH) measurements (50 readings/plot) using an acrylic plastic meter as described by Rayburn and Rayburn (1998). Only measurements collected during the experimental period are reported in this experiment. Clip samples to determine botanical composition and growth rate of pasture, pluck samples of forage representing the grazed horizon and fecal grab samples to determine fecal output were collected twice daily at the same time as feeding and analyzed as described by Gekara et al. (2001). Clip

samples were collected once every two weeks for the entire grazing season; pluck samples were taken every two days starting d 9 through d 13 and fecal grab samples were collected twice daily at the time the supplement was fed starting d 10 until d 14 of each 15 d experimental period. Dried samples were ground in a Wiley mill (Thomas Scientific, Swedensboro, NJ) to pass through a 1-mm screen. The samples were subsequently analyzed for dry matter (DM), crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), and alkaline peroxide lignin (APL).

Measurements and Analytical Methods

To allow comparison with other investigations, sward surface height (SSH) using the Hill Farming Research Organization (HFRO) sward stick (Barthram, 1986) was calculated from the SH obtained using the acrylic plate disc meter. The following prediction equation, developed from paired samples (SH and SSH) taken on experimental pastures in 2001 using the method of Bryan et al. (1990), was used:

$$\text{SSH (cm)} = 1.1851 \times \text{SH (cm)} - 0.6011, R^2 = 0.90$$

The relationship between sward height and herbage mass was estimated from the equation developed from paired samples (plate height and herbage DM) taken on experimental pastures in 2001 using the method of Bryan et al (1990).

$$\text{Herbage mass (kg/ha)} = 229.14 \times \text{SH (cm)} + 348.38, R^2 = 0.60$$

Herbage growth rate was determined using exclusion cages (four per paddock) as described by Gekara et al. (2001).

Dry matter and CP of the pluck samples were analyzed according to procedures described by AOAC (1990). Neutral detergent fiber and ADF were analyzed following procedures described by Van Soest et al. (1991) and Robertson and Van Soest (1981), respectively. In vitro dry matter digestibility (IVDMD) of the supplement was determined as described by Goering and Van Soest (1970), using a ruminal fluid inoculum obtained from a ruminally cannulated dry dairy cow grazing a similar type of pasture.

Ytterbium (Yb) was used as an external indicator to estimate fecal output. Ytterbium labeled oats were prepared by spraying YbCl₃ solution on whole oats according to procedures described by Baker et al. (1988). Each cow received 100 g of Yb-labeled oats/d (as fed) starting day 1 until d 14 of each period (50 g at each feeding). Samples of the composited feces and labeled oats were analyzed for Yb concentration according to procedures of Baker et al. (1988). Fecal output (DM basis) was calculated from indicator concentrations using the following formula:

$$\text{Fecal output (g/day)} = \frac{\text{Indicator dose, mg/day}}{\text{Indicator concentration in feces, mg/g feces}}$$

The contribution of pasture to fecal output was estimated by subtracting the IVDMD indigestible fraction of supplement (0.08) from the total fecal output as described by Gekara et al. (2001) using the following formulae:

$$\text{Supp fecal output, kg/day} = (\text{Supp intake, kg/day}) \times (1 - \text{Supp IVDMD}); \text{IVDMD} = 0.92$$

$$\text{Forage fecal output, kg/day} = (\text{Fecal output, kg/day}) - (\text{Supp fecal output, kg/day})$$

To estimate forage intake, alkaline peroxide lignin (APL) content of pasture and feces was used as a marker as described by Sunvold and Cochran (1991). The following formula was then applied:

$$\text{Forage DMI (kg/day)} = \frac{(\text{APL in feces, kg/d}) - (\text{APL in suppl., kg/d})}{\text{APL content in forage (kg/kg forage DM)}}$$

Forage digestibility was calculated using the following formula:

$$\text{Forage digestibility (\%)} = \frac{(\text{Forage DMI, kg/d}) - (\text{Forage fecal output, kg/d})}{\text{Forage DMI (kg/d)}} \times 100$$

Grazing time (GT) was measured as described by Gekara et al. (2001) using the vibracorder equipment (Kienzle Apparate GmbH, Villingen, Germany) fitted around the neck of each cow during each experimental period. The vibracorder remained on the animal for a period of 48 h. An animal was considered either grazing or ruminating/idling if it spent at least 5 continuous minutes doing this activity.

Statistical Analysis

Forage botanical and chemical composition variables for each paddock were averaged within period and analyzed using the GLM procedure of SAS (SAS Inst. Inc., Cary, NC) using a split plot in time design and replicate x treatment as the error term. Animal variables were analyzed using least squares procedure of SAS and ANOVA based on a split-split plot design with SH as main plot, supplement feeding time and grazing management in combination as sub-plot treatments and period as sub-sub-plot. Paddock within height and block was

the error term used to test SH. Cow within height, plot and block tested supplement feeding time and grazing management whereas residual error tested all other independent variables. Fisher's test (LSD) was used to do multiple comparisons among periods. The F -test ($\alpha < 0.10$) was used to determine the effect of SH, supplement feeding time and grazing time management on forage DMI, DM digestibility, digestible DMI, pasture grazing pattern, grazing time and efficiency, and ADG.

CHAPTER 5: RESULTS AND DISCUSSION

Weather

Weather data (temperature and precipitation) as reported by the National weather station, Hart Field Airport, Morgantown, WV, was summarized over the grazing season (Table 2). The mean weekly temperature and precipitation during the experimental periods were within normal range for this area. The ambient temperatures were lower for period 1 compared to period 2 and 3, and this was considered normal seasonal variation.

Sward height and herbage mass

Mean sward height (SH) and sward surface height (SSH) for the low and high swards as well as herbage growth rate and the corresponding herbage mass are shown in Table 3. The SSH difference was 5.6 cm between the low and high SH pastures and was what we expected to achieve by varying the grazing pressure. The two measurements for sward height were included to allow for comparison with other literature on the subject. The SSH is measured without disturbing the canopy of a pasture, whereas to measure SH pressure exerted by the plate disturbs the canopy of a pasture as the height is being taken.

Sward height was found to influence ($P < .05$) herbage growth rate (Table 3), which was greater for the low compared to the high sward. In a previous study on the same pasture, carrying capacity per ha or stocking density increased as SH decreased from 12 to 4 cm as measured by the Hill Farming Research Organization sward stick (Prigge et al., 1997). The results of these

experiments suggest that a low sward height was needed to optimize forage growth rate for those types of pasture. In the present study, herbage growth rate decreased ($P < .05$) as the season progressed (Table 4), which was considered to be a normal response due to temperature and moisture limitations (Pearson and Ison, 1997).

Botanical and chemical composition of pasture

There was no interaction ($P > .10$) between sward height (SH) and period (P) for the proportion of legume and weeds in the pasture. A SH x P interaction ($P < .10$) for the proportion of grass and dead material was observed. For the high sward height pasture, the proportion of grass decreased (Figure 1) whereas dead material increased (Figure 2) as the season progressed. For the low sward height pasture, the proportion of grass was greater (Figure 1) and the proportion of dead material was lower during P2 (Figure 2) compared to other periods. Forage maturity and the resulting senescence (Hodgson, 1990) probably contributed to these results. During P1, the high proportion of dead material (for both swards) may have been due to carryover material from the fall (Prigge et al., 1999). During P3, increased maturity and reduced growth rate (Table 4) probably contributed to senescence, especially for the high sward. Sward height influenced ($P < 0.10$) the proportion of legume and weeds (Table 3). Legume proportion was greater for low compared to high SH (6.9 vs 3.9%). Similarly, the proportion of weeds was greater for the low compared to the high SH (12.7 vs 9.1%). Sward height may have influenced the competition between grass

and legume and/or weeds for resources such as light and soil nutrients (Bullock, 1996). Period had no influence ($P > .10$) on the proportion of legume and weeds in the sward.

Sward height influenced ($P < .05$) the concentrations of fiber and CP in pasture (Table 5). Crude protein decreased whereas NDF and ADF increased as SH increased, as would be expected with more mature swards (Minson, 1990; Van Soest, 1994). Period influenced the concentration of ADF ($P < .001$) and CP ($P < .01$). The ADF content of pasture increased (Table 6) as season progressed, as would be expected, again, indicative of increasingly mature forage (Van Soest, 1994). Crude protein concentration was lower in P2 compared to other periods probably because of a proportional increase in fiber content (ADF) over the same period.

Forage and total dry matter intake

There were no three or four-way interactions ($P > .10$) involving SH, supplement-feeding time, grazing time management and period for forage DMI. An interaction between T and MGT ($P < .05$) for forage DMI was evident. For cows restricted to 12 h/d grazing, supplementing in the AM as opposed to PM (Figure 3) resulted in greater forage DMI (8.6 vs 8.1 kg/d). Cows that were allowed to graze for 24 h/d had greater forage DMI when supplemented in the PM as opposed to AM (8.4 vs 8.2 kg/d). A possible explanation for these findings is that cows on restricted management, having been withheld from grazing during the night, perhaps exhibited a compensatory forage intake in the

AM when most grazing activity occurred. Satiety or rumen fill (Forbes, 1988) may have limited forage DMI for unrestricted cows fed in the AM as opposed to PM. In addition, supplemental nutrients may have influenced forage DM digestibility (Figure 4) of unrestricted cows resulting in increased forage DMI for the PM group compared to AM.

In a study reported by Adams (1985), AM supplemented steers (with corn at 0.3% of BW) had greater ($P < .05$) forage DMI than the PM group. The author suggested that steers fed a supplement in the PM probably substituted corn for forage more than the AM supplemented group did. In fact, the PM steers had greater ($P < .10$) digestible energy intake (8.4 vs 7.7 Mcal/100 kg BW) and ADG ($P < .01$) compared to the AM group probably because of increased intake of total DM. Differences in animal response to feeding time between this study and that of Adams (1985) probably lie in the quality of forages available to animals or perhaps the density of the sward. The ADF and CP content of forage used in our study was 33% and greater than 12%, respectively, while in Adams (1985) study it was 48% and less than 7%, respectively. Adams (1985) did not report forage availability estimate.

Fiber utilization usually increases when ruminal availability of CHO and N is synchronous (Hoover, 1986). Studies by Sinclair et al. (1993) concluded that a synchronized supply of N and energy substrates could achieve a stable ruminal environment (less pH fluctuation and optimal microbial protein synthesis). Supplying one (N) or both of these nutrients in the PM when amount available

from forage was probably diminishing or availability in the rumen was limited, may have elicited the animal response (increased intake) observed in this study.

Forage digestibility

There was no three or four-way interaction ($P > .10$) involving SH, T, MGT and period for forage DM digestibility. An interaction between SH and T ($P < .05$) for herbage DM digestibility was detected. Supplementing in the PM as opposed to AM resulted in greater herbage DM digestibility (67.7 vs 65.4%) for cows on high sward height (Figure 4). Cows on low sward height had greater herbage DM digestibility (66.3 vs 64.5%) when supplemented in the AM, as opposed to PM. Because the CP content of high sward height forage was lower and fiber content higher than that of low sward height (Table 3), ruminal NH_3 levels may have been limiting for optimal fiber digestion at certain times of the day. Supplementing cows on high sward height in the PM, as opposed to AM, may have provided additional ruminal $\text{NH}_3\text{-N}$ at times when needed resulting in greater microbial digestion of the forage fiber. Similarly, cows on low sward height and supplemented in the AM, as opposed to PM, had greater DM digestibility compared to cows on high sward height. The lower fiber levels of the low SH pasture in conjunction with a slower rate of fiber consumption as one would expect on a pasture of lower SH (Rook et al., 1994a) may have resulted in the AM supplement having less of a pH related inhibition of ruminal fiber digestion (Hoover, 1986). In addition, diurnal fluctuations of forage nutrients

(Younberg et al., 1972) could have also contributed to the digestibility response observed in this study by influencing the ruminal environment.

Microbial growth and protein synthesis can be stimulated by stable ruminal fermentation with a constant supply of fermentation substrate and nutrients (Khorasani et al., 1994; Sniffen and Robinson, 1987). In our study, it is possible that N and energy synchronization may have been achieved at different times for each forage height, AM for low sward height and PM for high sward height. Measurements of ruminal fermentation variables (mainly $\text{NH}_3\text{-N}$ concentration) collected over time on pastures of this type (Hess et al., 1996) support these explanations.

Digestible dry matter intake

There were no three or four-way interaction ($P > .10$) involving sward height, supplement feeding time, grazing time management and period for forage digestible DMI (DDMI). An interaction, supplement feeding time x grazing time management ($P < .10$), for forage DDMI was apparent. Cows restricted to 12 h/d grazing consumed a greater amount of forage digestible DM (Figure 5) when supplemented in the AM as opposed to PM (5.0 vs 4.7 kg/d) mainly due to increased forage DMI (Figure 3). Cows that were unrestricted had greater forage DDMI (4.9 vs 4.6 kg/d) when supplemented in the PM as opposed to AM. Unrestricted cows had greater forage DDMI when supplemented in the PM compared to AM most likely because of enhanced or

less inhibition of forage digestibility (Figure 4) whereas satiety or rumen fill (Forbes, 1988) probably limited forage DDMI for the AM supplemented cows.

Insufficient intake of digestible nutrients, mainly because of increased consumption of slowly degradable fiber, could restrict the productivity of grazing ruminants (Minson, 1982). Forage DMI is limited by mainly fill with slowly digestible feeds, thus, animals with high energy requirements consuming relatively low energy, high fill diets are affected to the greatest extent (Allen, 1996). The characteristics that contribute most to intake of forage include solubility or cell content of pasture, insoluble but potentially fermentable fraction, degradation rate, rumen outflow rate and rate of particle size reduction (Ørskov and Fraser, 1975). These factors may have contributed to the animal responses in forage DDMI observed in this study.

Pasture grazing pattern

In this study, grazing intensity of cows was mainly concentrated in the mid morning (0700 to 1000 h) and early evening between 1800 and 2000 h (Figure 9 and 10) generally agreeing with other reports (Stobbs, 1970; Rook et al., 1994a). For ruminants grazing cool season pastures, two main grazing bouts (meals) lasting 2 to 4 h occur in the mid morning (0700 to 1000 h) and early evening between 1800 and 2000 h (Rook et al., 1994a). Most grazing activities of cattle take place during the daytime (>87%) and the rest at nighttime (Stobbs, 1970; Rook et al., 1994a). Penning et al. (1991b) suggested that the large evening meal could be an optimal foraging response to build up of

readily digestible products of photosynthesis in plant leaves at this time. The large mid morning meal could be attributed to animal response to reduced gut fill (Forbes, 1988) and low ambient temperature (Seath and Miller, 1946), especially during the summer months.

In examining the diurnal nutrient variation in pasture, Holt and Hilst (1969) found that water-soluble carbohydrates of cool season forages increased linearly from 0600 h to 1800 h and nonstructural polysaccharides (mainly starch) followed a non-linear trend peaking in the afternoon. Youngberg et al. (1972) reported that total N, water soluble N and amino acid N in alfalfa leaves and stems were highest between 0300 and 0600 h and declined throughout the day. Time of supplementation of grazing cattle in relation to the daily pasture consumption pattern as well as the diurnal change in pasture composition could influence the intake and digestibility variables reported in this study, by providing substrates that could inhibit (i.e. decrease ruminal pH) or enhance (i.e. $\text{NH}_3\text{-N}$) fiber digestibility or metabolites that could influence voluntary intake (i.e. VFA's).

Sward height did not influence ($P > .10$) the grazing pattern of cows (Figure 10). This observation was somewhat surprising as cows on low sward height were expected to allocate more time to grazing activity compared to those on high sward height to make up for the smaller bite size. This usually is the case with ruminants grazing low swards (Rook et al., 1994a; Penning et al., 1991a). The grazing pattern was not disrupted following supplementation (Figure 9 and 10) contrasting with other reports (Adams, 1985). In the study

reported by Adams (1985), steers grazing native pasture and supplemented with concentrates (at 0730 and 1330 h) did not graze for about two to four hours following supplementation. Disparity in forage quality may be responsible for the differences in results observed between the two studies.

Grazing time management influenced ($P < .05$) the grazing pattern of cows. Cows restricted to 12 h/d grazing grazed with greater intensity throughout the day compared to unrestricted cows (Figure 9) probably because the stimulus for intake was more intensive. Cows restricted to 12 h/d consumed greater ($P < .05$) amounts of forage DM (Figure 3) and digestible DM (Figure 5) when supplemented in the AM as opposed to PM. Unrestricted cows consumed greater amounts of forage DM and digestible DM when supplemented in the PM as opposed to AM. Increased forage DMI observed in the AM for restricted cows and PM for unrestricted cows (Figure 3) was possibly related to diurnal changes in forage DMI and/or nutrient composition in pasture, mainly energy and N.

Grazing time and efficiency

Three or four-way interactions involving SH, T, MGT and period for grazing time (h/d) and grazing efficiency (kg forage DMI/h of grazing time) were not evident ($P > .10$). However, an interaction between T and MGT for grazing time was apparent ($P < .10$). Supplementing in the PM as opposed to AM, increased the actual time spent grazing to a greater extent for cows restricted to 12 h/d grazing than for unrestricted cows (Figure 6). Supplementing in the AM,

as opposed to PM, had greater grazing efficiency (DM intake/h of grazing time) for cows restricted to 12 h/d grazing (Figure 7) compared to unrestricted cows (1.3 vs. 1.2 kg DM/h of grazing time). Therefore, the decrease in grazing time for restricted cows was compensated by an increase in grazing efficiency (Figure 7). Cows restricted to 12 h/d probably grazed with greater intensity (Figure 9) compared to unrestricted cows, in response to a stimulus initiated by low rumen fill following a 12-h lapse of no grazing activity. This would suggest that less selectivity occurred for higher quality components of the pasture (Minson, 1990) by the restricted compared to unrestricted cows. However, the methodology of using pluck samples to represent quality of herbage consumed in this study would not be sensitive enough to detect these differences.

An interaction between SH and period ($P < .05$) for grazing time was evident. Cows grazing low sward height pasture allocated more time to grazing activity during P1 compared to P2 and P3 (Figure 8). Cows grazing high sward height pasture spent more time grazing during P1 and P2 compared to P3. The decreased grazing time observed for the later periods (for both groups) was possibly related to the high ambient temperatures at this time of the year and a decline in nutrient requirements for the cows in the later stages of lactation.

Average daily gain

Although average daily gain (ADG) was measured over short durations, the results can perhaps relate to the differences observed in intake and digestibility. There were no three or four-way interactions ($P > .10$) involving

SH, T, MGT and period for ADG of both cows and calves. There were no two-way interactions ($P > .10$) involving SH, T, MGT and period for the ADG of calves. An interaction between SH and T ($P < .10$) for ADG of cows was apparent. Supplementing in the PM as opposed to AM increased ADG (Figure 10) of cows on high sward height when compared to those on low sward height, probably because of increased forage DM digestibility (Figure 4) and possibly DMI (Figure 3). In addition, supplemental nutrients fed at this time (PM) may have enhanced animal performance. However, time of supplementation did not influence ($P > .10$) cow gain for either SH treatment. The greater forage DMI and DDMI for cows restricted to 12 h/d grazing and supplemented in the AM as opposed to PM (Figure 3) was not reflected in ADG perhaps due to the short duration of the experiment and gut fill differences at the AM weighing time.

Adams (1985) reported that ADG was greater ($P < .01$) for PM supplemented steers than for the AM supplemented steers (0.82 vs. 0.62 kg/d). The greater ADG for PM supplemented steers compared to AM supplemented steers may have been due to higher digestible energy intake (8.4 vs. 7.7 Mcal/100 kg BW). In our study, ADG of calves was not influenced ($P > .10$) by sward height and supplement feeding time probably because performance was buffered by milk. However, the sensitivity of weight change measurements was limited by the length of the experimental period in this study. This probably explains the lack of response to treatments observed with calves. Further

research is needed to quantify the animal response (ADG) with experiments designed to last longer than 15 d.

CHAPTER 6: SUMMARY AND CONCLUSION

Results of this study suggest that cows allowed limited access (12 h/d) to pasture consumed greater amounts of forage DM when supplemented in the AM as opposed to PM. Similarly, cows supplemented in the AM consumed a greater amount of forage digestible DM compared to cows fed in the PM. Cows on an unlimited grazing regimen consumed a greater amount of forage DM as well as digestible DM when supplemented in the PM. Increased forage DMI and digestibility resulted in greater intake of forage digestible DM, thus, additional substrates supplied by the supplement probably had less inhibitive effects on ruminal fermentation of fiber. When forage or grazing time is limiting, supplementing in the AM, as opposed to PM, may result in greater forage utilization because of compensatory intake of forage DM and digestible DM. However, when forage or grazing time is not limiting, supplementing in the PM, as opposed to AM, may result in greater pasture utilization because of greater forage digestibility.

CHAPTER 7: LITERATURE CITED

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TABLES AND FIGURES

Table 1: Composition and calculated nutrient content of concentrate supplement

Item	DM basis
Corn, Dent Yellow, ground, %	82.60
Soybean meal, solvent extracted, 44% protein, %	16.40
Limestone, ground, %	1.00
Calculated nutritional content ^a , %	
NE _M , Mcal/kg ^b	2.07
NE _G , Mcal/kg	1.41
NE _L , Mcal/kg	1.94
CP, %	16.45
Ca, %	0.41
P, %	0.35

^aValues based on National Research Council, 2001, Nutrient Requirements of Dairy Cattle

^bNE_M = net energy for maintenance; NE_G = net energy for gain; NE_L = net energy for lactation

Table 2: Weekly mean maximum and minimum temperatures and total precipitation during the experimental periods

<u>Week^a</u>	<u>Maximum (°C)</u>	<u>Minimum (°C)</u>	<u>Precipitation (mm)</u>
5/05 – 5/11	27.1	13.2	10.2
5/12 – 5/18	24.0	10.7	18.5
5/19 – 5/25	22.1	13.5	99.1
5/26 – 6/01	22.4	11.7	17.5
6/02 – 6/08	23.4	10.7	27.9
6/09 – 6/15	29.8	18.5	30.0
6/16 – 6/22	27.2	17.2	23.8
6/23 – 6/29	27.3	17.9	27.7
6/30 – 7/06	26.5	14.8	20.3
7/07 – 7/13	27.3	15.7	27.2
7/14 – 7/20	25.5	16.3	10.1
7/21 – 7/27	25.0	13.9	7.4
7/28 – 8/03	27.3	18.8	43.7
8/04 – 8/10	26.7	17.9	14.2
8/11 – 8/17	25.2	14.5	13.2
8/18 – 8/24	23.9	14.6	17.0
8/25 – 8/31	26.1	15.9	1.8
9/01 – 9/07	26.4	15.7	2.0

^aWeek: Week 5/12 – 5/25 = P1, Week 6/30 – 7/13 = P2, Week 8/18 – 8/29 = P3

Table 3: Influence of sward height on botanical composition of forage

Variable	Sward height		sem ¹	Significance ²
	Low	High		
Sward height, cm	6.0	9.9		
Mean SSH ³ , cm	6.5	11.1		
Herbage mass, Kg DM/ha	1723.0	2617.0		
Herbage growth rate ⁴ , Kg DM/ha/d	57.5	43.8	3.57	*
Grass, %	62.7	47.6	7.26	**
Legume, %	6.9	3.9	1.79	†
Weeds, %	12.7	9.1	1.71	†
Dead, %	17.8	39.4	4.58	***

¹n = 12

²*** = $P < 0.001$; ** = $P < 0.01$; * $P < 0.05$; † = $P < 0.10$

³SSH = estimated sward surface height using Hill Farming Research Organization sward stick

⁴Herbage growth rate = growth rate of pasture over the experimental periods

Table 4: Influence of period on botanical composition of forage

Variable	Period ¹			sem ²	Significance ³
	1	2	3		
Mean SH, cm	9.4	8.2	8.1		
Herbage growth rate ⁴ , Kg/ha/d	63.2 ^a	56.4 ^b	32.4 ^c	4.80	**
Grass, %	55.7 ^a	60.3 ^a	49.4 ^b	4.68	†
Legume, %	3.9	7.2	5.0	1.86	NS
Weeds, %	8.1	12.0	12.6	2.24	NS
Dead, %	32.3 ^a	20.5 ^b	33.0 ^a	4.44	**

¹Period: 1 = May, 2 = June/July, 3 = August

²n = 8

³** = $P < 0.01$; † = $P < 0.10$; NS = non significance

⁴Herbage growth rate = growth rate of pasture over the experimental periods

^{a,b,c}Within a row, means lacking a common superscript differ at $P < 0.05$

Table 5: Influence of sward height on chemical composition of forage

Variable	Sward height		sem ¹	Significance ²
	Low	High		
Sward height, cm	6.0	9.9		
NDF ³ , %	59.8	64.4	1.54	*
ADF, %	31.9	35.2	1.39	†
CP, %	16.5	12.8	0.70	**
APL, %	3.7	3.6	0.25	NS

¹n = 12

²** = $P < 0.01$; * = $P < 0.05$; † = $P < 0.10$; NS = non significance

³NDF = neutral detergent fiber; ADF = acid detergent fiber; CP = crude protein; APL = alkaline peroxide lignin

Table 6: Influence of period on chemical composition of forage

Variable	Period ¹			sem ²	Significance ³
	1	2	3		
NDF ⁴ , %	62.0	62.0	62.4	1.13	NS
ADF, %	31.9 ^b	34.1 ^a	34.6 ^a	0.89	***
CP, %	14.9 ^a	13.9 ^b	15.1 ^a	0.32	**
APL, %	3.7	3.7	3.6	0.36	NS

¹Period: 1 = May, 2 = June/July, 3 = August

²n = 8

³NS = non significance; *** = $P < 0.001$; ** = $P < 0.01$

⁴NDF = neutral detergent fiber; ADF = acid detergent fiber; CP = crude protein; APL = alkaline peroxide lignin

^{a,b}Within a row, means lacking a common superscript differ at $P < 0.01$

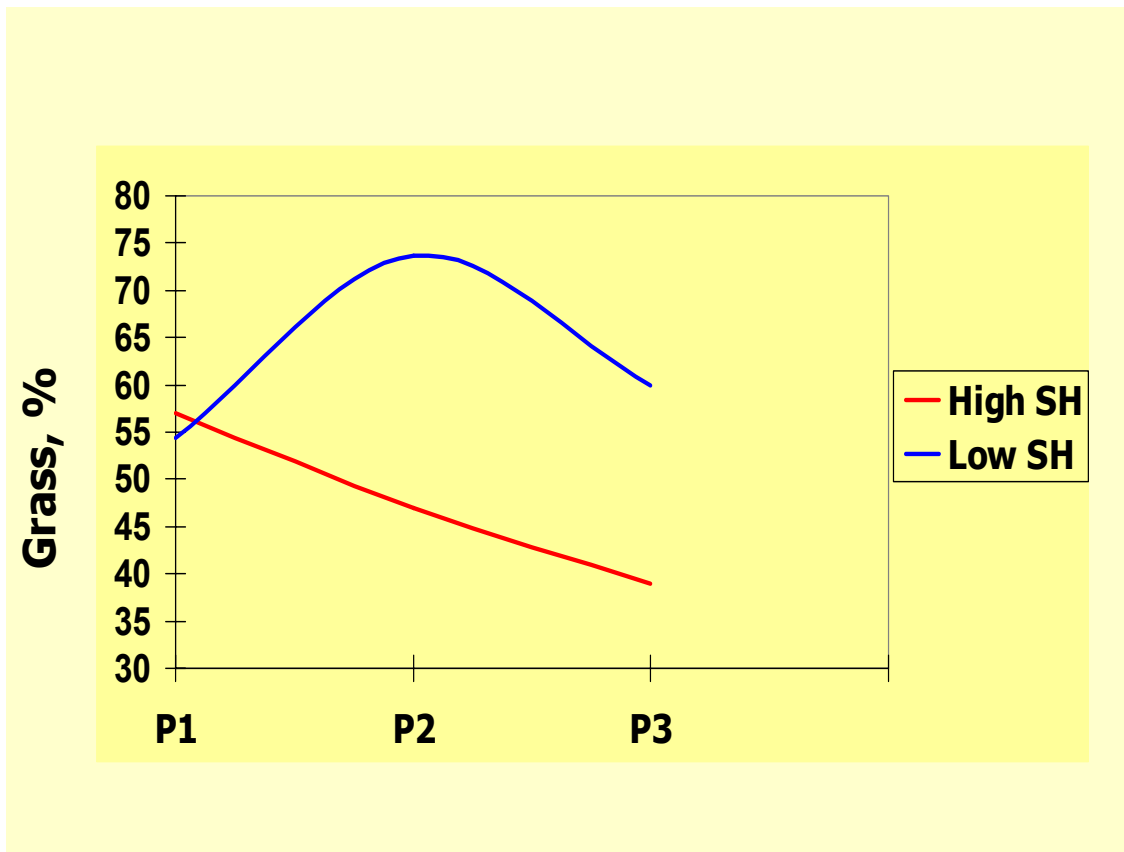


Figure 1: Influence of sward height and period on proportion of grass
High SH = high sward height; Low SH = low sward height; Sward height x
Period interaction ($P < 0.10$)

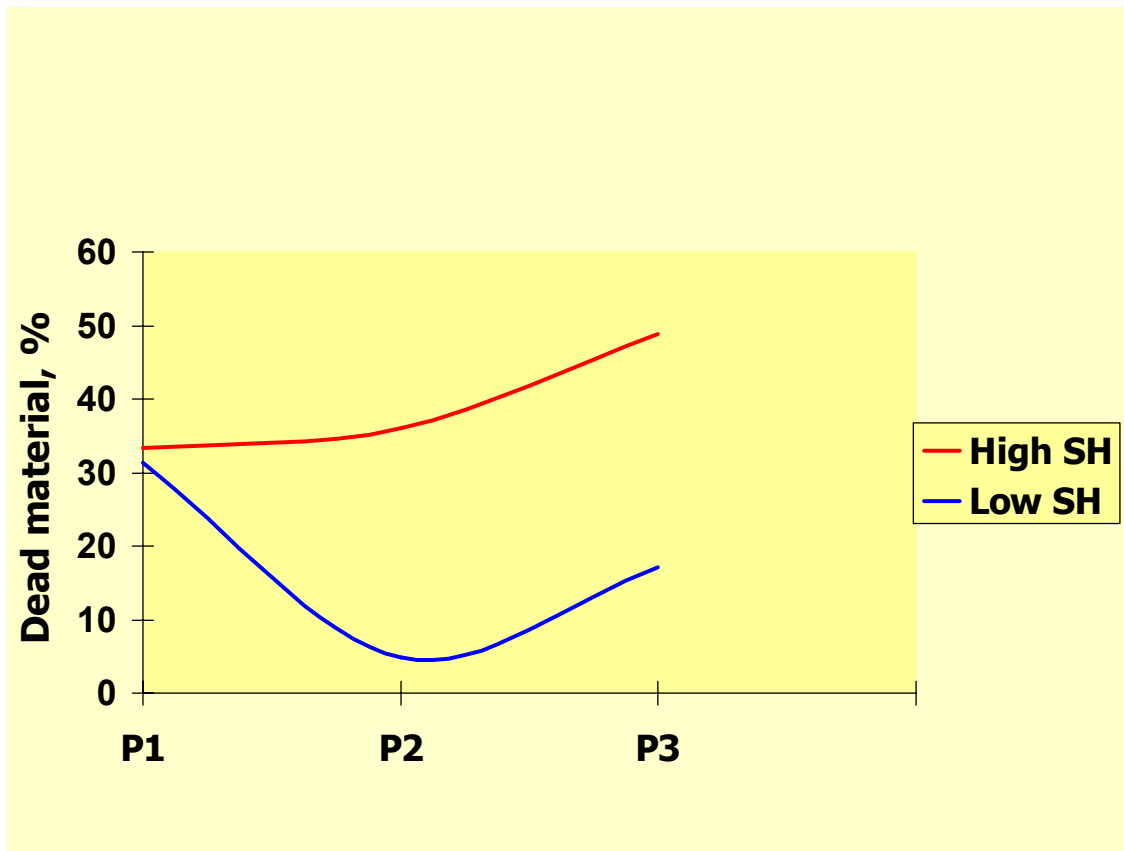


Figure 2: Influence of sward height and period on proportion of dead material
High SH = high sward height; Low SH = low sward height; Sward height x
Period interaction ($P < 0.01$)

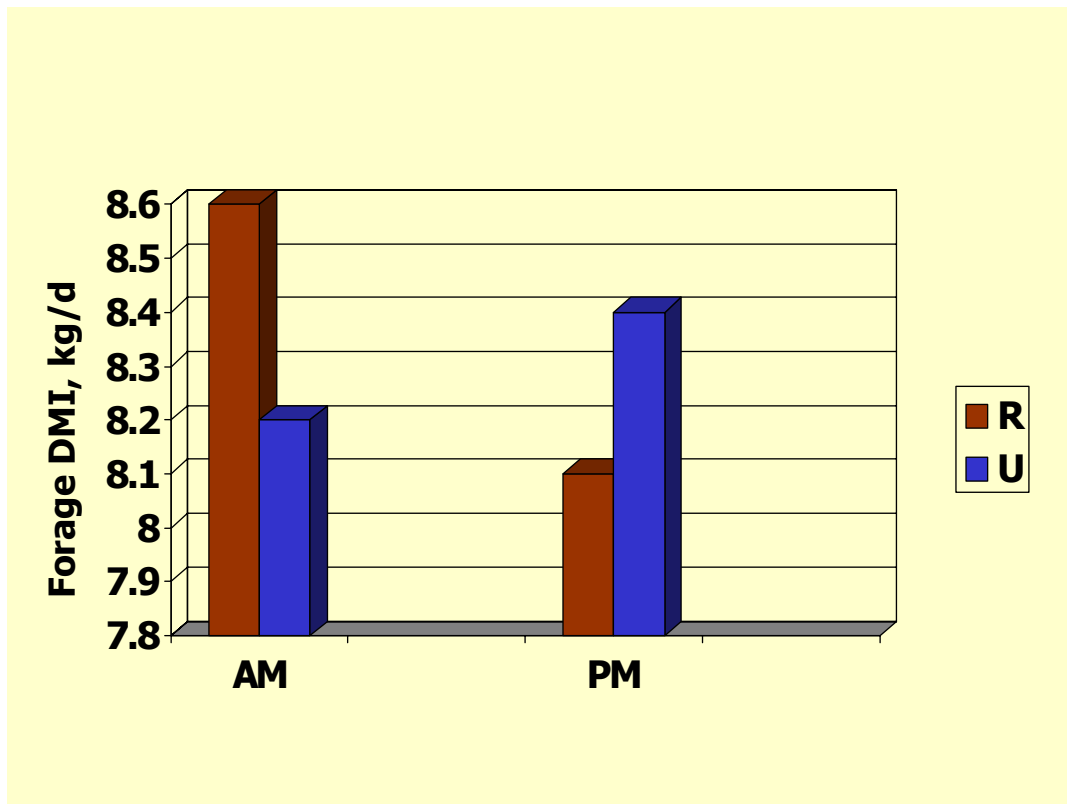


Figure 3: Influence of supplement feeding time and grazing time management on forage DMI of cows
R = Restricted grazing (12 h/d); U = Unrestricted grazing (24 h/d); Supplement feeding time x Grazing time management interaction ($P < 0.05$)

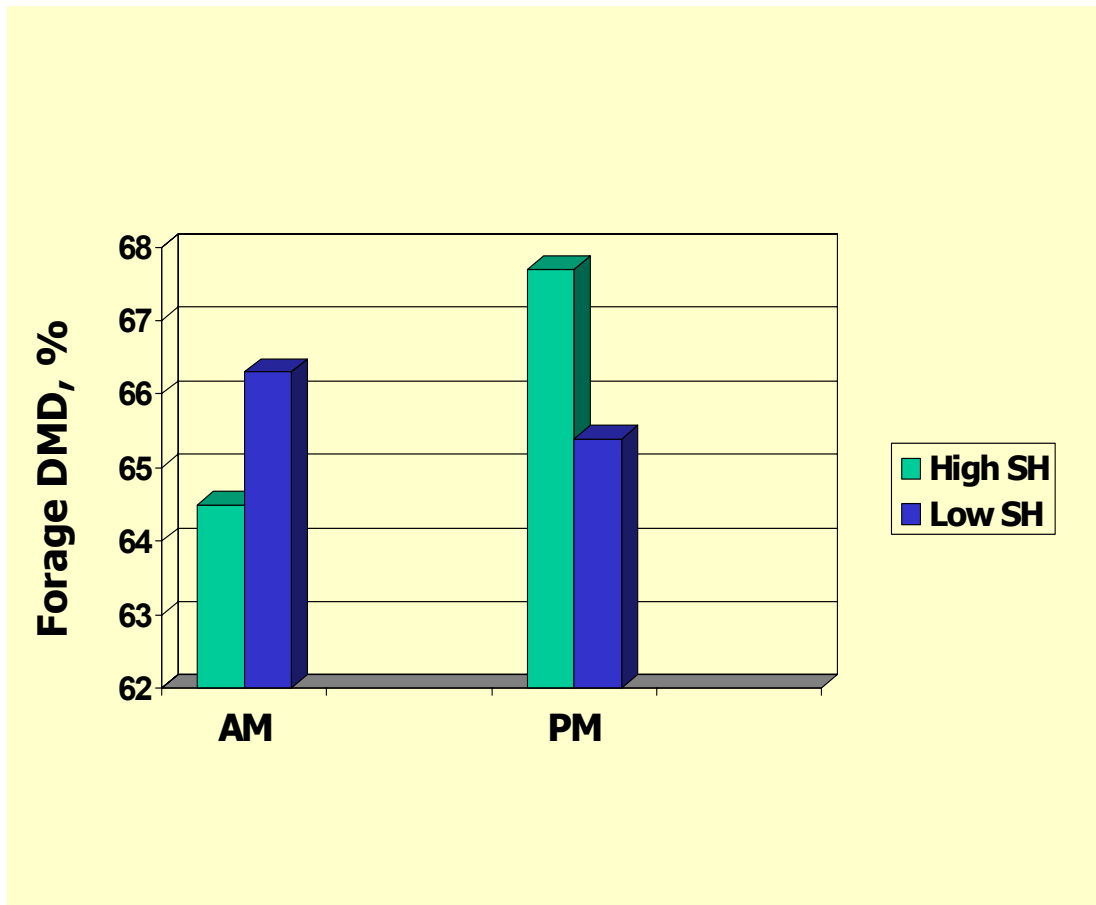


Figure 4: Influence of sward height and supplement feeding time on forage DM digestibility of cows
High SH = high sward height; Low SH = low sward height; Sward height x Supplement feeding time interaction ($P < 0.05$)

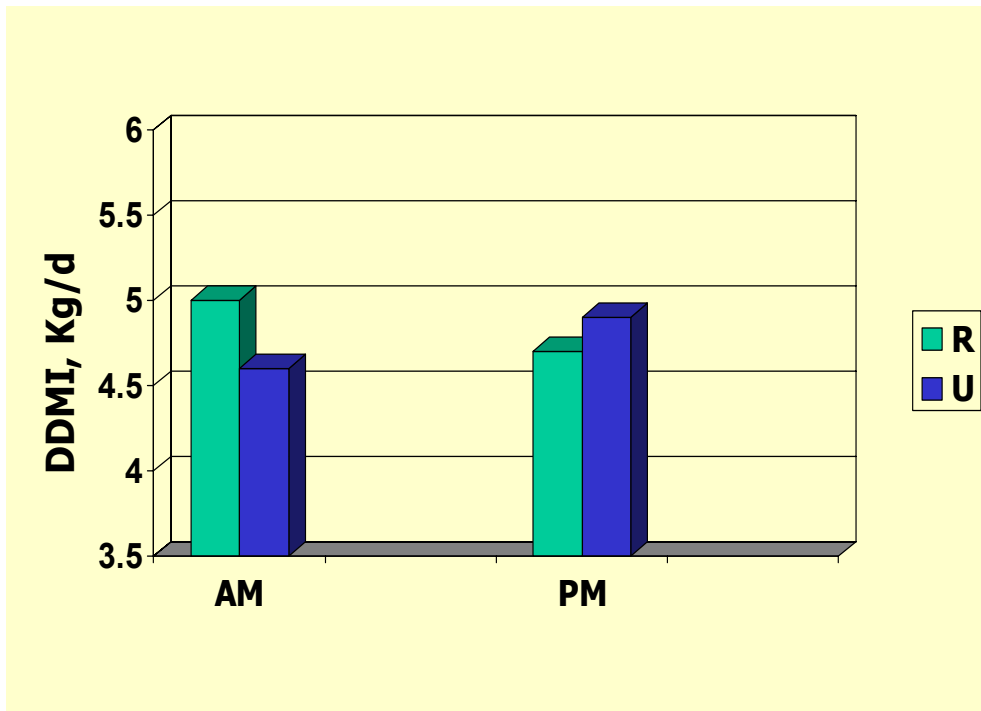


Figure 5: Influence of supplement feeding time and grazing time management on forage digestible DMI of cows
 R = Restricted grazing (12 h/d); U = Unrestricted grazing (24 h/d); Supplement feeding time x Grazing time management interaction ($P < 0.10$)
 DDMI = forage digestible DMI

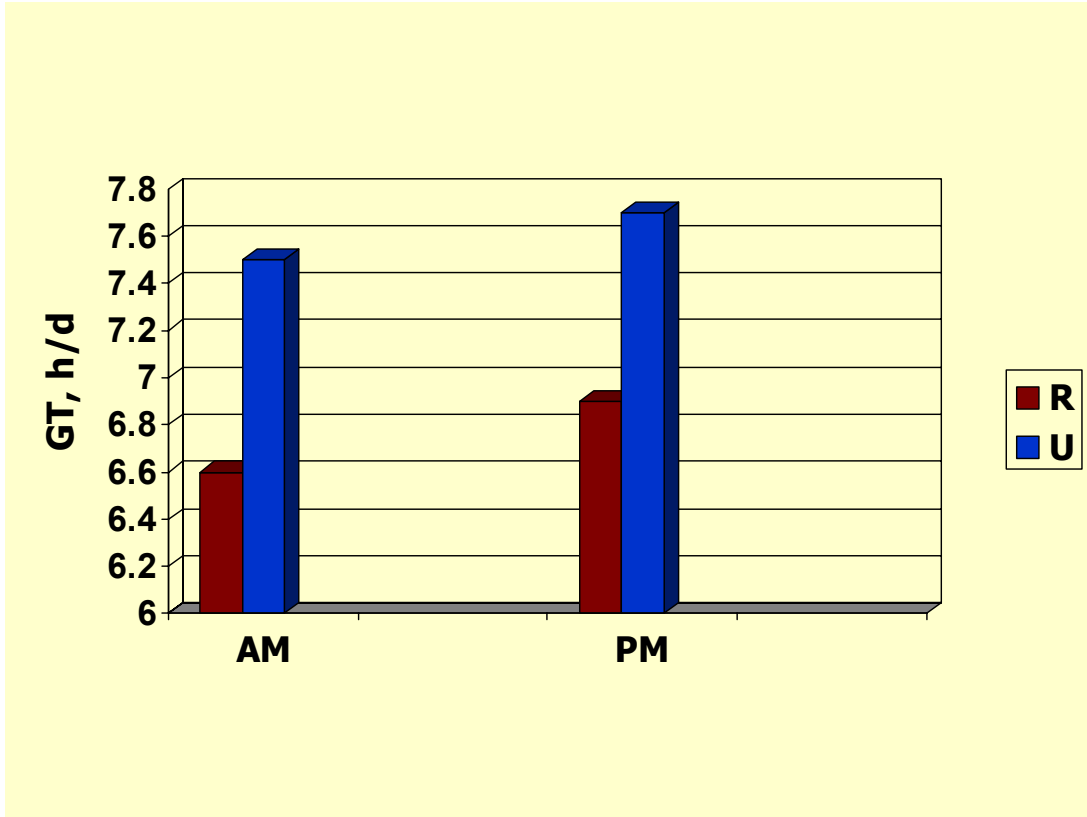


Figure 6: Influence of supplement feeding time and grazing time management on grazing time of cows
R = Restricted grazing (12 h/d); U = Unrestricted grazing (24 h/d); Supplement feeding time x Grazing time management interaction ($P < 0.10$)

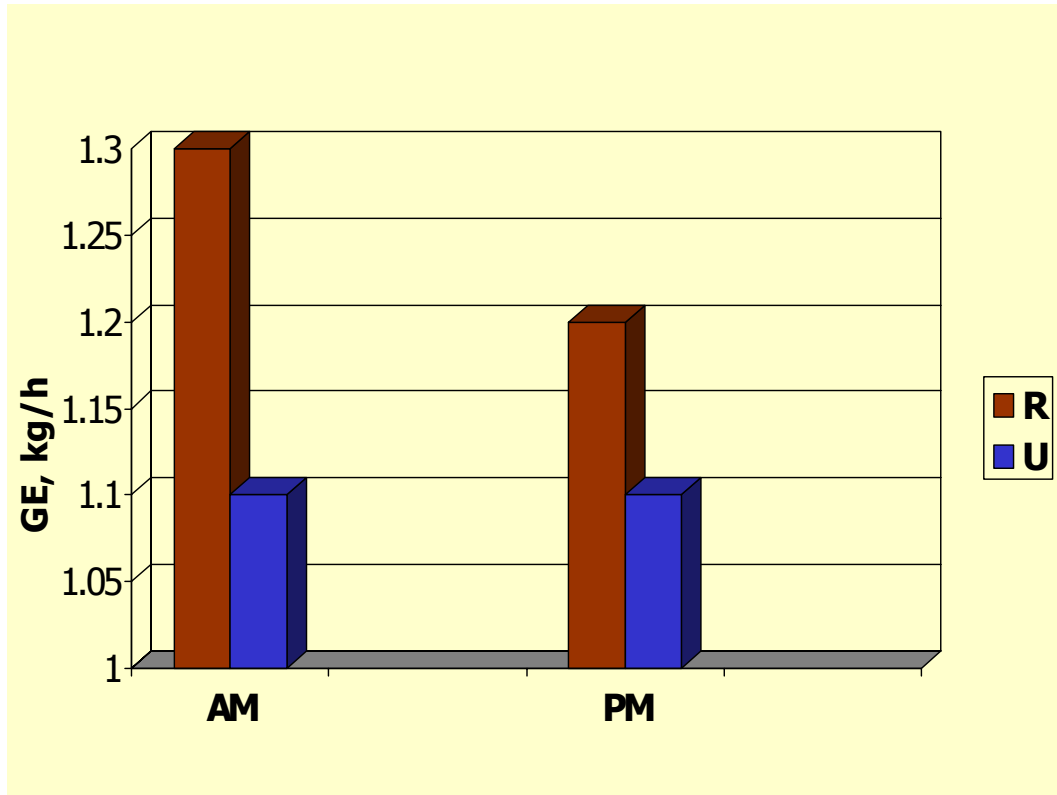


Figure 7: Influence of supplement feeding time and grazing time management on grazing efficiency of cows
R = Restricted grazing (12 h/d); U = Unrestricted grazing (24 h/d); Supplement feeding time x Grazing time management interaction ($P < 0.01$)

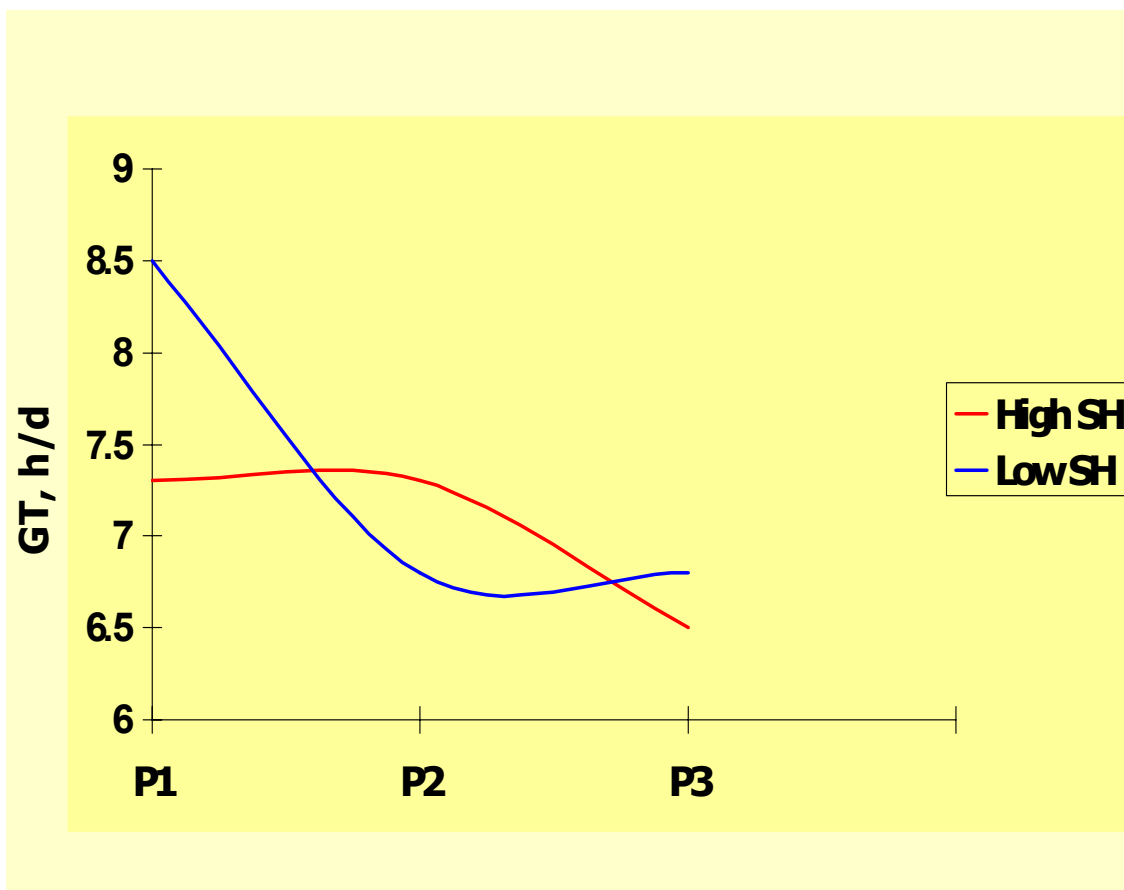


Figure 8: Influence of sward height and period on grazing time of cows
 P1 = May, P2 = June/July, P3 = August; Sward height x Period interaction ($P < 0.05$)
 High SH = high sward height; Low SH = low sward height

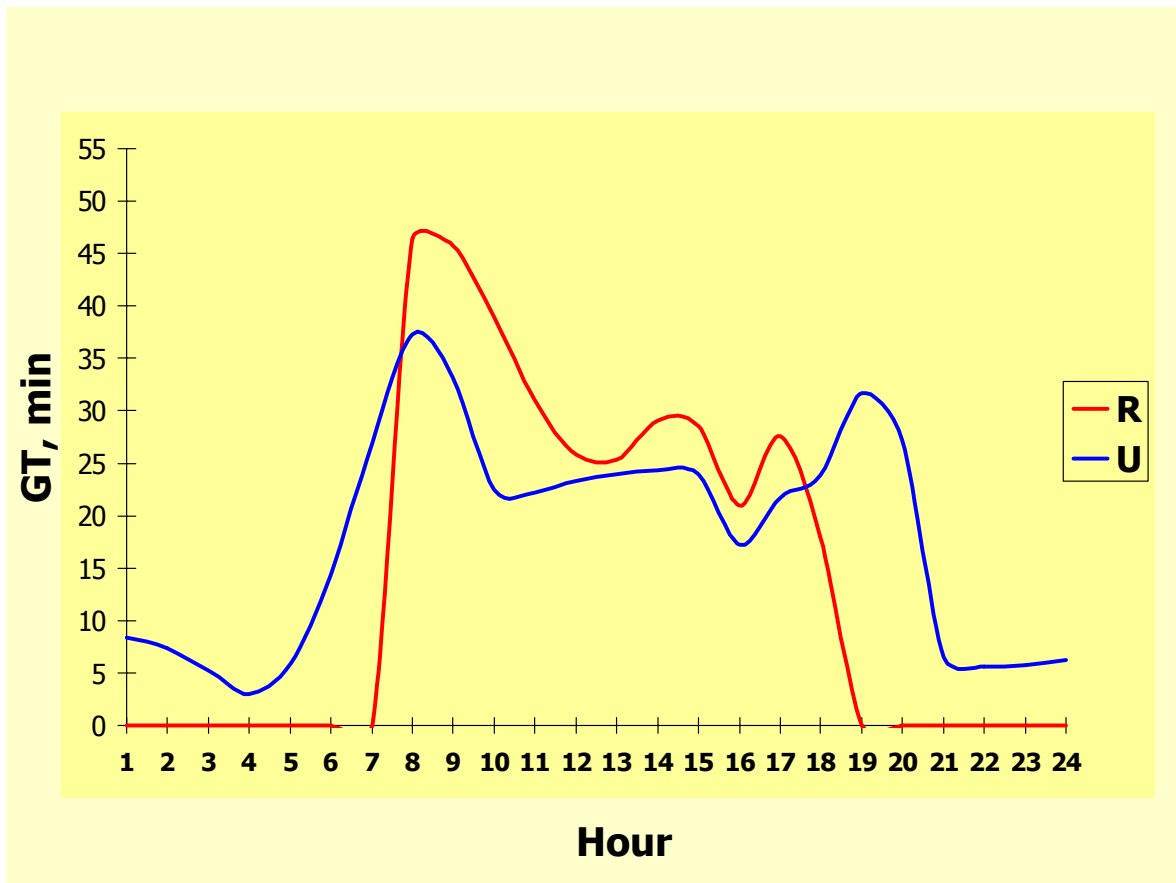


Figure 9: Influence of grazing time management and hour on grazing pattern of cows

R = Restricted grazing (12 h/d); U = Unrestricted (24 h/d); Grazing time management x Grazing hour interaction ($P < 0.10$)

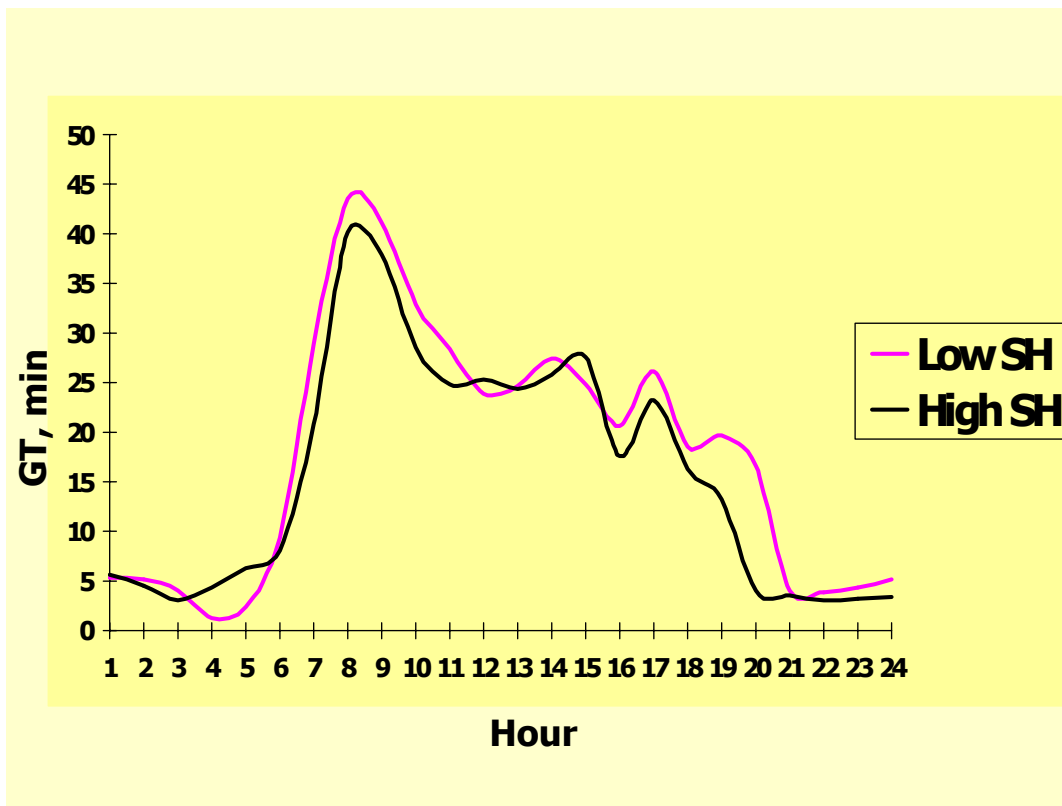


Figure 10: Influence of sward height and hour on grazing pattern of cows
 Low SH = low sward height; High SH = high sward height; Sward height x
 Grazing hour interaction ($P > 0.10$)

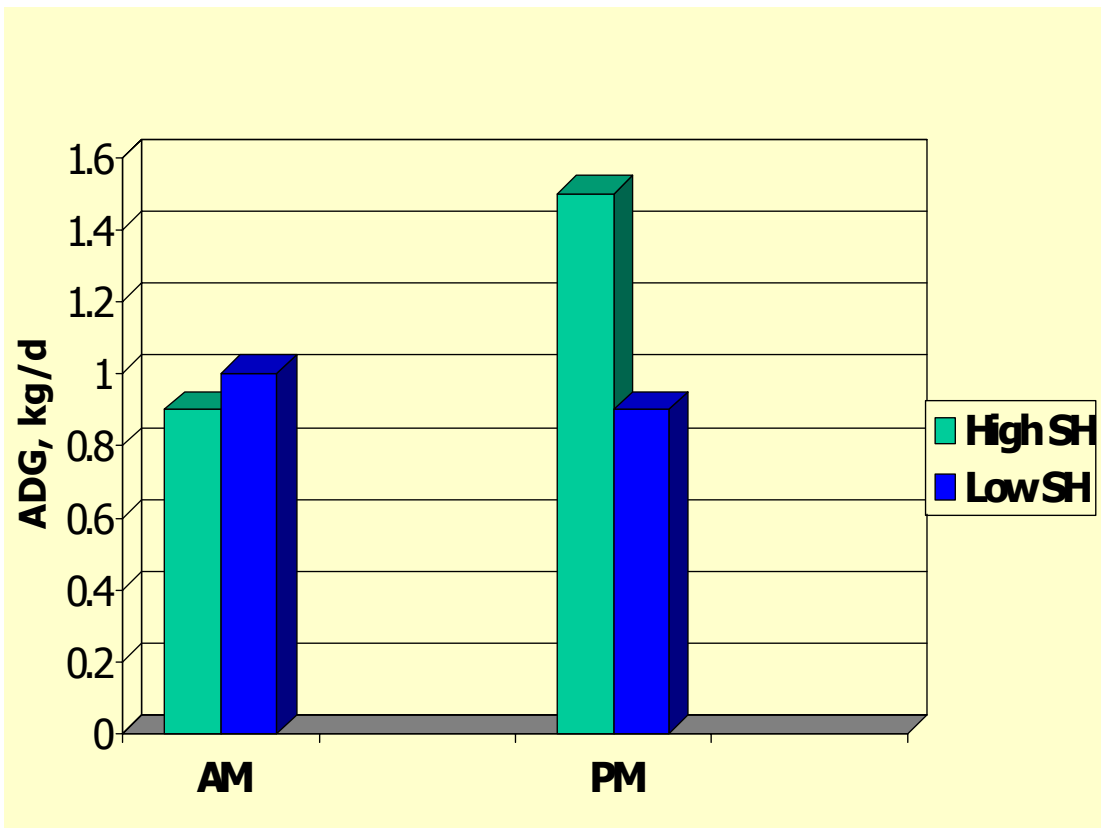


Figure 11: Influence of sward height and supplement feeding time on cow gain
 High SH = high sward height; Low SH = low sward height; Sward height x Supplement feeding time interaction ($P < 0.10$)

APPENDIX

Table 1: Summary of animal responses to experimental treatments

SH ^c	T ^d	MGT ^e	P ^f	Forage	Total	Forage	Forage	GT ^a	GE ^b	ADG	ADG
				DMI	DMI	DMD	DDMI	h/d	kg/h	kg/d	kg/d
H	A	R	1	9.4	13.5	63.9	5.4	7.1	1.3	1.0	1.3
H	A	U	1	9.2	13.3	62.7	5.2	7.7	1.2	1.1	1.4
H	P	R	1	9.3	13.4	63.1	5.2	7.0	1.3	-0.3	1.4
H	P	U	1	10.5	14.6	66.9	6.4	7.4	1.5	2.2	1.0
H	A	R	2	8.5	12.6	63.5	4.8	6.6	1.3	-0.1	0.2
H	A	U	2	8.5	12.6	63.8	4.8	7.9	1.1	0.8	1.2
H	P	R	2	7.7	11.8	67.5	4.5	6.9	1.2	0.7	-0.4
H	P	U	2	7.7	11.8	67.6	4.5	7.7	1.0	1.3	1.2
H	A	R	3	7.7	11.8	69.0	4.2	6.0	1.3	0.4	1.0
H	A	U	3	6.7	10.8	64.0	3.6	6.6	1.0	2.3	1.3
H	P	R	3	7.2	11.3	70.1	4.5	6.4	1.2	1.8	1.2
H	P	U	3	7.2	11.3	70.9	4.4	7.0	1.1	2.9	1.5
L	A	R	1	9.5	11.6	64.1	4.7	8.3	1.1	-0.3	1.1
L	A	U	1	8.7	12.8	65.4	5.0	8.2	1.1	0.2	0.9
L	P	R	1	8.4	12.5	64.8	4.8	8.4	1.0	-0.8	1.2
L	P	U	1	9.5	13.6	65.0	5.6	9.0	1.1	1.5	1.3
L	A	R	2	8.3	12.4	68.4	5.0	5.8	1.4	0.1	0.6
L	A	U	2	7.5	11.6	62.9	4.1	7.5	1.0	1.5	0.9
L	P	R	2	7.7	11.8	64.6	4.3	6.5	1.2	0.5	0.2
L	P	U	2	7.8	11.9	64.9	4.4	7.3	1.1	1.7	1.4
L	A	R	3	8.0	12.1	69.5	5.8	6.0	1.3	1.8	0.3
L	A	U	3	8.2	12.3	67.4	4.9	7.4	1.1	2.7	1.7
L	P	R	3	7.8	11.9	69.1	4.8	6.2	1.3	0.9	1.0
L	P	U	3	7.2	11.3	64.0	4.0	7.5	1.0	1.6	1.1
SEM ^h				0.3	0.3	1.1	0.3	0.3	0.1	1.1	0.5
Significance level ⁱ :											
SHxT				NS	NS	*	NS	NS	NS	†	NS
SHxMGT				NS	NS	NS	NS	NS	NS	NS	NS
SHxP				NS	NS	NS	NS	*	*	NS	NS
TxMGT				*	*	NS	†	†	**	NS	NS
TxP				NS	NS	NS	NS	NS	NS	NS	NS
MGTxP				NS	NS	NS	NS	NS	†	NS	NS

^aGT = grazing time (h/d)

^bGE = grazing efficiency (kg DM/h of GT)

^cSH = sward height (cm): H = high SH, L = low SH

^dT = supplement feeding time: A = AM (0700 h); P = PM (1800 h)

^eMGT = management: R = restricted grazing (12 h/d); U = unrestricted grazing

^fP = period: P1 = May; P2 = June/July; P3 = August

^hn = 4

ⁱNS = non significance: ** = $P < 0.01$; * = $P < 0.05$; † = $P < 0.10$

Table 2: Influence of sward height on animal performance

Variable	Sward height		sem ¹	Significance ²
	Low	High		
Sward height, cm	6.0	9.9		
Forage DMI, kg/d	8.2	8.3	0.26	NS
Total DMI, kg/d	12.3	12.4	0.26	NS
Forage DMD, %	65.8	66.1	1.72	NS
Forage dig DMI, kg/d	4.8	4.8	0.25	NS
Total dig DMI, kg/d	8.6	8.6	0.25	NS
Grazing time, h/d	7.3	7.0	0.30	NS
Grazing efficiency, kg/h	1.2	1.2	0.06	NS
Digestible NDF, %	65.9	66.5	1.70	NS
Digestible ADF, %	55.3	58.0	1.71	NS
Digestible CP, %	77.2	74.0	1.46	†
Forage DMI/kg BW, g/d	13.2	12.8	0.38	NS
Total DMI/kg BW, g/d	19.6	19.0	0.39	NS
ADG (cows), kg/d	0.9	1.2	0.32	NS
ADG (calves), kg/d	1.0	1.0	0.17	NS

¹n = 48

²† = $P < 0.10$; NS = non significance

Table 3: Influence of feeding time on animal performance

Variable	Feeding time ¹		sem ²	Significance ³
	AM	PM		
Forage DMI, kg/d	8.4	8.2	0.20	NS
Total DMI, kg/d	12.4	12.2	0.20	NS
Forage DMD, %	65.4	66.6	0.81	NS
Forage dig DMI, kg/d	4.8	4.8	0.18	NS
Total dig DMI, kg/d	8.6	8.6	0.18	NS
Grazing time, hr/d	7.1	7.3	0.24	NS
Grazing efficiency, kg/hr	1.2	1.2	0.05	NS
Digestible NDF, %	65.6	66.9	0.67	NS
Digestible ADF, %	56.0	57.2	0.92	NS
Digestible CP, %	74.9	76.3	0.50	†
Forage DMI/kg BW, g/d	13.0	13.0	0.66	NS
Total DMI/kg BW, g/d	19.3	19.4	0.89	NS
ADG (cows), kg/d	1.0	1.2	0.28	NS
ADG (calves), kg/d	1.0	1.0	0.12	NS

¹AM = 0700 h; PM = 1800 h

²n = 48

³† = $P < 0.10$; NS = non significance

Table 4: Influence of management on animal performance

Variable	Management ¹		sem ²	Significance ³
	R	U		
Forage DMI, kg/d	8.3	8.3	0.20	NS
Total DMI, kg/d	12.4	12.4	0.20	NS
Forage DMD, %	66.5	65.4	0.81	NS
Forage dig DMI, kg/d	4.8	4.7	0.18	NS
Total dig DMI, kg/d	8.6	8.5	0.18	NS
Grazing time, hr/d	6.8	7.6	0.24	**
Grazing efficiency, kg/hr	1.3	1.1	0.05	*
Digestible NDF, %	66.8	65.7	0.67	NS
Digestible ADF, %	57.3	55.9	0.92	NS
Digestible CP, %	75.5	75.6	0.50	NS
Forage DMI/kg BW, g/d	13.0	13.0	0.66	NS
Total DMI/kg BW, g/d	19.4	19.3	0.89	NS
ADG (cows), kg/d	0.5	1.6	0.28	***
ADG (calves), kg/d	0.8	1.2	0.12	***

¹R = restricted grazing (12 h/d); U = unrestricted grazing

²n = 48

³*** = $P < 0.001$; ** = $P < 0.01$; * = $P < 0.05$; NS = non significance

Table 5: Influence of period on animal performance

Variable	Period ¹			sem ²	Significance ³
	1	2	3		
Forage DMI, kg/d	9.3 ^a	8.0 ^b	7.5 ^b	0.34	***
Total DMI, kg/d	13.4 ^a	12.1 ^b	11.6 ^b	0.34	***
Forage DMD, %	64.5 ^b	65.4 ^b	68.0 ^a	1.16	*
Forage dig DMI, kg/d	5.3 ^a	4.6 ^b	4.5 ^b	0.34	†
Total dig DMI, kg/d	9.1 ^a	8.4 ^b	8.3 ^b	0.34	†
Grazing time, hr/d	7.9 ^a	7.0 ^b	6.6 ^b	0.29	***
Grazing efficiency, kg/hr	1.2	1.2	1.2	0.07	NS
Digestible NDF, %	65.7 ^b	64.7 ^b	68.2 ^a	1.21	*
Digestible ADF, %	56.7 ^b	54.6 ^{ab}	58.6 ^a	1.69	†
Digestible CP, %	72.4 ^c	76.0 ^b	78.4 ^a	0.88	***
Forage DMI/kg BW, g/d	14.7 ^a	12.3 ^b	12.0 ^b	0.62	***
Total DMI/kg BW, g/d	21.2 ^a	18.4 ^b	18.4 ^b	0.64	***
ADG (cows), kg/d	0.6 ^b	0.8 ^b	1.8 ^a	0.39	**
ADG (calves), kg/d	1.2 ^a	0.6 ^b	1.1 ^a	0.18	*

¹1 = May, 2 = June/July, 3 = August

²n = 32

³*** = $P < 0.001$; ** = $P < 0.01$; * = $P < 0.05$; † = $P < 0.10$; NS = non significance

^{a,b,c}Within a row, means lacking a common superscript differ at $P < 0.10$

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