Effect of Rotation Frequency and Stocking Rate on Herbage Quality and Animal Performance of Cow-calf Pairs Raised on Permanent Pasture in Quebec

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EFFECT OF ROTATION FREQUENCY AND STOCKING RATE ON HERBAGE QUALITY AND ANIMAL PERFORMANCE OF COW-CALF PAIRS RAISED ON PERMANENT PASTURE IN QUEBEC

ABSTRACT

Michel Bergeron M. Sc. Animal Science

In Quebec, 62% of agricultural land is devoted to forage production and 20 % of this is pasture. Pasture management provides the opportunity for farmers to maintain and improve the productivity of agricultural land, and to engage in sustainable ruminant production. An experiment was conducted on 42 hectares of pasture land to study the impact of management intensive grazing (MIG) on cow-calf productivity. The pasture area was divided into 18 paddocks and the experiment was conducted as a randomized complete block design with two blocks. The treatments were arranged as a 3 x 3 factorial of stocking rate and rotational frequency. The stocking rates (SR) were 0.5, 0.7, and 0.9 hectares per cow (HSR, MSR and LSR respectively); the rotation frequencies (RF) were two days, six days and continuous grazing (2d, 6d and C). Sixty-one purebred Angus cow-calf pairs were randomly assigned to each of the nine treatments, and the animals were grazed during two consecutive grazing seasons (1997 and 1998). Hay harvested early in the season was used for pasture supplementation late in the season. Increasing RF had no effect ($P>0.05$) on forage mass available. Increasing SR from 0.9 to 0.5 cow-calf pairs ha^{-1} resulted in a linear reduction ($P<0.01$) in individual cow gain, but increasing the SR caused a linear increase in cow gains ha^{-1}. Calf gain ha^{-1} increased linearly ($P<0.01$) in response to SR, but was unaffected ($P>0.05$) by RF. A system of 6d rotation and high SR generated the greatest net revenue. The study showed little benefit of MIG on animal performance, but substantial benefits on efficiency of land use and economic performance.

LES EFFETS DE LA FRÉQUENCE DE ROTATION ET DU TAUX DE CHARGEMENT SUR LA QUALITÉ DE L'HERBE ET LA PERFORMANCE ZOOTECHNIQUE DU VACHE-VEAU DANS DES PÂTURAGES PERMANENTS AU QUÉBEC

RÉSUMÉ

Michel Bergeron M. Sc. Sciences Animales

Au Québec, 60% des terres agricoles sont utilisées pour la production de fourrages; les pâturages occupent 20 % de cette superficie. La régie des pâturages offre aux fermiers une occasion de maintenir et améliorer la productivité de leurs terres, en plus de représenter un système de production durable. Un projet de recherche a été mené dans un pâturage de 42 hectares afin d'étudier les effets de la régie intensive des pâturages (RIP) sur la productivité de la production vache-veau. Le pâturage a été divisé en 18 enclos et l'expérience a été conduite sous le schéma d'un bloc complet aléatoire. Les traitements constituaient un arrangement factoriel 3 X 3 de la fréquence de rotation et du taux de chargement. Les taux de chargement (TC) étaient de 0.5, 0.7 et de 0.9 hectares par vache (taux élevé, moyen et léger respectivement); les fréquences de rotation (FR) ont été de deux jours, six jours et de paissance en continu (2j, 6j, Cont). Soixante-et-une vaches Angus et leurs veaux pur-sangs ont été assignés de manière aléatoire à chacune des neuf régies de pâturage, et ont été pâturés pendant deux années consécutives (1997 et 1998). Le foin récolté en début de saison a été utilisé pour la supplémentation des pâturages plus tard dans la saison. L'augmentation de la fréquence de rotation n'a eu aucun effet sur la disponibilité de l'herbe au pâturage. L'augmentation du TC de 0.9 à 0.5 hectare par vache a réduit de façon linéaire les gains individuels des vaches, mais l'augmentation du TC a augmenté les gains ha^{-1} des vaches. Les gains ha^{-1} des veaux ont augmenté de façon linéaire (P<0.01) en réponse au TC, mais sont restés inchangés en réponse à la FR (P>0.05). Le

système de rotation 6j à TC élevé a généré le plus de revenu net. Ce projet a démontré peu d'avantages à la RIP sur les performances zootechniques, mais des bénéfices importants au niveau de l'utilisation des terres et des performances économiques.

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May God protect and bless us all.

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1. INTRODUCTION

Grazing lands, which include range and pasture, account for approximately 25% of the world's land area and have contributed to farming systems throughout the ages. Indeed, grasses and ruminants have co-evolved since prehistoric times and have been manipulated by man for several thousand years, when growing crops and herding animals were established ways of life (De Wet 1981). The advent of mechanized agricultural production systems in the middle of the twentieth century and the dependence on fossil fuel for food production led to reduced interest in the use of pasture to sustain ruminant production.

Recently, however, there has been renewed interest in pasture utilization for reasons related to environmental sustainability, and efficiency of utilization of fossil energy and agricultural resources. Vavra (1996) has defined sustainability of agricultural production as meeting the food and fiber needs of the present population without compromising the ability of future generations to meet their own needs. Sustainable systems should, therefore, conserve and possibly upgrade the resources available.

A study of the sustainability of the beef cattle industry in the United States, (Heitschmidt et al. 1996) concluded that the beef industry was highly dependent on fossil fuels, fertilizers and pesticides and that this dependency was creating a high degree of ecological and economic risk. The implication of this finding is that a system of beef production that relies heavily on grazing land will be ecologically desirable. Pasture provides vegetative cover that minimizes land erosion from wind and water, and when integrated into proper crop rotation, the use of pasture breaks cycles of pests and disease, helps to restore soil nitrogen reserves, and improves soil biota and structure.

Native pasture is a source of cheap forage for ruminant production because there are minimal machinery and reseeding expenses to maintain the pasture. The use of pasture is therefore essential for the viability and profitability of ruminant production. When ruminant production is based on pasture, land that is too poor or too erodable to cultivate becomes productive (Oltjen and Beckett 1996), and this increases the economic and ecological value of marginal land. In fact, when pasture is used as a forage resource, it can cost 20-50 % as much as harvested forage (Papadopoulos et al. 1993, Moore 1997).

In Canada, 50 % of the 36.6 million ha of agricultural land is in forage crops; of this forage land, 72 % is in range and 11 % is cultivated pasture (McCartney and Horton 1997). Thus, pasture makes a substantial contribution to the agricultural resource base in Canada. In Quebec, 62 % of agricultural land is devoted to forage production, and 20 % of this is pasture; in 1996, this represented more than 500,000 ha, a decrease of 20 % from 1991 figures (Statistics Canada 1997).

Beef production relies on a viable cow-calf production sector, which, in Quebec, takes place on private pasture land (Schissel et al. 1995). With improvement of pasture management techniques, the pasture resources in Quebec can be improved to increase beef production within the province. There is, currently, a low rate of adoption of pasture management for cow-calf production in Quebec. This may be due to several factors including low pasture productivity and inadequate knowledge about grazing management. According to Clark (1991), when pasture receives as much management consideration as cash crops, it will prove to be competitive in agricultural production systems.

1.1 Objectives

The objectives of this research were: 1) to determine the influence and interaction of rotational frequency and stocking rate on pasture availability and quality, and on beef cow-calf performance; 2) to determine the optimal combination of rotational grazing frequency and stocking rate that would optimize cow-calf performance on pasture.

1.2 Hypotheses:

Three hypotheses were formulated:

1: Pasture productivity can be improved by increasing the rotational frequency of grazing but the response depends on the stocking rate.

2: Rotational frequency will have the greatest effect on animal performance at a high stocking rate.

3: The stocking rate - rotational frequency combination optimizing pasture productivity, depends on whether animals are grazing early or late in the season.

2. LITERATURE REVIEW

2.1 Pasture Productivity and Improvement

2.1.1 *Constraints on pasture productivity*

The productivity of native pastures in Canada is low and variable. For example, in Quebec where there is more native than seeded pasture, native pasture productivity ranges from 500 to 3000 kg DM ha^{-1}, compared to 3000 to 8000 kg DM ha^{-1} for improved pastures (Petit 1993). Permanent pasture with poor soil structure results in variable herbage production (Bélanger and Winch 1985) since the plants adapted to those conditions become semi-dormant in summer, resulting in a severe shortage of forage and poor animal performance (Calder and Nicholson 1970). Factors that limit productivity of both improved and unimproved pasture include soil moisture and nitrogen, temperature and plant species composition (Willms and Jefferson 1993). Productivity of unimproved pasture depends very much on the composition of the plant community. Plants present in unimproved pasture are often not very productive but are very competitive for resources such as water and soil nutrients (Willms and Jefferson 1993).

Studies conducted in the Prairies region of Canada indicate that water and soil nutrients impose the greatest constraints on pasture productivity (Willms and Jefferson 1993). Menzi et al. (1991) concluded that climatic factors had greater effects on sward growth than did species composition or harvest management. Lowlands bordering the St-Lawrence River in Quebec receive on average 760 to 1140 mm of precipitation per year (Kunelius and Fraser 1992). Irrigation will increase grass productivity and beef production in summer and drought conditions (Calder and Nicholson 1970; Black 1978), but is not practiced extensively in Quebec due to regular precipitation in relatively high amounts. Northern Quebec (North of 50th) receives an average of 800 mm of precipitation per year (200mm snow and 600 mm rain), Central Quebec receives an average of 950 mm of precipitation (270 mm snow and 770 mm rain), the Laurentian Park area receives an average of 1200 mm of precipitation (375 mm snow and 825 mm rain), Southern Quebec (South of 46th) receives an average of 860 mm of precipitation receives (235 mm of snow and 675 mm rain) and Gaspesia receives an average of 1250-1300 total precipitation (Gagné 1999).

Lack of soil water limits forage yield but temperature controls the phenological development of native grasses (Willms and Jefferson 1993). When water is not scarce, nitrogen (N) can become the limiting factor. The limiting effect of soil nutrients is reflected in the fact that substantial increase in pasture productivity can result from addition of nitrogen (Willms and Jefferson 1993). Pasture response to applied nitrogen depends on the composition of the sward (Papadopoulos et al. 1993). Nitrogen application increases root mass, improving water-use efficiency (WUE). Nitrogen application also changes the plant population. Introduction of legumes such as alfalfa and clovers can reduce the need for N fertilizer application (Kunelius and Fraser 1992).

The winter season is long in most parts of Canada and cold temperatures persist. Freezing and thawing in combination with diseases exert severe stress on overwintering forage plants. The growing season ranges from 80 days in the northern regions of Canada to over 200 days in southern Ontario (Kunelius and Fraser 1992) and this variation in growing season affects pasture productivity. The seasonality of dry matter production from pasture is a result of high growth rates in early summer and low dry matter accumulation in late summer and fall (Kunelius and Fraser 1992). Typically, the dry matter production of cultivated species in the late spring - early summer exceeds 100 kg ha^{-1} d^{-1} (Kunelius 1990), and in some instances 200 kg ha^{-1} d^{-1} (Deinum et al. 1981).

2.1.2 *Species composition and pasture productivity*

Plant composition of native pastures consists of a climax population, the dominant species influencing the production potential of each community. Complex species composition is more profitable and provides more stable production than monoculture (Clark et al. 1993). The mix of species tends to maximize resource extraction and conservation (Willms and Jefferson 1993). Changing plant composition affects the total productivity of land. Different mixtures should be used in different pastures to accommodate seasonally varying constraints on herbage productivity (Clark et al. 1993). Introduction of mixtures of improved species (and varieties) is preferable but the effects of reseeding on soil are not well understood

(Willms and Jefferson 1993).

Only a limited number of studies have focused on the influence of grazing tolerance on pasture productivity. The actual trials for forage are based on DM production under clipping trial, which does not reflect the grazing tolerance of these species (Papadopoulos et al. 1993). Persistence of the forage species is also great pressure for selection: winter hardiness is important because of the climate prevailing under Quebec conditions. Long frost periods, freezing and heaving ice encastment have adverse effects on plant viability (Kunelius and Fraser 1992). In eastern Canada, the principal grass herbage is *Phleum pratense* L. which is the most winterhardy species (Kunelius and Fraser 1992). *Ladino* clover is the most recommended legume in Quebec.

The frequency and severity of defoliation events affect productivity of the plant. Grazing pressure can increase plant vigor and productivity, which can in turn improve animal performance (Rowan et al. 1994). A low stocking rate results in undergrazing and inefficient use of forage available; and a too high stocking rate results in overgrazing and can affect the ability of plants to recover. Grazing animals affect directly the plant by disrupting its physiological activity and indirectly by its action on the soil environment (Willms and Jefferson 1993). Grazing may also affect the WUE by reducing evapotranspiration and soil moisture depletion, resulting in better water status during the summer period (Willms and Jefferson 1993). However, litter removal results in increased soil temperature, increased evapotranspiration, and reduced water available for plant growth. Livestock activity on pasture also affects plant composition through manuring and trampling. Calder et al. (1970) demonstrated that grazed areas were more productive than clipped areas. Wildlife grazing can also limit the productivity of pasture land (Willms and Jefferson 1993).

2.1.3 *Improvement of pasture productivity*

Dry matter yields from pasture can be increased significantly through fertilization, interseeding and proper utilization (Kunelius and Fraser 1992). For example, Black (1978) found that split applications of N during the season resulted in higher yields of grass and grass-legume swards, but had no effect on legume swards. Fertilization increases DM production, sustaining more animal production (Calder and Nicholson 1970; McCartney et al. 1999). Tallowin and Jefferson (1999) report increased DM production due to fertilization ranging from 50 % to over 100 % on natural grasslands. In another experiment, Lalande et al. (1974) was able to double the stocking rate of steers by increasing fertilization while maintaining similar animal gains. Clark (1991) reported that one dollar invested in fertilization yields more than four dollars of beef.

Reseeding old pastures can also increase pasture DM production. Sown pastures often decrease in productivity over years as pasture reverts back to unsown native species because of poor persistence of introduced species and poor grazing tolerance (Papadopoulos et al. 1993). Moreover, in order to maintain pasture productivity with latter years after reseeding, fertilization should be maintained. However, the high costs involved in reseeding prevent this practice from being implemented extensively. Proper management of forage crops and pasture increases the productivity, quality and carrying capacity of the land (Kunelius and Fraser 1992). Grazing management strategies also provide opportunities to increase pasture productivity (Willms and Jefferson 1993).

2.2 <u>Seasonality Effects on Pasture Productivity and Animal Performance</u>

2.2.1 *Seasonal changes in pasture productivity*

The changes in pasture productivity from one month to another within a grazing season are referred to as seasonality of pasture production. However, year to year variation in pasture productivity is an important aspect of pasture management. In most studies of pasture management, distinct and significant seasonal effects on plants and animal productivity have been reported (Gross et al. 1966; Allen et al. 1992; Popp et al. 1997b; Marshall et al. 1998b). Gross et al. (1966) found year to year variations in productivity of steers maintained on pasture. Allen et al. (1992) found that the optimal stocking rate changed according to plant climatic conditions prevalent during the season. Marshall et al. (1998b) noticed monthly variations of forage quality affecting cow-calf production. Countries such as New Zealand and Australia adjust the grazing systems on the seasonal availability of pasture, and develop their industry and marketing strategies to fully take advantage of the seasonality of production (Macmillan and Kirton 1997). For example, they increase herd size to minimize labour per animal and fully use the rapid forage growth; the dairy industry has developed seasonal packaging and processing plants, in order to process the large volumes of milk produced more economically during forage availability. Therefore, in the development of grazing systems, it must be recognized that plant growth or pasture is not uniform over the year, or even over the growing season (Hoveland 1992).

The production curve of cool-season grasses is seasonal and is characterized by a slump during the hot summer months. The variation of plant growth throughout the growing season is due to variation in weather and climate. Different growth patterns impact directly on the productivity of pasture plants, the productivity of the land, and the productivity of the animals. Later in the season, the decreased nutritional value of maturing plants can compromise animal production (Kirby and Webb 1989), unless grazing management counteracts this seasonal decline in forage availability and quality (Marshall et al. 1998b).

2.2.2 *Effects of seasonality on pasture productivity and quality*

The seasonality of dry matter production of perennial cool-season grasses is a result of high growth rates in early summer and low dry matter accumulation during summer (Kunelius and Fraser 1992). Primary growth is rapid in the spring. In the Northeastern United States, 50 % of the seasonal yield of a cool-season grasses pasture grows in the first two months of the growing season, while the other 50 % is accrued in the remaining four months (Rayburn 1993). Growth of cool-season grasses is decreased in mid- to late summer by high temperatures and low precipitation. Good growth in the fall can be observed if temperatures and moisture conditions permit (Kunelius and Fraser 1992).

The phenological state of the sward and its botanical composition impact on the nutritive value of the forage. Quality and botanical composition of the sward changes over the grazing season and between seasons (Marshall et al. 1998b). Dry matter yield increases as plants mature form vegetative to reproductive stages, but digestibility, CP and mineral concentrations decrease (Mayland et al. 1992), and ADF and NDF increase (Hodgson 1990). With senescence, nutrients are translocated from aging tissues to areas of meristematic activity, and fiber constituents increase. The net result is a dilution of mineral concentration and reduction in digestibility of herbage (Mayland et al. 1992). This decline in herbage quality parameters with maturation occurs in a quadratic fashion (Mayland et al. 1992). High temperatures of summer produce higher fiber and lower protein, while lower fiber and higher protein content are produced in the cooler months (Marshall et al. 1998b).

The protein content of the plant is affected by the stem to leaf ratio, being higher in the leaf compared to stem which consists of more lignified tissues, and decreases from the beginning of the grazing season (May) to late June as plants mature (Marshall et al. 1998b). The stem to leaf ratio increases rapidly in a vegetative sward in the spring (Hodgson 1990). This modification, coupled with the changes in cell wall constituents, results in a characteristic decline in digestibility with increasing maturity of the sward. The cell wall lignification process is more rapid for grasses than legumes, resulting in a more rapid decrease in grasses cell wall digestibility with maturation (Buxton and Russell 1988). Legumes also maintain a higher leaf to stem ratio with advancing maturation compared with grasses. Moreover, leaves from legumes retain a higher digestibility than leaves from grasses at comparable stages of maturity (Hodgson 1990).

Grazing or clipping will help maintain the plants in a vegetative stage. Clipping or harvesting at different stages of maturity will have an impact on plant regrowth; the more vegetative the plant is when clipped, the faster it can recover (Mayland et al. 1992). The regrowth of most species is slow, which reduces the dry matter production and the carrying capacity later in the season (Kunelius and Fraser 1992). While regrowth tissue will have greater concentrations of nutrients and be more digestible, the net seasonal benefit to the herbivore will be a function of the total dry matter yield (Willms and Beauchemin 1991).

2.2.3 *Seasonality of animal performance on pasture*

The performance of grazing animals depends on a complex balance between the changing requirements of the animals and the changing supply of nutrients from pasture (Rode et al. 1986), but herbage should be utilized while it is at its optimum nutritive value (Allen et al. 1992). Seasonality of pasture production is therefore a major factor influencing animal production from pasture in temperate regions. Liveweight gains of beef cows on pasture have been shown to decrease at the end of the grazing season due to low forage quality (Bryant et al. 1960). In fall, pasture quality can fall below maintenance requirements for dry, pregnant beef cows (Kirby and Webb 1989; McCartney et al. 1999), but beef cows body condition can be maintained on pasture, provided that management practices minimize seasonal variation in pasture quality and availability (Marshall et al. 1998a).

When forage availability declines below 2000 kg DM/ha, forage intake by the animals decreases gradually, but the rate of decline is very rapid when forage availability falls below 1000 kg DM/ha (Marshall et al. 1998a). In rotational grazing systems, forage availability can become limiting at the end of the grazing cycle, since plant regrowth decreases as season progresses (Marshall et al. 1998b). The low forage productivity late in the summer can result in a need for supplementation to maintain the animals (Van Keuren 1970).

Lalande et al. (1974) grazed beef steers rotationally and reported up to 1500 g/hd/d of gain in mid-June but as low as 475 g per day in mid-July; in August and September, the average daily gain fluctuated between 640 and 1100 g. In a 14-year project involving 275-kg steers on pasture, Beacom (1970) observed that 46 % of annual weight gains were obtained in the first quarter of the growing season. Steers grazed continuously gained 1.4 kg and 0.5 kg daily in the first and second half of the grazing season respectively (Tyson et al. 1992). Heifer weight gains are also seasonal and decrease as season progresses (Jung et al. 1985).

The liveweight gains of nursing calves are usually not affected by forage availability or pasture management (Marshall et al. 1998a). Calves derive most of their nutritional needs from their dam's milk (Bagley et al. 1987a; Hart et al 1988a, Rouquette 1988). Studies have shown that creep grazing or creep feeding will improve calves daily gains only when forage availability is limiting (Gerrish et al. 1986; Blaser et al. 1987; Allen et al. 1992).

2.3 Grazing Systems and Management Intensive Grazing

Grazing systems are management plans used by the producers to coordinate plant and animal growth during the pasture season (Papadopoulos et al. 1993). They are developed to control the timing and distribution of livestock on pasture, in order to control rest period of the pasture, forage availability and frequency of defoliation (Volesky et al. 1994). Producers adopt grazing plans to enhance forage production and quality (Rowan et al 1994), and animal performance. Hence, grazing management objectives are usually to optimize utilization of pasture forage.

Grazing management practices vary and can range from continuous to rotational grazing with varying frequencies of rotation. A change from continuous to rotational grazing has been reported to increase carrying capacity and maintenance of animal gain throughout the season, both of which depend on stocking rate and forage quality.

Grazing management involves the intensification of management rather than the intensification of grazing, allowing the producers to invest in management skills rather than physical assets (Gerrish and Ohlenbusch 1998). Management-intensive grazing represents a holistic approach to pasture management and emphasizes the need for meeting the needs of the plant and animal species. Pasture management is more an art than a science since the managers rely on instinctive cues to apply management.

2.3.1 *Continuous grazing versus rotational grazing systems*

Continuous grazing is the least labour demanding grazing system. It involves minimal management skills, except the decision about the number of animals to allocate to a restricted land area. Some limitations of continuous grazing systems include animals having unlimited access to forage which leads to selective grazing, overgrazing of desirable plant species and decreased live weight gains later in the season (Papadopoulos et al. 1993). During the early part of the grazing season, continuous grazing can result in higher individual animal gains when compared to rotational grazing. For example, Wilkeem et al. (1993) observed higher calf gains (0.92 vs. 0.83 kg d^{-1}) under continuous vs. rotational grazing. The higher animal gains result from the ability of the animals to graze selectively under continuous grazing systems. These higher individual gains are counterbalanced by a low productivity per land unit area (Mott 1960). There are reports, however, of similar performance of heifers (Bertelsen et al. 1993), steers (Hart et al. 1988b) and cows when subjected to continuous versus rotational grazing.

Later in the season, the presence of standing dead forage with continuous grazing can hinder the capacity of the animals to graze selectively (Kirby and Webb 1989; Knight et al. 1990). Heitschmidt et al. (1987b) noticed that the presence of dead forage, more important in continuous than rotational grazing, decreases the CP content of the forage available. When compared to continuous grazing, rotational grazing has been shown to maintain higher individual animal gains at the end of the season (Volesky et al. 1994).

In contrast to continuous grazing, rotational (intermittent) grazing involves the moving of animals into new pasture according to a schedule. Rotational management practices range from occasional moving to more frequent rotation, up to strip grazing, which involves the daily rotation of the animals. Rotational grazing has many reported advantages, including the provision of higher quality plant material, undisturbed growth, increased carrying capacity of the land (Foley et al. 1930; Heitschmidt et al. 1989; Derner et al. 1994; Hirschfeld et al. 1996) and increased harvesting efficiency (Heitschmidt et al. 1987a ; Volesky 1994; Volesky et al. 1994). Even under conditions of limited water, poor soil conditions, the additional costs for fencing associated with rotational grazing and the higher level of management required, there are economic benefits to rotational grazing systems (Walton et al. 1981).

Implementation of rotational grazing has increased carrying capacity (Heitschmidt et al. 1987c; Derner et al. 1994; Popp et al. 1997a). This increased carrying capacity results in higher gains per land area. Rotational grazing also permits lengthening of the grazing season (Popp et al. 1997c), but does not alleviate the dangers inherent with excessively high stocking rate (Heitschmidt et al. 1987c; Willms and Jefferson 1993). Rotational grazing can result in improved animal performance if forage quality is high (Rowan et al. 1994). Rotation permits control of the frequency and severity of defoliation. Rotation schemes can be developed on fixed schedule or on forage availability in the paddock. Rotational grazing allows for improved forage utilization, maintained production throughout the season (Volesky et al. 1994) and maintenance of desired pasture species (Derner et al. 1994; Papadopoulos et al. 1993). Rotational grazing can also permit forage conservation and the transfer of surplus forage to periods of low availability (Burns 1984).

An important aspect of rotational grazing is that it reduces the opportunity for selective grazing and the animals have to eat the less desirable species (Coleman 1992), therefore increasing the harvesting efficiency. Patterns of selection and defoliation are the most important effects of grazing animals on the pasture (Volesky et al. 1994).

2.3.2 *The role of stocking rate in grazing management*

Stocking rate is defined as the number of animals per land area, and is considered, after seasonality, as the most important factor affecting grazing system productivity (Fales et al. 1995, Parsch et al. 1997). A key decision in pasture management is determination of the appropriate stocking rate (Parsch et al. 1997), which can change every year, depending on climatic conditions and market forces. It is a key factor in establishing the most profitable operation: if too low, it will result in suboptimal gain per hectare; if too high, it will affect gain per animal. Stocking rate should be calculated to match forage demand by the animals with pasture productivity (Petit 1993).

Mott (1960) described the relationship between animal performance and stocking rate. At low stocking rate, animal performance (expressed as gain/animal) is maximized, but gain per land area is low. In lightly stocked pasture, animals have the capacity to graze selectively. This selectivity allows them to select diet higher in quality than forage available (Bagley et al. 1987a; Popp et al. 1997b). As stocking rate increases, gain per animal decreases, but gain per land area increases to a point beyond which a continued increase in stocking rate reduces both gain per animal and gain per land area. Mott's curve has been validated in many trials (Bryant et al. 1960; McMeekan and Walshe 1963; Knight et al. 1990; Popp et al. 1997a). The optimal stocking rate represents a compromise between maximal animal performance and maximal gain per hectare, and optimal stocking rate depends on factors such as land productivity, herd requirements and level of production (Fales et al. 1995). Moderately stocked systems have more stable production per cow (Knight et al.

1990). An economic simulation by Parsch et al. (1997), using GRAZE Beef-Forage simulation system, revealed that maximal gain per animal was achieved at 6 steers per hectare, maximal gain per hectare achieved at 10 head per hectare and the maximum profits at 12 head per hectare. This optimal stocking rate changes every year and is dependent mainly on the weather (Parsch et al. 1997).

Stocking rate not only affects animal performance, but also plant performance. A low stocking rate results in undergrazing and inefficient use of forage available. High stocking rate can reduce forage mass and stimulate new vegetative growth, but an excessively high stocking rate results in overgrazing and can affect the ability of plants to recover (Burns 1984). Stocking rate is a major factor controlling the frequency and severity of defoliation of individual plants (Heitschmidt and Walker 1983). Stocking rate affects herbage allowance, and thus herbage intake. By determining the proportion of pasture that the animals consume, the stocking rate affects production per acre (Fales et al. 1995). In a study with dairy cattle, McMeekan and Walshe (1963) estimated the effect of stocking rate to be twice as important as grazing management system. There is a linear relationship between animal performance and production per land area to stocking rate (Petersen et al. 1965).

In lightly stocked pasture, forage availability tends to be higher but cattle diet is not affected since the animals have the capacity to graze selectively (Popp et al. 1997b). Forage availability can increase assimilation rate, decrease grazing time and competition between animals, resulting in higher gains per animal (Popp et al. 1997c).

Selectivity results in the diet quality being higher than quality of forage available. As mentioned before, animal production per animal will be affected at high stocking rate: forage availability is not maintained when the stocking rates are too high (Ralphs et al. 1990). The opportunity for selective grazing also allows the animals to maintain level of production under unfavorable conditions by switching to less palatable species (Rowan et al. 1994). High stocking rates can be achieved, leading to increased profits, but production stability decreases as stocking rate increases (Heitschmidt et al. 1990) and long-term profitability is not ensured (Hart et al. 1988a).

2.3.3 *Interaction between stocking rate and rotational frequency in grazing systems*

Some researchers report a significant interaction between stocking rate and grazing system (Riewe 1961; Hull et al. 1967), but still others claim no such interaction (McCollum III et al. 1994). However, most studies performed were not designed to address this interaction, even though Riewe (1961) explicitly stated that all grazing experiments should evaluate interactions between stocking rate and grazing management. Furthermore, Wheeler (1962) and later Connolly (1976) noted that, as a prerequisite for successful grazing experiment, at last three stocking rates should be examined. Despite such caution, many experiments were conducted comparing only two levels of stocking rate and rotational frequency (Heitschmidt et al. 1987c; Volesky et al. 1994). There is a need for better understanding of potential interactions between stocking rate and rotational frequency.

2.4 A System's Approach to Pasture Management

2.4.1 *The concept of "system efficiency"*

Researchers work in relatively safe controlled environments, evaluating forage and/or animal responses, whereas farmers deal with agricultural systems of different complexity and risks (Frank 1995a). In grazing systems, three levels of production responses can be evaluated. Primary production is the herbage yield in response to the environment and different edaphic factors. Secondary production is the animal response that results in gain, milk, wool and other harvestable products. The tertiary response includes economic, environmental and agro-touristic responses. Although it has its limitations, monetization of production permits evaluation of the production units (Antle and Wagenet 1995).

Intensification of grazing management has been reported to improve economic performance (Fales et al. 1995; Parsch et al. 1997). Increased harvest efficiency is, in fact, the best way to promote secondary production (Willms and Jefferson 1993). But farmers are overwhelmed with contradictory information. The results from grazing steers are not fully applicable to cow-calf operations since the animals do not have the same nutritive requirements and since different classes of livestock may respond differently to pasture management. Moreover, extrapolation of study results to operation-scale farms has to be done cautiously (Gerrish et al. 1992): results form clipping studies are not directly transposable into a grazing system and a system is not necessarily the summation of all its parts (Burton Jr. et al. 1984). A systemic approach must be used with pasture (Frank 1997).

Lack of knowledge about grazing management results in inefficient use of pastures (Frankow-Lindberg and Danielson 1997). As knowledge increases, the manager has a greater and more effective base for decisions (Dziuk and Bellows 1983). In different cow-calf grazing systems, forage utilization efficiencies were reported to be 30 %, 50 % and 60 % respectively for continuous, rotational and management-intensive grazing (Barnhart 1998). The researchers have to think in a more integrated way, have a more systemic approach since the grazing animals have to live (in Canada) during the non-grazing seasons and that these periods have an impact on the profitability of grazing systems. Producers prefer to have excess forage rather than risk reduced production. In experiments, the put and take method permits to use the excess forage by allowing extra animals onto pasture during rapid forage growth and retrieving animals when pasture availability is at risk (Calder and Nicholson 1970). On-farm, these practices are often not applicable since most producers use continuous stocking or vary pasture availability by changing the amount of land available to the animals.

2.4.2 *Supplemental feeding on pasture*

Wilkeem et al. (1993) reported that ranchers should make optimal use of resources for optimal returns to the livestock industry within an integrated-use framework. Optimal use of resources can mean harvesting hay when forage surpluses occur and providing supplemental feeding in times of pasture shortage. Harvesting forage excess resulting from rapid spring pasture growth is an excellent practice (Blaser et al. 1987). Ranch managers have to adapt to seasonal pasture conditions or use management plans to minimize its effects. In grazing systems, the seasonality of pasture production and increased stocking rate may lead to a need for supplementation (Petit 1993). Supplemental feeding can provide a nutrient not provided by pasture forage and is an option too often neglected (Burns 1984). On pasture, supplemental feeding is usually provided during periods of summer dormancy, during drought, during fall and winter (Caton and Dhuyvetter 1997), or when the quality or availability of forage is too low to meet the production levels expected. Feeding highly concentrated protein sources requires less labour and equipment than feeding supplemental energy or hay, which are fed in larger quantities and need to be fed every day (Dhuyvetter et al. 1993). The benefits of protein supplementation result from shifts in fermentation patterns and meeting the requirements of the animals (Judkins et al. 1987).

Hay supplementation usually consists of alfalfa due to its high crude protein content (Villalobos et al. 1997). Alfalfa hay supplementation helped to maintain weight and body condition score of fall-winter grazing cattle at half the costs of other protein sources (Cochran et al. 1986). Grass hay has also proven to be an effective alternative to traditional soybean meal-based supplements (Villalobos et al. 1997). Cow productivity can be increased through supplementation during drought years

(Bellido et al. 1981). However, when forage availability is not limiting, there is no advantage in supplementation (Vadiveloo and Holmes 1979) since animal production will be either enhanced or unaffected by energy supplementation (Caton and Dhuyvetter 1997). Under good grazing conditions, the benefits of feed supplementation are small since herbage intake will be depressed and the intake of nutrients is only slightly increased (Vadiveloo and Holmes 1979). A study on pasture productivity and fertilization found that under intensive pasture management concentrate or protein supplementation was not needed to maintain average daily gains (Petit 1993). The economic benefits of supplementation will depend on the cost of feeds (Bellido et al. 1981) and the economic advantages of pasture management should include all feeding costs. No single management procedure is good for an area or a region. Producers adapt their farming practices to their experience and strengths.

2.4.3 *Benefits of grazing compared to other enterprises*

Grazed forage costs about half the price of conserved forage (Clark 1991; Papadopoulos et al. 1993; Moore 1997). Pasture can therefore help decrease the costs of production. The economic benefits of higher management usually result from a drastic increase in productivity per land area (Bagley et al. 1995), due to increased carrying capacity. Many simulations and experiments claim the economic merits of intensive management of grazing systems. In dairy cattle production, the benefits of grazing can amount to as much as $300 increased profit per cow vs. confinement feeding (Ford and Musser 1998). Moore and Gerrish (1995) claimed that grazing systems are more profitable than row cropping. In the beef industry, a simulation by Parsch et al. (1997) proved that increased profits could be expected at higher stocking rates. Pasture management intensification will yield economic benefits when pasture productivity potential is high. Intensification of pasture management can help decrease the need for machinery, decrease workload, decrease the need for manure management and handling. Veterinary costs can be decreased due to better health and decreased veterinary costs for grazing animals (Ford and Musser 1998). Even when considering the watering, fencing and implantation costs, there can be economic advantages to pasture management intensification. Other non-pecuniary advantages of pasture management intensification include quality of life and less environmental risks. However, the adoption of MIG is slow and not widely accepted by the beef industry in Quebec.

2.5 Constraints to Technology Adoption in Grazing Management

According to Parker et al. (1992), the low adoption of grazing management is due to the lack of information on economic benefits of grazing for dairy producers. Technology adoption is usually associated with higher yields with increased input levels. In dairy production, milk production can decrease in grazing conditions compared to confinement feeding, but the lower costs of production are the economic benefits of grazing production (Hanson et al. 1998). Cost constraints, low cash flow and high debts to assets will influence the adoption of grazing technology of dairy enterprises (Hanson et al. 1998). Economic benefits will depend on the limiting factor of the farm (Fales et al. 1995).

The objective of pastoral livestock enterprises is to maximize profits (Bransby 1989). The lower costs of production are excellent agents for the promotion of pasture management intensification, but part-time cow-calf producers are not profit maximizers (Young and Shumway 1991). Most of North-American cow-calf producers are part-time producers since they rely on off-farm income (Schissel et al. 1995). In Quebec, in 1997, 80% of the producers had less than 50 cows and owned 54% of the cow-calf herd; only 9% of the producers had more than 75 cows, but these larger enterprises produced 26% of the animals (FPBQ 1998). These part-time producers will likely minimize the time spent on labor, minimize farm work and minimize investments. Moreover, the objective of many beef producers is to "enjoy work in the open air" (Frank 1995a).

Adoption of a new technology from beef industry in North Queensland was described as a rational, step-wise process (Frank 1995a, 1995b) involving four major steps: 1) awareness, 2) consideration, 3) analysis and 4) adoption or non-adoption. The successful adoption will depend on the usefulness and the perceived profitability of the technology, but also on the personal satisfaction resulting from adoption (Frank, 1995a). The presence of a learning curve (Wilson et al. 1987) and the timing of results may represent an obstacle to the adoption of intensive grazing management.

Moreover, the importance of farmer-to-farmer information exchange should not be overlooked, producer meetings and information sessions being the most appropriate ways to promote pasture management.

The high costs and time required for animal experimentation on pasture minimize their use and limit their replication in the beef industry (Wilkeem et al. 1993). To alleviate the high costs of grazing studies, some work is done using clipping schemes, and the herbage or hay is fed to the animals (Cameron 1966) for nutritive assessment. However, clipping is not accurate to determine the rate of plant growth and disappearance in pastures (Scarnecchia 1994). Calder et al. (1970), in an experiment comparing grazed and clipped areas, concluded that data obtained from clipping experiments should be extrapolated with extreme caution to real grazing situations. Indeed, research protocols are not readily transferable to practical pasture management (Clark et al. 1993).

Computer simulations are used by researchers and extensionists to promote the intensification of pasture. Computers are effective and cheap tools to integrate notions from many disciplines (LeBris and Duru 1988). Decision support systems (DSS) are being developed and integrate the research results from many disciplines: soil and forage productivity, forage management systems, animal biological models (such as CNCPS) and economic simulations (Parsch et al. 1997). Computer simulation can be used to make predictions, evaluations of the effects of new technology adoption, and find solutions to new problems (LeBris and Duru 1988).

For example, Parsch et al. (1997) evaluated the risk uncertainty related to weather using a simulation model, whereas Mohtar and Buckmaster (1995) used a DSS to generate economically and environmentally efficient pasture systems. GRASIM was developed to simulate dairy pasture (Mohtar and Buckmaster 1995), and GRAZE was used to simulate stocker steers on pasture (Parsch et al. 1997). Even if the databases can be updated or modified to account for regional differences (Cohen et al. 1995; Parsch et al. 1997), the decision support systems will be as reliable as their references are coherent and accurate. Despite the advent of computers and multidisciplinary approach, the effects of forage systems on soil degradation are still unknown (Petit 1993). Moreover, no computer model can fully account for the effect the animals have on the soil and plants (Petit 1993; Clark et al. 1993; Clément and McClelland 1992; Derner et al. 1994). No pasture system has been evaluated in Quebec to compare continuous versus rotational grazing (Petit 1993).

Technology transfer is but one of the steps towards technology adoption and researchers need to adopt a more holistic, interactive and participatory approach incorporating social and economic parameters of potential users (Frank 1995a). Producers will not adopt if they are satisfied with their present situation (Frank 1995b). Non-adoption of the technology is rational and consistent with the producers' choice of lifestyle (Frank 1995b).

3. MATERIALS AND METHODS

3.1 Site Description

The research was conducted on a site located in Senneville, Quebec. The land represented improved, untiled mixed-grass spring-summer pasture of 40.7 ha. The perimeter of the site was fenced with three-strand high tensile electric wire attached to permanent wooden posts. The pasture was partitioned into two blocks (east block and west block), and each block was divided into nine paddocks fenced with two-strand high tensile wire; thus, in total, 18 grazing cells were created (Figure 3.1).

The continuous grazing treatments consisted of six cells with no internal fencing (Figure 3.2 a). To accommodate the medium-frequency rotational grazing systems, internal fences were established in each of six cells using two-strand high tensile wire; the wire was attached to semi-permanent posts and this arrangement resulted in six medium frequency rotational grazing paddocks (Figure 3.2 b). To accommodate the high-frequency rotational grazing treatments, internal fences were used to partition each of six cells into four sections; each section was further partitioned into four subdivisions using electrified tape set on tumble wheels. This arrangement resulted in 16 paddocks for each of the six high-frequency rotational grazing cells (Figure 3.2 c).

Botanical composition of the pasture was determined at six different locations in each of the 18 cells. At each location, the pasture species within a circumscribed area (radius 4.5m) were identified, and their abundance estimated; plant species

Figure 3.1.
Map of the experimental site (cell number and land area).

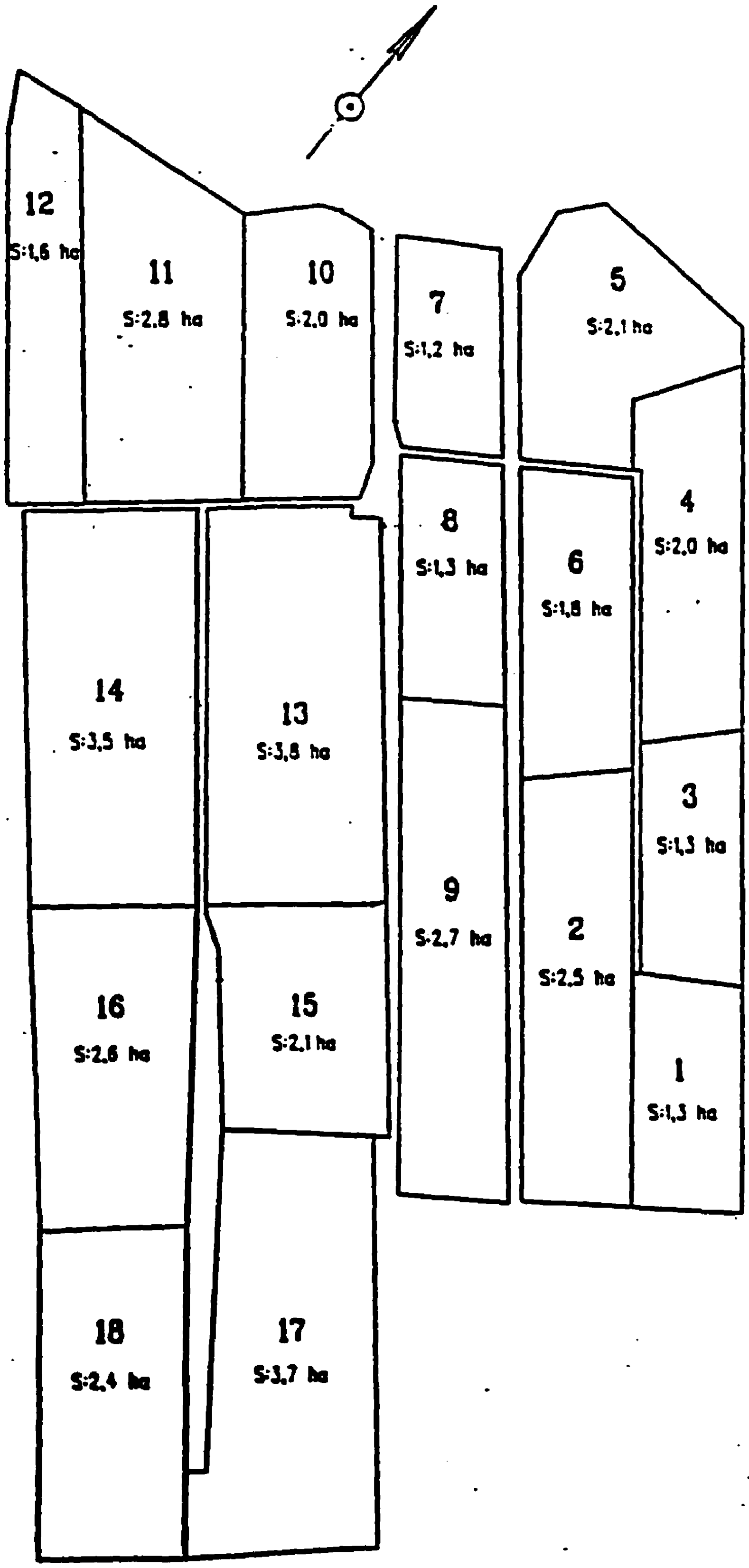
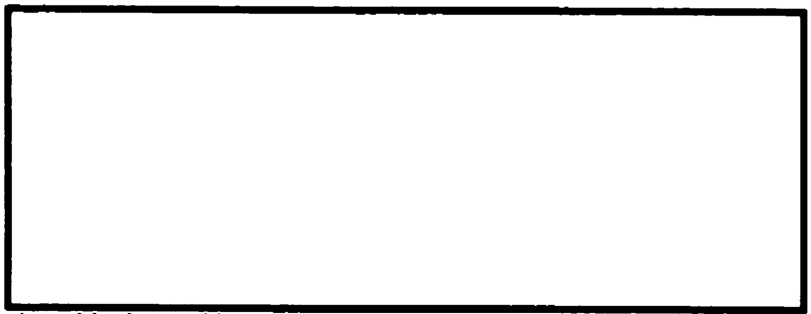


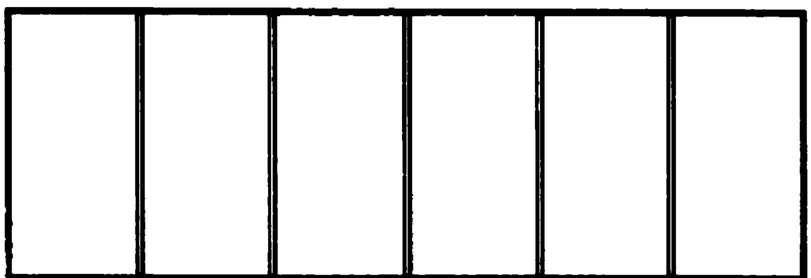
Figure 3.2. Grazing cells layout.

Figure 3.2 a) Layout of continuous grazing cells.



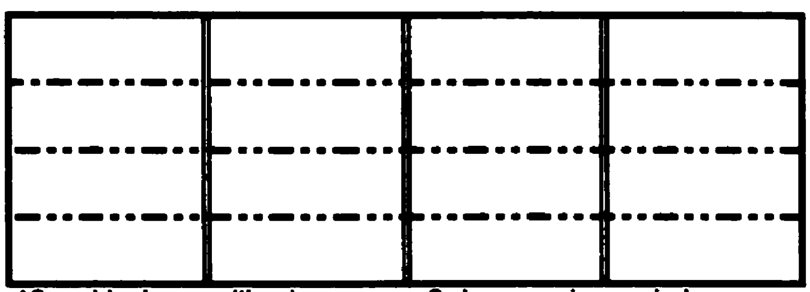
1 paddock resulting in continuous grazing.

Figure 3.2 b) Layout of 6-day rotational grazing cells.



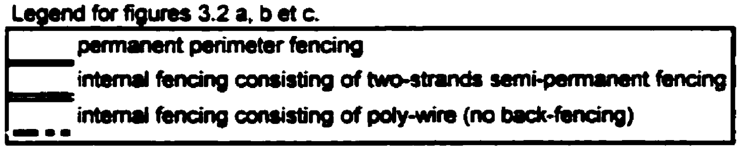
6 paddocks resulting on average 6-days grazing period.

Figure 3.2 c) Layout of 2-day rotational grazing cells.



16 paddocks resulting in average 2-days grazing period.

Legend for figures 3.2 a, b et c.



estimated to be present to the extent of less than 1% of the pasture were excluded. At spring turn-out (end of May, beginning of June) in 1997, the pasture consisted of a mixed-grasses species sod containing 29.6% smooth bromegrass *(Bromus inermis* Leyss.), 27.5% reed canarygrass (*Phalaris arundinacea* L.), 16.6% quackgrass (*Elytrigia repens* (L.) Nevski), 8.8% timothy (*Phleum pratense* L.), 7.7% Kentucky bluegrass (*Poa pratensis* L.), 4.0% red clover (*Trifolium pratense* L.), and traces of alfalfa; in mid summer (mid-August) the pasture contained 18.9% smooth bromegrass, 22.7% reed canarygrass, 8.4% quackgrass, 17.8% timothy, 7.4% Kentucky bluegrass and 9.7% red clover; at the end of the first grazing season (end of October) 1997, the pasture contained 21.8% smooth bromegrass, 20.0% reed canarygrass, 6.8% quackgrass, 25.7% timothy, 8.3% Kentucky bluegrass and 9.3% red clover.

The weather and rainfall data for 1997 and 1998 are contained in table 3.1. This table also presents the normal (average) temperature and precipitation for a 20-year period (from 1969 to 1990).

3.2 Animals and Experimental Design

The research was conducted during each of two successive years (June to October 1997, and May to October 1998) with registered purebred Black Angus and Red Angus cow-calf pairs. Three producers from the Quebec Angus Association

Table 3.1. Monthly rainfall and temperature data for the grazing seasons of 1997 and 1998 at the Lodds Agronomic Research Center weather station (Ste-Anne de Bellevue)[1].

Month	1997 Rainfall (mm)	1997 Mean Temp (°C)	1998 Rainfall (mm)	1998 Mean Temp (°C)	Normal[2] Rainfall (mm)	Normal[2] Mean Temp (°C)
April	139.2	4.9	26.0	7.9	70.0	5.9
May	78.5	10.7	58.8	16.8	70.8	13.1
June	88.0	19.5	137.7	18.8	88.3	18.1
July	161.7	20.0	75.2	20.2	89.7	21.1
August	138.2	18.5	79.0	20.0	99.9	19.8
Sept.	96.7	14.2	46.1	15.5	97.9	14.7
Seasonal Total	702.3	N/A	422.8	N/A	516.6	N/A

[1]Source: Environment Canada.

[2] based on annual data from 1969 to 1990.

supplied the animals; the participating producers retained ownership of their animals throughout the experiment. Sixty-one cows were used for the experiment in each of the two years.

For the 1997 grazing season, the animals arrived at the research station on November 20, 1996. During this winter, animals were fed on round hay bales and a commercial mineral mixture (Ralston Purina Canada, Strathroy, ON, Canada) which was combined with salt (NaCl) in a 2:1 ratio and provided free choice. The composition of the mineral was as follows: calcium (16%), phosphorus (16%), magnesium (5%), sulfur (1%), iodine (45 mg/kg), iron (5000 mg/kg), manganese (2300 mg/kg), zinc (2300 mg/kg), cobalt (500 mg/kg), fluorine (500 mg/kg), vitamin A (220,000 IU/kg), vitamin D_3 (66,000 IU/kg) and vitamin E (200 IU/kg). The animals were fed and managed as a single herd until they were moved to the grazing cells on June 3, 1997, when the experiment began. The average age of the cows at the start of the first year was four years.

The study was repeated in 1998 with 40 cows from the previous year because one of the producers opted out of the project. The two remaining participants supplied the additional 21 cows; these additional animals arrived on the site on November 14, 1997. The animals were managed and fed as a single herd and turned out to pasture on May 15th 1998. Winter feeding management in the second year was similar to the previous year. The average age of the herd in 1998 was five years.

The experiment was conducted as a randomized complete block design with two blocks. The treatments were arranged as a 3 x 3 factorial, the two factors being stocking rate (SR) and rotational frequency (RF) (i.e., the average number of days animals would spend in one paddock). Each factor was applied at three different levels as follows: high SR (0.5 ha per animal), medium SR (0.7 ha per animal) and low SR (0.9 ha per animal); high RF (average of 2d rotational grazing), medium RF (average of 6d rotational grazing) and no rotation (continuous grazing). When assigning the cows to the 18 cells, care was taken to ensure that animals from each owner were represented in each treatment group, but the sex of the calf was not taken into account.

In the east block, three cows were assigned to eight of the nine grazing treatment combinations and two cows were assigned to the remaining treatment combination (high RF/medium SR). In the west block, four animals were assigned to eight of the nine grazing treatment combinations and three cows were assigned to the remaining treatment (medium RF/high SR). It was necessary to adjust the numbers of animals in each grazing cell to achieve the desired stocking rates. Therefore, there were unequal numbers of animals in the different grazing treatments. The statistical model accounted for these unequal numbers of animals in the different grazing cells. With stocking rates of 0.5, 0.7 and 0.9ha/animal, and rotational frequencies of 0, 6 and 2d, the experiment covered not only normal management practices but encompassed the extremes of grazing treatments that might be encountered in pasture management systems for cow-calf operations.

3.3 Pasture and Feeding Management

Each cell was managed as an independent unit but the management procedures were consistent throughout the study. In the continuous grazing treatments, the animals were free to graze the entire area within the cells. Hay was never harvested from these cells. Clipping was carried out once, at the end of July, during both grazing seasons. In 1997, mowing was clipping was performed to a target height of 45 cm in order to prevent heading of grass and to stimulate vegetative regrowth. In 1998, due to mechanical difficulty with the machinery, the target height for clipping was reduced to 15 cm. In the medium RF treatments (6 paddocks), the animals were moved to a new paddock, on average, every six days; in the high RF treatments (16 paddocks), the animals were moved, on average, every two days. An average 30-d rest period was allowed for each paddock between grazing periods.

Hay was harvested as round bales from the rotationally grazed paddocks when there was excess herbage. The hay was harvested using a tractor (model 5500; John Deere & Co. Augusta, GA, USA) fitted with a disc mower-conditioner (Discbine model 411, 1996; New Holland, Grand Island, NE, USA), then with a Rolabar® rake (model 260H, Ford New Holland, New Holland, PA, USA) and Roll-Belt® round baler (model 644; New Holland, Saskatoon, SK, Canada). Supplemental hay was provided in those paddocks where herbage availability was lower than 1 ton DM ha^{-1}. A mineral supplement was provided free choice to all animals on the experiment; the mineral supplement was described previously. Water was available at all times to the animals. The water delivery system consisted of an underground pipe supplying a water bowl (model 25, S.M. Bauman, Wallenstein, ON, Canada) which was mounted in each paddock or grazing cell. A maximum of four cows and their calves had access to a bowl.

A condition for producers' participation in the study was that the animals would achieve a minimum body condition score of 3.0 at the end of the grazing season. Those animals requiring supplemental hay were confined to a particular paddock until there was sufficient herbage to allow the system of rotation to be resumed. The amount of hay consumed was quantified. Representative samples of hay from at least 20 % of the bales harvested were collected using a core sampler (5-cm diameter). Hay samples were dried and ground for chemical analysis in order to assess hay quality.

3.4 Reproductive Management

During the experiment, the animals were managed to ensure successful breeding. A program of estrus synchronization and artificial insemination (AI) was adopted for all cows. Artificial insemination was deemed an appropriate approach to breed the cows, given that they were dispersed among 18 different paddocks. The use of AI also avoided the disrupting presence of one or more bulls on the site. The cows were artificially inseminated at a minimum of 50 days post-calving by experienced technicians from the Centre d'Insémination Artificielle du Québec (St-Hyacinthe, QC, Canada).

During the 1997 season, the estrus synchronization program involved the use of an intrauterine progesterone releasing device (PRID; Sanofi Santé Animale, Canada, Inc., Victoriaville, QC, Canada) and injection of prostaglandin (Lutalyse ®, Upjohn Animal Health, Orangeville, ON, Canada). The PRID was inserted into the uterus and removed after 8 to 10 d; the animal was injected with Lutalyse ® (5 ml) at the time the PRID was removed. The animals were then artificially inseminated 84 to 90 h after prostaglandin injection or at signs of estrus; a «clean-up» bull was used to impregnate those cows which did not respond.

During the 1998 season the method of estrus synchronization was modified by adopting a program of Lutalyse ® injections and milk progesterone assays. All animals were injected with Lutalyse ® at a minimum 45 days after calving and inseminated on signs of estrus. Animals not displaying signs of estrus were re-injected 14 d after first injection then bred on signs of heat or at 84 to 90 h after the second injection of Lutalyse ®. Milk progesterone assays (BioMetallics, Princeton, NJ, USA) were used to confirm cyclicity of the cows prior to the second injection.

Heat detection procedures in both years generally involved observing the cows three times each day (0600, 1200 and 1800) for physical and behavioral signs of estrus; these signs included swollen or colored vulva, vaginal discharges, mounting and standing. Heat detection was also facilitated with the use of Kamar heat mount detectors (Kamar Marketing Group Inc., Steamboat Springs, CO 80477, USA).

Pregnancy was confirmed by rectal palpation 35 to 40 d after breeding.

There was no data collection on reproductive performance of the herd since this was beyond the scope of the study. Nevertheless, body condition scoring was performed and used as an indicator of breeding success.

3.5 Herd Health Management

All animals were kept under veterinary surveillance by professionals from Clinique Vétérinaire St-Louis (St-Louis de Gonzague, QC, Canada). On arrival at the research site, all cows were vaccinated with Triangle 9 ® (Ayerst Veterinary Laboratories, Guelph, ON, Canada) against IBR, BVD, PI-3 and BRSV. They were also treated against diarrhea with Ecolan ® RC (Ayerst Veterinary Laboratories, Guelph, ON, Canada) one month prior to calving. Late in February, the cows were injected with Poten A.D.® (Rogar / STB Inc., Pointe-Claire, QC, Canada) to supply vitamin A (5556 IU kg^{-1} BW) and vitamin D_3 (833 IU kg^{-1} BW). The cows were also injected with Dystosel DS ® (Rogar/STB Inc., Pointe-Claire, QC, Canada), to supply vitamin E (136 IU 90 kg^{-1} BW) and selenium (3 mg 90 kg^{-1} BW). At spring turnout, an insecticide ear tag was applied to all cows (Bovaid, Ciba-Geiry Canada Ltd., Mississauga, ON, Canada). Anthelmintic treatment was not deemed necessary because low fecal egg counts indicated very low worm burden. Cows suffering physical injuries or infections were treated with the antibiotics, Liquamycin LP® and Penlong S® (Rogar/STB Inc, Pointe-Claire, QC, Canada).

All calves were weighed at birth (see Appendix Table 3.1), identified with ear tags and injected (0.5 ml) with Poten A.D.® to supply 250,000 IU of vitamin A and 37,500 IU of vitamin D_3. The calves were also injected with Selon-E® (Vetoquinol Canada Inc, Joliette, QC, Canada) or with Dystosel DS ® to supply 136 IU of vitamin E and 3 mg selenium as a prevention against white muscle disease. Calves which did not suckle or which appeared weak were offered frozen colostrum obtained from dairy cows. At three months of age, all calves were treated with Blacklegol 8® with SPUR® (Miles Canada Inc., Etobicoke, ON, Canada) as prevention against black leg disease. No growth promoters were used since these animals were purebred and kept for reproduction. Male calves were kept intact for reproductive purpose.

3.6 Pasture and Forage Measurements

Samples of herbage were taken to assess forage availability and forage quality during each of the two grazing seasons. Herbage samples were taken from continuously grazed cells at the beginning and in the middle of each month; spot sampling was performed in those cells since the animals had access to the whole grazing cell. In rotationally grazed cells, herbage samples were obtained at the beginning of the month, before the animals entered a paddock (pre-grazing sample) and after they were removed from the paddock (post-grazing sample). This procedure was repeated in the middle of the month.

Herbage sampling was performed by throwing a 0.5 m x 0.5 m quadrant at six random locations within each paddock (or grazing cell); plant material rooted in the quadrant was clipped to 2-3 cm above the ground and placed in bags. The six fresh samples were composited and weighed, and a subsample (500 g) was dried in a forced-air oven (Model LHD2-29; Despatch Industries Inc. Minneapolis, USA) for 24 h at 60 ^{0}C. Forage mass was estimated based on the weight of the herbage in the quadrant and herbage DM content. Forage mass available was determined as the average of forage mass pre-grazing and forage mass post-grazing.

Quality of forage mass available was assessed based on the protein and fibre content of the herbage samples, being obtained by averaging the pre-grazing and post-grazing forage composition. The dried samples were ground in a hammermill (Thomas-Wiley Laboratory Mill, Model 4; Thomas Scientific TM, Philadelphia, USA) to pass through a 1mm sieve. The samples were analyzed for crude protein (CP), acid detergent fibre (ADF) and neutral detergent fibre (NDF) by a commercial laboratory (Daco Laboratories, Stratford, ON, Canada) using procedures of AOAC (1990). Once each month, a sample from each paddock was further analyzed for calcium (Ca), phosphorus (P), potassium (K) and magnesium (Mg). These mineral concentrations were determined using the direct current plasma emission spectrometer method of Isaac and Johnson (1985).

3.7 Animal Performance

All cows and calves were weighed using an electronic twin-beam-scale (Model

U2500, Norca Systems International Inc., Saskatoon, SK, Canada). At the beginning and end of each grazing season the animals were weighed on two consecutive days (see Appendix Table 3.2). Body weights were also taken once in the month of June, and twice in the months of July, August and September to monitor live weight changes.

All cows were assessed for body condition according to the procedure outlined by Field (1985). Tactile assessment was made at the tailhead, hookbone and pinbone regions of the cow; when assigning a score, particular attention was given to the presence of fat at the chine, loin and rump. The scores ranged from 1 to 5, where a score of 1 corresponded to a «very thin», 2 corresponded to a «thin», 3 corresponded to «good condition», 4 corresponded to «moderately fat», and 5 corresponded to «extremely fat». Body condition scoring was performed once each month, at time of weighing.

3.8 <u>Statistical analysis</u>

To remove the influence of season, all data were analyzed for each month separately as a randomized complete block design (Steel and Torrie 1960) with a factorial combination of RF and SR. The effects of RF and SR and the interaction of RF and SR were partitioned into linear and quadratic contrasts (Steel and Torrie 1960). Statistical significance was declared at level of $p<0.05$. For all data pertaining to forage mass available, forage quality and gross revenue, the grazing cells were the experimental units and data was analyzed using the GLM procedure of SAS (1987); the effects of year and block were accounted for in the model. The statistical model used was $Y_{ijkl} = \mu + RF_i + SR_j + RF*SR_{ij} + Block_k + Year_l + \varepsilon$, where μ= mean, RF = rotation frequency effect, SR = stocking rate effect , Block = block effect, Year = year effect and ε = error term.

All data pertaining to animal performance was analyzed using Proc Mixed procedure of SAS (Littel et al. 1996); animals were the experimental units, but the effect of animals was considered random, while rotational frequency, stocking rate and the interaction between RF and SR were considered fixed effects. The model was $Y_{ijkl} = \mu + RF_i + SR_j + RF*SR_{ij} + Block_k + Year_l + Cell_{ijkl} + \varepsilon$, where μ = mean, RF = rotation frequency effect, SR = stocking rate effect, Block = block effect, Year = year effect , Cell = grazing cell random effect, and ε = error term.

4. RESULTS AND DISCUSSION

4.1 Forage Production and Forage Quality

4.1.1 *Forage mass available*

Forage mass available is meant to describe the herbage mass available for consumption by the animals during the grazing period; it characterizes the ability of the different systems to maintain feed in front of the grazing animals. FMA allows the comparison of the average mass of forage that all treatments provide to the grazing animals on a per hectare basis. In the continuously grazed cells, FMA is obtained by spot sampling the herbage two times each month. In the rotationally grazed cells, FMA is obtained by averaging the estimates of herbage mass pre and post-grazing . The estimates of herbage mass pre and post-grazing are presented in Appendix Table 4.4 and Appendix Table 4.5.

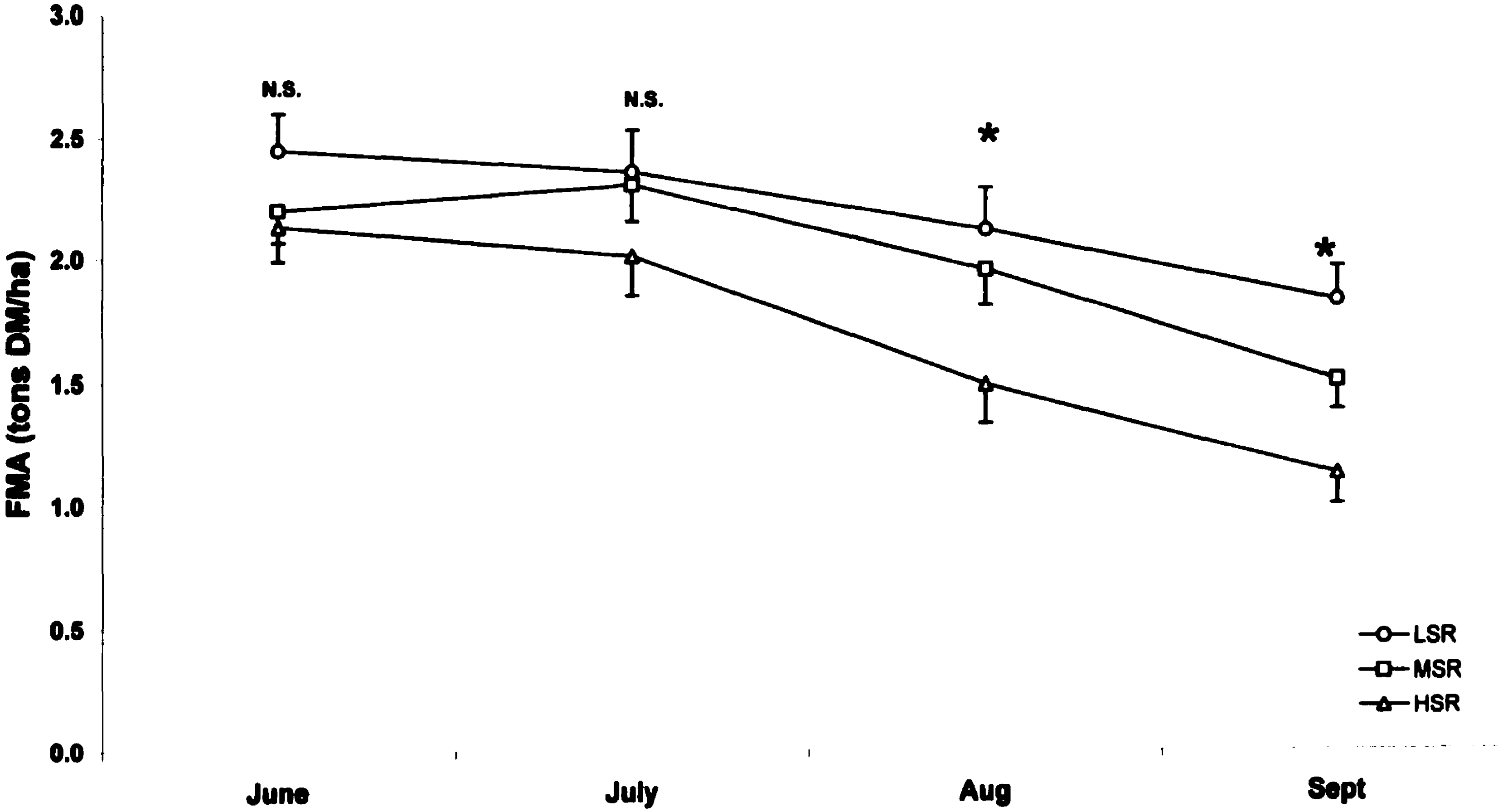
Exclusion cages are the most common approach for attempting to assess forage production under continuous grazing. Large et al. (1985) and Parsons et al. (1984) concluded, however, that by excluding animals from the experimental grazing areas, unreliable estimates of forage production are obtained. Thus, rather than attempting to assess total forage production using the cage technique, the FMA approach was adopted and permitted the comparison of all grazing treatments.

Averaged across stocking rates and rotational frequency, estimates of FMA were 2.27, 2.21, 1.82 and 1.49 t DM ha^{-1} in June, July, August and September respectively. This seasonal decline in FMA represents the normal availability of cool-season perennial grasses (Kunelius and Fraser 1992; Marshall et al. 1998a) under grazing. This seasonal decline in forage availability is presented in Figure 4.1, where the effect of SR on FMA is graphically represented. Since there was no significant interaction ($p>0.05$) between RF and SR on FMA, and since RF had no effect on FMA, the data is represented graphically. The detailed results of both RF and SR are shown in Appendix Table 4.1.

There was a linear reduction in FMA as SR increased in August ($p=0.0245$) and September ($p=0.0019$). This agrees with other studies (Mott 1960; McMeekan and Walshe 1963; Bransby 1989) concluding that stocking rate was the most important factor affecting pasture productivity.

The results of forage protein concentration (CP) and amounts of crude protein available (CPA, expressed in kg of protein ha^{-1}) are presented in Table 4.1. As expected, CP content decreased from June to July due to maturation of the plants. CP content of forage available increased in August and September, when the conditions were more favorable for the growth of cool-season grasses (see Table 3.1). Mean CP concentrations were 11.7, 10.9, 11.7 and 12.6 % respectively for June, July, August and September. The moderate response of CP content compared to results from other studies is likely caused by the use of CP content of available forage during the grazing period. The use of average forage composition is more representative of the forage composition available to the animals than the forage composition of forage at the beginning of a grazing period.

Figure 4.1 Effect of stocking rate on forage mass available (FMA) during four different grazing months.



N.S.= not significant (p>0.05); * = significant at p<0.05.
LSR , MSR and HSR = low, medium and high stocking rates respectively.

Table 4.1. Least square means of crude protein content and protein available (CPA) on pasture during four months under different rotaional frequency (RF) and stocking rates (SR).

	Continuous			6 days			2 days			Significance of Effects (P-values)							
										RF		SR		RF X SR			
	LSR	MSR	HSR	LSR	MSR	HSR	LSR	MSR	HSR	L	Q	L	Q	LxL	LxQ	QxL	QxQ
								Period 1									
CP (%)	11.4	11.7	12.6	11.2	11.5	11.9	12.3	11.5	11.0	0.4190	0.5023	0.6619	0.4971	0.0199	0.8794	0.3280	0.8472
SE	0.44	0.44	0.44	0.44	0.44	0.44	0.65	0.37	0.44								
CPA, kg ha^{-1}	258.7	257.6	274.6	265.7	253.9	285.9	294.9	217.0	162.7	0.1320	0.2538	0.2223	0.4900	0.0320	0.9564	0.1457	0.7918
SE	28.79	28.79	28.79	28.79	28.79	28.79	41.92	23.74	28.79								
								Period 2									
CP (%)	9.8	9.6	10.9	11.2	11.2	13.0	11.5	10.8	10.5	0.2154	0.0257	0.3613	0.2712	0.2215	0.6302	0.2037	0.7246
SE	0.76	0.76	0.76	0.76	0.76	0.76	1.10	0.62	0.76								
CPA, kg ha^{-1}	215.8	200.1	217.6	264.5	273.7	266.2	218.2	239.7	182.3	0.9337	0.0180	0.6946	0.6352	0.5919	0.3005	0.7379	0.9476
SE	30.62	30.62	30.62	30.62	30.62	30.62	44.58	25.25	30.62								
								Period 3									
CP (%)	10.1	10.9	11.2	11.8	12.4	13.2	11.8	11.4	12.3	0.0474	0.0116	0.0703	0.6381	0.6951	0.4070	0.6199	0.9359
SE	0.60	0.60	0.60	0.60	0.60	0.60	0.88	0.50	0.60								
CPA, kg ha^{-1}	222.7	181.6	187.7	247.0	284.4	235.4	204.5	211.1	141.0	0.6449	0.0056	0.1718	0.3604	0.6721	0.2339	0.4858	0.4237
SE	29.33	29.33	29.33	29.33	29.33	29.33	42.71	24.19	29.33								
								Period 4									
CP (%)	10.8	10.8	12.5	14.1	12.9	14.2	12.8	12.8	12.9	0.0658	0.0177	0.4081	0.2499	0.4234	0.5447	0.6433	0.5313
SE	0.88	0.88	0.88	0.88	0.88	0.88	1.28	0.72	0.88								
CPA, kg ha^{-1}	203.4	164.4	148.9	249.3	224.9	199.4	223.1	180.9	103.6	0.8997	0.0123	0.0056	0.9148	0.3090	0.5458	0.4672	0.9542
SE	27.66	27.66	27.66	27.66	27.66	27.66	40.27	22.81	27.66								

LSR, MSR and HSR = low, medium and high stocking rates, respectively.

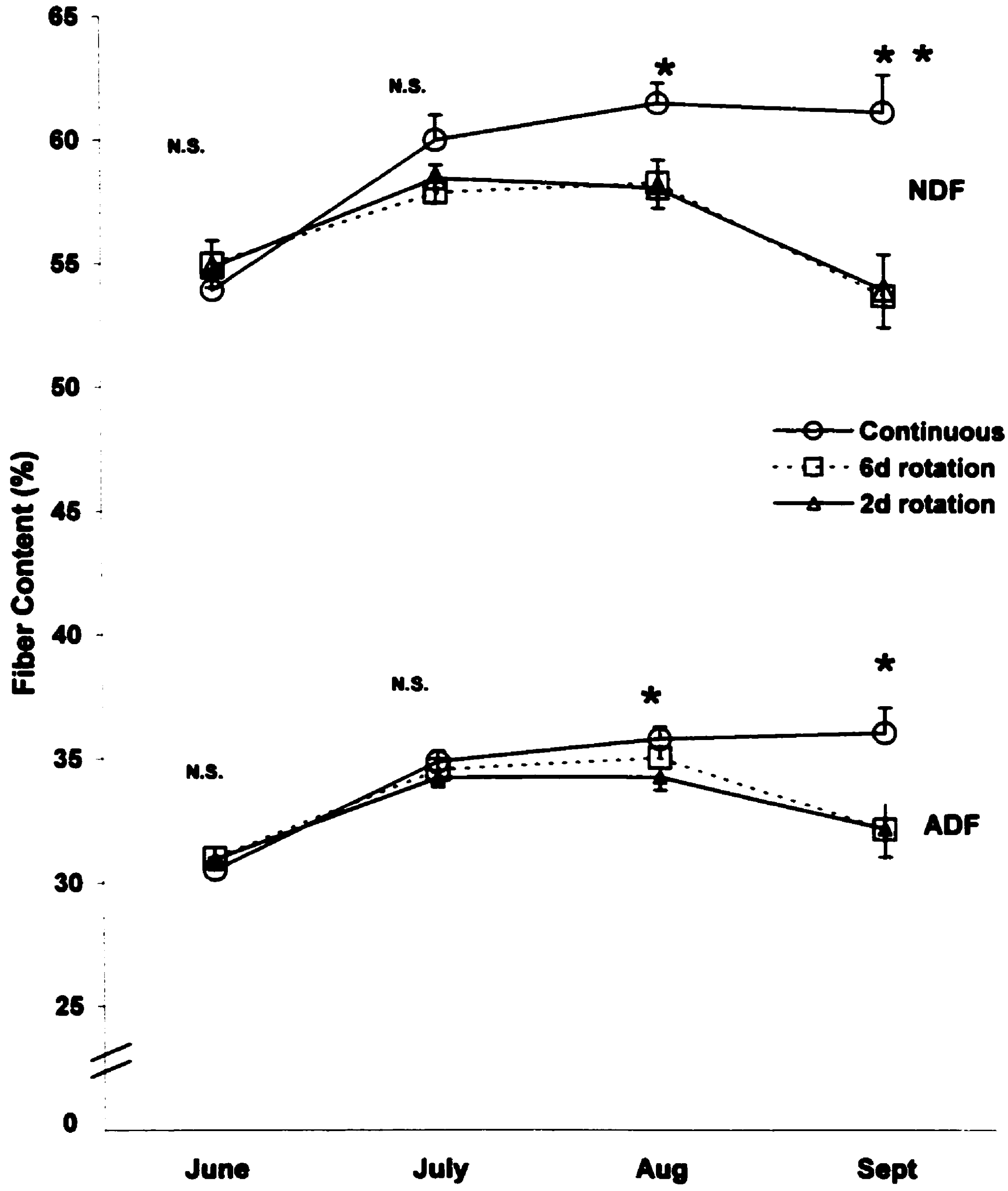
SE = standard error; L = linear; Q = quadratic.

The effects of management on CP and CPA content were not as distinct as they were for FMA. In June, there was a significant (p=0.0199) interaction between RF and SR on CP content. This L X L interaction indicates that increasing the RF increased CP content while increasing SR at high RF resulted in a decrease of CP content. Throughout the rest of the season, there was no interaction (p>0.05) between SR and RF. RF significantly affected CP content of pasture herbage available. In July, August and September, RF had a significant quadratic effect on CP content of the forage with p-values of 0.0257, 0.0116 and 0.0177 for the respective months. This quadratic response was caused by the highest values for CP observed in the 6-d rotational systems. When averaged across stocking rates, estimates of CP content of the pastures on 6-d rotation were 14 to 21 % higher than those for pasture subjected to continuous grazing, and 5 to 8 % higher than those for pasture subjected to 2-d rotation. Bertelsen et al. (1993), comparing continuous vs. rotational grazing of beef heifers, also reported that continuously grazed forage was higher in ADF, NDF and lower in CP compared to rotationally grazed forage, except at the beginning of the season. This absence of response in the first part of the season is due to the rapid growth of forage in all the grazing systems. Maturation of plants results in a decrease in overall quality (Buxton and Russell 1988; Cherney et al. 1992). CP content decreases and the fiber contents (ADF and NDF) increase as the plant matures (Abaye et al. 1994). As expected, the implementation of rotational grazing permitted to increase the CP content of the available pasture forage at the end of the grazing season, as was reported by Walker et al. (1989) and Marshall et al. (1998b). Stocking rate had minimal effects on CP content.

Over the entire season, CPA tended to decrease, a reflection of the seasonal decline in FMA. This forage quality parameter was derived from FMA and the CP content of forage. The changes in forage CPA would be expected to reflect the changes in FMA during the season. Like CP, CPA was affected by an interaction between RF and SR in June ($p=0.0320$). As for FMA, RF had a quadratic effect on CPA in July, August and September, with respective P-values of $p=0.0180$, $p=0.0056$ and $p=0.0123$. Stocking rate had a significant linear effect ($p=0.0056$) on CPA in September. CPA was observed to be highest in the 6-d grazing systems during the four months.

A graphical representation of the effect of RF on fibre content of pasture available is presented in Figure 4.2 and the data are presented in Table 4.2 as least square means. ADF and NDF contents are related and they responded similarly to pasture management. ADF content of forage available was significantly linearly affected by RF in the second part of the grazing season, in August ($p=0.0402$) and September ($p=0.0178$). NDF content of forage available was affected by RF in August ($p=0.0101$) and September ($p=0.0041$). In August, SR had a significant quadratic effect ($p<0.05$) on NDF content. Fiber content increased during the grazing season, according to the maturation of cool-season grasses (Cherney et al. 1992). The implementation of rotational grazing probably helped to maintain the sward in a more

Figure 4.2
Effects of rotational frequency on ADF and NDF content during a four-month grazing season.



N.S.= not significant (p>0.05); * = significant at p<0.05; ** = significant at p<0.01.

Table 4.2. Least square means of fiber content of pasture during four months under different rotational frequency (RF) and stocking rates (SR).

	Continuous			6 days			2 days		
	LSR	MSR	HSR	LSR	MSR	HSR	LSR	MSR	HSR
Period 1									
ADF, %	30.1	31.5	29.9	31.0	31.0	31.1	30.9	31.2	30.8
SE	0.73	0.73	0.73	0.73	0.73	0.73	1.06	0.60	0.73
NDF, %	54.3	56.3	51.2	55.5	55.2	54.4	53.7	55.7	55.2
SE	1.45	1.45	1.45	1.45	1.45	1.45	2.11	1.19	1.45
Period 2									
ADF, %	35.0	35.6	34.1	34.0	34.9	34.9	33.4	34.9	34.5
SE	0.61	0.61	0.61	0.61	0.61	0.61	0.88	0.50	0.61
NDF, %	59.8	61.6	58.8	56.9	59.0	57.8	58.0	58.7	58.8
SE	1.72	1.72	1.72	1.72	1.72	1.72	2.51	1.42	1.72
Period 3									
ADF, %	35.6	35.9	36.0	35.1	35.4	34.6	33.4	35.4	34.0
SE	0.82	0.82	0.82	0.82	0.82	0.82	1.20	0.68	0.82
NDF, %	61.5	62.6	60.5	58.1	59.3	57.7	56.5	60.4	57.6
SE	1.42	1.42	1.42	1.42	1.42	1.42	2.07	1.17	1.42
Period 4									
ADF, %	36.6	36.5	35.2	32.3	31.4	32.8	31.8	34.5	30.3
SE	1.77	1.77	1.77	1.77	1.77	1.77	2.58	1.46	1.77
NDF, %	62.4	63.0	58.2	52.9	53.3	55.1	53.0	57.3	51.8
SE	2.64	2.64	2.64	2.64	2.64	2.64	3.84	2.17	2.64

	Significance of Effects (P-values)							
	RF		SR		RF X SR			
	L	Q	L	Q	LxL	LxQ	QxL	QxQ
Period 1								
ADF, %	0.4949	0.6187	0.9068	0.2822	0.9400	0.3605	0.8645	0.3781
NDF, %	0.4605	0.5650	0.4842	0.1109	0.1681	0.3825	0.9215	0.3268
Period 2								
ADF, %	0.2118	0.9938	0.4761	0.0631	0.1780	0.9019	0.4746	0.5630
NDF, %	0.3097	0.2884	0.8764	0.2605	0.6489	0.4896	0.7632	0.8852
Period 3								
ADF, %	0.0402	0.9978	0.8147	0.1894	0.9350	0.2781	0.5000	0.7436
NDF, %	0.0101	0.1581	0.9443	0.0436	0.5251	0.4990	0.8397	0.6433
Period 4								
ADF, %	0.0178	0.1371	0.6212	0.4489	0.9751	0.3478	0.5552	0.2314
NDF, %	0.0041	0.0540	0.6504	0.2312	0.6312	0.6390	0.3169	0.2628

LSR, MSR and HSR = low, medium and high stocking rates, respectively.

SE = standard error; L = linear; Q = quadratic.

vegetative stage later in the season. In this experiment, the grazing management of 6d rotational grazing provided the animals with more forage of higher quality.

Table 4.3 presents the results of fiber mass available. This measure of forage quality was also derived using FMA and the fiber content (ADF % and NDF %) of the forage, and the changes in fiber mass available would be expected to reflect the changes in FMA during the season. There was a significant interaction of RF and SR in June and August ($p<0.05$). SR had a significant effect ($p<0.01$) on fiber mass in September. Fiber mass was lowest throughout the season in the HSR treatments compared to LSR and MSR. It was also lowest in 2d compared to 6d and Cont throughout the season, in variance with FMA.

4.1.2 *Hay production and supplementation*

One of the benefits of rotational grazing may be the provision of forage for harvesting and use in times of low pasture availability. In this experiment, implementation of the rotation schedule permitted the harvest of some hay during the rapid spring growth of forage, when it was in excess of animal needs. On average, 0.7 tons per hectare were harvested, but the vast majority of hay was harvested from the 6-d rotational grazing systems at low and medium SR (see Table 4.4).

Hay supplementation was necessary to sustain the animals in August and September in 1997, and in July, August and September in 1998. Supplementation of hay probably moderated the effects of HSR on forage availability. Lower forage

Table 4.3. Least square means of forage fiber produced from pasture during four months under different rotational frequency (RF) and stocking rates (SR).

	Continuous			6 days			2 days			Significance of Effects (P-values)							
										RF		SR		RF X SR			
	LSR	MSR	HSR	LSR	MSR	HSR	LSR	MSR	HSR	L	Q	L	Q	LxL	LxQ	QxL	QxQ
								Period 1									
ADF, kg ha^{-1}	728.2	765.0	713.9	773.4	732.7	808.6	823.9	634.6	487.9	0.1522	0.1187	0.0952	0.8077	0.0472	0.5851	0.1003	0.5016
SE	68.08	68.08	68.08	68.08	68.08	68.08	99.13	56.13	68.08								
NDF, kg ha^{-1}	1310.7	1369.5	1225.3	1378.3	1301.8	1404.1	1428.8	1119.6	863.4	0.1175	0.1066	0.0572	0.9542	0.0831	0.5349	0.1113	0.4779
SE	117.49	117.49	117.49	117.49	117.49	117.49	171.06	96.88	117.49								
								Period 2									
ADF, kg ha^{-1}	795.6	775.9	698.0	909.2	894.4	736.3	657.8	770.8	657.5	0.5027	0.1202	0.3385	0.3418	0.6826	0.6451	0.5167	0.9972
SE	104.01	104.01	104.01	104.01	104.01	104.01	151.44	85.77	104.01								
NDF, kg ha^{-1}	1368.3	1340.3	1205.6	1538.2	1517.6	1201.2	1143.6	1297.5	1120.3	0.4415	0.1800	0.2707	0.3299	0.7262	0.7130	0.4462	0.8844
SE	174.01	174.01	174.01	174.01	174.01	174.01	253.36	143.49	174.01								
								Period 3									
ADF, kg ha^{-1}	848.5	624.1	616.6	721.3	794.6	584.1	532.3	671.2	339.6	0.0254	0.1512	0.0255	0.1654	0.8463	0.0343	0.6437	0.5601
SE	88.62	88.62	88.62	88.62	88.62	88.62	129.04	73.08	88.62								
NDF, kg ha^{-1}	1472.6	1080.9	1036.2	1190.2	1327.1	963.2	895.6	1136.2	573.6	0.0140	0.2294	0.0165	0.1291	0.7277	0.0294	0.5636	0.5327
SE	143.67	143.67	143.67	143.67	143.67	143.67	209.18	118.47	143.67								
								Period 4									
ADF, kg ha^{-1}	713.0	578.2	423.8	560.9	521.9	448.0	556.8	482.0	261.3	0.0732	0.9010	0.0053	0.5860	0.9740	0.6732	0.2577	0.8531
SE	85.55	85.55	85.55	85.55	85.55	85.55	124.56	70.55	85.55								
NDF, kg ha^{-1}	1217.2	1000.2	708.0	916.9	880.3	752.3	935.9	797.2	456.0	0.0547	0.9798	0.0051	0.5424	0.9277	0.7965	0.2079	0.9118
SE	140.93	140.93	140.93	140.93	140.93	140.93	205.20	116.21	140.93								

LSR, MSR and HSR = low, medium and high stocking rates, respectively.

SE = standard error; L = linear; Q = quadratic.

Table 4.4 Amounts of hay (kg DM/ha) harvested and supplemented monthly in different cells in 1997 and 1998.

Cell	Management RF[1]	SR[2]	Hay Supplemented (kg DM/ha) July	August	Sept	Hay harvested (kg DM/ha) June	July
				1997			
1	Cont	HSR	0	530	1172	0	0
10	Cont	HSR	0	0	0	0	0
5	Cont	MSR	0	276	717	556	0
18	Cont	MSR	0	0	615	603	0
2	Cont	LSR	0	0	0	0	0
17	Cont	LSR	0	0	230	803	0
8	6d	HSR	0	0	0	1649	0
12	6d	HSR	0	0	0	1633	0
6	6d	MSR	0	0	0	1529	0
11	6d	MSR	0	0	0	0	0
9	6d	LSR	0	0	0	1140	0
14	6d	LSR	0	0	428	1485	0
3	2d	HSR	0	0	0	1213	0
15	2d	HSR	0	0	0	1666	0
4	2d	MSR	0	0	565	0	0
7	2d	MSR	0	0	247	560	0
16	2d	MSR	0	0	0	0	0
13	2d	LSR	0	0	149	0	0
				1998			
1	Cont	HSR	287	436	954	0	0
10	Cont	HSR	0	0	0	0	0
5	Cont	MSR	0	0	708	0	0
18	Cont	MSR	0	0	0	434	0
2	Cont	LSR	0	0	0	0	0
17	Cont	LSR	0	0	0	177	0
8	6d	HSR	0	0	0	289	566
12	6d	HSR	0	0	198	325	0
6	6d	MSR	0	0	0	700	392
11	6d	MSR	0	0	0	0	0
9	6d	LSR	0	0	0	0	502
14	6d	LSR	0	0	607	392	301
3	2d	HSR	0	0	0	456	0
15	2d	HSR	0	0	0	248	0
4	2d	MSR	500	103	804	0	0
7	2d	MSR	0	0	0	323	0
16	2d	MSR	0	0	0	0	0
13	2d	LSR	0	0	393	0	0

[1] RF = rotational frequency, where Cont = continuous, 6d = 6-day rotational grazing, 2d = 2-day rotational grazing

[2] SR = stocking rate, where LSR, MSR and HSR = .9, .7 and .5 ha per cow-calf pair, respectively.

availability results in lower herbage allowance to the animals (Volesky et al. 1994), which can compromise animal performance. When forage availability is lower than 1000 kg DM ha $^{-1}$, cow performance is at risk (Marshall et al. 1998a). Hay was supplemented in those paddocks where SR limited forage availability (see Table 4.4). Animals in CONT at HSR were supplemented as early as 60 days after the onset of the grazing season in both 1997 and 1998.

The quality of hay supplemented is presented in Table 4.5. The quality of hay harvested from experimental and non-experimental areas in 1997 and 1998 is reported in Appendix Table 4.2 and Appendix Table 4.3 respectively. The amounts and quality of hay harvested and fed was not subjected to statistical analysis.

4.2 Animal Performance and Productivity

4.2.1 *Animal performance per head*

The ultimate measure of pasture quality is animal performance. Different classes of animals have different nutritional needs and will respond differently to management. Aiken and Bransby (1991) reported that individual animal performance decreased as SR increased, but that the decline in individual animal performance was more severe for steers than for cows and calves.

The results of animal performance per head are presented in Table 4.6. Cow performance per head was affected by RF in June (p=0.0158) and July (p=0.0171). The lower performance observed for the rotationally vs. continuously grazed animals

Table 4.5. Chemical composition (% DM) of hay supplemented in 1997 and 1998.

% DM	1997[a]	1998[b]
CP	10.1	12.7
ADF	40.7	33.6
NDF	63.0	57.3
Ca	0.54	0.53
P	0.21	0.22
Mg	0.24	0.19
K	2.08	2.10

[a] Mean of 4 samples in 1997.

[b] Mean of 10 samples in 1998.

Table 4.6. Least square means of live weight change (LWC) for cow-calf pairs grazing pasture during four months under different rotational frequency (RF) and stocking rates (SR).

	Continuous			6 days			2 days			Significance of Effects (P-values)							
										RF		SR		RF X SR			
	LSR	MSR	HSR	LSR	MSR	HSR	LSR	MSR	HSR	L	Q	L	Q	LxL	LxQ	QxL	QxQ
Period 1																	
Cow LWC, kg	59.1	57.7	59.5	51.0	53.3	45.2	53.2	43.4	30.1	0.0158	0.9088	0.1758	0.7514	0.1784	0.8093	0.7025	0.6752
SE	7.89	7.89	7.89	7.89	7.89	8.51	10.79	6.96	7.89								
Calf LWC, kg	56.7	49.3	52.6	54.1	40.2	53.9	52.1	51.2	49.9	0.5504	0.2795	0.4552	0.0155	0.8073	0.3805	0.5993	0.0358
SE	3.07	3.64	2.78	2.93	3.71	2.88	5.83	3.23	2.93								
Period 2																	
Cow LWC, kg	7.0	5.9	7.7	22.1	10.4	17.6	10.8	15.5	23.6	0.0171	0.1534	0.4754	0.2183	0.2439	0.9724	0.1935	0.2724
SE	4.72	4.72	4.72	4.72	4.72	5.10	6.46	4.17	4.72								
Calf LWC, kg	35.4	31.9	34.7	31.5	35.3	35.2	30.1	34.2	30.7	0.1856	0.414 4	0.4843	0.5647	0.7652	0.0588	0.2769	0.6287
SE	2.12	2.21	1.91	1.84	2.21	2.00	2.79	1.84	1.84								
Period 3																	
Cow LWC, kg	13.8	11.4	18.0	4.9	5.1	6.8	22.4	12.2	-5.2	0.2802	0.0757	0.1038	0.8764	0.0044	0.3469	0.1354	0.9640
SE	4.96	4.96	4.96	4.96	4.96	5.35	6.78	4.37	4.96								
Calf LWC, kg	36.8	36.3	33.9	38.6	37.3	39.8	38.3	36.4	32.9	0.9102	0.0433	0.1548	0.9593	0.5545	0.9670	0.1196	0.3336
SE	1.95	2.27	1.87	1.80	1.80	2.03	2.64	1.81	1.88								
Period 4																	
Cow LWC, kg	10.7	0.1	-2.8	22.3	16.0	7.2	16.3	11.2	11.4	0.0070	0.0234	0.0049	0.5730	0.3729	0.8711	0.4692	0.4888
SE	4.37	4.37	4.37	4.37	4.37	4.71	5.97	3.85	4.37								
Calf LWC, kg	42.7	36.6	41.0	42.6	46.0	44.5	43.7	39.7	40.1	0.5163	0.0059	0.4821	0.2132	0.6374	0.3755	0.1728	0.0279
SE	1.91	2.12	1.84	1.77	1.77	1.91	2.58	1.61	1.77								

LSR, MSR and HSR = low, medium and high stocking rates, respectively.

SE = standard error; L = linear; Q = quadratic.

may have been due to decreased forage intake and decreased defoliation events (Derner et al. 1994). Rotational grazing results in greater grazing pressure and thus lower forage availability, cows are sensitive to forage restriction (Rouquette 1988). Continuously grazed animals are allowed to graze selectively, and thus graze more forage of higher quality. In this study, most of cow gain occurred in the first part of the season. A similar observation was made by Martz et al. (1992).

In August, a linear X linear interaction between RF and SR was observed (p=0.0044). In September, RF and SR independently affected individual cow performance: a linear effect of SR (p=0.0049) and quadratic effect of RF (p=0.0234) were observed. These results are in agreement with Bransby and Sladden (1991) who reported a weak response of cows and calves to SR. A computer simulation by Woodward et al. (1995) has shown that increasing time period between grazing events increases herbage intake, whereas increasing paddocks number decreases herbage intake; at some point, increasing subdivision will restrict animal intake more than it increases additional pasture growth. They concluded that a small number of paddocks is sufficient to maximize intake (Woodward et al. 1995).

In this trial, individual calf performance was affected by a quadratic X quadratic interaction between RF and SR in June (p=0.0358) and September (p=0.0279). In August, a quadratic effect of RF (p=0.0433) was observed for calf performance. The quadratic effect was due to higher calf gains in the 6d rotational system. It is thought that grazing management has little impact on calf performance

(Knight et al. 1990). Aiken and Bransby (1991) showed that the ADG for calves did not respond to SR. Bertelsen et al. (1993) reported that increasing from 6 to 11 paddocks did not alter calves' ADG.

Overall, the provision of higher quality herbage in the 6d rotational system resulted in better individual animal performance. Hirschfeld et al. (1996) concluded that livestock under proper rotational grazing can eat more high quality forage, resulting in improved animal performance.

4.2.2 *Animal performance per hectare*

The results of animal performance in relation to land area are presented in Table 4.7. SR and RF affected cow performance per hectare in June and July. In June, linear effects of RF ($p=0.0069$) and SR ($p=0.0068$) were observed: increasing RF decreased gains per hectare, while increasing SR increased the gain per hectare. In July, a linear effect of RF ($p=0.0088$) and a linear effect of SR were observed, but increasing RF resulted in increased (or maintained) gain per ha. In August, a linear X linear interaction of RF and SR ($p=0.0012$) significantly affected cow performance per hectare. In September, only RF had a significant ($p=0.0044$) effect on cow performance per hectare.

With regard to cow performance per ha, continuous grazing outperformed rotational grazing in the first month. This was probably due to the high selectivity opportunity for those animals continuously grazed. The rotational systems maintained

Table 4.7. Least square means of animal productivity (LWC ha^{-1}) for cow-calf pairs grazing pasture during four months under different rotational frequency (RF) and stocking rates (SR).

	Continuous			6 days			2 days			Significance of Effects (P-values)							
										RF		SR		RF X SR			
	LSR	MSR	HSR	LSR	MSR	HSR	LSR	MSR	HSR	L	Q	L	Q	LxL	LxQ	QxL	QxQ
									Period 1								
Cow LWC, kg ha^{-1}	68.0	92.9	124.1	58.3	83.7	92.2	63.2	67.4	65.4	0.0069	0.8194	0.0068	0.7562	0.0547	0.7753	0.8388	0.6356
SE	12.62	12.62	12.62	12.62	12.62	13.61	17.26	11.13	12.62								
Calf LWC, kg ha^{-1}	67.0	80.1	109.3	66.0	64.8	110.4	60.1	81.3	103.1	0.4903	0.4927	0.0001	0.0311	0.9670	0.5184	0.8711	0.0558
SE	5.82	6.89	5.27	5.56	7.03	5.46	11.06	6.13	5.56								
									Period 2								
Cow LWC, kg ha^{-1}	8.2	9.4	15.0	25.2	14.7	37.8	11.8	24.4	49.6	0.0088	0.2822	0.0066	0.1315	0.0745	0.7627	0.4999	0.2882
SE	7.80	7.80	7.80	7.80	7.80	8.41	10.67	6.88	7.80								
Calf LWC, kg ha^{-1}	41.2	51.3	73.4	36.5	54.9	72.3	35.4	53.7	64.8	0.2052	0.6352	0.0001	0.8114	0.7213	0.1500	0.4233	0.7658
SE	3.84	4.00	3.46	3.34	4.00	3.62	5.07	3.34	3.34								
									Period 3								
Cow LWC, kg ha^{-1}	16.4	18.2	39.9	6.0	9.0	15.5	28.4	19.4	-11.8	0.0875	0.1954	0.7567	0.9733	0.0012	0.1659	0.2684	0.8571
SE	8.70	8.70	8.70	8.70	8.70	9.39	11.90	7.67	8.70								
Calf LWC, kg ha^{-1}	42.2	59.2	71.5	44.0	57.3	82.6	43.0	57.0	68.6	0.6344	0.0782	0.0001	0.7422	0.6240	0.8565	0.0719	0.1363
SE	3.48	4.05	3.33	3.22	3.22	3.63	4.71	3.22	3.35								
									Period 4								
Cow LWC, kg ha^{-1}	12.4	0.3	-6.0	24.6	23.1	12.8	16.2	17.5	24.0	0.0044	0.0612	0.2215	0.9348	0.0842	0.9761	0.6038	0.4908
SE	6.80	6.80	7.06	6.80	6.80	7.34	9.31	6.00	6.80								
Calf LWC, kg ha^{-1}	49.4	60.3	86.3	48.6	71.0	91.4	50.2	62.3	84.1	0.9378	0.0207	0.0001	0.0754	0.6499	0.6151	0.1541	0.1008
SE	3.01	3.33	2.88	2.78	2.78	3.00	4.06	2.53	2.78								

LSR, MSR and HSR = low, medium and high stocking rates, respectively.

SE = standard error; L = linear; Q = quadratic.

better performance later in the grazing season, as is shown clearly by the performance of rotationally grazed cows in September. The performance of animals in the continuous systems in August was influenced by the start of supplemental feeding to the animals grazed continuously at HSR. Hull et al. (1967) also had to supplement heavily stocked steers grazing continuously since forage availability was lower than animals requirements, whereas rotational grazing provided the animals with enough forage. Hay supplementation could have masked the effects of SR on animal performance in the latter part of the grazing season. The impact of supplemental feeding on system efficiency is captured in the calculation of the net revenue per hectare (see Table 4.9).

No interaction between SR and RF ($p>0.05$) was detected on calves' gain per ha. RF had a significant quadratic effect ($p=0.0207$) on calves' productivity per hectare only in September. The 6-d rotation system yielded more calf gain per hectare than any other rotational systems during the months of August and September. These results are likely attributable to the higher quality of pasture in the 6-d rotational grazing systems.

SR had a quadratic effect on calf gain ha^{-1} in June ($p=0.0311$). In each of the subsequent periods, the calf gain ha^{-1} was linearly affected by SR (p=0,0001). The HSR treatments outyielded other SR in all four periods, resulting in a total of 153 kg and 339 kg of weight gain per hectare for cows and calves respectively, compared to 113 and 195, and 127 and 251 kg ha^{-1} for LSR and MSR respectively. Higher management usually results in a drastic increase in productivity per land area (Bagley et al. 1995).

4.2.3 *Body condition score of cows*

Table 4.8 presents the data pertaining to the body condition score (BCS) of the cows. Visual scoring of animals is considered a subjective measure of animal condition, but is a better tool than BW to evaluate cows' nutritional status while not accounting for frame score (Paradis 1997). Body condition score has proven to be a good indicator of the reproductive capacity of the animals; very thin animals have low reproductive capacity and their anoestrous period is longer compared to cows in better condition. SR has been shown to affect BCS in some experiments (Paradis 1997). In this experiment, BCS was not affected by grazing method ($p>0.05$) in any of the four periods. Estimates of BCS were 3.0, 3.1, 3.2 and 3.3 for June, July, August and September respectively. This seasonal increase in BCS is graphically represented in Figure 4.3. This increasing BCS is favorable for reproduction since animals gaining or maintaining body condition have shorter anoestrous interval than cows loosing condition score (Paradis 1997). Moreover, the producers involved in our experiment did not want the animals to lose BCS under experimental conditions. Hay supplementation could have masked potential detrimental effects of some pasture management combinations on BCS. The body condition score was high enough to facilitate reproduction (BCS>3.0), and would facilitate winter nutrition. This is very

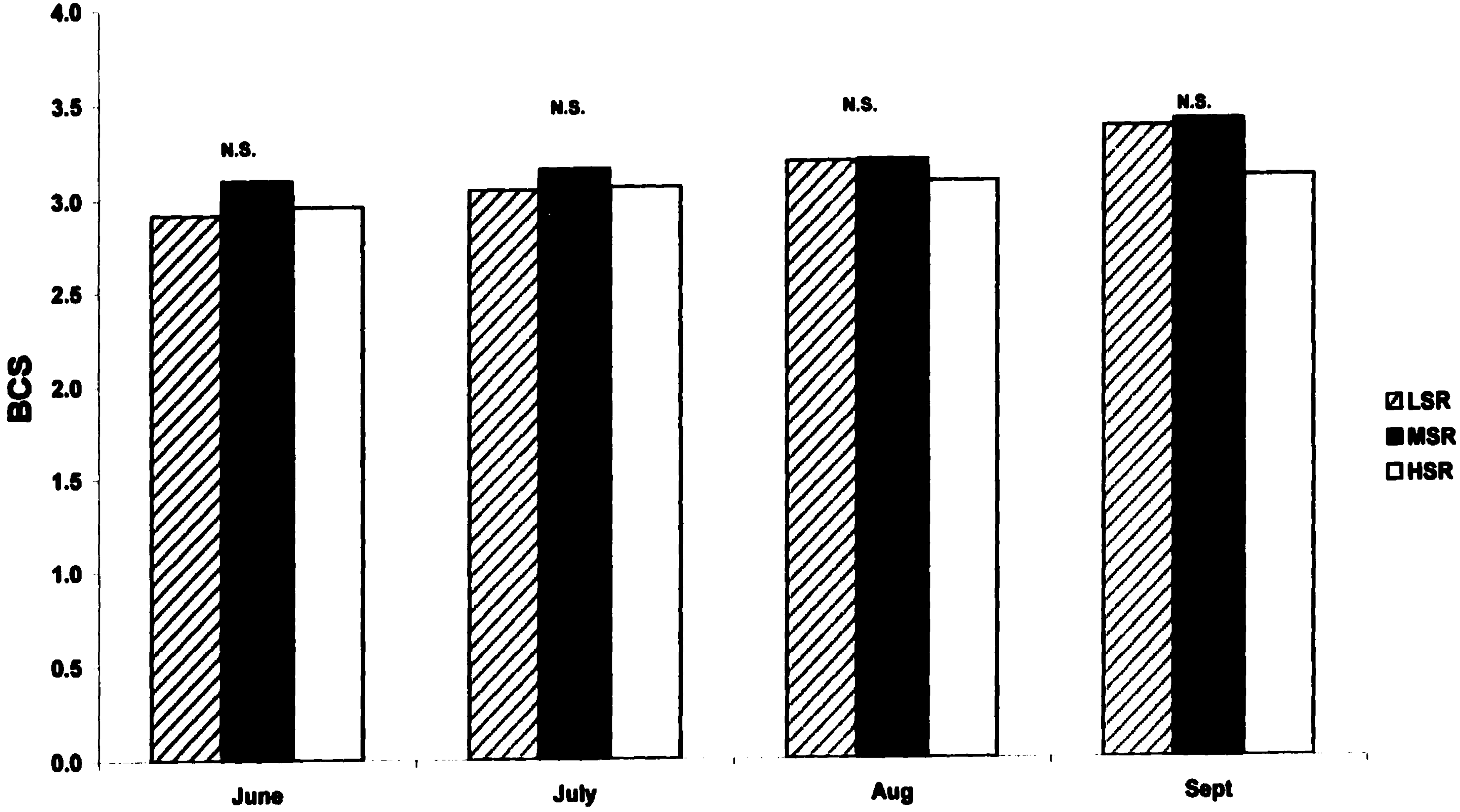
Table 4.8. Least square means of body condition score (BCS) for cows grazing pasture during four months under different rotational frequency (RF) and stocking rates (SR).

	Continuous			6 days			2 days			Significance of Effects (P-values)							
										RF		SR		RF X SR			
	LSR	MSR	HSR	LSR	MSR	HSR	LSR	MSR	HSR	L	Q	L	Q	LxL	LxQ	QxL	QxQ
										Period 1							
BCS	3.0	3.1	2.9	2.8	3.2	3.2	2.9	3.0	2.8	0.4749	0.3861	0.7122	0.1021	0.9963	0.9514	0.1053	0.8727
SE	0.14	0.14	0.14	0.14	0.14	0.15	0.19	0.12	0.14								
										Period 2							
BCS	3.1	3.3	3.2	3.1	3.0	3.1	3.0	3.2	3.0	0.2410	0.5449	0.8935	0.2962	0.7606	0.7206	0.7545	0.1922
SE	0.14	0.14	0.14	0.14	0.14	0.15	0.19	0.12	0.14								
										Period 3							
BCS	3.1	3.3	3.3	3.3	3.2	3.2	3.2	3.1	2.8	0.0569	0.3139	0.3452	0.5015	0.0753	0.8353	0.8412	0.4441
SE	0.13	0.13	0.13	0.13	0.13	0.14	0.17	0.11	0.13								
										Period 4							
BCS	3.4	3.4	3.3	3.4	3.4	3.1	3.3	3.4	2.9	0.1797	0.9555	0.0510	0.1266	0.4275	0.3617	0.9904	0.9749
SE	0.15	0.15	0.15	0.15	0.15	0.16	0.20	0.13	0.15								

LSR, MSR and HSR = low, medium and high stocking rates, respectively.

SE = standard error; L = linear; Q = quadratic.

Figure 4.3 Effects of stocking rate on body condition score (BCS) of cows during a four-month grazing season.



N.S.= not significant ($p>0.05$).
LSR , MSR and HSR = low, medium and high stocking rates respectively.

important since the reproduction of beef cows is the limiting factor in the beef cattle industry (Dziuk and Bellows 1983) and that the wintering costs represent a major expense for the cow-calf industry.

4.3 System Net Revenue and Revenue Analysis

The calculation of net revenue (NR) is intended to capture some of the economic forces determining producer satisfaction with grazing systems, even though monetization has its limitations (Antle and Wagenet 1995). By accounting for hay production and supplementation in addition to animal performance, the optimum response is being defined not by a single production function (e.g. cow live weight change or calf weight gain) but by a combination of outcome variables ultimately reflected in NR. It must be noted, however, that the calf weight gain is an important variable influencing NR because it is the main source of income to the cow-calf producers. Indeed, a complete system is not necessarily the simple summation of all its parts (Burton Jr. et al. 1984).

For the calculation of net revenue, the cows and calves weight gains were monetized at the average annual price for the respective classes of animals (AAFC 1998; AAFC 1999), and the revenue generated from hay production was calculated with the price obtained for hay at Macdonald Campus Farm. Prices used were the annual average prices for Quebec in 1997 and 1998 contained in Table 4.9. The least square means for the net revenue generated from the different pasture management

Table 4.9 Prices for selected farm commodities in 1997 and 1998.

Farm commodity	1997	1998
Calves, $/100lbs liveweight	85.69[1]	144.39[2]
Culled cows, $/100 lbs liveweight	39.39[1]	47.79[2]
Hay, $/bale [3,4]	35	20
$/kg DM [3]	0.12	0.07

[1] AAFC 1998.

[2] AAFC 1999.

[3] Average price for hay sold at Macdonald Campus Farm.

[4] Bale of 360 kg.

systems are presented in Table 4.10. There was no interaction between SR and RF in any of the four periods of the grazing season. Both SR and RF had distinct effects on net revenue. RF had a quadratic effect on NR in June ($p<0.05$) and September ($p<0.01$), due to the better performance of the 6-d rotational system. SR was significant in all four periods ($p<0.05$); there was a linear increase in net revenue as SR increased. The highest net revenue was observed with the combination of 6-d rotational grazing and HSR, returning 32 % more than the next best system (6-d rotation at MSR) and over 100 % more than the lowest performing system (continuous grazing at LSR). Production stability is greater under moderate stocking, as seen in periods July, August and September, in Figure 4.4, but greatest returns were achieved under high stocking rates (Knight et al. 1990). The use of multiple SR allowed measurement of greater responses and could be used to simulate wider array of economic conditions (Bransby 1989). When interpreting and extrapolating economic data from grazing experiments, care should be taken since the revenue is SR dependent for rotational grazing systems, whereas it is independent for continuous grazing systems (Gerrish et al. 1992).

These results suggest that hay supplementation can be profitable in highly stocked systems by maintaining acceptable animal performance and generating more net revenue. The profitable SR will depend on the limiting factor of the farm (labor, land, accessibility to supplemental feed, etc.).

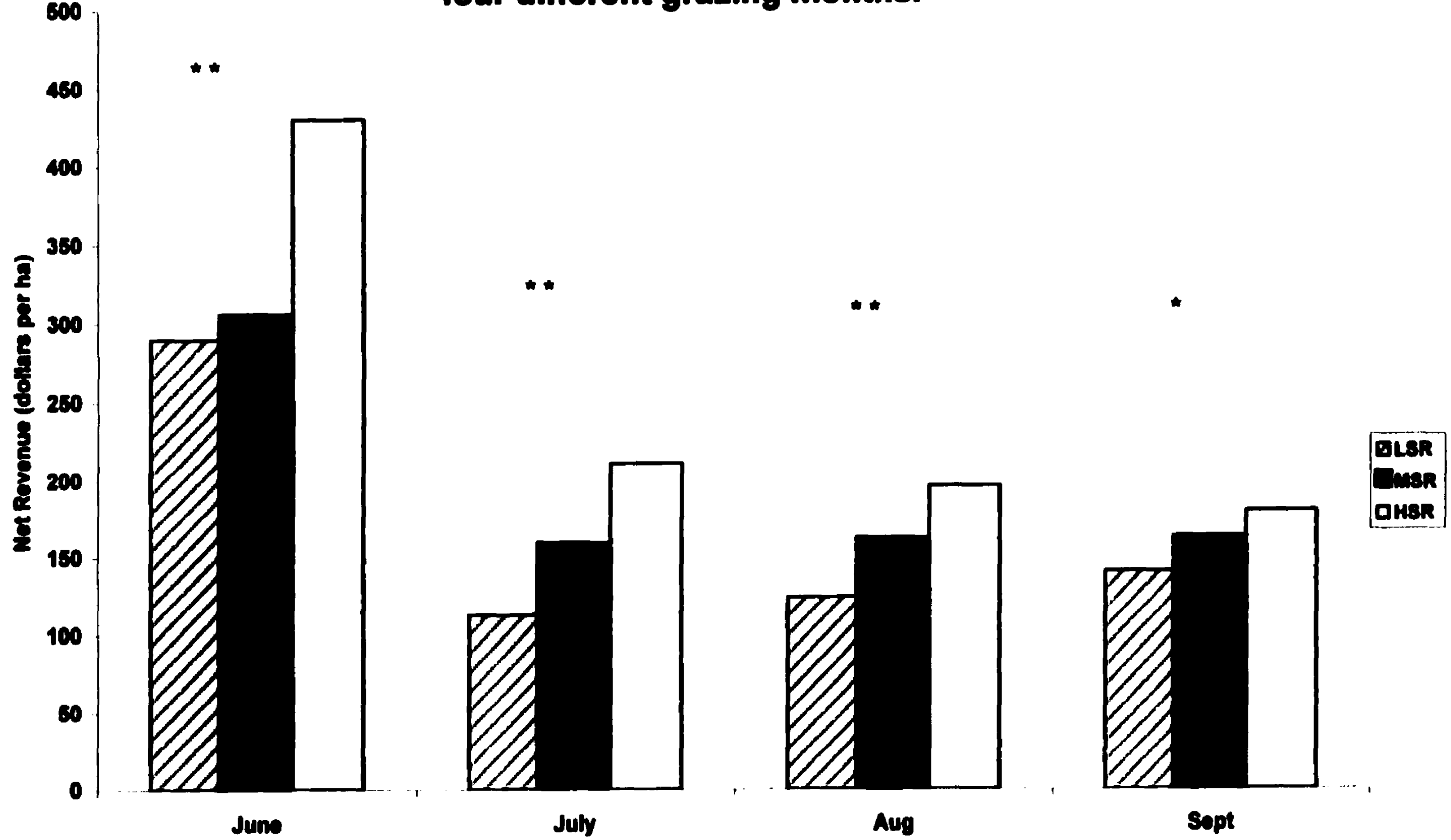
Table 4.10. Least square means for system net revenue during four months under different rotational frequency (RF) and stocking rates (SR).

	Continuous			6 days			2 days			Significance of Effects (P-values)							
										RF		SR		RF X SR			
	LSR	MSR	HSR	LSR	MSR	HSR	LSR	MSR	HSR	L	Q	L	Q	LxL	LxQ	QxL	QxQ
								Period 1									
Revenue, $ ha^{-1}	230.90	285.46	439.84	331.63	340.23	493.14	306.48	288.42	356.61	0.9589	0.0142	0.0002	0.0506	0.0508	0.9148	0.6230	0.6513
SE	33.808	33.808	33.808	39.465	39.495	33.808	49.472	34.982	33.808								
								Period 2									
Revenue, $ ha^{-1}	115.20	138.73	196.25	119.28	158.94	230.10	103.71	176.27	207.67	0.5073	0.4047	0.0001	0.7919	0.6415	0.3222	0.6418	0.5908
SE	21.483	21.483	21.483	21.483	21.483	21.483	31.280	17.716	21.483								
								Period 3									
Revenue, $ ha^{-1}	122.61	159.94	206.11	115.78	158.27	230.12	133.46	163.99	153.83	0.4837	0.4381	0.0004	0.9775	0.1723	0.5069	0.0951	0.4609
SE	19.823	23.127	19.823	19.823	19.823	19.823	28.898	16.354	19.823								
								Period 4									
Revenue, $ ha^{-1}	135.84	132.33	158.51	149.09	192.96	214.32	137.21	159.73	167.00	0.4209	0.0069	0.0169	0.9156	0.8563	0.4870	0.2219	0.5753
SE	17.166	20.027	17.166	17.166	17.166	17.166	25.024	14.161	17.166								

LSR, MSR and HSR = low, medium and high stocking rates, respectively.

SE = standard error; L = linear; Q = quadratic.

Figure 4.4 Effects of stocking rate on net revenue per hectare during the four different grazing months.



* = significant at p<0.05; ** = significant at p<.0.01.
LSR, MSR and HSR = low, medium and high stocking rates respectively.

5. CONCLUSION

There were seasonal changes in pasture production and pasture quality, and on cattle performance on pasture in response to grazing management systems. Early in the grazing season, continuous grazing systems outperformed rotationally grazed systems because of forage abundance and the opportunity for cattle to graze selectively. Late in the season, however, the results were reversed. There were also significant interactions between RF and SR with regard to pasture and animal performance. When net revenue, a measure of profitability and system efficiency, was taken into account, a system of high stocking rate and 6-d rotational grazing maximized profitability of the cow-calf grazing systems observed for two 4-months grazing seasons in 1997 and 1998. The intensification of grazing management for cow-calf production is beneficial: moving from continuous to rotational grazing yields economic benefits through increased return per land area and the production of hay. Rotational grazing provides animals with higher quality forage at the end of the grazing season but the lower requirements of beef cattle do not require the use of rapid rotation, which can be detrimental at high stocking rates. The weekly rotation of pasture for beef cows and their calves seems to yield the benefits with grazing to the animals, optimizing the use of pasture resources.

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APPENDIX

Appendix Table 3.1 Date of birth, sex and birth weights of calves born in 1997 and 1998.

	1997			1998		
Grazing cell	Date of birth	Sex[1]	Birth weight (kg)	Date of birth	Sex[1]	Birth weight (kg)
10	20-May	F	30.4	14-Jun	F	38.0
10	19-Mar	M	36.3	16-Jul	M	42.5
10	24-Mar	F	36.3	18-May	M	40.0
10	3-Jun	M	33.1	29-Apr	M	39.5
11	30-Apr	M	31.8	18-Jun	F	36.0
11	27-May	F	30.4	29-May	F	32.5
11	29-May	F	31.8	2-Jun	M	32.0
11	2-Apr	F	36.3	4-Jul	M	40.0
12	16-Apr	M	36.3	19-Jun	F	33.0
12	22-Apr	M	36.7	17-May	M	41.0
12	27-May	F	32.2	26-Mar	M	34.0
13	9-Jun	F	33.1	3-Jun	F	35.0
13	—	—	—	29-Apr	M	37.0
13	17-Jun	F	42.6	5-Jul	M	43.0
13	2-Apr	F	34.0	17-May	M	37.0
14	23-Feb	F	36.3	21-May	F	34.5
14	24-Mar	F	34.0	12-Jun	M	40.0
14	2-Jul	F	42.2	30-Mar	F	43.0
14	20-May	M	38.1	4-Mar	F	34.0
15	22-Apr	F	33.1	20-May	F	40.5
15	24-May	F	31.8	26-May	F	38.5
15	4-Apr	M	37.2	19-Mar	M	32.0
15	15-Apr	F	34.0	20-May	F	48.0
16	22-Jan	F	42.6	31-May	F	31.5
16	25-Feb	F	39.5	21-May	F	38.0
16	1-Apr	—	—	1-Aug	F	49.0
16	20-May	F	42.2	29-Jun	M	39.5
17	17-May	F	32.7	4-Jun	M	41.0
17	29-Jan	—	—	1-May	F	30.0
17	31-May	F	40.4	19-Jun	F	39.0
17	11-Mar	F	28.6	17-May	M	42.5
18	—	—	—	11-Jul	F	40.0
18	18-Mar	F	39.0	20-May	M	35.5
18	23-Mar	F	38.6	10-May	M	34.0
18	13-Jun	F	40.4	6-Jul	M	35.5
1	17-Apr	F	33.1	18-Jun	F	32.5
1	10-Feb	M	33.6	23-Jun	F	43.0
1	29-May	M	38.6	22-Mar	M	29.0
2	15-Mar	F	45.4	16-May	M	30.0
2	7-Jul	M	39.9	30-Apr	F	36.0
2	30-Dec	—	—	16-Feb	F	31.0
3	15-Jun	M	33.6	7-Jun	F	38.0
3	10-Jan	F	40.8	4-May	F	39.0
3	29-Apr	F	34.0	14-Jun	F	37.5
4	27-Mar	F	44.0	23-May	M	37.0
4	4-Jan	F	36.3	18-Jun	F	34.5
4	9-Mar	F	42.2	31-Jul	M	42.0
5	9-Jun	M	36.3	13-Jul	M	46.0
5	28-May	F	38.1	18-May	M	33.0
5	—	—	—	5-May	F	33.0
6	3-May	F	43.1	5-May	F	35.5
6	22-May	M	40.4	30-Jul	M	37.5
6	7-Apr	M	38.6	18-May	M	42.5
7	23-Jun	F	28.1	29-Jul	M	46.0
7	30-Mar	M	38.6	12-Mar	M	37.3
8	24-Jun	F	38.1	3-Jun	F	35.5
8	24-Apr	F	37.6	23-Apr	F	39.0
8	23-Apr	M	38.6	14-May	F	38.0
9	2-Mar	F	37.2	31-May	F	30.0
9	21-Feb	F	44.5	18-May	M	37.0
9	1-Jun	M	33.6	7-Jul	M	35.5

[1] where F = female and M = male.

Appendix Table 3.2 Weights of cows and calves at start and end of grazing seasons.

Grazing cell	1997 Calf weight start[1] (kg)	1997 Calf weight end[2] (kg)	1997 Cow weight start[1] (kg)	1997 Cow weight end[2] (kg)	1998 Calf weight start[1] (kg)	1998 Calf weight end[2] (kg)	1998 Cow weight start[1] (kg)	1998 Cow weight end[2] (kg)
10	47.6	174.0	452.9	520.7	—	167.7	508.5	564.6
10	104.6	—	615.5	—	—	123.7	429.5	516.5
10	117.0	265.8	571.9	658.8	—	236.5	748.5	712.9
10	—	192.8	573.3	568.8	57	233.8	627.5	673.1
11	67.6	230.0	574.4	606.9	—	176.5	684.0	686.3
11	34.5	163.9	401.0	512.6	—	166.7	458.0	516.3
11	43.8	188.4	731.6	807.4	—	185.9	453.0	499.5
11	110.7	259.2	528.0	564.3	—	160.3	748.5	828.3
12	90.9	282.8	508.5	594.7	—	147.2	557.5	624.0
12	74.6	223.4	516.1	603.1	—	230.5	595.0	633.5
12	39.5	189.4	572.9	604.9	102.2	326	574.0	644.8
13	—	164.9	481.7	531.6	—	176	482.0	547.2
13	—	—	620.0	654.3	61.8	253.7	552.0	655.4
13	—	161.7	529.8	709.1	—	169.2	698.5	739.3
13	94.8	250.5	549.0	632.8	—	198.5	602.5	623.6
14	126.6	284.6	436.0	508.7	—	179.9	663.0	703.3
14	116.6	274.1	492.4	568.8	—	168	527.0	603.1
14	—	159.4	570.2	561.5	82.7	251.1	631.0	715.1
14	47.9	184.6	453.6	562.5	106.5	290.9	507.0	583.8
15	88.5	253.3	535.0	554.1	—	153.9	576.5	644.5
15	44.6	154.1	437.9	502.8	—	188.2	558.0	583.1
15	114.2	278.3	568.5	617.6	87	253	420.0	479.3
15	88.7	242.9	631.6	669.3	—	206.6	758.0	731.0
16	142.7	281.5	613.5	667.1	—	168	439.0	468.4
16	107.3	222.5	494.4	553.8	—	200.2	571.0	598.2
16	—	—	590.1	707.8	—	116.3	595.5	640.5
16	54.8	185.5	393.9	411.9	—	154.3	755.0	820.0
17	59.9	216.6	540.5	625.4	—	192.3	474.0	528.8
17	—	—	567.4	667.3	51.4	215.3	494.5	579.1
17	39.7	218.9	633.4	699.4	—	181.1	714.5	736.5
17	94.6	227.9	489.0	594.0	—	231.9	668.5	718.1
18	—	—	552.5	542.7	—	117	619.5	666.0
18	106.8	257.0	559.1	662.0	—	226.4	614.0	619.4
18	98.1	238.4	623.7	672.0	38.35	205.7	466.5	559.0
18	—	172.4	515.9	633.7	—	131.6	668.5	689.5
1	83.7	235.2	584.9	718.9	—	146.5	439.5	501.9
1	118.7	267.8	641.4	764.8	—	176.1	656.0	709.7
1	36.4	166.1	378.7	491.2	109	316.7	645.5	682.8
2	132.4	282.8	561.5	663.4	—	192	460.0	526.8
2	—	134.3	678.1	736.2	67.2	279.2	767.5	844.2
2	—	—	667.0	755.8	127	307.1	478.0	543.4
3	—	131.7	401.9	430.2	55.5	212.9	457.5	489.9
3	180.5	323.3	596.5	639.3	—	182.8	541.5	585.5
3	70.1	209.3	626.0	716.0	—	169.7	742.0	782.4
4	129.3	309.1	545.0	624.5	—	224.3	514.5	591.0
4	183.5	328.9	520.7	607.4	—	154.1	516.0	580.1
4	130.9	303.9	635.0	714.9	—	122.2	710.0	772.2
5	—	166.0	575.6	566.3	—	142.9	611.5	630.1
5	41.1	179.8	419.8	519.8	—	193.2	611.5	627.5
5	—	—	509.8	628.0	47.9	215.6	538.0	601.5
6	77.1	228.9	636.4	692.2	42.2	198	448.0	576.8
6	50.2	205.0	393.5	484.7	—	124.4	628.0	727.4
6	97.1	285.3	623.4	707.0	—	237	672.5	692.7
7	—	121.1	480.8	509.2	—	97	715.0	775.0
7	100.7	285.5	471.3	544.5	102	291.6	453.5	536.4
8	—	162.6	619.2	667.2	—	170.4	519.5	589.2
8	80.7	229.7	564.9	640.7	60.5	233.1	487.0	568.4
8	89.6	252.2	493.1	541.1	34	218.2	708.5	758.2
9	110.8	275.3	476.3	582.4	—	189.1	511.5	586.3
9	130.6	291.7	586.1	688.3	—	212.3	486.5	588.9
9	33.8	179.2	486.9	589.4	—	150.2	712.0	837.9

[1] where start of the grazing season was on June 3rd in 1997 and May 15th in 1998.

[2] where end of the grazing season was on Oct 1st in 1997 and Oct 2nd in 1998.

Appendix Table 4.1. Least square means of forage mass available (FMA) during four months under different rotational frequency (RF) and stocking rates (SR).

	Continuous			6 days			2 days			Significance of Effects (P-values)							
										RF		SR		RF X SR			
	LSR	MSR	HSR	LSR	MSR	HSR	LSR	MSR	HSR	L	Q	L	Q	LxL	LxQ	QxL	QxQ
									Period 1								
FMA t DM ha^{-1}	2.4	2.4	2.3	2.5	2.3	2.5	2.6	2.0	1.6	0.1087	0.1648	0.0901	0.6383	0.0533	0.7879	0.1593	0.6618
SE	0.22	0.22	0.22	0.22	0.22	0.22	0.32	0.18	0.22								
									Period 2								
FMA t DM ha^{-1}	2.3	2.2	2.0	2.6	2.5	2.1	2.2	2.1	1.9	0.5734	0.1236	0.2993	0.4145	0.7883	0.5593	0.4589	0.9374
SE	0.29	0.29	0.29	0.29	0.29	0.29	0.42	0.24	0.29								
									Period 3								
FMA t DM ha^{-1}	2.4	1.7	1.7	2.1	2.3	1.7	1.7	1.9	1.1	0.0775	0.1351	0.0245	0.2707	0.8780	0.0676	0.5550	0.5187
SE	0.25	0.25	0.25	0.25	0.25	0.25	0.37	0.21	0.25								
									Period 4								
FMA t DM ha^{-1}	1.9	1.6	1.2	1.7	1.6	1.4	1.8	1.4	0.8	0.2039	0.4692	0.0019	0.7444	0.6889	0.7471	0.2730	0.8872
SE	0.22	0.22	0.22	0.22	0.22	0.22	0.32	0.18	0.22								

LSR, MSR and HSR = low, medium and high stocking rates, respectively.

SE = standard error; L = linear; Q = quadratic.

Appendix Table 4.2 Quality of hay harvested (% DM) from either experimental or non-experimental area in 1997.

	Management		CP	ADF	NDF	Ca	P	Mg	K
	RF[1]	SR[2]	% DM	% DM	% DM	% DM	% DM	% DM	% DM
Non-experimental area									
field 01			10.3	41.1	61.8	0.58	0.22	0.24	2.13
field 01			11.0	38.7	61.9	0.49	0.22	0.23	2.34
field 02			9.4	40.3	62.7	0.47	0.20	0.22	2.09
field 02			9.6	42.8	65.7	0.63	0.19	0.26	1.76
average composition			**10.1**	**40.7**	**63.0**	**0.54**	**0.21**	**0.24**	**2.08**
Experimental area									
cell 03	2d	HSR	9.4	39.9	69.8	0.43	0.20	0.17	1.95
cell 07	2d	MSR	8.4	38.2	66.6	0.33	0.22	0.14	1.94
cell 09	6d	LSR	7.6	45.1	74.2	0.29	0.12	0.12	0.57
cell 11	6d	MSR	6.9	36.4	63.8	0.37	0.15	0.15	1.75
cell 12	6d	HSR	10.1	38.3	64.8	0.38	0.21	0.16	2.21
cell 13	2d	LSR	7.6	37.0	65.6	0.32	0.14	0.15	1.70
cell 14	6d	LSR	5.7	40.8	65.9	0.34	0.11	0.11	1.42
cell 16	2d	MSR	6.8	42.2	68.0	0.36	0.11	0.12	1.24
average composition			**7.8**	**39.7**	**67.3**	**0.35**	**0.16**	**0.14**	**1.60**

[1] RF = rotational frequency, 2d = 2-day rotation and 6d = 6-day rotation.

[2] SR = stocking rate and HSR, MSR and LSR = .5, .7 and .9 ha per cow-calf pair respectively.

Appendix Table 4.3 Quality of hay harvested (% DM) from experimental area in June and July 1998.

Grazing cell	Management RF[1]	SR[2]	CP % DM	ADF % DM	NDF % DM	Ca % DM	P % DM	Mg % DM	K % DM
					June				
cell 04	2d	MSR	11.3	35.4	61.1	0.52	0.19	0.16	2.25
cell 06	6d	MSR	13.6	32.3	56.3	0.57	0.28	0.20	2.70
cell 07	2d	MSR	11.8	31.0	57.2	0.51	0.24	0.19	2.41
cell 09	6d	LSR	13.7	36.2	59.6	0.74	0.21	0.23	2.28
cell 11	6d	MSR	10.6	32.3	59.3	0.36	0.19	0.14	2.20
cell 12	6d	HSR	12.9	32.2	58.1	0.48	0.21	0.17	2.43
cell 13	2d	LSR	10.5	31.6	58.6	0.35	0.16	0.15	2.08
cell 14	6d	LSR	10.7	32.7	59.5	0.42	0.19	0.16	2.16
cell 16	2d	MSR	10.9	31.3	59.5	0.34	0.19	0.16	2.23
					July				
cell 08	6d	HSR	13.3	28.9	52.7	0.58	0.24	0.20	2.52
cell 09	6d	LSR	17.7	31.8	48.0	0.78	0.30	0.29	2.67
cell 09	6d	LSR	14.1	37.5	61.1	0.60	0.23	0.20	1.61
cell 11	6d	MSR	14.0	32.9	54.1	0.65	0.22	0.23	2.24
cell 12	6d	HSR	10.1	37.2	65.5	0.47	0.20	0.15	1.11
cell 13	2d	LSR	11.2	35.3	58.4	0.47	0.20	0.18	1.81

[1] RF = rotational frequency, 2d = 2-day rotation and 6d = 6-day rotation.

[2] SR = stocking rate and HSR, MSR and LSR = .5, .7 and .9 ha per cow-calf pair respectively.

Appendix Table 4.4 Quantity of forage (1000 kg DM/ha) available to the animals during four months in 1997.

Grazing cell	Management RF[1]	Management SR[2]	June forage mass pre	June forage mass post	July forage mass pre	July forage mass post	August forage mass pre	August forage mass post	September forage mass pre	September forage mass post
1	Cont	HSR	-- 2.00 --		-- 1.94 --		-- 1.40 --		-- 1.05 --	
10	Cont	HSR	-- 3.60 --		-- 2.53 --		-- 2.14 --		-- 1.44 --	
5	Cont	MSR	-- 2.51 --		-- 2.39 --		-- 2.14 --		-- 2.12 --	
18	Cont	MSR	-- 2.88 --		-- 2.08 --		-- 2.18 --		-- 2.02 --	
2	Cont	LSR	-- 2.79 --		-- 1.82 --		-- 2.71 --		-- 2.23 --	
17	Cont	LSR	-- 2.47 --		-- 2.92 --		-- 3.26 --		-- 2.32 --	
8	6d	HSR	3.95	2.70	2.45	1.40	1.46	0.82	2.03	1.03
12	6d	HSR	2.78	1.85	2.42	1.09	2.30	1.22	0.88	0.74
6	6d	MSR	2.14	2.00	1.73	1.65	2.13	1.27	0.98	0.51
11	6d	MSR	3.27	2.56	4.24	2.68	2.40	1.48	1.54	1.32
9	6d	LSR	3.12	2.80	2.89	1.61	2.19	1.58	2.09	1.34
14	6d	LSR	2.64	2.12	4.76	3.66	2.58	1.96	1.44	1.07
3	2d	HSR	2.59	1.11	3.16	1.75	0.61	0.44	0.75	0.15
15	2d	HSR	2.95	0.98	3.49	1.75	0.97	0.66	1.27	0.95
4	2d	MSR	3.06	2.05	3.13	2.27	2.97	1.81	1.56	0.89
7	2d	MSR	3.12	1.60	2.09	1.36	1.62	1.04	1.67	1.08
16	2d	MSR	2.75	1.59	2.48	2.00	1.49	1.63	0.86	0.84
13	2d	LSR	3.27	2.62	3.36	1.76	1.82	1.05	2.33	1.42

[1] RF = rotational frequency, where Cont = continuous, 6d = 6-day rotational grazing, 2d = 2-day rotational grazing.

[2] SR = stocking rate, where LSR, MSR and HSR = .9, .7 and .5 ha per cow-calf pair, respectively.

Appendix Table 4.5 Quantity of forage (1000 kg DM/ha) available to the animals during four months in 1998.

Grazing cell	Management RF[1]	Management SR[2]	June forage mass pre	June forage mass post	July forage mass pre	July forage mass post	August forage mass pre	August forage mass post	September forage mass pre	September forage mass post
1	Cont	HSR	-- 1.78 --		-- 1.29 --		-- 1.27 --		-- 0.82 --	
10	Cont	HSR	-- 1.94 --		-- 2.40 --		-- 1.96 --		-- 1.49 --	
5	Cont	MSR	-- 2.10 --		-- 2.17 --		-- 1.52 --		-- 1.02 --	
18	Cont	MSR	-- 2.00 --		-- 2.02 --		-- 1.08 --		-- 1.13 --	
2	Cont	LSR	-- 2.10 --		-- 1.61 --		-- 1.67 --		-- 1.42 --	
17	Cont	LSR	-- 2.09 --		-- 2.73 --		-- 1.84 --		-- 1.77 --	
8	6d	HSR	3.36	2.08	3.37	2.20	3.27	1.59	2.41	1.15
12	6d	HSR	2.13	1.15	2.09	1.67	2.04	0.98	1.77	0.90
6	6d	MSR	2.29	1.42	2.53	1.39	3.62	1.78	2.08	1.52
11	6d	MSR	2.71	2.07	3.69	2.48	3.38	1.99	2.99	1.66
9	6d	LSR	3.18	2.53	2.06	1.62	2.77	1.80	2.51	1.55
14	6d	LSR	1.91	1.38	2.66	1.72	2.12	1.52	2.96	1.01
3	2d	HSR	1.68	0.86	1.55	1.11	2.19	1.05	0.71	0.40
15	2d	HSR	1.44	0.80	1.42	0.88	1.46	1.03	1.17	1.02
4	2d	MSR	1.56	1.22	2.25	1.56	2.47	1.83	2.32	1.36
7	2d	MSR	2.37	2.23	2.61	2.15	2.23	1.92	1.61	0.85
16	2d	MSR	1.60	0.99	2.34	1.52	2.13	1.41	2.29	1.30
13	2d	LSR	2.37	1.84	1.81	1.72	2.34	1.41	2.07	1.38

[1] RF = rotational frequency, where Cont = continuous, 6d = 6-day rotational grazing, 2d = 2-day rotational grazing.

[2] SR = stocking rate, where LSR, MSR and HSR = .9, .7 and .5 ha per cow-calf pair, respectively.