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ABSTRACT

Grazing experiments were conducted in summer, autumn and winter to assess the effects of stock density, grazing duration, pre-grazing pasture mass and stock type on forage intake by sheep grazing at high stock densities for short durations. In summer and winter, sheep were stocked at 200 sheep/ha on 0.1 ha plots for 9 and 4 days, respectively. Total dry matter (TDM) and green dry matter (GDM) were estimated each day by clipping 0.2 m^2 plots to ground level. In autumn, ewes and lambs separately grazed 0.333 ha pastures at stock densities of 270, 540 or 810 sheep/ha for 1, 2, or 3 days. Pre- and post-grazing TDM were estimated with a single probe capacitance meter. The percent GDM of TDM was estimated using a spectophotometer. In each study TDM and GDM pasture mass were analyzed using a non-linear (negative exponential) multi-variate regression model. Intake was estimated from results of pasture mass analysis. In autumn, ewes and lambs consumed similar amounts of TDM, but ewes consumed 43% more GDM ($P<.05$) than lambs; differences between treatments at the same grazing pressure (stock density X grazing duration) in intake of both TDM and GDM were not significantly different. In all analyses regression coefficients for grazing pressure, i.e. instantaneous rates of forage decline per stock day, were significant ($P<.01$). Instantaneous rates per stock day in TDM analyses were 0.0007, 0.0001 and 0.0002, and in GDM analyses were 0.0019, 0.0003 and 0.0010 for summer, autumn and winter, respectively. A simulation model was also developed which predicted intake of GDM and DDM by sheep grazing at high stock densities for short durations. Model predictions of intake agreed favorably with summer and winter observations, but the model overestimated intake during autumn. In agreement with previous studies, the model predicted intake would increase at a decreasing rate as forage allowance (kg/sheep/day) increased.

Effects of Pasture and Management Variables on Forage Intake by Grazing Sheep

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EFFECTS OF PASTURE AND MANAGEMENT VARIABLES ON FORAGE INTAKE BY GRAZING SHEEP

INTRODUCTION

Sheep are used extensively throughout the world to convert forage into meat and wool. In pastoral sheep production systems the yield per hectare of these products depends on the quantity, quality and timely distribution of forage production and its consumption as well as the efficiency of conversion.

The quantity and quality of forage consumed has long been recognized as important to the profitability of pastoral sheep production systems. However, research focusing on forage intake during grazing has been relatively limited compared to efforts made at improving animal conversion efficiency and forage production. Consequently, most past improvements in product yield per hectare have resulted from new or improved plant and animal genotypes and an increased understanding of factors affecting plant and animal growth.

The increased use of rotational grazing systems in recent years has re-focused attention on factors which affect forage intake by grazing animals. Rotational grazing systems which involve large numbers of animals per hectare for short grazing durations have been widely recommended both for rationing forage during periods of feed shortages and for controlling grass growth. Profitable use of such systems requires a thorough understanding of how forage intake is affected by pasture and management variables such as stock density, grazing duration, total forage mass and green forage mass.

Most research in this area has been conducted in New Zealand where the quality of grazing management is especially important in determining the margins of profitability. Most research in New Zealand has been directed towards understanding the effects of forage allowance (kg forage available/sheep/day) on average daily intake (kg forage consumed/sheep/day) by grazing sheep. Forage allowance is usually defined as the pre-grazing mass divided by the product of stock density and grazing duration. Therefore, forage allowance represents the combined effect of several pasture and management variables. Consequently, good quantitative agreement between studies is often lacking since a common forage allowance may have been achieved by many different combinations of pasture and management variables.

The majority of studies examining the effect of pasture and management variables on forage intake have been indirect estimates of variables correlated to intake, e.g live weight change, ovulation rate and wool growth. Such studies have been valuable for describing general relationships, but can not quantitatively describe the effects of pasture and management variables on forage intake during grazing.

Accurate quantitative estimates of the effects of pasture and management variables on forage intake are essential if tools such as computer simulation models of sheep production systems are to be used in developing superior grazing strategies. Several such simulation models of pastoral sheep production systems have been developed to date, but all have been based on extensive or continuous grazing management (Christian et al., 1978; France and Thornley, 1981; White et al., 1983). Development of models that can also address rotational grazing could provide a framework for developing further understanding of pastoral production systems and could aid in developing optimal production strategies.

The first objective of this study was to determine the effects of the pasture and management variables stock density, grazing duration, stock type, total forage mass and green forage mass on the pattern of forage intake during grazing. The second objective was to develop a model of forage intake under conditions of high stock density and short duration grazing based on previously published studies and to compare the model predictions with results of our field experiments.

CHAPTER 1

LITERATURE REVIEW

For thousands of years, sheep and other ruminants have been exploited by people for their ability to convert resources which are not in competition with human needs into usable products. The level of output of a conversion process is dependent on the efficiency of the converting mechanism and the absolute level of inputs. In a pastoral sheep production system the mechanism is the grazing animal and the major input is the quantity and quality of forage consumed. While breed choice (Dickerson, 1977), exogenous hormone treatment (Meyer and Lewis, 1988) and other management options (health care, date of mating, etc...) influence the output mix and the level of production, on a global perspective it is more likely that the level of nutrient inputs, i.e. intake of forage by grazing, is the major determinant of the level of output of the overall pastoral sheep system (Hodgson, 1982).

The intake of forage by sheep is a complex biological system of physiological and behavioral responses to physical conditions. Even under highly controlled environments, such as sheep fed ad lib a homogenous diet in metabolism cages, factors used to predict intake lack a great deal of precision and accuracy (Baile and Forbes, 1974; Blaxter et al, 1961). Under grazing conditions the forage intake system is further complicated by the impact of the diversity and distribution of forage on the animal's process of feed prehension (Arnold and Dudzinski, 1978). In addition, the feed prehension process may modify the action of the factors which influence intake under controlled environments (Allden and Whittaker, 1970).

Feed prehension by the grazing animal can be described mechanistically as the product of grazing time and intake rate (forage consumed per unit of time); the latter can be further divided into the product of bite size (quantity of forage per bite) and bite rate (number of bites per unit time) (Allden and Whittaker, 1970). Changes in the grazing environs (Chacon and Stobbs, 1976) as well as within the animal itself (Arnold and Birrell, 1977) can alter the relationships between these components through compensatory behavior.

Allden and Whittaker (1970) observed that as pasture mass declined from 4000 down to 2500 kg/ha the forage consumed per bite by sheep decreased and their biting rate increased proportionally such that the intake rate (g/min) remained constant. As pasture mass fell below 2500 kg/ha increases in biting rate failed to match decreases in bite size, and intake rate, as well as daily intake, declined despite a 50% increase in grazing time. They also reported that once grazing had reduced the pasture height to less than 5 cm, grazing time became erratic and bite rate dropped dramatically despite very small bite sizes. The radical change in grazing behavior at short pasture heights may have resulted from some other factor such as grazing fatigue influencing compensatory behavior (Poppi et al, 1987). Other studies which have found increases in biting rate with decreases in bite size, have also reported that increases were not sufficient to maintain the rate of intake (Black and Kenney, 1984; Penning, 1986).

Grazing time per day appears to increase less than proportionally to decreases in intake rate (Penning 1986; Allden and Whittaker, 1970). Although conclusive evidence is lacking, it has been postulated that grazing duration has an upper limit of approximately 13-15 hours, the remaining hours being necessary for rumination and other behavioral requirements (Arnold, 1964; Poppi et al., 1987). Based on a number of studies examining grazing time under a wide variety of pasture conditions, Bergren-Thomas (1984) calculated an average grazing time of 9 hours per day with a range of 5 to 12 hours.

The labor needed to estimate the primary components affecting intake - bite size, bite rate and grazing time - makes quantification of the mechanics of grazing difficult. Nevertheless, there has been a recent increase in such work in the United States (Demment et al., 1987). An alternative often followed overseas is to describe dry matter intake as an empirical function of animal and pasture characteristics, such as pasture height and digestibility of forage. However, field techniques for measuring apparent dry matter intake (e.g. pre-grazing pasture mass minus post-grazing pasture mass) lead to large standard errors. Therefore, researchers often substitute measurements of animal response, such as particular live weight change, for measurements of reductions in pasture mass, assuming that weight changes directly reflect dry matter intake (Rattray and Clark, 1984). This assumption, however, is to be viewed with caution because unrelated animal processes often confound estimates of live weight change (Hodgson, 1984).

Whether the approach is empirical or mechanistic, the majority of factors which influence dry matter intake by the grazing animal have been typically divided into those attributable to the animal and those attributable to the pasture (Willoughby, 1959). Animal factors, described as nutrient drive (Osborn, 1980), consist broadly of physiological status (Arnold, 1975), age and weight (Weston, 1982), body condition (Arnold and Birrell, 1977) and cold stress (Hutchinson and McRae, 1969). Pasture characteristics include structural composition and plant species (Laredo and Minson, 1975), leaf length or tiller height (Black and Kenney, 1984), dry matter mass per hectare (Rattray and Clark, 1984), green mass per hectare (Arnold, 1964), and plant density (Allden and Whittaker, 1970).

Other important factors which may limit intake fall into a gray area as to whether they are characteristic of the animal or of the pasture. From a mechanistic perspective, digestibility, rumen fill and rumen retention time have been modeled as physical control factors of the animal which interact with the animal's metabolic rate or nutrient demand (Forbes, 1977). The empirical approach has been to label digestibility and factors affecting the rumen response as pasture characteristics which change with species, season and grazing management. This latter approach has been followed often by researchers modeling whole-farm grazing systems (e.g. White et al, 1983; McCall, 1984; Christian et al., 1978).

In a recent review, Poppi et al. (1987) put forth an alternative classification scheme based on an intuitive conceptual model of forage intake. In this conceptual model, as non-nutritional constraints eased, grazing intake increased at a diminishing rate from zero up to a theoretical limit or plateau defined by nutritional factors. Mathematically, this relationship between intake, nutritional effects and non-nutritional effects can be approximated with a natural growth function of the form N(1-exp(-K*P)), where N represents the plateau or asymptote, P represents the non-nutritional factors and K represents the instantaneous rate of increase of intake as non-nutritional constraints ease. Computer simulation models of intake by Arnold et al. (1977), Vera et al. (1977) and Sibbald et al. (1979) have all used similar natural growth functions in which N represented maximum potential intake (kg/animal) and P was pasture mass (kg/ha). These simulation models differ from the conceptual model proposed by Poppi et al. (1987) in the manner in which forage digestibility affects intake. In the simulation models digestibility controls the instantaneous rate of intake, i.e. the "speed" with which intake reaches the nutritional plateau. In contrast, Poppi et al. (1987) contends that digestibility can influence only the height of the nutritional plateau.

In this review, the natural growth function will provide the structure for a discussion of factors affecting nutrient intake of sheep. The first section will review factors associated with nutrient drive which influence the maximum voluntary intake per sheep per day, the asymptote. The second section will focus on both nutritional and non-nutritional factors which affect the approach of intake to the asymptote in the context of both continuous and short-duration, high stock density grazing systems.

DETERMINANTS OF MAXIMUM VOLUNTARY INTAKE OF FORAGE

1. PHYSIOLOGICAL STATE

A mature sheep is in one of three physiological states: non-pregnant, gestating or lactating. The latter two states may be further sub-divided based on the number of fetuses or suckling lambs. Due to the seasonality of reproduction in the ewe, experiments examining simultaneously the effects of all three physiological states on forage intake are rare and usually limited to spring pastures.

Reid and Hinks (1962) reported that blood ketone levels of pen-fed twin-bearing ewes held at a constant level of feed intake significantly increased with increasing number of days pregnant, particularly in the third trimester, relative to single-bearing and non-pregnant ewes on the same diet. These results suggest that twin-bearing ewes may have much higher nutrient demands than non-pregnant ewes, while single-bearing ewes may have only slightly higher demands than non-pregnant ewes. Increased nutrient demands might be expected to cause increased intake. However, in several pen experiments conducted over a wide range of diets, pregnant ewes have tended towards lower (non-significant) ad lib dry matter intakes than non-pregnant ewes (Hadjipieris and Holmes, 1966; Owen et al., 1980). Decreases in rumen volume due to growth of the uterus, particularly in the last three weeks of gestation, may be physically limiting intake and counteracting the demand for increased nutrients (Forbes, 1969). Since abdominal fat deposits further reduce rumen volume, abdominal volume may be a more limiting factor than rumen volume (Baile and Forbes, 1974).

Arnold and Dudzinski (1967a) failed to detect any difference in grazing dry matter intake between non-pregnant and pregnant ewes throughout gestation. However, in a subsequent study, Arnold (1975) found a significant 34% increase in grazing intake of gestating ewes in the last trimester relative to non-pregnant controls. The author suggested that the lack of agreement within pasture trials was probably due to differences in quantity of forage available. The lack of agreement between pasture and pen experiments may be due to differences in diet quality. Even though the average quality of forage on offer may be the same in both types of experiments, grazing animals, unlike penned animals, are usually able to exercise selectivity and consume diets higher in quality than the average of that on offer (Rattray et al, 1983). If variation in forage availability and quality are responsible for the lack of agreement between trials, as suggested, then the increased nutrient demand of pregnancy affects intake only if other factors, such as pasture mass and digestibility, are not limiting.

It has long been recognized that nutrient demands by the ewe are at a peak during lactation, and that high-producing ewes are unable to maintain weight during this period (Rattray et al., 1974). Dry matter intakes of mature lactating ewes have been found to be considerably higher than for non-pregnant ewes in both pen experiments (10% - 60%)

(Hadjipieris and Holmes, 1966; Owen et al., 1980) and pasture experiments (25% - 40%) (Cook et al., 1961; Arnold and Dudzinski, 1967a; Arnold, 1975). In contrast to pregnancy effects, Arnold (1975) has reported that the increased nutrient demand caused by lactation resulted in increases in forage intake even when forage digestibility and mass appeared to be at limiting levels.

Not all age classes of lactating sheep show increased forage intake relative to non-lactating ewes of the same age. McEwan et al. (1985) observed quite similar intakes of forage by lactating and non-lactating hoggets (one year of age) grazing on spring pastures ranging from limiting to non-limiting forage on offer. No comparison with mature lactating or non-lactating ewes were available, but the results at least suggest that in this case the relative increases in dry matter intake normally associated with lactation may have been superseded by pre-existing high nutrient demands for growth.

The conceptual model described earlier (Poppi et al., 1987) which defines an asymptotic relationship between pasture intake and pasture constraints appears to be widely accepted in New Zealand (Rattray and Jagusch, 1978; Rattray et al., 1987). However, the level at which such a plateau occurs during lactation still has yet to be established. Gibb and Treacher (1978) and Rattray and Jagusch et al. (1978) both reported a linear relationship between pasture allowance (kg dry matter on offer per sheep per day) and intake of lactating ewes grazing pastures with high pre-grazing pasture mass up to an allowance which was three times intake. Penning et al. (1986) offered a range of allowance up to five times intake during the first four weeks of lactation. Forage intake, ewe live-weight change and lamb growth showed no indications of reaching a plateau in response to the increasing forage allowance.

2. LIVE WEIGHT

Estimation of the effect of live-weight on the maximum voluntary intake of dry matter by grazing sheep is usually confounded by one or more of the following factors: age, body condition (fat reserves), previous nutritional level, and seasonal changes in the pasture. Consequently, direct comparison of experimental results from different trials is difficult and only gross generalizations have been attempted in the literature.

The acceptance of an allometric function ($Y = a*W^b$) to express metabolic rate as a function of weight, where b equals 0.73 or 0.75 (Graham et al.,1974), has tempted researchers to hypothesize that potential voluntary intake may possess a similar relationship to weight (Freer, 1981; Weston, 1982). This hypothesis has been incorporated into simulation models (Graham et al., 1976; France et al., 1981); however, in two tests of this hypothesis, more of the variation in total dry matter intake was explained with either a linear (Hadjipieris et al., 1965) or quadratic regression on weight (Langlands, 1968) than by use of an allometric function. It may be, as Freer (1981) argues, that the complexity of the interaction between basal metabolic rate and the nutrient supply over time presupposes any single appropriate exponent for expressing intake in terms of weight.

While young lambs consume much less total dry matter than mature sheep, intake per kilogram body weight (raised to the power 0.75 or 1.0) exceeds mature sheep intake by 27 to 63% (Hadjipieris et al., 1965; Langlands, 1968; Langlands and Hamilton, 1969). Peak forage intake per unit live-weight may occur as early as 8 weeks of age regardless of whether the lamb has been weaned or not (Gibb et al., 1981). As lambs age and/or gain weight, intake per unit body weight decreases, but reported estimates of the age at which their relative intake equals that of mature sheep have ranged from 5 months (Gibb et al., 1981) to 20 months (Langlands and Hamilton, 1969).

3. PREVIOUS NUTRITION

Gibb et al. (1981) examined the effects of previous nutrition on grazing intakes of lambs. Ewes and lambs were grazed on either sparse or abundant pastures from shortly after birth to weaning. After weaning all lambs were grazed on pastures with abundant available forage. Prior nutritional level had no effect on forage intake per lamb, but lambs from sparse pastures had lighter weaning weights and, consequently, higher intakes per unit live-weight than lambs weaned from abundant pastures.

In a pen experiment, Drew and Reid (1975) examined growth rates and intake of previously deprived vs. control lambs (average weights prior to depravation were 35 kg.) on high quality, ad lib diets. No significant differences in intake were observed between groups, but previously deprived lambs had higher average daily gains than control lambs. At initial weights less than 20 kg, Searle and Graham (1975) observed large compensatory increases in both intake and average daily gain by deprived lambs.

Reports on the effect of deprivation or low body condition on the voluntary intake of forage by mature sheep are equally cloudy. Sheep placed in pens on ad lib pelleted rations after having been forced into poor condition by limited feed either in pens (Keenan et al., 1970) or on pastures (Donnelly et al., 1974), failed to consume more than control sheep who weighed on average up to 8 kg more and had twice the fat covering.

In contrast, Arnold and Birrell (1977) reported that when ewes which had previously grazed on sparse pastures for two months were joined with non-deprived ewes on abundant pasture the deprived ewes ate, on average, 31% more dry matter per animal and 117% more per unit live-weight. The lack of agreement between pen and pasture experiments may be due to different factors (quality vs. quantity) limiting intake and different effects of the factors on nutrient demand in the two environments.

4. COLD STRESS

The most common environmental factor which increases nutrient demand in sheep is cold stress immediately following shearing. Hutchinson and McRae (1969) examined intake of forage by two groups of wethers grazing pastures either of high or low availability during the first two weeks following shearing. At minimum daily temperatures less than 6 degrees celsius, dry matter intake increased by 30% and 59% in the first and second week, respectively, regardless of pasture availability. Wheeler et al. (1963) also observed higher intakes by shorn than by unshorn wethers grazing pastures of high availability at comparable air temperatures. Differences between shorn and unshorn wethers increased with decreasing pasture mass. Arnold and Birrell (1977) reported that differences in grazing intake of shorn vs. unshorn sheep were sensitive to changes in the air temperature. Intakes of shorn sheep were 44% higher than unshorn sheep at 8 degrees celsius, but no significant differences were observed at 11 degrees celsius.

LIMITS TO INTAKE

1. NUTRIENT ABSORPTION AND RATE OF PASSAGE

Numerous published reviews have described the limiting effect of food bulk on voluntary intake by ruminants (Campling, 1970; Baile and Forbes, 1974; Hughes et al., 1980; Freer, 1981; Minson, 1982). The effect of food bulk on intake is a function of rumen fill (as influenced by rate of passage of material through the reticulo-omasal orfice), digestion and absorption of nutrients, and abdominal size (Baile and Forbes, 1974; Hughes et al, 1980). A classic study on the role of digestibility, defined as the proportion of nutrients absorbed of those consumed, was conducted by Blaxter et al. (1961). These researchers observed that groups of sheep fed ad lib hay of either low (45%), medium (59%) or high (74%) digestibility all ate, on average, to the same rumen fill. These results, supported by those of other similar experiments (Troelsen and Campbell, 1968; Campling, 1970; Thorton and Minson, 1972), indicate that intake is limited primarily by the rate of passage of material through the reticulo-omasal orifice and the rate of digestion and absorption of nutrients (Baile and Forbes, 1974). The rate of passage and digestion are determined by a complex interaction between rumen microorganisms and components of the feed (Ulyatt et al., 1976) which include chemical composition (Van Soest, 1965), particle size (Troelsen and Campbell, 1968) and specific gravity (Baldwin et al, 1977).

Simulation models of rumen digestion have indicated that the rate of passage of material through the rumen may have up to twice the potential impact on intake as does the rate of digestion (Ulyatt et al., 1976; Mertens and Ely, 1979). In grazing experiments these two factors are usually highly correlated. The same characteristics in forage which limit the rate of passage, i.e. proportion of cell wall and lignin content, also greatly limit the digestibility of the forage (Smith et al., 1972; Freer, 1981). Digestibility is relatively easier and more precisely measured than rate of passage (Ulyatt, 1971) and therefore has been the primary independent variable in studies examining the role of physical limitations of the rumen on voluntary intake.

Researchers have closely examined the relationship between digestibility of forage on offer and voluntary intake by ruminants under controlled environments in which the animal consumes a homogenous diet of known digestibility with little or no opportunity for selection. Based on three digestibility levels, Blaxter et al. (1961) initially suggested that intake of prepared forages was curvilinearly related to digestibility. But more extensive subsequent studies with sheep have reported a linear relationship between intake and digestibility in the range of 40% to 85% digestibility within grass species at different stages of maturity (Minson et al., 1964; Blaxter et al., 1966; Hogan et al., 1969; Thorton and Minson, 1973) and across species at the same maturity (Vona et al, 1984; Armstrong et al., 1986). At low to intermediate digestibility levels, intake has been shown to increase when rumen contents are removed (Campling, 1970) indicating that digestibility, as a measure of both digestion and rate of passage, was indeed limiting intake.

Based on evidence such as presented above, most published computer simulation models of sheep systems have assumed a direct, positive linear relationship between dry matter intake and digestibility of forage in the pasture (Freer et al., 1970; Edelsten and Newton, 1977; Christian et al., 1978; Sibbald, 1979; France et al., 1981; McCall, 1984). However, alternative functional relationships to a linear model have also been used in simulation models. These include the logistic function (Arnold et al, 1977) and natural growth function (White et al, 1983). The simulation models using non-linear relationships have assumed that intake plateaus at about 80% digestibility.

The extensive consideration of digestibility as a physically limiting factor in grazing models would suggest that the hypothesis of digestibility being the major limiting factor of forage intake has been well accepted. Yet, the extrapolation of the results from pen experiments, in which animals are fed homogenous diets, to the pasture environment should be viewed with caution.

Compared to grazing animals, pen-fed animals have very little opportunity to selectivly choose between components of the feed on offer. The grazing animal may be able to select diets higher in digestibility than the average digestibility of the pasture. The relationship between pasture and diet digestibility has been examined using both suckling (Penning and Gibb, 1979) and weaned (Jamieson and Hodgson, 1979) esophageal fistulated lambs grazing pasture from spring through summer. Penning and Gibb (1979) reported that digestibility of diets selected by lambs averaged approximately 80% with no evidence of a decline as forage matured, i.e. pasture digestibility decreased, from spring into summer. In contrast, Jamieson and Hodgson (1979) observed a significantly positive linear relationship between diet digestibility and pasture digestibility. Yet even at the lowest pasture digestibility level (55%), diet digestibility was above 70%. Although the pasture digestibility and rumen development were highly correlated in this study, the results suggest that lambs can maintain a fairly high level of digestibility in their diet in the face of declining quality of forage in the pasture.

Esophageal fistulation has also been used to examine the diet digestibility of mature sheep on pasture. Over a five year period, Clark et al (1982) compared pasture digestibility to diet digestibility for ewes on rotational or set stock grazing systems. Except for a two month winter period, diet digestibility was consistently above 70% (even though plant material ranged from new spring growth to mature vegetation) and grazing system had no effect on diet digestibility. However, during the winter period when the sparse available forage was low in legume content and high in dead material, diet digestibility dropped to 65% and 56% for the rotational and set stocked systems, respectively.

In a summer-autumn trial, Guy et al. (1981) measured diet and pasture digestibility on days one and three of a three day rotation. Digestibility of the pasture prior to grazing ranged from 55% to 75%. and decreased only slightly from the first to the third day of each grazing period. On average, diet digestibility declined from 70% to 65% over the three day grazing period. Overall, diet digestibility was 13 percentage points higher than that of the pasture. When McMiniman et al. (1986) compared diet and pasture digestibility under extremely dry conditions, pasture digestibility dropped below 40%, near the minimum digestibility of any forage (Ulyatt, 1981), but diet digestibility remained 10 to 15 units higher.

The studies with esophageal fistulated lambs and mature sheep cited above suggest that the diet digestibility of grazing animals remains constant or declines only slightly as digestibility of forage on offer declines. The results further suggest that diet digestibility rarely drops to levels which would physically limit either intake through the mechanism of retention or decreased absorption as was observed in controlled pen feeding experiments. Consequently, the role of digestibility in physically limiting grazing intake may well be either overemphasized in grazing simulation models and in reviews such as Waldo (1985), or its effect on forage intake is at least empirical rather than mechanistic.

2. SELECTION

Any positive relationship between pasture digestibility and forage intake most likely occurs indirectly as a result of the relationship between digestibility and the proportion of green material in the pasture (Rattray, 1978) and the animal's preference for green material over dead material (Arnold, 1964; Arnold, 1981). The digestibilities of green and dead forage in the pasture are approximately 80% and 40%, respectively (Rattray et al, 1983). As might be expected, average digestibility has been shown to have a strong linear relationship with the percentage of green material in the pasture. Rattray et al. (1983) found that for each 1% increase in the percent green there was a 0.5% increase in the digestibility of the forage on offer. Therefore, variation in total dry matter intake could be accounted for by changes in the percent green forage in the pasture as well as by changes in the digestibility of the pasture. So it appears that as pasture digestibility decreases, it is not the physical limitations of the rumen which limit intake, but rather the selective effort required by the animal to maintain a diet high in desirable components.

Differences between components of the diet and components of the pasture do not necessarily imply that the animal is actively selecting a particular diet. In a study on high quality pastures at low grazing pressures, Milne et al. (1979) observed differences between components of the diet and the pasture due to the sheep simply grazing the surface horizon, i.e. the readily prehended forage. In this study, the surface horizon was not representative of the forage available throughout all horizons since various species and their parts occupied different horizons.

Under moderate to high grazing pressure, or when the percentage of dead material in the pasture is high, selection for green material is strong. Clark et al. (1982) reported that sheep maintained diets above 80% green material when the percentage of green material in the pasture fell as low as 20%. L'Huillier et al. (1984) reported that when green material was as low as 4% of the pasture, sheep appeared to still consume diets above 65% green material by grazing through the surface horizon to locate green material within 3 cm of the ground. However, results reported by Hamilton et al. (1973) suggest that once the absolute level of green material drops to less than 500 kg/ha the percentage of green in the diet drops quickly.

Maintenance of a high quality diet may be accomplished at the expense of absolute intake (Hamilton et al, 1973; Langlands and Sanson, 1976). In a study with lambs, Jamieson and Hodgson (1979) observed that as the amount of green material in the pasture declined from 3000 to 1000 kg per ha, bite size decreased while both biting rate and grazing time increased. As a result, both intake and the percent green in the diet remained virtually unchanged. However, at levels below 1000 kg per ha of green material, intake dropped since lambs were unable to compensate for the reduction in bite size with adequate increases in grazing time and biting rate. Qualitatively similar results have been reported for grazing cattle (Chacon and Stubbs, 1976) except that at very low levels of green material bite size, bite rate and grazing time decreased simultaneously.

3. EASE OF PREHENSION

Little has been published examining the relationship between grazing mechanics and the proportion of green material in the diet of mature sheep. Nevertheless, it appears to be well accepted in the literature that the ease of prehension, measured by bite size, of green forage is a major factor limiting potential voluntary intake (Arnold, 1981; Hodgson, 1982; Rattray and Clark, 1984; Poppi et al., 1987), and intake is the primary determinant of the nutrional value of a pasture (Clarke and Ulyatt, 1985).

The ease of prehension of forage may be directly a function of the vertical distribution (L'Huillier et al., 1984) and the height and density of green material (Allden and Whittaker, 1970; Black and Kenney, 1984). To examine the relationship between pasture height, green leaf height and intake, L'Huillier et al. (1986) grazed sheep for 3 days on either ryegrass or prairie grass swards in summer. Both the ryegrass and prairie grass pastures were of the same mass (kg/ha) and overall height (20 cm). The green leaf height was 5 cm (low) and 12 cm (moderate) for the ryegrass and prairie grass, respectively. Apparent grazing horizon was determined by a stratified cutting technique at three heights (0 to 3 cm, 3 to 6 cm and greater than 6 cm). Sheep grazed predominately in the horizon containing the green leaf and intakes were 50% lower on the shorter, ryegrass pastures. The authors concluded that the lower intakes on ryegrass pastures was due to the difficulty of prehending the less accessible green material, although other differences between ryegrass and prairie grass may also have accounted for some of the discrepancy in intakes of the two forages.

In order to by-pass the confounding between height, density and plant maturity which normally plagues grazing trials, Black and Kenney (1984) created artificial pastures of varying height and density by inserting grass tillers through holes in plywood sheets. Each "pasture" was grazed by one sheep for 30 seconds. A positive curvilinear relationship between intake rate (grams dry matter per min, g DM/min) and both height and density was observed with an asymptote of 6 g DM/min. This result was close to that observed with sheep continuously grazing natural real pastures grazed in which only forage intake and height was measured (Penning, 1986). Black and Kenney (1984) found no significant interaction between plant height and plant density. They suggested that forage mass, a combination of height and density, was a better predictor of intake rate than either component alone.

In an earlier study, Allden and Whittaker (1970) used a 3x5 factorial arrangement of plant height and plant density to remove confounding of the two factors. The three pastures heights were achieved by varying the regrowth interval following a grazing and mowing regimen. The different plant densities were obtained by removing strips of vegetation. In contrast to the results of Black and Kenney (1984), Allden and Whittaker (1970) reported that only height had an effect on intake rate and concluded that dry matter per unit area, i.e. pasture or forage mass, was not a reliable guide to the intrinsic availability of forage to the animal. An alternative conclusion is that the two techniques for creating different densities in the pasture do not have similar effects on the animal, i.e. the two experiments are measuring two distinctly different effects. Black and Kenney (1984) measured plant density at the site of grazing whereas Allden and Whittaker (1970) measured plant density over the entire land area available for grazing.

4. PASTURE MASS

Little agreement exists between studies on the effect of pasture mass (kg/ha) on forage intake of sheep grazing pastures continuously for several months (Arnold, 1964; Arnold and Dudzinski, 1967b; Hodgson, 1981). Two of the studies reported a curvilinear relationship between intake and mass but with asymptotes at 2500 kg DM/ha (Arnold and Dudzinski, 1967b) vs. 5000 kg DM/ha (Langlands and Bennet, 1973). In the latter study, intake dropped rapidly once pasture mass dipped below 2000 kg DM/ha. Others have observed no reductions in forage intake by lactating ewes at levels as low as of 1000 kg DM/ha in spring and 2000 kg DM/ha in summer (Hodgson and Maxwell, 1984). In contrast, Arnold (1964) observed that as pasture mass increased from 1000 to 3000 kg DM/ha forage intake declined. The author suggested that this result was due to increased demand by the animal caused by increased grazing effort as mass declined. More likely, the negative correlation between pasture mass and intake reported by Arnold (1964), as well as the differences in reported levels of pasture mass where intake begins to decline, result from positive relationships between pasture mass and plant maturity.

In the face of poor agreement on how pasture mass (M) affects intake of grazing sheep, most simulation models of continuous grazing systems have described the effect of pasture mass on forage intake by using a curvilinear function in which intake increases at a decreasing rate as pasture mass increases. Asymptotes have been defined as the maximum voluntary intake (A) when digestibility was not limiting. The curvilinear functions employed include the natural growth function, $A * (1-\exp(-k*M)$, (Arnold et al., 1977, Vera et al., 1977; Sibbald et al., 1979) with the parameter K ranging from 0.0013 to 0.0028; the natural growth function in altered form, $A * (1 - \exp(-k*M^2)$ with k values of 2.4×10^{-7} (Edelsten and Newton, 1977) and 20.0×10^{-7} (White et al, 1983); the Michaelis-Menton function (rectangular hyperbola), $A * [(M-M_r) / \{(M-M_r) + (M_k-M_r)\}]$, where M_r is the minimum pasture mass to which animals can graze and M_k, the Michaelis-Menton constant, is the pasture mass at which intake is half of the maximum voluntary intake (Noy Meir, 1976); and an unnamed function, $A* [(1 - k_3 * \{\exp(k_4*M)\}) * (\exp\{k_1*\exp(k_2* M*A/(N*T))\}]$ where N is the number of animals and T the days of grazing (McCall, 1984). Most of these models have been validated to some extent at the whole system level - usually in terms of live weight body changes or kilograms of lamb weaned under a given set of pasture conditions. That each of these models, which differ considerably in functional form and parameter values, has been validated in some respect attest either to the large natural variation of the biological systems or to the lack of sensitivity of whole system models to the intake subsystem.

5. FORAGE ALLOWANCE

In continuous grazing systems lasting from several weeks to several months, pasture height and mass are useful indicators of forage intake and grazing pressure (Hodgson and Maxwell, 1984). But in rotational grazing systems, characterized by short grazing durations (1 to 7 days) and high stock densities, changes in the pasture are occurring too rapidly for these variables alone to describe intake (During and Dyson, 1980). Whether rotational grazing actually produces higher annual production levels of either pasture or animal products relative to a continuous grazing system continues to be a matter of great speculation and will not be covered here. In New Zealand, where much of the research on this topic has been conducted, rotational grazing is widely promoted for the primary purpose of rationing feed supplies in winter in order to build up pasture forage for the critical spring lactation period (Rattray et al, 1982a). Studies have shown that large changes in body weight, e.g. up to 8 kg gained or lost, created by differential grazing conditions pre-parturition produced no important differences in ewe and lamb mortality, incidence of pregnancy toxemia, or lamb weaning weights provided that ample high quality forage was available during lactation (Rattray and Jagusch, 1978; Geenty and Sykes, 1986). However, milk production of lighter ewes has been shown to be easily depressed by low levels of green forage (Gibb and Treacher, 1978; Geenty and Sykes, 1986).

In an attempt to better predict rotational grazing intake by ruminants, Hodgson (1984) defined additional descriptors of pasture conditions: residual or post-grazing pasture mass (kg DM/ha); forage utilization [(pre-grazing mass - post grazing mass) / (pre-grazing mass)]; and allowance (mass of forage per animal at a point in time). Allowance is usually expressed as an average daily ration on offer, i.e. kg DM/animal/day (Rattray and Clark, 1984; Hodgson, 1984), although Gibb et al. (1981) suggested that allowance be defined as grams of forage per kg of live weight per day in order that results from a wide range of studies (within and between species) might be compared. Additional difficulties in the comparison of results across trials for any of these descriptors are caused by the failure of authors to consistently distinguish between kg of green DM and kg of total DM (green plus dead).

Both forage utilization and residual dry matter (RDM) are popular predictors of intake on New Zealand farms (Milligan, 1983). While these predictors are conceptually easy to understand, their value in research trials is limited. The effect of utilization and RDM on intake is heavily dependent on other pre-grazing conditions which may render results difficult to interpret. For example, utilization estimates of 50 percent can be achieved either by sheep grazing a pasture from 3000 kg DM/ha down to 1500 kg DM/ha or grazing from 1000 kg DM/ha down to 500 kg DM/ha, but intakes in these two situations are quite different (Rattray et al., 1987). In field trials with pasture conditions similar to those in the previous example, RDM has been shown to be a good predictor of intake (Rattray et al., 1982b). Within a given set of data, RDM may be as good (Smeaton and Knight, 1981; Hawker et al., 1985) or better predictor of intake than forage allowance (During and Dyson, 1980; Smeaton et al., 1983). However, estimates of RDM alone account for neither the effect of pre-grazing pasture mass nor grazing pressure (product of number of animals and duration of grazing). In particular, RDM has been shown to be a poor predictor of changes in forage intake due to alterations in animals per ha (Jagusch et al, 1981).

The large majority of published grazing trials have focused on forage allowance as a predictor of intake or animal performance since the variable encompasses the major pasture and management variables of pre-grazing forage mass, animal density and grazing duration. Since forage allowance is a composite variable, a given allowance can be achieved by an infinite number of combinations of mass, density and duration. Grazing trials in which allowance was varied by altering only animal density or grazing duration (i.e. pre-grazing pasture mass was the same at all allowances) have shown a curvilinear asymptotic relationship between allowance and forage intake of both mature ewes (Geenty and Sykes, 1982; Rattray et al., 1982a; Rattray et al., 1983; Geenty and Sykes, 1986) and lambs (Gibb and Treacher, 1976; Jagusch et al., 1979). Similar relationships have been observed between allowance and live weight change of weaned lambs (Gibb and Treacher, 1976; Jagusch et al., 1979; Thompson et al., 1980; McEwan et al, 1988), of hoggets (During and Dyson, 1980), non-pregnant ewes (Rattray et al., 1978; Rattray et al., 1983), gestating ewes (Rattray and Jagusch, 1978), and lactating ewes (Rattray et al., 1982b; Geenty and Sykes, 1986). Curvilinear relationships have also been found between allowance and production parameters such as ovulation rate (Rattray et al., 1980; Rattray et al., 1981; Rattray et al., 1983), lambs born per ewe joined (Rattray et al., 1978) and wool growth throughout the year (Hawker et al., 1982; Hawker et al., 1985). Munro and Geenty (1983) reported that live weight change of suckling lambs up to 6 weeks of age appeared to be unaffected by the allowance offered ewes and lambs. The authors suggested this was due to the buffering capacity of the ewe since lamb growth during this period is largely dependent on milk intake rather than forage intake.

The asymptotic value of intake at high allowances is influenced by the pre-grazing pasture mass (Rattray et al., 1982a; Rattray et al., 1983; McEwan et al, 1988), animal nutrient drive (Penning et al., 1986) and the physical ability of the sheep to prehend feed, i.e. mouth soundness (Moss, 1987). Using a factorial arrangement of animal density and pre-grazing green forage mass, Rattray et al. (1983) found that the asymptotic value for intake increased linearly as pre-grazing mass increased. The authors also noted that the allowance at which maximum intakes occurred increased from 3 to 5 kg green DM/animal/day as pre-grazing mass increased from 700 to 2500 kg DM per ha. McEwan et al. (1988) recorded lamb live-weight change over a wide distribution of allowances and pre-grazing pasture masses occurring over a seven year period. They reported that at any given allowance lamb growth increased at a diminishing rate as pasture mass increased up to 3500 kg DM/ha. Pasture masses over 4500 kg DM/ha caused declines in the rate of growth at all allowances. The level at which allowance did not limit lamb growth occurred at about 5 and 7 kg DM/animal/day for high and low pre-grazing pasture masses, respectively. In contrast, Jagusch et al. (1979) found no change in the effect of allowance on lamb growth rate at pasture masses of 2500 vs. 3500 kg DM/ha, indicating that pasture mass above 2500 kg DM/ha was not limiting intake.

The objective in early studies of forage allowance and animal performance or forage intake was to provide farmers with a set of grazing management guidelines (Cooney and Thompson, 1978; Jagusch et al., 1978). In recent years, more effort has been focused on the nature of the relationship between allowance and intake using both experimentation and simulation (Bircham and Sheath, 1986; McEwan et al., 1988). Yet it appears that this relationship - intake increases at a decreasing rate as forage allowance increases - is an artifact of the definition of forage allowance and the effect over time of decreasing pasture mass. At high allowances achieved by low grazing pressures, the amount of forage consumed relative to the pre-grazing mass is very small. Consequently, both pasture mass and intake, as a function of pasture mass, are virtually constant over the grazing period. If allowances are increased further by reducing the grazing pressure, animal intake over the grazing period will remain unchanged since pasture mass is unchanging.

At low allowances and high grazing pressures, the pasture mass is continuously changing due to the large amount of forage consumed relative to forage available. In this region of the curve where decreases in forage allowance cause decreases in forage intake, allowance is simply a tool for averaging over time the effect of a declining pasture mass on intake.

THE PATTERN OF DECLINE IN PASTURE MASS BY SHEEP GRAZING AT A HIGH STOCK DENSITY DURING SUMMER AND WINTER

CHAPTER 2

SUMMARY

Daily changes in total dry matter (TDM) and green dry matter (GDM) forage mass (kg/ha) were studied on pastures grazed by sheep in two seasons. Groups of 20 mature ewes grazed adjacent 0.1 ha pastures at a stock density of 200 sheep/ha for 9 days in summer (September) and again for 4 days in winter (January). The TDM in each pasture was estimated on each day of grazing by clipping ten 0.2 m^2 plots to ground level. In summer, GDM was estimated from clipped samples based on the percent moisture in the sample and percent moisture in standard samples of 100% green forage and 100% dead forage collected in adjacent pastures. In winter a spectophotometer was used to estimate the percent green of the clipped forage. Daily forage mass (kg/ha) of both TDM and GDM were analyzed by a negative exponential model. The regression coefficients for TDM mass on day of grazing, i.e. the instantaneous rates of decline of forage per day, were 0.1320 ($P<.001$) and 0.04800 ($P<.001$) in summer and winter, respectively. In winter, the decline in GDM accounted for over 95% of the decline in TDM. The instantaneous rates of decline of GDM were 0.3800 ($P<.001$) and 0.5000 ($P<.001$) per day in summer and winter, respectively. Daily finite rates of GDM decline, defined as the proportion of GDM mass on day t

INTRODUCTION

In pastoral livestock production systems the level of animal performance depends largely on the quantity and quality of forage consumed. Knowledge of how forage consumption changes during grazing is especially critical in intensive grazing systems in which each day of grazing has a considerable impact on the quantity of forage subsequently available.

Most studies have indirectly estimated the effects of forage availability on forage intake by measuring components of animal performance such as liveweight change, ovulation rate or wool growth over a period of several weeks or months (Hawker et al., 1982; Hodgson, 1984; Poppi et al. 1987; McEwan et al. 1988). While such studies are quite useful for providing general grazing management guidelines for farmers, they are unable to describe changes in forage intake on a daily basis.

An alternative approach has been to estimate the effect of pasture variables on the mechanics of forage consumption, i.e. bite size, bite rate and grazing time (Allden and Whittaker, 1970). While this approach may eventually provide a more fundamental understanding of forage intake, techniques have yet to be developed which would allow accurate measurement of bite size and bite rate for large numbers of animals over several days of grazing.

Despite the limitations of these two approaches, few studies have been published which have determined the effects of pasture variables on daily forage intake. Due to the large standard errors associated with estimates of forage mass, researchers conducting forage intake studies have been satisfied to estimate only average daily intake derived from pre-grazing and post-grazing forage mass estimates (Rattray and Clark, 1984). Bircham and Sheath (1986) provided the first estimates of forage decline during grazing, but they terminated grazing at a target forage allowance without the animals necessarily grazing to minimum forage levels. Consequently, little is known about changes in forage consumption as forage declines to such low levels that animals stop grazing.

The primary objective of this study was to quantify the daily decline in total dry matter and green dry matter forage mass as sheep reduced forage to the lower limit of prehension. A second objective was to compare the effects of dry summer pasture with high forage mass vs. green winter pasture of low forage mass on the pattern of forage decline during grazing.

MATERIALS AND METHODS

In each of two seasons, summer and winter, a total of 36 Hampshire and 24 Coopworth mature ewes, averaging 65 kg, were randomly divided within genotype into three replicates each of 20 ewes. Each replicate was allocated a 0.1 ha pasture for 8 and 4 days in the summer and winter grazing periods, respectively. The same pastures were used for both summer (early September) and winter (January) grazing. Animals grazed similar, adjacent 0.2 ha pastures for two days prior to each grazing period.

Pastures had been lightly grazed in the spring and early summer prior to trial initiation. Pastures in summer consisted of large amounts (6000 kg/ha) of standing dry forage lightly interspersed with clumps of green Tall Fescue plants. Forage in the winter was either erect, green Ryegrass-Fescue autumn regrowth and annual grasses (560 kg/ha), or dead material remaining after summer grazing (900 kg/ha).

Weather conditions in both summer and winter trials were fairly typical of western Oregon. Summers consist of several months of hot, dry conditions followed by a mild, wet autumn period. Winters are also wet and average air temperatures are well above freezing. However, soil temperatures are usually too low for significant grass growth.

Total dry matter (TDM) and green dry matter (GDM) were estimated in each pasture prior to grazing initiation and after each day of grazing. The TDM within a pasture was estimated from 10 randomly selected 0.2 m^2 quadrats. Quadrats were cut to ground level and the collected forage was weighed, dried at 50 degrees celsius for five days and re-weighed.

The GDM of each sample collected during the summer grazing period was estimated by simultaneous solution of the following system of equations:

(2.1) GREEN DM + DEAD DM = DRY WEIGHT

(2.2) (A * GREEN DM) + (B * DEAD DM) = WET WEIGHT ,

where A and B are the ratio of wet weight to dry weight in 100 percent green and 100 percent dead samples, respectively. The GDM of samples collected during the winter grazing period was estimated by spectophotometry as described in the "Materials and Methods" section of chapter 3.

Daily forage consumption can be estimated by the difference in forage mass from one day to the next during grazing. However, such consumption estimates lack accuracy since their variation is cumulative from the two forage mass estimates. Pasture estimates typically have coefficients of variation ranging from 20 to 40%. To improve accuracy, forage mass was chosen as the dependent variable in data analyses since each estimate of forage mass is independent of the previous day's estimate.

Data from each grazing period was analyzed using least squares procedures (Harvey, 1975). The dependent variables, i.e. TDM and GDM forage mass (kg/ha), were transformed with the natural logarithm function and analyzed with replicate fitted as a fixed effect and day of grazing as a continuous variable. The two-way interaction between replicate and grazing pressure was tested, but was not included in the final model due to its lack of statistical significance ($P>.20$). The non-linear functional form (negative exponential function) was:

$$M_t = EXP(B_0) * EXP(-B_1*t) \quad (2.3)$$

where t is the day of grazing, M_t is forage mass at day t, B_0 is the regression constant and B_1 is the instantaneous rate of forage decline per day.

In addition, daily finite rates of forage decline (DFR) were calculated using the equation:

$$DFR = M_t / M_{t-1} \quad (2.4)$$

where M_t and M_{t-1} represent average forage mass of the three replicates at day t and day t-1, respectively.

RESULTS AND DISCUSSION

The pattern of decline in total dry matter (TDM) forage mass over the summer grazing period is shown in figure 2.1. The negative exponential curve, equation 2.4, appeared to fit the data well (R^2=.94). The instantaneous rate of TDM decline per day of grazing, B_1 (equation 2.3), was 0.1320 (P<.001). The instantaneous rate of forage decline per day determines the curvature of the negative exponential function and may be interpreted as representing the efficiency with which animals cause forage to decline, presumably by consumption.

The finite rate of forage decline over the entire grazing period, EXP($-B_1$), was 0.876. The finite rate represents the amount of forage remaining after one day of grazing as a proportion of the initial forage mass. Therefore, approximately 12% of TDM mass was consumed each day of grazing at the stock density of 200 sheep/ha.

In order to compare the results of this trial with results from previous studies, the instantaneous rate of forage decline per day must be expressed at the same stock density. This was achieved by multiplying the instantaneous rate of decline per stock day observed in other studies by 200 sheep/ha, the stock density of this trial. The instantaneous rate of TDM decline per day observed in the summer period agrees well with results of summer grazing trials conducted in New Zealand even though initial pasture conditions varied greatly between this study and those reported previously. For instance, L'Huillier et al. (1986) measured forage disappearance for each day of a three day grazing period. Pasture type and size, animal density and percent green (15%) were similar to this study, but initial forage mass was 2000 kg TDM/ha compared to approximately 6000 kg TDM/ha in this study. Examination of their data with a negative exponential model produces a similar estimate of the instantaneous rate of TDM decline (0.1480 per day) despite large differences in initial forage mass.

Bircham and Sheath (1986) fitted negative exponential curves to individual hill country pastures grazed for periods ranging from 3 to 12 days. Forage mass was estimated at 0, 1/3, 2/3 and 3/3 days of grazing (data reported previously by Sheath (1983)). Animal density, pasture size, percent green forage and initial forage mass all varied greatly from this study; nevertheless, Bircham and Sheath (1986) reported estimates of the instantaneous rate of TDM decline ranging from 0.078 to 0.184 and averaging 0.116 per day.

The close agreement between results from these studies suggests that the relative rate of forage decline may be rather stable on summer pastures despite large variations in total biomass and proportions of green material. However, it may be misleading to assume that at high levels of pasture biomass all disappearance of forage is animal intake. Most likely, the trampling of dry, brittle forage found in summer pastures also contributes to forage disappearance.

The instantaneous rate of TDM decline, B_1 (equation 2.3), in winter was 0.048 per day (P<.01), approximately one third of the summer value. During both the summer and winter grazing periods, sheep appeared to greatly prefer green forage to dead forage. Green dry matter declined by approximately 50% in the first 24 hours of summer grazing and had disappeared nearly completely from the pastures by the end of the trial. During the winter grazing period over 95% of the total decline in forage was GDM even though the percent (36%) and amount (525 kg/ha) of GDM initially in the pasture were low. A high degree of selectivity for green forage over dead forage by grazing sheep has been reported previously on numerous occasions (Arnold, 1981; Guy et al., 1981; Clark et al. 1982). The difference in instantaneous rates between the two seasons was most likely due to differences in the rejection of non-green or "dead" material resulting from physical changes in the dead material from summer to winter. In the summer, dead forage was golden brown in color and primarily erect. Between the summer and winter trials the paddocks were not grazed but dead forage declined, due to decomposition, from 2000 kg/ha to less than 1000 kg/ha at the initiation of winter grazing. The dead forage remaining at the initiation of the winter trial was lodged and gray to black in color.

The negative exponential curve fitted to summer and winter daily observations of green dry matter (GDM) are shown in figures 2.2 and 2.3, respectively. The model appeared to fit the summer data well

(R^2 = 0.89) with an estimated instantaneous rate of GDM decline, B_1 (equation 2.3), equal to 0.380 per day (P<.001).

In the analysis of the winter data, a better fit of the data was obtained by assuming that the lowest residual GDM mass to which the animals either could or would graze, represented by the asymptote of the negative exponential function, was 150 kg/ha rather than 0 kg/ha as was assumed in the summer analysis. The estimated instantaneous rate of GDM decline, B_1, in winter was 0.482 per day (P<.001) with the model R^2 equal to 0.72.

The poorer fit of the model in the winter trial relative to the summer trial was caused by the less consistent winter daily finite rates of forage decline, the ratio of GDM mass on day t to GDM mass on day t-1 (equation 2.4). The finite rates were fairly constant in summer, but in winter they increased steadily from 0.3829 for the first day of grazing to more than 0.9980, i.e. virtually no forage disappearance, on the last day of grazing. This increase suggests that the efficiency with which sheep were able to consume GDM in winter was decreasing as GDM in the pasture declined. The difference in variation of finite rates between the two periods may have resulted from differences in accessibility of the green forage. In the summer the green forage was present in large clumps. However, in the winter the green forage was emerging through a dense cover of dead material and the sheep may have had increased difficulty prehending green forage as GDM declined.

The instantaneous rates of forage decline of GDM observed in this study are larger than the average of values reported by Bircham and

Sheath (1986) in summer (0.280 per day) and winter (0.206 per day) trials. Bircham and Sheath observed a lower estimate of instantaneous rate in winter relative to summer, whereas the opposite was observed in this trial. However, the discrepancy in instantaneous rates between studies may be largely a result of the assumed minimum residual to which sheep can prehend forage. If, like the Bircham and Sheath (1986) study, a minimum residual of 0 kg/ha is assumed in the analysis of the winter data, then the resulting instantaneous rate, 0.212 ($P<.001$), is very close to their value.

While the decline in forage mass on temperate pastures during high density grazing is probably more complex than a simple negative exponential model would suggest, the results of this study indicate that an exponential model can quite closely describe the decline in total dry matter under a wide variety of pasture conditions. The comparison of the results of this trial with those from other studies was favorable. However, such comparisons between instantaneous rates derived under different stock densities and grazing durations are based on the assumption that the combination of stock density and grazing duration used to achieve a target grazing pressure (stock density X grazing duration) has no effect on the instantaneous rate of forage decline. The validity of this assumption needs to be examined before the negative exponential function can serve as a general description of the decline in forage mass during intensive (high stock densities and short grazing durations) grazing.

FIGURE 2.1 LEAST SQUARES FIT OF TOTAL DRY MATTER (TDM) MASS (KG/HA) ON DAY OF GRAZING (t) IN SUMMER.

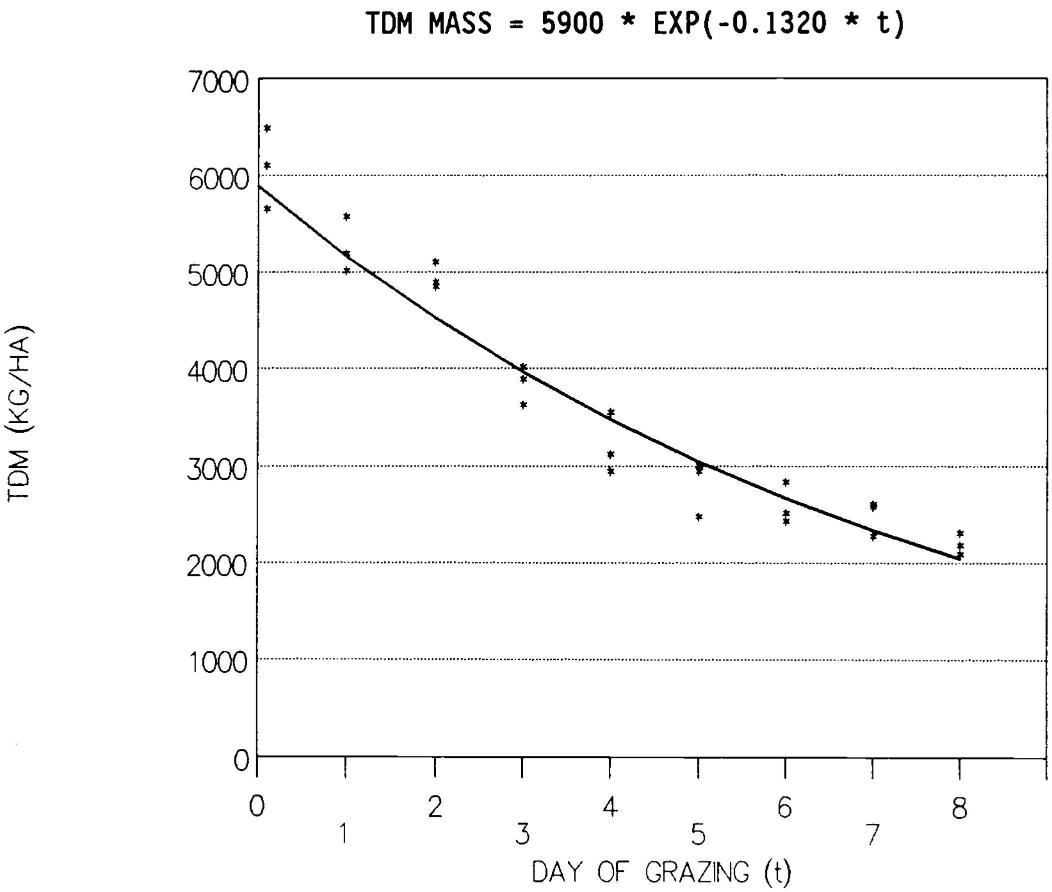


FIGURE 2.2 LEAST SQUARES FIT OF GREEN DRY MATTER (GDM) MASS (KG/HA) ON DAY OF GRAZING (t) IN SUMMER.

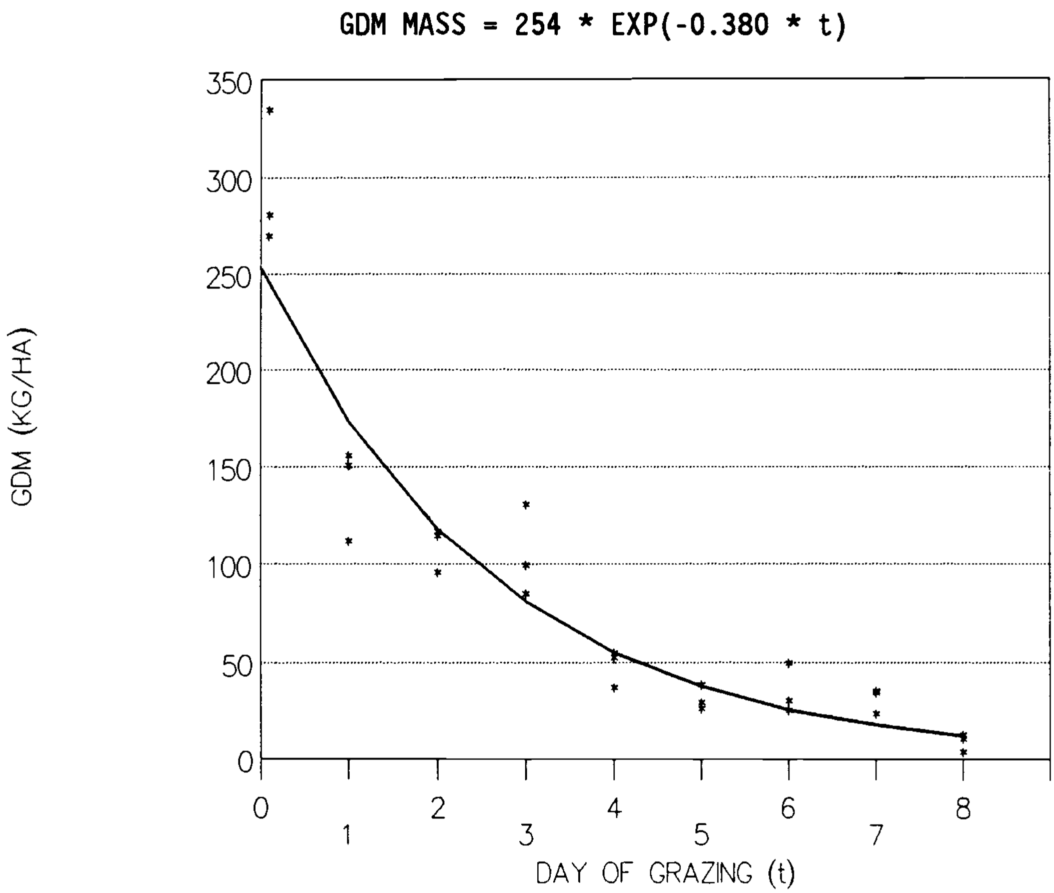
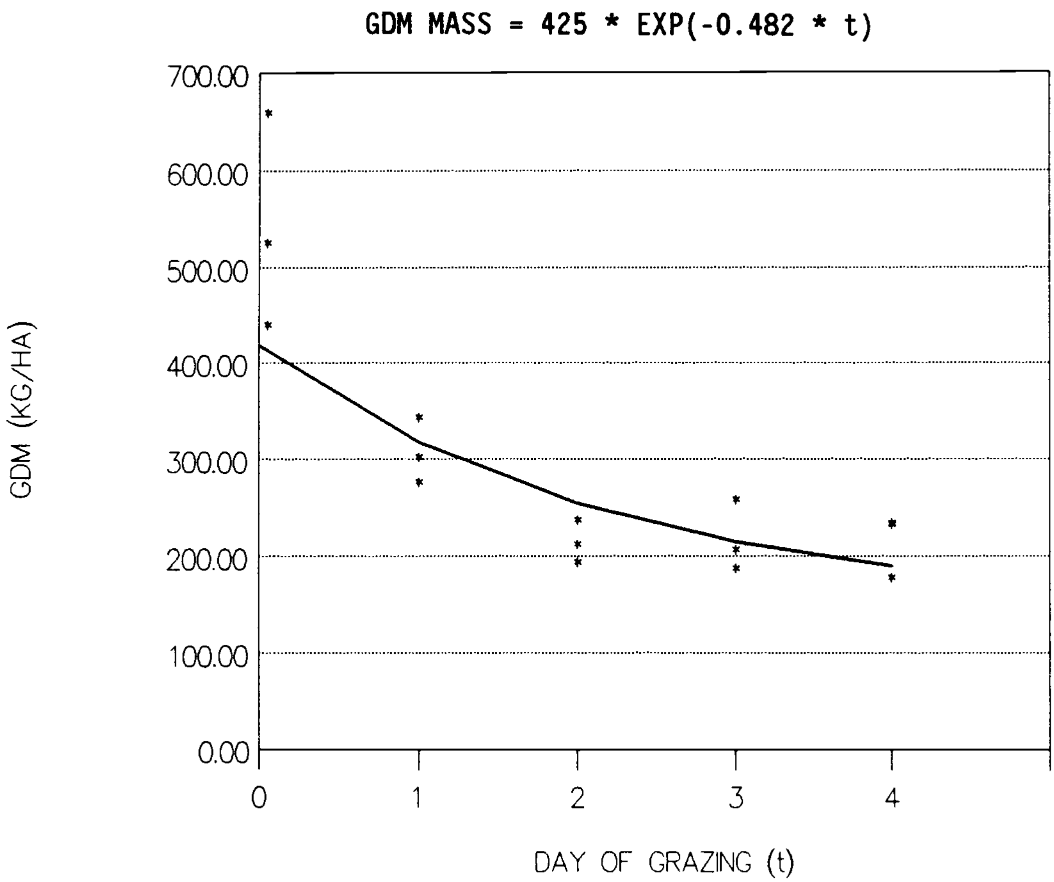


FIGURE 2.3 LEAST SQUARES FIT OF GREEN DRY MATTER (GDM) MASS (KG/HA) ON DAY OF GRAZING (t) IN WINTER.



REFERENCES

Allden, W.G. and I.A.M. Whittaker. 1970. The determinants of herbage intake by grazing sheep: the interrelationships of factors influencing herbage intake and availability. Aust. J. Ag. Res. 21:755-766.

Arnold, G.W. 1981. Grazing behaviour. In: Moreley, F.H.W. (ed.) Grazing animals. Elsevier. Amsterdam, Netherlands. pp 79-104.

Bircham, J.S. and G.W. Sheath. 1986. Pasture utilization in hill country 2. A general model describing pasture mass and intake under sheep and cattle grazing. N.Z. J. of Agr. Res. 29:639-648.

Clark, D.A., M.G. Lambert and D.F. Chapman. 1982. Pasture management and hill country production. Proc. N.Z. Grassland Assoc. 43:205-214.

Guy, M.C., B.R. Watkin and D.A. Clark. 1981. Effect of season, stocking rate and grazing duration on diet selected by hoggets grazing mixed grass-clover pastures. N.Z. J. of Exp. Agr. 9:141-146.

Harvey, W.R. 1975. Least-squares analysis of data with unequal subclass numbers. Publ. No. A-4, ARS, USDA, Washington, D.C.

Hawker, H., S.F. Crosbie and K.F. Thompson. 1982. Effects of season and pasture allowance on the wool growth of romney ewes. Proc. N.Z. Soc. Anim. Prod. 42:183-185.

Hodgson, J. 1984. Sward conditions, herbage allowance and animal production: an evaluation of research results. Proc. N.Z. Soc. Anim. Prod. 44:99-104.

L'Huillier, P.J., D.P. Poppi and T.J. Fraser. 1986. Influence of structure and composition of ryegrass and prairie grass-white clover swards on the grazed horizon and diet harvested by sheep. Grass and Forage Sci. 41:259-267.

McEwan, J.C., R.C. McDonald, P.F. Fennessy, K.F. Thompson, C.G. Hughson and K.G. Dodds. 1988. Pasture quality and nutrition in weaned lambs. Sheep and Beef Cattle Soc. N.Z. Vet. Assoc. 18:178-188.

Poppi, D.P., T.P. Hughes and P.J. L'Huillier. 1987. Intake of pasture by grazing ruminants. N.Z. Soc. Anim. Prod. Occ. Publ. #10: 55-63.

Rattray, P.V. and D.A. Clark. 1984. Factors affecting the intake of pasture. N.Z. Agr. Sci. 18:141-146.

Sheath, G.W. 1983. Pasture utilization in hill country. 1. Influence of grazing duration and land contour. N.Z. J. Exp. Agr. 11:309-319.

EFFECTS OF STOCK DENSITY, GRAZING DURATION AND STOCK TYPE ON FORAGE INTAKE OF SHEEP GRAZING AT HIGH STOCK DENSITIES

CHAPTER 3

SUMMARY

The effect of animal density and grazing duration on forage intake was investigated with ewes and lambs. In a 2x3x3 factorial design, ewes and lambs separately grazed 0.033 ha perennial ryegrass - tall fescue dominant paddocks in groups of 9, 18 or 27 sheep for 1,2 or 3 days. Each treatment was replicated three times for a total of 54 observations. Pre-grazing and post-grazing total dry matter (TDM) were estimated using a probe capacitance meter which was calibrated with TDM estimates from two 0.2 m^2 plots clipped to ground level within each paddock. Pre- and post-grazing green dry matter (GDM) was estimated for each paddock from the product of the TDM estimate and the percent green in the clipped samples. The percent green was estimated using a spectophotometer. Ewes and lambs consumed approximately equal amounts of total dry matter; however, ewes consumed on average 0.10 more kg green dry matter per day than lambs ($P<.05$). Forage consumption of groups grazing at the same grazing pressure, i.e. stock days/ha (stock density X grazing duration), but at different combinations of stock density and grazing duration were not significantly different. The effect of grazing pressure on post-grazing total and green dry matter was analyzed using a negative

exponential model with pre-grazing dry matter as a covariate. The regression coefficients for post-grazing mass on grazing pressure, i.e. the instantaneous rates of decline of forage per stock day, were 0.00011 ($P<.01$) and 0.00030 ($P<.01$) for total and green dry matter, respectively. Pre-grazing mass had a significant, approximately linear, effect on post-grazing mass. At a grazing pressure of 1080 stock days/ha, post-grazing total and green dry matter mass increased 0.25 and 0.12 kg/ha for each kg/ha increase in pre-grazing mass, respectively.

INTRODUCTION

The success of intensive grazing systems involving high stock densities (large numbers of animals per hectare) and short grazing durations (1 to 3 days) depends on sound knowledge of the effect of grazing conditions on daily forage intake per animal. The list of variables which have been used to define grazing conditions includes stock density (sheep/ha), grazing duration (days), grazing pressure (stock days, i.e. the product of stock density and grazing duration), pre- and post-grazing forage mass (kg dry matter (DM) per ha) and forage allowance (kg DM/sheep/day). However, research efforts have focused primarily on forage allowance, defined as pre-grazing mass divided by grazing pressure) as a predictor of animal performance (Hodgson, 1984).

In recent years, numerous grazing trials have been conducted, mostly in New Zealand, which have found a general curvilinear relationship between forage allowance (kg DM/animal/day) and animal performance. As forage allowance increases, production traits such as liveweight change (McEwan et al. 1988), ovulation rate (Rattray et al. 1983) and wool growth (Smeaton et al. 1983) increase at a decreasing rate. Few studies have related forage allowance to intake, either directly or as pasture disappearance.

Due to the complexity of defining forage allowance, it is difficult to gain more than a general interpretation of the effect of forage allowance on either animal performance or forage intake. A given forage allowance can be achieved through a near infinite array of pre-grazing forage mass, animal number, pasture size and grazing duration combinations. Not all combinations creating a given forage allowance need produce the same intake. For instance, increasing pre-grazing forage mass while keeping forage allowance constant has been shown to produce an increase in average daily intake (Rattray and Clark, 1984). Nevertheless, research to date has assumed that at a given forage allowance, the particular combination of contributing remaining variables at a given allowance will have no effect on forage intake.

The objectives of this study were: 1. to examine the effect on forage intake of altering the combination of stock density and grazing duration used to achieve a target grazing pressure; 2. to determine the relationship between grazing pressure and forage intake; and, 3. to compare the forage intake of ewes and lambs at varying grazing pressures.

MATERIALS AND METHODS

DESIGN

Experimental plots consisted of three sequential replications of 18 grazing treatments arranged in a 2x3x3 factorial array. The 18 treatments were composed of lambs or ewes stocked at densities of 270, 540 or 810 sheep/ha for durations of 1, 2 or 3 days. Grazing occurred between November 16 and December 7, 1989.

PASTURES

Three permanent pastures, one for each replication, were each subdivided into 18 similarly shaped paddocks of .033 ha. Pastures had been irrigated and grazed during hot, dry summer months. A mild and wet autumn, typical of the region, had provided favorable conditions for autumn regrowth. Forage was composed of a mixture of the autumn regrowth and mature summer growth with a thick understory of dead grass. Species composition was visually estimated at approximately 80% perennial ryegrass and tall fescue and 20% white clover.

ANIMALS

For each replication, a total of 108 female lambs and 108 mature ewes were randomly allocated to 12 of the 18 treatment groups. The 12 treatments consisted of all density and stock class combinations and two of the three grazing durations selected at random. Upon completion of grazing, animals were mixed within age groups and half of each group were randomly re-allocated to the remaining six treatments. The remainder stock were grazed on pastures of similar type at a low stock density until their allocation in the successive replicate.

Lambs were either Coopworth x Polypay or Hampshire and averaged 7 months of age and 40 kg. Ewes were either Polypay or Coopworth x Polypay crossbreds. Ewes ranged in age from 2 - 5 yrs and averaged 55 kg. Animals were all in moderate to good body condition.

MEASUREMENTS

Pre-grazing total dry matter (TDM) was estimated for each paddock the day preceding grazing and post-grazing TDM was estimated within three days of stock removal. Estimates of forage mass were made using a probe capacitance meter calibrated by probing and clipping to ground level two 0.2 m^2 quadrats per paddock (total of 216 samples). The mean probe reading for each plot was determined from a minimum of 75 probe readings obtained by the operator while crisscrossing the plot. Within each paddock the two areas to be clipped were chosen as being visually representative of the average forage mass in the paddock and had a mean probe reading (based on 15 probings) within 5% of the probe mean for the paddock. Forage clipped from each area was weighed and a sample was washed and dried at 50 degrees Celsius until no further weight change was observed over a 24 hr period.

The proportions of green and dead forage in each plot pre- and post-grazing were estimated from the clipped samples. After drying, each sample was ground to <1 mm particle size. A sub-sample of 0.166 g from each ground sample was soaked in 100 ml of 95% ethanol for 18 hours and centrifuged. The absorption of light at wavelength 433 nm was recorded for each subsample using a spectophotometer. Absorption values were converted into percent green dry matter using a regression equation of percent green on absorption. The regression equation was based on samples of 100% green and 100% dead forage from the same pastures, processed as described above and mixed in proportions of percent green ranging from 0% to 100% in steps of 10%.

Forage consumption, i.e. the total amount of forage consumed during the grazing period (kg/ha), was defined as the difference between pre-grazing and post-grazing forage mass. Average daily intake (ADI) was defined as forage consumption divided by grazing pressure.

STATISTICAL ANALYSES

Data were analyzed using least squares procedures (Harvey, 1975). The capacitance probe was calibrated by regressing dried sample weights on their respective paddock probe readings. Replication and time of clipping relative to grazing (pre- or post-grazing) were fitted as fixed effects. The model also included the interaction between time of clipping and probe reading.

Post-grazing forage mass, measured as both total dry matter per ha (TDM) and green dry matter per ha (GDM), was analyzed with replication, stock class, stock density, grazing duration and significant ($P<.10$) two-way interactions fitted as fixed effects. Pre-grazing forage mass (PRE) was fitted as a covariate. In order to correct for unequal variances within treatment pre-grazing and post-grazing forage mass were transformed utilizing the natural logarithm function. Results were expressed in terms of forage consumption (kg/ha) and average daily intake (kg/sheep/day).

Post-grazing forage mass (POST) was also analyzed as a function of grazing pressure using the following fixed effects model:

$$(3.1) \qquad Y = Mu + REP + STOCK + B_1(X_1-\overline{X_1}) + B_2(X_2-\overline{X_2}) \ ,$$

where X_1, X_2 and Y were continuous variables. The variable X_1 was grazing pressure; X_2 was the natural logarithm of pre-grazing forage mass; and, Y was the natural logarithm of post-grazing forage mass. The independent variables, REP and STOCK, were fitted as class effects for replication and stock type, respectively.

Using the exponential function, equation (3.1) was transformed into:

$$(3.2) \qquad POST = EXP(B_0) * EXP(B_1*X_1) * PRE^{**}B_2$$

where B_0 was the mean plus the additive effects of REP, STOCK and regression variables. Adjustment of equation (3.2) to the mean pre-grazing mass resulted in:

$$(3.3) \qquad \text{Adjusted POST} = k * EXP(B_1*X_1) \ ,$$

where k is equal to $EXP(B_0+B_2*\overline{X_2})$. Forage consumption was estimated by subtracting the adjusted post grazing forage mass, equation (3.3), from the mean pre-grazing forage mass. The resulting equation describes the effect of grazing pressure on forage consumption (FC):

$$(3.4) \qquad FC = PRE * [1 - (k/ PRE) * EXP(B_1*X_1)] \ .$$

Average daily intake was estimated by dividing equation (3.4) by the grazing pressure.

Observations on one group were discarded from all analyses as a result of heavy rains flooding the plot and causing excessively muddy conditions. Due to damage to the samples of the first replication, the analysis of green dry matter included only two of the three replications for a total of 35 observations.

RESULTS

The effects of grazing duration, stock density and stock type on forage consumption of total dry matter (TDM) and green dry matter (GDM) are shown in table 3.1. Standard errors of treatment means were large and most differences between treatments within stock type were not significantly different (P>.05).

The effects of varying stock density (sheep/ha) and grazing duration (days) at a specified grazing pressure (stock days/ha) on forage consumption (kg/ha) and average daily intake (kg/sheep/day) are presented in tables 3.2 and 3.3, respectively. Forage consumption (FC) of TDM and GDM were not significantly affected by the combination of grazing duration and stock density used to achieve a given level of grazing pressure. At grazing pressures of 540 and 810 stock days/ha, animals grazing at lower densities for longer durations tended to select diets with higher concentrations of GDM than animals stocked at higher densities for shorter durations. However, the two combinations used to achieve 1620 stock days/ha had a similar proportion of GDM intake.

Since no significant differences in forage consumption were observed between treatment groups of different combinations of stock density and grazing duration, but at the same grazing pressure, a second analysis was conducted in which grazing pressure replaced stock density and grazing duration (equation 3.1). The instantaneous rate of forage decline per stock day, $-B_1$, was .00011 (P<.01). The regression coefficient for the natural logarithm of pre-grazing TDM, B_2, was 0.31 (P<.01). The R^2 of the model was 0.70.

The effect of pre-grazing forage mass on post-grazing mass was modeled using a curvilinear function of the form: $Y = X^a$, where Y was the post-grazing forage mass and X was the pre-grazing forage mass. However, in the range of pre-grazing TDM recorded (1800 to 3900 kg DM/ha), the effect was approximately linear. At the mean grazing pressure of 1080 stock days/ha the linear approximation had a slope of 0.25 kg TDM/ha post-grazing per kg TDM/ha pre-grazing. Consequently, the effect of pre-grazing TDM on FC and average daily intake (ADI) was also positive, e.g. ADI increased by .07 kg/sheep/day for each 100 kg/ha increase in pre-grazing TDM.

In figure 3.1 the non-linear regression of forage consumption (kg/ha) on grazing pressure (stock days/ha), equation (3.4), is shown with the estimates of TDM consumption. The regression and estimates in figure 3.1 have been adjusted to the mean pre-grazing TDM, PRE, of 2793 kg/ha. The value of the multiplier in equation (3.4), k/PRE, was 0.90.

The relationship between ADI (kg/sheep/day) and grazing pressure is shown in figure 3.2. Average daily intake declined at a decreasing rate from approximately 1.3 kg/sheep/day for sheep grazing at 270 stock days/ha to less than 0.4 kg/sheep/day for sheep grazing at 2430 stock days/ha.

Analysis of post-grazing GDM suggested a positive ($B_2 = 0.18$), but not significant, relationship between post-grazing GDM and pre-grazing GDM within the range of pre-grazing GDM observed (470 to 1490 kg/ha). The instantaneous rate of forage decline per stock day, $-B_1$, was 0.00030 ($P<.01$), nearly three times larger than the same regression coefficient in the analysis of TDM.

Based on equation (3.4) the relationship between consumption of GDM (kg/ha) and grazing pressure (stock days/ha) is shown in figure 3.3. The regression and estimates of GDM consumption have been adjusted to the GDM pre-grazing mean of 858 kg/ha. The value of the multiplier, k/PRE, was 0.88.

The effect of grazing pressure on ADI of GDM (kg/sheep/day) is shown in figure 3.4. The ADI of GDM was low at all grazing pressures and ranged from 0.6 kg/ha to 0.2 kg/ha for grazing pressures of 270 and 2430 stock days/ha, respectively. The average level of green forage in the diet was about 50% and appeared to be unaffected by the level of grazing pressure.

The ADI of TDM and GDM by each stock class is shown in table 3.4. No interactions were observed between stock class and either grazing duration or stock density. The ADI of TDM for ewes and lambs were similar, but ewes consumed an average of 0.10 kg/sheep/day more GDM than lambs ($P<.05$), an increase of 43% over the lambs. Pre-grazing TDM was composed of 31% GDM, while ewe and lamb diets were composed of 60% and 45% GDM, respectively.

DISCUSSION

In short duration grazing trials both grazing days and stock densities are often altered to achieve treatment target grazing pressures or allowances. The design of such trials assumes that the combination of stock density and grazing duration used to create a specified grazing pressure has no influence on either intake (Bircham and Sheath, 1986) or variables dependent on intake such as rate of gain (McEwan et al., 1988). In this study, the effects of different combinations of stock density and grazing duration at the same grazing pressure, either 540, 810 or 1620 stock days/ha, on forage intake were not significant. These results suggest that at least for short-duration, high stock density grazing trials the effect of density/duration combinations by which a target grazing pressure is achieved may be small relative to other sources of variation such as estimation technique and natural pasture variation. Whether differences exist at more extreme combinations of density and duration will probably depend on the amount of forage growth during long grazing durations, the extent of treading damage to pasture at very high stock densities, and differences in animal behavior between extreme combinations.

A positive, but not significant relationship, was observed in this experiment between the average daily intake of GDM and pre-grazing GDM masses, the latter ranging from 470 to 1500 kg/ha. High density-short duration grazing trials conducted in New Zealand have also found positive correlations between pre-grazing GDM and GDM intake during grazing. Rattray et al. (1983) reported a series of curves describing the relationship between GDM allowance and GDM intake by ewes grazing pastures of different pre-grazing green forage mass. As pre-grazing GDM increased from 500 to 2500 kg GDM/ha, average daily intake increased approximately linearly at all allowances. In a study involving lambs, Rattray and Clark (1984) reported that intake of green forage increased as pre-grazing green forage mass increased from 1000 to 1300 kg GDM/ha. However, at higher pre-grazing GDM levels of 1500 to 4000 kg GDM/ha they found no effect of pre-grazing GDM on lamb intake.

Rattray et al. (1987) suggested that intake of GDM increases with increasing pre-grazing GDM due to the greater accessibility of the forage and consequently greater ease of apprehension. Most New Zealand studies which support this hypothesis have been conducted on pastures with proportions of green forage in excess of 80% of total forage. Little is known about the relationship between green forage mass and intake when the percent green in the pasture is less than 80%, but Rattray et al. (1987) speculated that any correlation between the two variables may be small. The results presented here support that view. The high proportion of dead material present in this trial (on average 69%), may have restricted accessibility of GDM to the point that differences in the amount of GDM present had no impact on the animal's ability to selectively consume GDM.

In contrast to GDM, a significant positive linear relationship was observed between forage intake of total dry matter (TDM) and pre-grazing TDM in the range of 1800 to 3900 kg/ha. A positive relationship between intake and pre-grazing mass appears to be well accepted in the literature (Poppi et al. 1987). However, the reported pre-grazing TDM at which maximum intake occurs varies considerably between trials. In a re-analysis of data from four separate trials, McEwan et al. (1988) reported that maximum lamb liveweight gains were achieved at 3500 kg/ha pre-grazing TDM. Maximum intakes have been reported occurring at pre-grazing forage masses as low as 1500 kg TDM/ha (Rattray and Clark, 1984) and as high as 5000 kg TDM/ha (Langlands and Bennet, 1973). Quantitative differences between trials might be expected if study sites vary considerably in forage composition, structure and maturity - all factors which may affect the animal's perception of forage availability without affecting estimates of pre-grazing forage mass.

The natural growth (exponential decay) function (equation 3.4) was chosen to describe the relationship between pasture disappearance and grazing pressure based on the assumptions that animals could not eat more than was present pre-grazing (allowing for zero growth) and that animals would consume forage at a steadily decreasing rate as grazing pressure increased. The natural growth function was a reasonably good fit of both TDM (R^2=.70) and GDM (R^2=.61) forage consumption. As might be expected from the curves in figures 3.1 and 3.2, a linear model was found to fit the data nearly as well as the natural growth function.

The instantaneous rates of decline of post-grazing total dry matter and green dry matter per stock day, i.e. the regression coefficient of grazing pressure ($-B_1$), were 0.00011 and 0.00030, respectively. Higher values have been reported previously by Bircham and Sheath (1986) in both summer (0.00033 to 0.00050) and winter (0.00078 to 0.0014) grazing trials. Bircham and Sheath (1986) calculated instantaneous rates separately for each of their plots based on observations taken at 0, 1/3, 2/3 and 3/3 of the total time grazing. However, in order to directly compare the results presented in this paper with those of Bircham and Sheath (1986) the pre- and post-grazing observations of their data were re-analyzed with each pasture regarded as one experimental unit. Re-analysis resulted in close agreement between the instantaneous rate of TDM decline in their summer pasture and that reported in this paper, 0.00012 vs. 0.00011, respectively. However, the instantaneous rate of decline for their winter pastures was considerably higher 0.0012. The summer pastures in the Bircham and Sheath (1986) study, like those in this trial, had a low proportion of green forage whereas winter pastures consisted almost entirely of green forage. This suggests that decreasing the proportion of green forage in the pasture may decrease the instantaneous rate of pasture decline. The causative mechanism may be that increasing amounts of dead material reduce both the sheep's ease of prehension of green forage and overall forage palatability.

The y-intercept of the natural growth function relating forage consumption of TDM to grazing pressure was 273 kg/ha (figure 3.1), i.e. the model predicts that forage will be consumed when no animals are grazing. Extrapolation to grazing pressures of less than 100 stock days/ha resulted in model predictions of average daily intakes exceeding 3.0 kg TDM/sheep/day, levels greater than the potential intake of a non-lactating grazing sheep (Blaxter et al., 1961). It would appear that at low grazing pressures, ad libitum daily intakes occur and intake predictions based on the natural growth function would be erroneous.

The shape of the curves describing the effect of grazing pressure on ADI of TDM and GDM (figures 3.2 and 3.4) approximates an inverse linear function. While this might be expected as the relationship between forage consumption and grazing pressure was approximately linear with a positive y-intercept, describing the data in this fashion illustrates clearly that changes in ADI in this study were not proportional to increases in grazing pressure. Tripling the grazing pressure from 270 to 810 stock days/ha resulted in a 54% and 47% reduction in ADI of TDM and GDM, respectively. But when the grazing pressure was tripled from 810 to 2430 stock days/ha, ADI of TDM and GDM were reduced by only 37% and 38%, respectively.

Most studies have estimated ADI relative to forage allowance (pre-grazing kg DM/sheep/day) using either curvilinear (Gibb and Treacher, 1976; Rattray and Clark, 1984) or linear functions (Penning et al. 1986). The results of this study similarly expressed in terms of ADI relative to forage allowance of TDM and GDM are shown in figures 3.5 and 3.6, respectively. The regression and estimates were adjusted to the mean pre-grazing pasture mass, consequently, different levels of allowance were achieved by different grazing pressures.

No evidence of an asymptote of TDM intake by ewes and lambs was observed for allowances as high as 10 kg/animal/day. Using lactating ewes grazing spring pastures, Penning et al. (1986) also showed increasing intakes at higher forage allowances with no asymptote detected at allowances as high as 8 kg/sheep/day. In contrast, Rattray et al. (1987) found no clear relationship between forage allowance and TDM intake by dry ewes when offered allowances in a similar range.

The lack of a definitive asymptote for GDM intake as forage allowance increased in this study may have been due to GDM allowances not exceeding 3.2 kg/sheep/day. Rattray and Clark (1984) have suggested that GDM allowance must exceed 4 kg/animal before maximum GDM intakes will be achieved.

Whether the observed values of ADI in a particular trial can be explained with linear or curvilinear relationships to allowance depends on the range of allowances offered as well as other factors such as season and physiological state of the animal (Penning et al., 1986; Poppi et al., 1987). A curvilinear function in which ADI increases at a decreasing rate as forage allowance increases would seem to be a reasonable choice since ADI most likely has an upper physical limit due to factors such as rumen fill, bite size, bite rate and grazing time.

In this study, ewes consumed 43% more GDM daily than did lambs (0.33 vs. 0.23 kg/sheep/day) but consumed no more TDM. Therefore, ewe and lamb intakes differed primarily in the percent green forage in their diet, 60% vs. 45%, respectively. The higher proportion of green forage in the diet may have been the result of ewes possessing more grazing experience than lambs. Although no direct evidence was collected to support this hypothesis, the ewes appeared to become settled more quickly at the commencement of each grazing period and to remain more settled for the duration than lambs. Such behavioral differences may have allowed the ewes longer grazing periods and greater chance to exercise selectivity.

TABLE 3.1 LEAST SQUARES MEANS AND STANDARD ERRORS OF TOTAL DRY MATTER (TDM) AND GREEN DRY MATTER (GDM) CONSUMPTION (KG/HA) BY STOCK DENSITY (SHEEP/HA), GRAZING DURATION (DAYS) AND STOCK TYPE (EWES OR LAMBS).

		Stock density (sheep/ha)					
		270		540		810	
	Days	TDM[a]	GDM[b]	TDM	GDM	TDM	GDM
Ewes							
	1	270 ± 89^{c}	154 ± 110	405 ± 77^{c}	237 ± 97	493 ± 79	235 ± 98
	2	119 ± 92^{c}	15 ± 140	628 ± 70^{cd}	485 ± 60	744 ± 66	474 ± 59
	3	683 ± 72^{d}	375 ± 76	836 ± 65^{d}	500 ± 56	742 ± 66	331 ± 83
Lambs							
	1	358 ± 127	234 ± 83	507 ± 119	57 ± 105^{c}	441 ± 139	-55 ± 130^{c}
	2	469 ± 123	266 ± 79	502 ± 119	164 ± 92^{c}	816 ± 103	429 ± 62^{d}
	3	387 ± 125	200 ± 88	941 ± 125	506 ± 70^{d}	737 ± 109	480 ± 52^{d}

[a] n=3 paddocks.
[b] n=2 paddocks.
[c,d] Means within the same column and same stock type with different superscripts differ (P<.05) according to the Student-Newman-Keuls multiple comparsion test.

TABLE 3.2 LEAST SQUARES MEANS AND STANDARD ERRORS OF TOTAL DRY MATTER (TDM) AND GREEN DRY MATTER (GDM) CONSUMPTION (KG/HA) BY GRAZING PRESSURE (STOCK DAYS/HA) AND GRAZING DURATION (DAYS).

	Grazing Pressure[a] (stock days/ha)					
	540[b]		810		1620	
Days	TDM[c]	GDM[d]	TDM	GDM	TDM	GDM
1	456 ± 72	158 ± 92	470 ± 72	151 ± 93		
2	299 ± 77	184 ± 89			778 ± 63	442 ± 56
3			543 ± 70	282 ± 77	880 ± 65	469 ± 60
	(NS)[e]	(NS)	(NS)	(NS)	(NS)	(NS)

[a] Sheep per ha * grazing duration.
[b] 540 stock days/ha was achieved by 540 sheep/ha for 1 day and by 270 sheep/ha for 2 days; similar appropriate combinations used to achieve other grazing pressures.
[c] Total dry matter (kg/ha), n=6 paddocks.
[d] Green dry matter (kg/ha), n=4 paddocks.
[e] P>.05

TABLE 3.3 LEAST SQUARES MEANS AND STANDARD ERRORS OF TOTAL DRY MATTER (TDM) AND GREEN DRY MATTER (GDM) DAILY INTAKE (KG/SHEEP/DAY) BY GRAZING PRESSURE (STOCK DAYS/HA) AND GRAZING DURATION (DAYS).

	Grazing Pressure[a] (stock days/ha)					
	540[b]		810		1620	
Days	TDM[c]	GDM[d]	TDM	GDM	TDM	GDM
1	.84 ± .13	.29 ± .17	.58 ± .09	.19 ± .11		
2	.56 ± .14	.34 ± .16			.48 ± .04	.27 ± .03
3			.67 ± .09	.35 ± .09	.54 ± .04	.29 ± .04
	(NS)[e]	(NS)	(NS)	(NS)	(NS)	(NS)

[a] Sheep per ha * grazing duration.

[b] 540 stock days/ha was achieved by 540 sheep/ha for 1 day and by 270 sheep/ha for 2 days; similar appropriate combinations used to achieve other grazing pressures.

[c] Total dry matter (kg/ha), n=6 paddocks.

[d] Green dry matter (kg/ha), n=4 paddocks.

[e] $P>.05$

TABLE 3.4 LEAST SQUARES MEANS AND STANDARD ERRORS OF TOTAL DRY MATTER (TDM) AND GREEN DRY MATTER (GDM) DAILY INTAKE (KG/SHEEP/DAY) BY STOCK CLASS.

Stock class	TDM[a]	GDM[b]
Ewes	.55 ± .03	.33[c] ± .03
Lambs	.51 ± .04	.23[d] ± .04

[a] Total dry matter (kg/ha), n=27 paddocks.
[b] Green dry matter (kg/ha), n=18 paddocks.
[c,d] Means within the same column with different superscripts differ ($P<.05$).

FIGURE 3.1 LEAST SQUARES FIT OF TOTAL DRY MATTER (TDM) CONSUMPTION (FC, KG/HA) ON GRAZING PRESSURE (X_1, STOCK DAYS/HA).

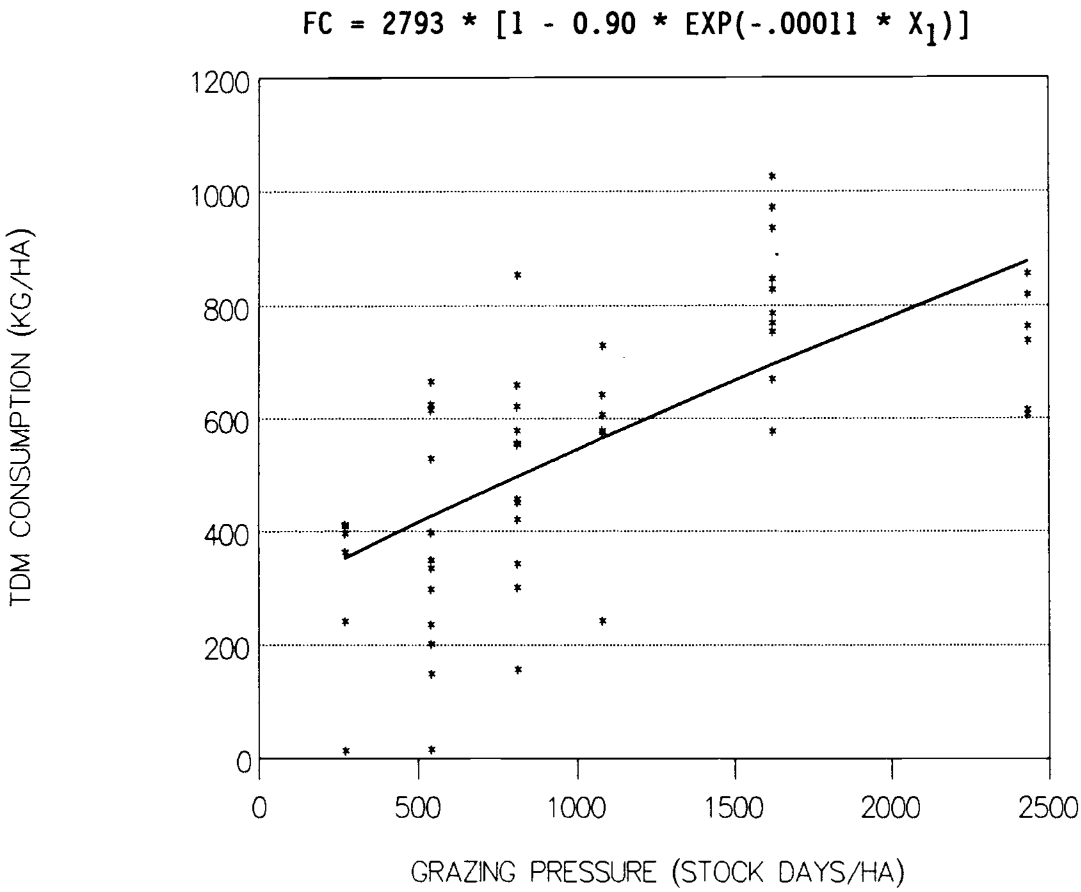


FIGURE 3.2 LEAST SQUARES FIT OF TOTAL DRY MATTER (TDM) DAILY INTAKE (ADI, KG/SHEEP/DAY) ON GRAZING PRESSURE (X_1, STOCK DAYS/HA).

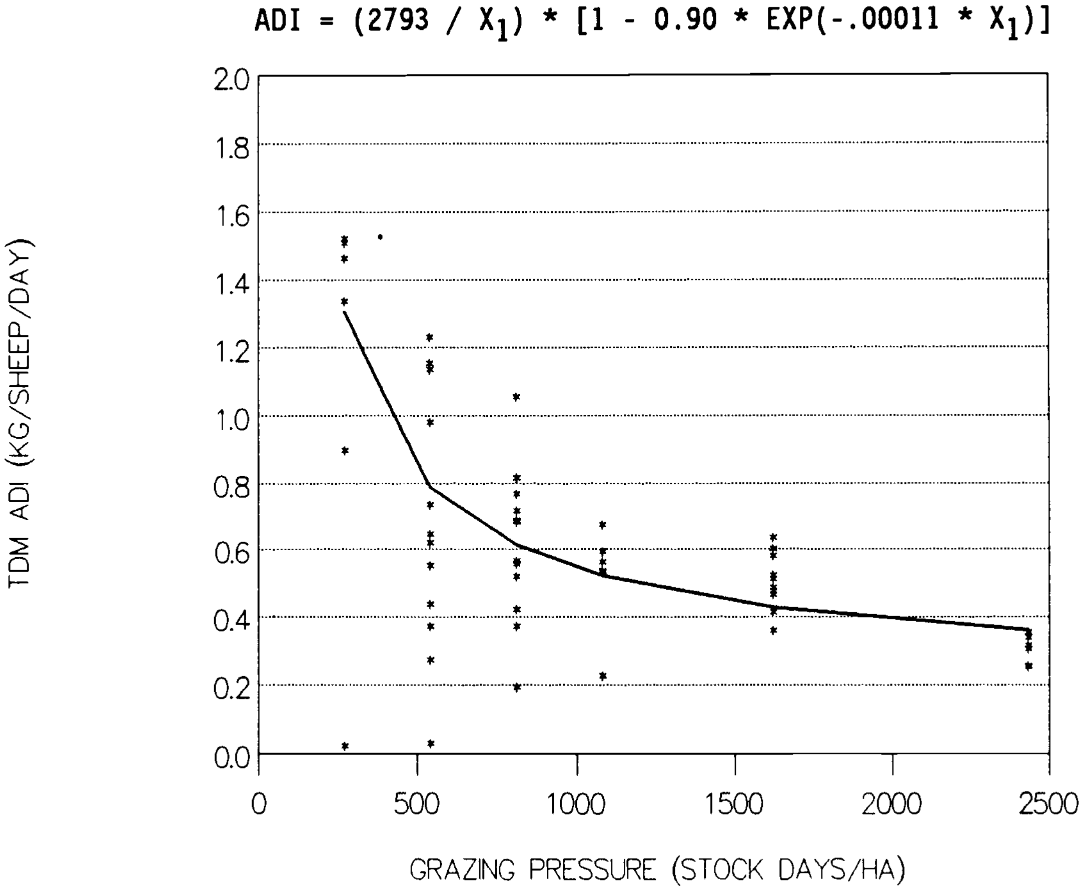


FIGURE 3.3 LEAST SQUARES FIT OF GREEN DRY MATTER (GDM) CONSUMPTION (FC, KG/HA) ON GRAZING PRESSURE (X_1, STOCK DAYS/HA).

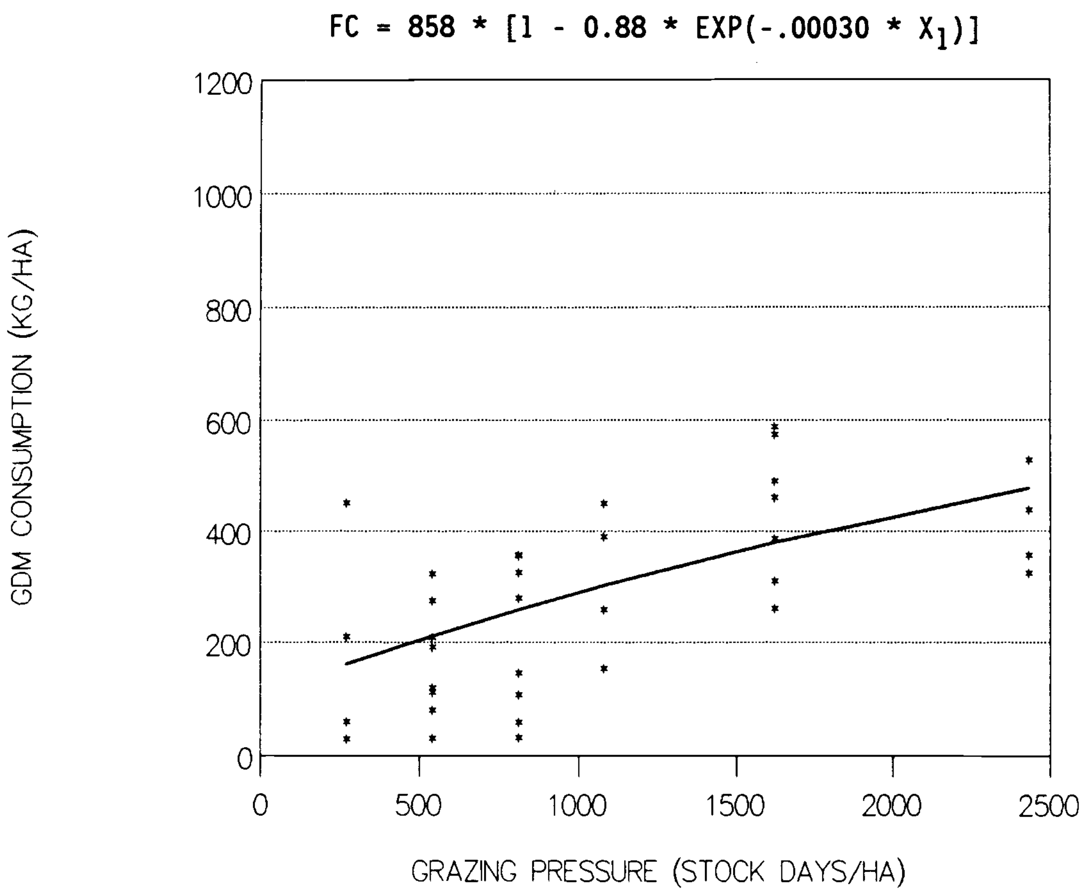


FIGURE 3.4 LEAST SQUARES FIT OF GREEN DRY MATTER (GDM) DAILY INTAKE (ADI, KG/SHEEP/DAY) ON GRAZING PRESSURE (X_1, STOCK DAYS/HA).

$$ADI = (858 / X_1) * [1 - 0.88 * EXP(-.00030 * X_1)]$$

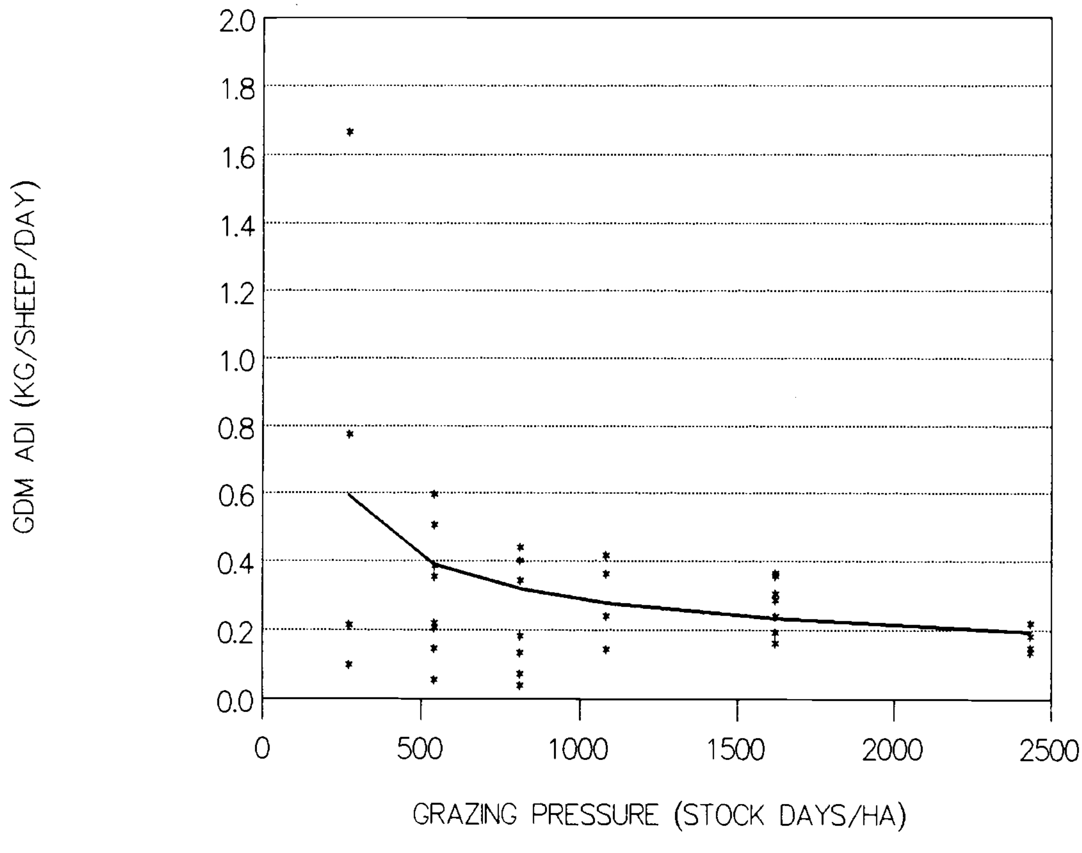


FIGURE 3.5 LEAST SQUARES FIT OF TOTAL DRY MATTER (TDM) DAILY INTAKE (ADI, KG/SHEEP/DAY) ON TDM ALLOWANCE (A, KG/SHEEP/DAY).

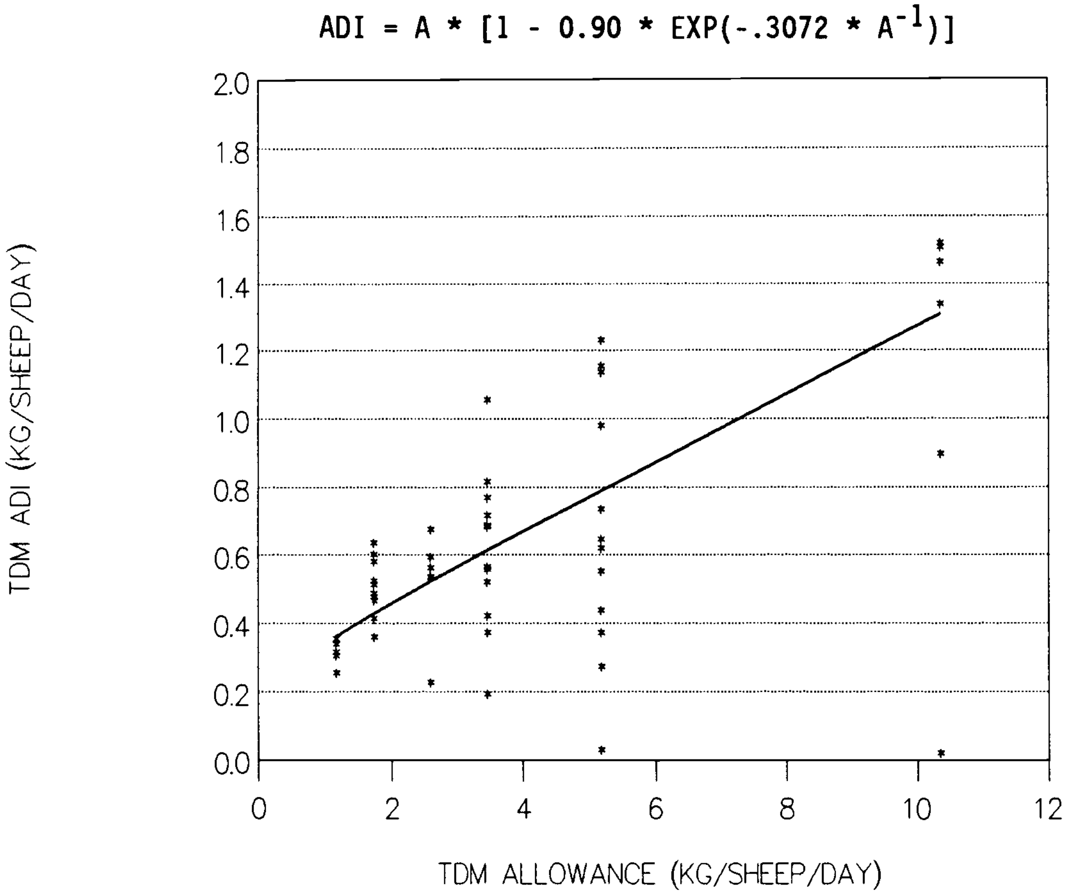
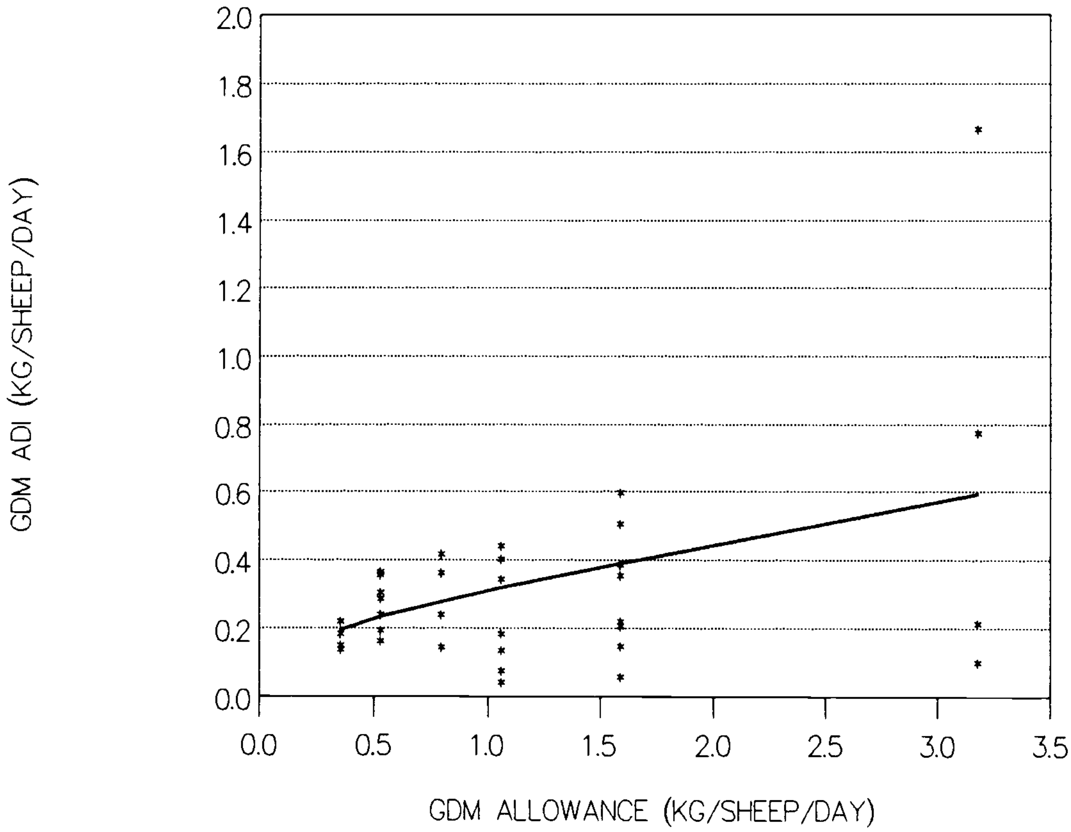


FIGURE 3.6 LEAST SQUARES FIT OF GREEN DRY MATTER (GDM) DAILY INTAKE (ADI, KG/SHEEP/DAY) ON GDM ALLOWANCE (A, KG/SHEEP/DAY).

$$ADI = A * [1 - 0.88 * EXP(-.2574 * A^{-1})]$$



REFERENCES

Bircham, J.S. and G.W. Sheath. 1986. Pasture utilization in hill country 2. A general model describing pasture mass and intake under sheep and cattle grazing. N.Z. J. of Agr. Res. 29:639-648.

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

Gibb, M.J. and T.T. Treacher. 1976. The effect of herbage allowance on herbage intake and performance of lambs grazing perennial ryegrass and red clover swards. J. Ag. Sci. 86:355-365.

Harvey, W.R. 1975. Least-squares analysis of data with unequal subclass numbers. Publ. No. A-4, ARS, USDA, Washington, D.C.

Hodgson, J. and T.J. Maxwell. 1984. Grazing studies for grassland sheep systems at the Hill Farming Research Organization, U.K. Proc. N.Z. Grassland Assoc. 45:184-189.

Langlands, J.P. and I.L. Bennet. 1973. Stocking intensity and pastoral production. II. Herbage intake of Merino sheep grazed at different stocking rates. J. Ag. Sci. 81:205-209.

McEwan, J.C., R.C. McDonald, P.F. Fennessy, K.F. Thompson, C.G. Hughson and K.G. Dodds. 1988. Pasture quality and nutrition in weaned lambs. Proc. N.Z. Vet. Assoc. Sheep and Beef Cattle Soc. 18:178-188.

Penning, P.D., G.E. Hooper and T.T. Treacher. 1986. The effect of herbage allowance on intake and performance of ewes suckling twin lambs. Grass and Forage Sci. 41:199-208.

Poppi, D.P., T.P. Hughes and P.J. L'Huillier. 1987. Intake of pastures by grazing ruminants. N.Z. Soc. Anim. Prod. Occ. Publ. No. 10: 55-63.

Rattray, P.V., K.T. Jagusch and D.C. Smeaton. 1983. Interactions between feed quality, feed quantity, body weight and flushing. Proc. N.Z. Vet. Assoc. Sheep and Beef Cattle. Soc. 13:21-34.

Rattray, P.V. and D.A. Clark. 1984. Factors affecting the intake of pasture. N.Z. Ag. Sci. 18:141-146.

Rattray, P.V., K.F. Thompson, H. Hawker and R.M.W. Sumner. 1987. Pastures for sheep production. N.Z. Soc. Anim. Prod. Occ. Publ. No. 10. pp. 89-103.

Smeaton, D.C., R.M. Sumner, T.W. Knight and T.K. Adams. 1983. Effects of time of weaning, pasture allowance and shearing time on ewe and lamb liveweight, wool growth and subsequent ovulation rate of the ewe. N.Z. J. Exp. Ag. 11:41-45.

A MODEL OF FORAGE INTAKE BY SHEEP GRAZING AT HIGH STOCK DENSITIES FOR SHORT GRAZING DURATIONS

CHAPTER 4

SUMMARY

A high stock density-short grazing duration forage intake model was developed which combined empirical relationships of green and dead dry matter disappearance in pasture over time with concepts of the animal's preference for green forage. Predictions of the model agreed favorably with results from pasture grazing trials conducted during summer and winter in western Oregon. However, comparison with autumn field trials indicated that the model consistently underestimated post-grazing green dry matter mass when tested over a wide range of grazing pressures. Model predictions were most sensitive to variation in the parameter representing the instantaneousrate of green dry matter decline. Changes in this parameter caused disproportionately larger changes in model predictions. The model predicted curvilinear relationships between average daily intake of total dry matter and both pasture allowance and pre-grazing percent green forage in the pasture. An approximately linear relationship was predicted between pre-grazing pasture mass and average daily intake.

INTRODUCTION

Much attention has been focused in the last decade on increasing profits of pastoral livestock systems through increased control of forage intake by grazing animals. Livestock managers have achieved greater control of forage intake by adopting rotational grazing systems in which large numbers of animals graze small areas for short periods of time (Clark et al, 1982). Profitable use of intensive grazing systems requires a thorough understanding of the effect of changing pasture conditions on forage intake.

Numerous field trials have been conducted aimed at describing the effect of pre-grazing forage mass, percent green forage of total forage, forage allowance and residual forage on forage intake and animal performance (Gibb and Treacher, 1976; Rattray and Jagusch, 1978; Rattray et al. 1983; McEwan et al., 1988). Integration of such information into a conceptual framework of forage intake can be aided by the use of computer simulation models.

Several published computer simulation models of animal production systems have included forage intake subsystems (Arnold et al., 1977; Christian et al., 1978; France et al., 1981; White et al, 1983). However, these whole system models were oriented towards continuous grazing systems and not appropriate to intensive rotational systems.

A simple model of pasture disappearance under rotational grazing, a negative exponential function, was proposed by Bircham and Sheath (1986). Their model has been used to predict forage intake for feed budgeting purposes (McCall et al., 1986). However, the predictions of the model were found to be quite sensitive to the assumptions used to derive parameter values, and the model failed to distinguish between dead and green dry matter intake.

Several published reviews have well documented that sheep prefer green forage to dead forage (e.g. Arnold, 1981; Rattray and Clark, 1984) and therefore at times of the year when available forage is mostly green material, e.g. winter and spring, intake of total forage and green forage are approximately equivalent. However, in other seasons, pastures often consist of large amounts of dead material and very little green forage. Models which fail to distinguish between the two types of forage would erroneously predict similar intakes on green spring pastures and dead summer pastures at similar total forage mass.

The primary objective of this study was to develop a forage intake model, based upon the negative exponential function, which would distinguish between apparent intake of green and dead forage by sheep grazing at high densities for several days. The resulting model was evaluated by comparing model predictions with observations of forage intake in grazing trials conducted under differing green vs. dead forage mass ratios.

MODEL DEVELOPMENT

The following assumptions were used in model development : 1. low availability of green and dead forage limit grazing intake; 2. the interval of grazing is sufficiently short that forage growth during the grazing period is negligible; and, 3. grazing sheep are approximately one year of age or older, weigh approximately 55 kg and are not lactating. These assumptions make the model most applicable to the difficult grazing management periods of the year when forage intake is limited by low pasture availability. When forage availability is not limiting, animals are usually set stocked to obtain maximum intakes and models based on rumen physiology and nutrient drive would likely be better suited to predict intake (Poppi et al. 1987).

The negative exponential function (exponential decay) was used to describe the decline in green dry matter (GDM, kg/ha) mass over time:

$$GDM_t = GDM_0 * EXP(-K_g * DEN * t), \tag{4.1}$$

where t is the day of grazing, GDM_0 is GDM prior to grazing, GDM_t is GDM on day t of grazing, and DEN is animal density (sheep/ha). The parameter K_g is the instantaneous rate of green forage decline per stock day. Functions of similar form have been used extensively in ecological models to describe population growth which occurs at an increasing rate over time (i.e, Pielou, 1974).

Equation (4.1) can be re-arranged to determine apparent intake of GDM, Ig, for one day of grazing:

$$Ig_t = (GDM_{t-1}/DEN) * (1 - EXP(-K_g * DEN)) \tag{4.2a}$$

In development of the model the parameter K_g was fixed at 0.0024 per stock day based on a New Zealand data set in which green and dead forage mass were estimated for each day of three-day grazing periods in summer and autumn (L'Huillier et al., 1986).

During summer, green forage present in pasture is usually elevated and completely accessible to the grazing animal. At other times since sheep may be unable to graze down to ground level some green forage may be remain after grazing. Equation (4.2a) can be modified to reflect the minimum pasture mass to which animals can graze by subtracting the minimum residual, G_r, from the pasture mass, GDM_{t-1} (see equation 4.2b). However, due to insufficient data of GDM_r, it was assumed that GDM_r was zero for all seasons.

(4.2b) $Ig_t = ((GDM_{t-1} - GDM_r)/DEN) * (1 - EXP(-K_g * DEN))$.

The predicted intake of dead forage by sheep grazing pastures consisting of 100% dead forage was calculated from an equation similar to that used to predict green intake :

(4.3) $IdMAX_t = (DDM_{t-1}/DEN) * (1 - EXP(-K_d * DEN))$,

where DDM_{t-1} is dead dry matter prior to grazing on day t. Two values for the parameter K_d, the instantaneous rate of decline of dead material per stock day, were derived from the data of L'Huillier et al. (1986). The value of K_d derived for summer was higher (0.0006 per stock day) than at other times of the year (0.0002 per stock day) which was assumed to reflect the greater palatability of dead forage in summer. Summer DDM is mostly mature, dried, bleached forage whereas after autumn rains this same DDM becomes partially decomposed and leached of nutrients.

The high degree of preference by grazing sheep for green forage over dead forage has been extensively reviewed in the literature (e.g. Arnold, 1981). However, the rate at which dead forage intake increases as green forage intake decreases has not been studied at various levels of DDM and GDM availability. Since sheep appear to sacrifice quantity of intake to maintain diets high in green forage (Guy et al., 1981), it was assumed in the model: 1. the increase in DDM intake was less than the decrease in GDM intake; and, 2. the rate of substitution of DDM intake for GDM increased at an increasing rate as GDM intake declined. This relationship between DDM and GDM intake was described by the following equation:

$$Id_t = IdMAX_t * EXP(-K_i * Ig_t) \quad , \tag{4.4}$$

where IdMAX was derived from equation (4.3). K_i is an adjustment parameter fixed at 1.75 based on the relationship between percent dead in the pasture and percent dead in the diet described by Clark et al. (1982) . The sum of Ig and Id was total intake of forage.

MODEL VALIDATION

By definition, models are not real systems but rather are simplified representations of defined subsystems of the whole of reality. In the simplicity of a model often lies its usefulness, but this same simplicity limits the validity of the model. Consequently, a model can never be validated as being the true representation of a real system. Rather the validation process is one of comparison of model predictions with field observations and subsequent evaluation of the adequacy of the model in predicting those observations.

Data from two sheep grazing trials conducted on temperate, improved pastures were used in the validation process. In the first trial (Chapter 2) total dry matter (TDM) and green dry matter (GDM) were measured prior to the onset of grazing and after each subsequent day of grazing. Three groups of 20 sheep each grazed 0.1 ha plots for periods of 8 and 4 days in summer and winter, respectively. Inputs to the model consisted of the pre-grazing TDM and GDM mass (kg/ha), animal density and grazing duration.

The comparison of model predictions and actual observations of the decline in TDM and GDM mass (kg/ha) for the summer grazing period are shown in figures 4.1 and 4.2, respectively. The model appeared to agree well qualitatively with the observed decline in TDM mass. At day two the observed rate of decline of TDM increased sharply and then decreased at a decreasing rate with time. The model underestimated the amount of TDM disappearance for each day of grazing; however, in reporting results of this trial (Chapter 2), it was suggested that the large amount of TDM disappearance over the trial probably reflected treading as well as intake.

The predicted decline in GDM mass over time was in good agreement with the observed change. The close agreement supports the hypothesis that sheep actively seek green forage even when the percent of green forage in the pasture is low. Furthermore, it suggests that the residual of GDM to which sheep can graze in summer is close to zero.

The results for the winter grazing period are shown in figures 4.3 and 4.4 for TDM and GDM, respectively. In contrast to the summer period the model predicted higher apparent intakes, and hence lower TDM residuals, than were observed. In the first two days of grazing the underestimate of TDM pasture mass was due to lower intake of DDM than was predicted by the model. However, in the last two days of grazing, the model overestimated the GDM intake. The data suggested that the minimum GDM residual to which sheep could graze was approximately 200 kg/ha, whereas the model assumed that sheep could consume all GDM in the pasture.

A second data set was used to compare model behavior at different stock densities, grazing periods and seasons of the year (Chapter 3). A total of 36 groups of sheep grazed 0.03 ha plots for 1, 2 or 3 days at densities of either 270, 540 or 810 sheep/ha. Total and green dry matter were estimated prior to and after grazing. Separate model runs were conducted for each paddock with pre-grazing TDM and GDM mass (kg/ha), stock density and grazing duration as inputs. Model predictions of residual pasture mass were averaged across each grazing pressure (270, 540, 810, 1080, 1620 and 2430 stock days/ha).

Model predictions and field estimates of TDM and GDM residual mass for the six grazing pressures are shown in figures 4.5 and 4.6, respectively. Good qualitative agreement was found between observed and expected TDM and GDM residuals over a wide range of grazing pressures. In general, residuals declined as grazing pressure increased, but exceptions to this trend occurred, apparently due in part to differences in pre-grazing TDM and GDM between paddocks.

Differences between expected and observed TDM residuals (figure 4.5) resulted primarily from underestimates of residual GDM by the model (figure 4.6). Low GDM residual predictions may be a consequence of model assumptions regarding pasture growth and the minimum GDM residual. Since it was assumed in the model that pasture growth was zero, the occurrence of pasture growth would increase observed GDM residuals and cause lower than expected apparent intakes. When GDM_r (equation 4.2b), the minimum GDM residual, was increased to 400 kg/ha, much better agreement between the model predictions and field estimates was observed, suggesting that the minimum GDM residual to which animals are able or willing to graze may be greater than zero. The minimum residual may depend on location of green material in the forage canopy as well as expectations by the animal that grazing conditions will soon improve.

MODEL SENSITIVITY

The parameters for this model were derived from estimates of pasture mass in livestock grazing trials. Estimates of pasture mass are typically accompanied by large coefficients of variation, usually in excess of 20%. Consequently, it might be expected that the derived parameter values also lack precision.

In order to evaluate the sensitivity of model predictions to changes in parameter values, each parameter was individually altered plus/minus 20% from the base value used in the model. The average resulting changes in TDM and GDM residuals and average daily intake were calculated at a pre-grazing mass of 2500 kg/ha, grazing duration of 5 days, and three levels of percent green (10%, 50% and 90%).

The results of the sensitivity analysis are shown in table 4.1. The GDM residual was particularly responsive to changes in K_g - a 20% change in K_g resulted in a 50% change in predicted GDM residual at all levels of GDM in the pasture. However, the effect of the same K_g change on average daily intake, ADI (kg/sheep/day), was only 5%. The magnitude of the influence of K_g on GDM residual and ADI is partially a function of low GDM residuals after 5 days of grazing. Decreasing the number of grazing days results in smaller proportional changes in GDM residual, but larger changes in ADI. A 20% change in K_g resulted in changes in GDM residual and ADI after three days simulated grazing of 27% and 9%, respectively.

The effect of changing GDM_r, the minimum residual to which sheep can graze GDM, on model predictions of GDM residual mass and ADI were very dependent on the level of pre-grazing GDM. Decreasing the pre-grazing percent green in the pasture from 50% down to 10% increased the effect of changing GDM_r on ADI of GDM from 3.8% to 81.1%. The sensitivity of ADI to changes in GDM_r at low pre-grazing GDM levels is due to pre-grazing GDM and GDM_r being nearly equal. The effect of altering GDM_r on TDM residual and ADI was small at all proportions of GDM in the pasture.

The model was much less sensitive to changes in the parameters K_d and K_i. This was to be expected as these two parameters influence only DDM intake which was a small proportion of TDM intake except when GDM was extremely low.

These results suggest that the accuracy of the model in predicting pasture residual and ADI will largely be dependent on the accuracy of the parameters K_g, the instantaneous rate of GDM decline and GDM_r, the amount of GDM sheep are unable to harvest. Consequently, further effort should be directed towards estimating these two parameters and the factors which influence them.

MODEL BEHAVIOR

Forage mass, percent green forage of total forage and forage allowance (kg DM/sheep/day) have been suggested as the principal factors affecting grazing intake (Rattray and Clark, 1984; Poppi et al., 1987). Studies directly assessing the effect of these variables on grazing intake in the field are few due to the difficulty and resource demands for measuring total and green forage mass. In contrast, a computer simulation model can easily provide predictions over a wide range of pasture conditions.

The model predictions of the response of ADI to changes in the proportion of green forage in pasture pre-grazing are shown in figure 4.7. Inputs for pre-grazing TDM, animal density and grazing duration were 2500 kg/ha, 200 sheep/ha and 5 days, respectively. The ADI of GDM increased linearly with increasing percent green in the pasture. The ADI of TDM approximated GDM ADI above 50% green due to the strong preference of green over dead built into the model. Most interesting to note was the predicted increase in TDM intake once percent green in the pasture dropped below 10% when K_d was 0.0006 per stock day. Whether this phenomenon occurs under grazing conditions is not known, but it is plausible that at very low levels of GDM in the pasture sheep reduce their selectivity effort and simply graze what is available. To what extent this behavior occurs probably depends on the acceptability of DDM.

The effect of pre-grazing pasture mass on TDM ADI over 5 days (200 sheep/ha) is shown in figure 4.8 for three levels of pre-grazing percent green forage. At 90% green forage in the pasture, ADI increased linearly with increasing pre-grazing mass. At lower proportions of green forage in the pasture, the relationship between ADI and mass appeared to be more asymptotic. As forage mass continues to increase, ADI obviously must plateau; however, the reported approach to this plateau and its estimated level vary considerably from study to study (Gibb and Treacher, 1976; Gibb and Treacher, 1978; Rattray and Clark, 1984; Penning et al., 1986).

Model predictions of the response of ADI to forage allowance (kg pre-grazing forage mass/sheep/day) at three levels of pre-grazing forage mass are shown in figure 4.9. The curvilinear shape of the response ADI to forage allowance was similar to that reported by Rattray et al. (1983). They found that ADI of GDM increased at a decreasing rate as GDM pasture allowance increased, and reached a plateau when forage allowance reached about 5 kg GDM/sheep/day. The model predictions also agreed with their observation that increasing the GDM pasture mass per ha shifted the entire ADI-allowance curve upwards. However, the model did not predict a definite plateau at high allowances. This was in part due to the assumption in the model that forage availability is the factor limiting intake, whereas forage intake by sheep grazing pastures with high forage mass available and at high allowances is probably limited by physiological factors of the animal rather than by available forage.

CONCLUSIONS

Simulation models of livestock production systems have the potential for providing a framework for better understanding the effect of management decisions on animal performance. If such models are to allow for intensive grazing management in which animals graze at high densities for short periods of time, then a forage intake sub-model which responds to rapidly decreasing pasture mass is essential. The objective of this study was to develop such a forage intake model.

The primary assumptions of this model were that the availability of GDM and DDM limit intake and that sheep demonstrate a low rate of substitution of DDM for declining GDM in the diet. Good qualitative and quantitative agreement was observed between model predictions and field observations over a wide range of grazing conditions in summer, fall and winter. Furthermore, the model appeared to echo general relationships between intake and forage allowance which are well accepted in the literature.

However, several assumptions of the model require further investigation. First, the results of comparing predictions with observations in both winter and fall grazing trials suggested that the minimum residual to which GDM is grazed may often be greater than zero. Factors which affect the level to which animals will graze in intensive management systems have not yet been reported in the literature. Secondly, the model was not tested under conditions of new spring forage and it may be that the instantaneous rate of GDM decline is altered due to characteristics of the forage. Lastly, the model should eventually allow for different physiological states of grazing animals, in particular lactation, since rotational grazing of spring pastures may be a useful management tool to improve animal performance by possibly extending the vegetative period and/or altering botantical composition of the pasture (Sharrow and Krueger, 1979; Sharrow, 1983).

TABLE 4.1 PERCENT CHANGE IN PREDICTIONS OF FORAGE RESIDUAL AND AVERAGE DAILY INTAKE (ADI) RESULTING FROM ALTERING BASE PARAMETER VALUES ±20% AT THREE LEVELS OF GREEN FORAGE AVAILABILITY IN THE PASTURE[a].

	Percent green forage					
	90%		50%		10%	
PARAMETER	RESIDUAL	ADI	RESIDUAL	ADI	RESIDUAL	ADI
K_g : TDM	24.0	5.1	5.9	5.5	0.5	0.7
GDM	50.0	5.0	50.0	5.0	50.0	5.0
GDM_r : TDM	3.3	1.9	1.6	3.1	1.0	2.8
GDM	4.5	1.9	6.8	3.8	14.4	81.1
K_d : TDM	0.7	0.1	2.5	2.3	7.9	12.2
K_i : TDM	1.1	0.2	2.7	2.6	2.9	4.5

[a] Assumed values of pre-grazing pasture mass, stock density and grazing duration were 2500 kg/ha, 200 sheep/ha and 5 days, respectively; base values of K_g, GDM_r, K_d, and K_i were .0024 per stock day, 200 kg/ha, .0006 per stock day and 1.75, respectively.

FIGURE 4.1 MODEL PREDICTIONS AND OBSERVED MEANS WITH STANDARD ERRORS OF TOTAL DRY MATTER FORAGE MASS (KG/HA) VS. DAY OF GRAZING IN SUMMER.

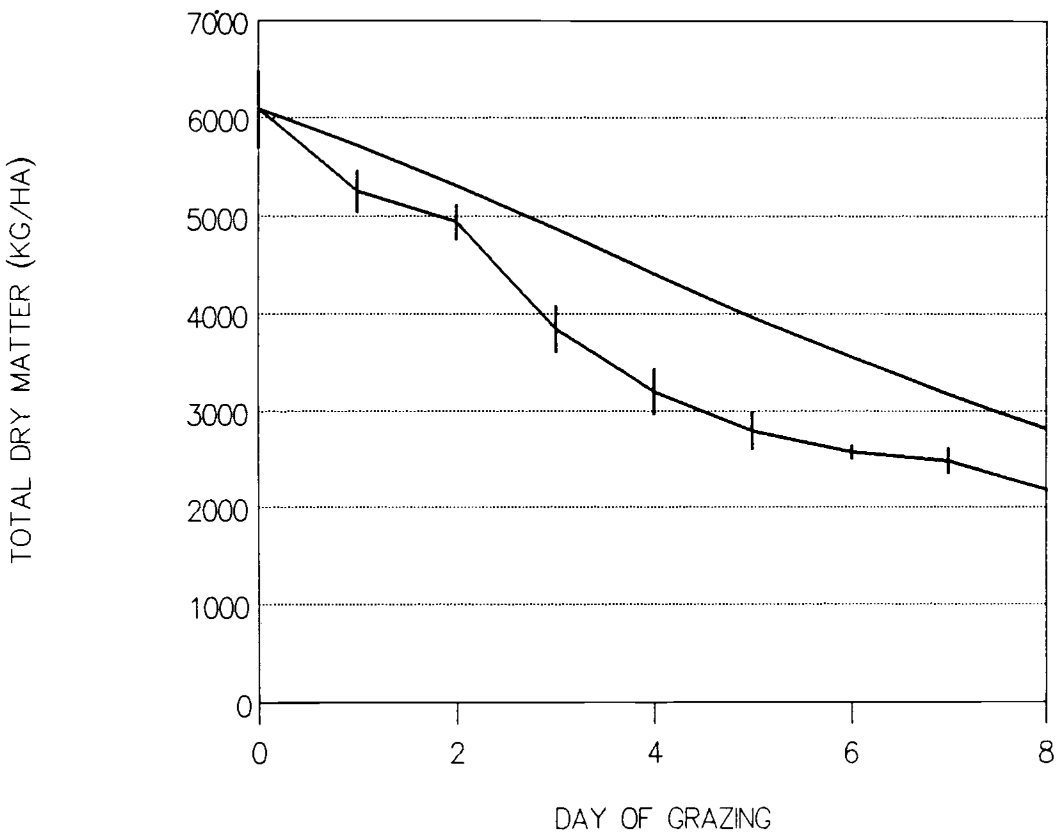


FIGURE 4.2 MODEL PREDICTIONS AND OBSERVED MEANS WITH STANDARD ERRORS OF GREEN DRY MATTER FORAGE MASS (KG/HA) VS. DAY OF GRAZING IN SUMMER.

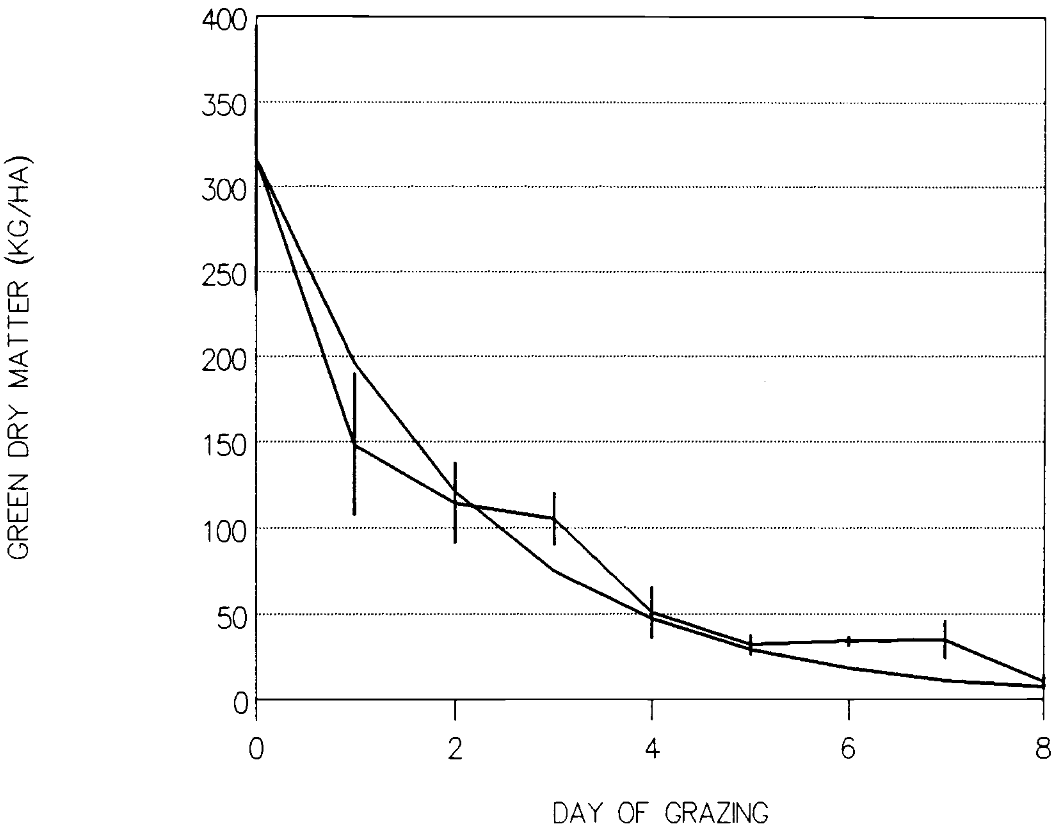


FIGURE 4.3 MODEL PREDICTIONS AND OBSERVED MEANS WITH STANDARD ERRORS OF TOTAL DRY MATTER FORAGE MASS (KG/HA) VS. DAY OF GRAZING IN WINTER.

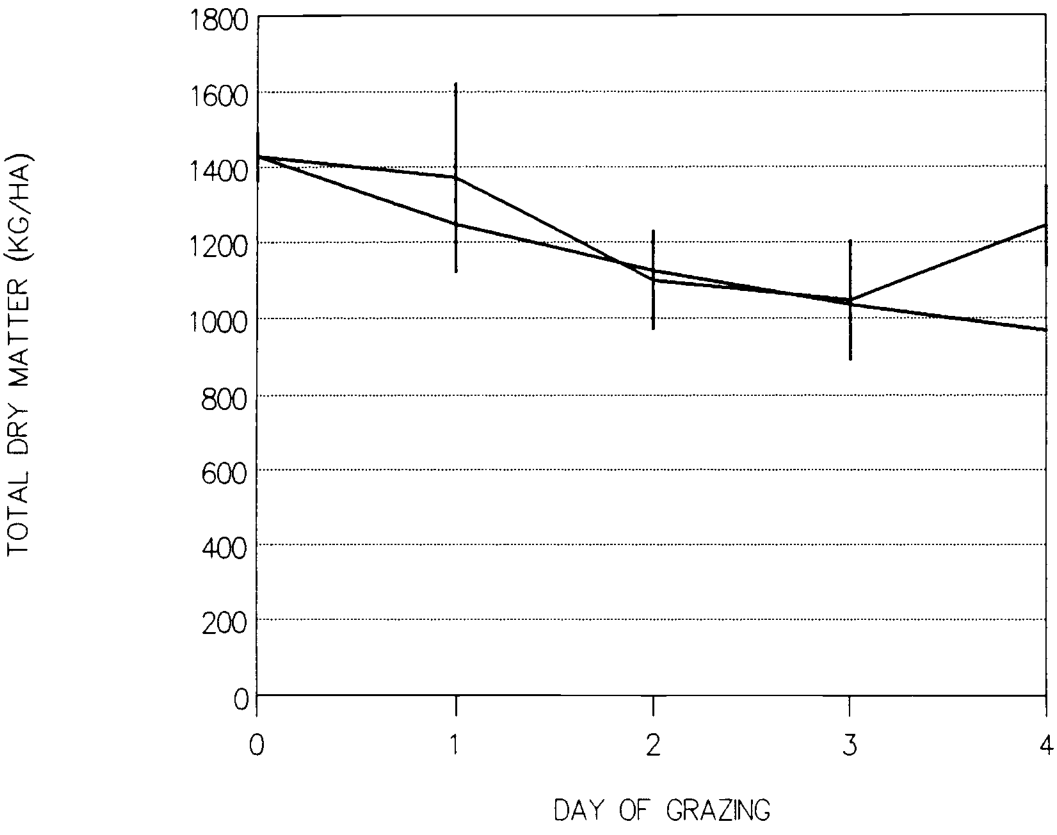


FIGURE 4.4 MODEL PREDICTIONS AND OBSERVED MEANS WITH STANDARD ERRORS OF GREEN DRY MATTER FORAGE MASS (KG/HA) VS. DAY OF GRAZING IN WINTER.

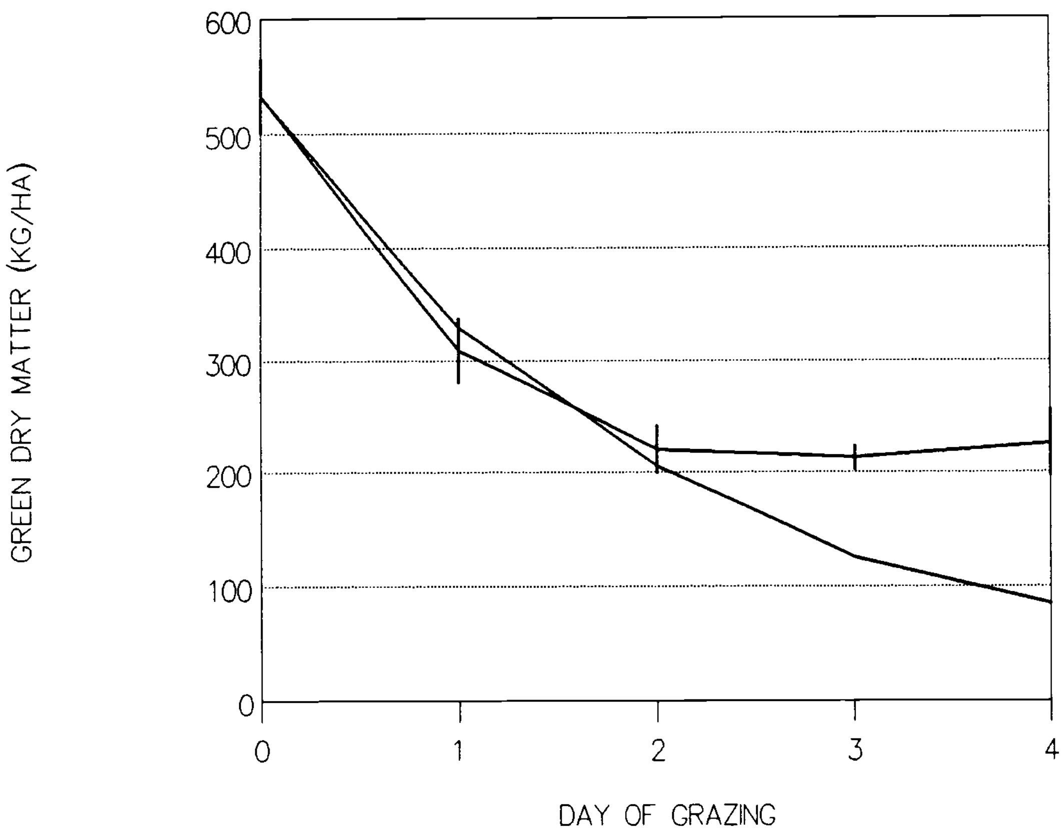


FIGURE 4.5 MODEL PREDICTIONS AND OBSERVED MEANS WITH STANDARD ERRORS OF TOTAL DRY MATTER FORAGE MASS (KG/HA) VS. GRAZING PRESSURE (STOCK DAYS) IN AUTUMN.

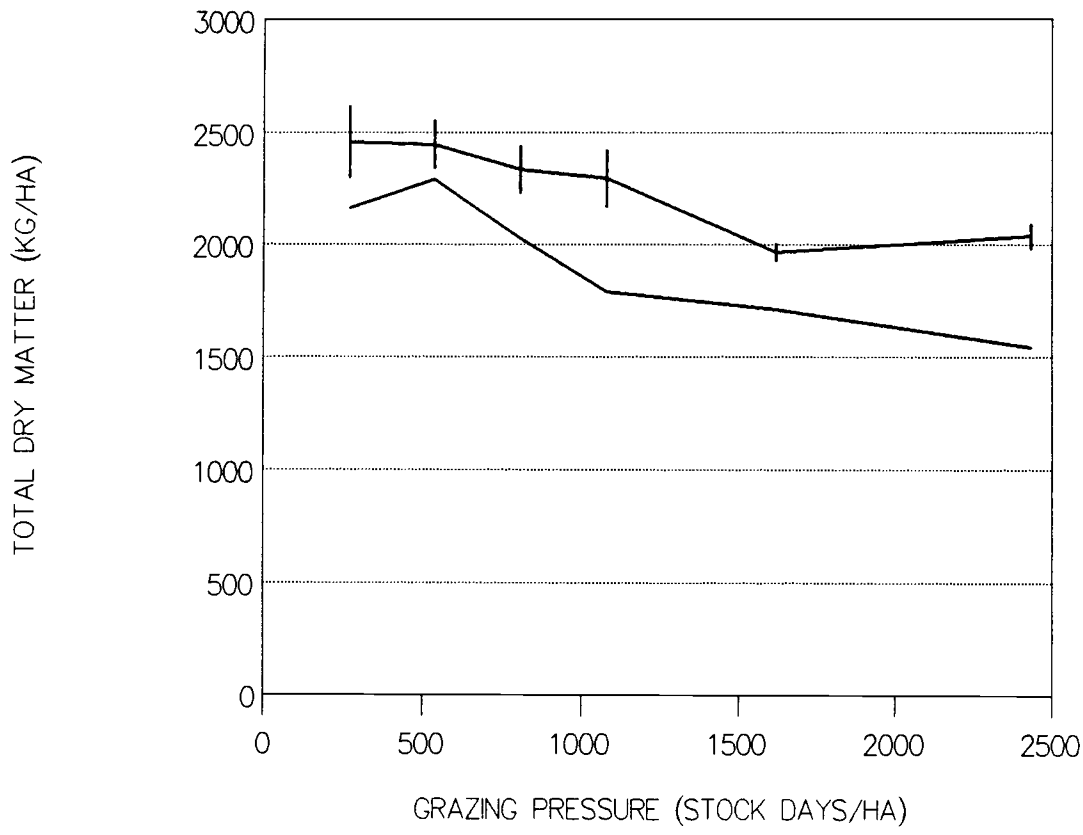


FIGURE 4.6 MODEL PREDICTIONS AND OBSERVED MEANS WITH STANDARD ERRORS OF GREEN DRY MATTER FORAGE MASS (KG/HA) VS. GRAZING PRESSURE (STOCK DAYS) IN AUTUMN.

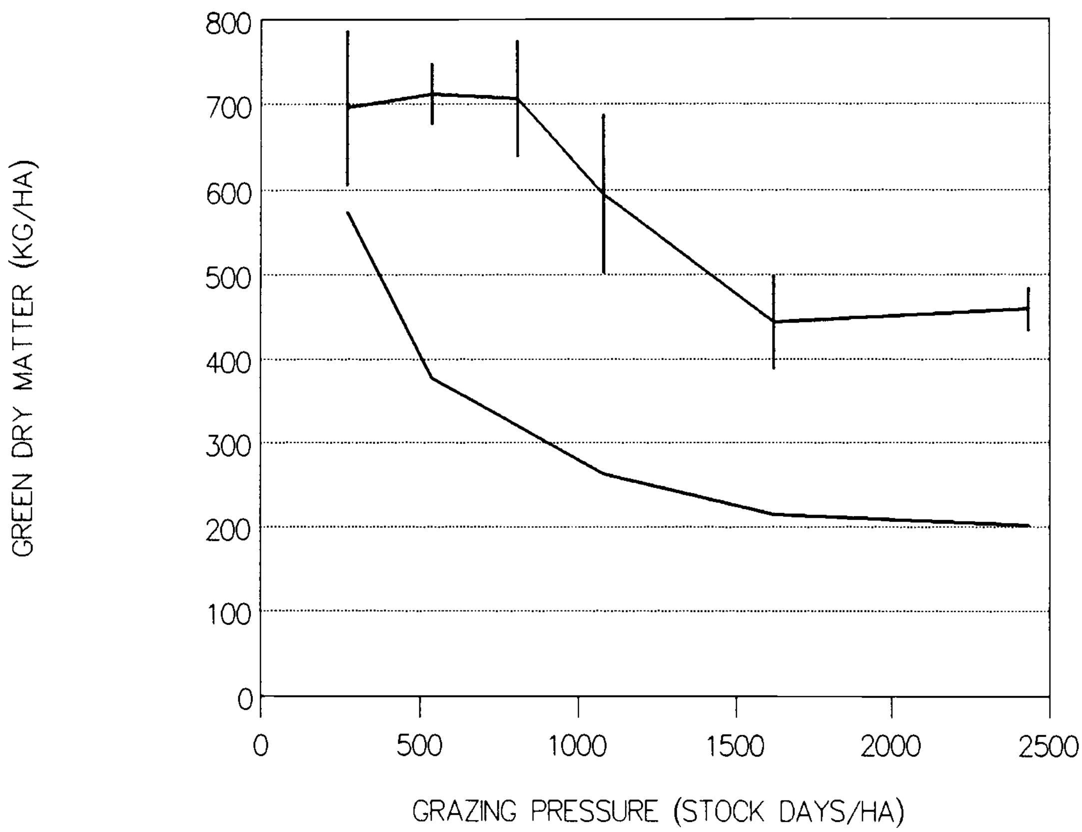
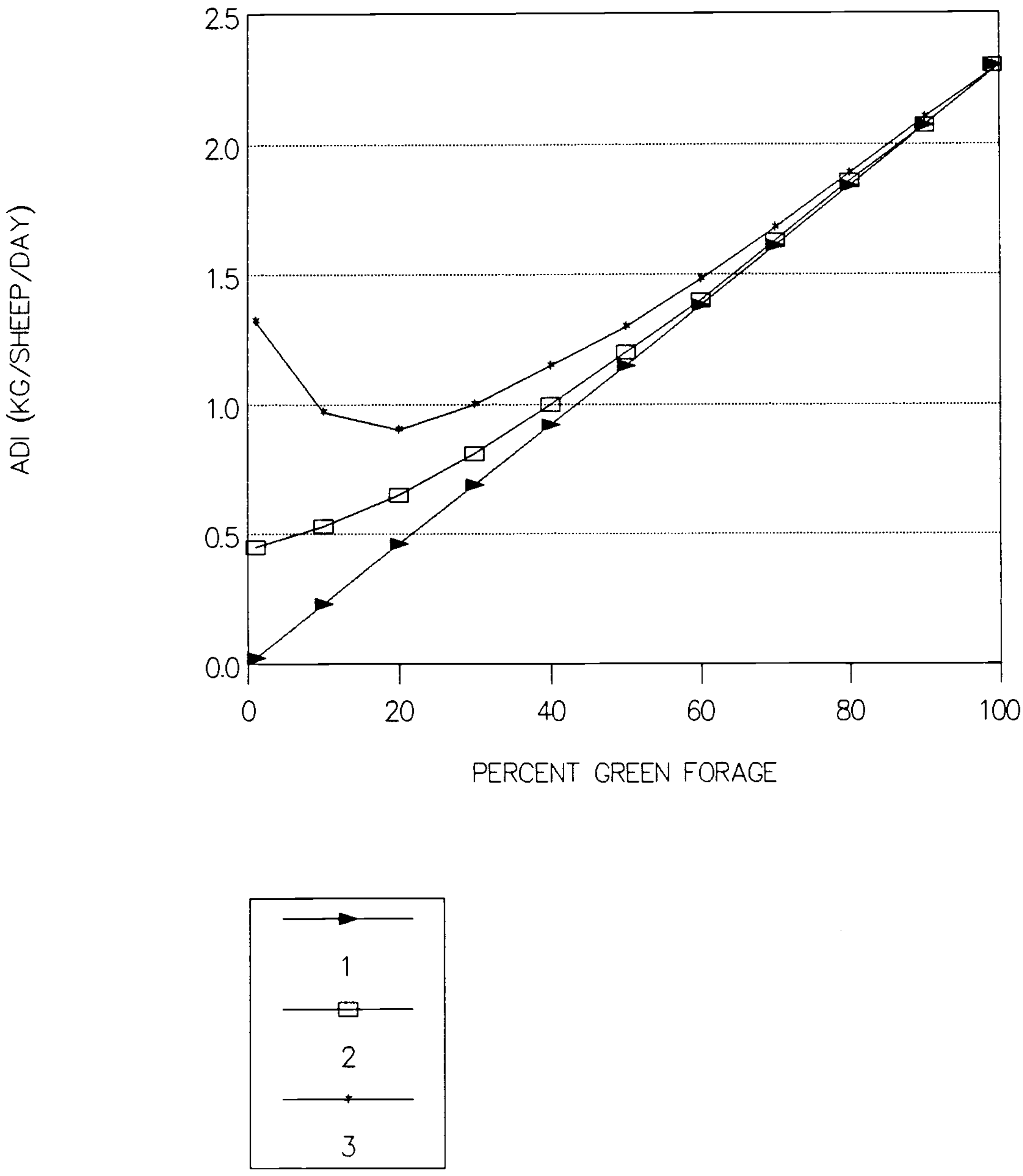
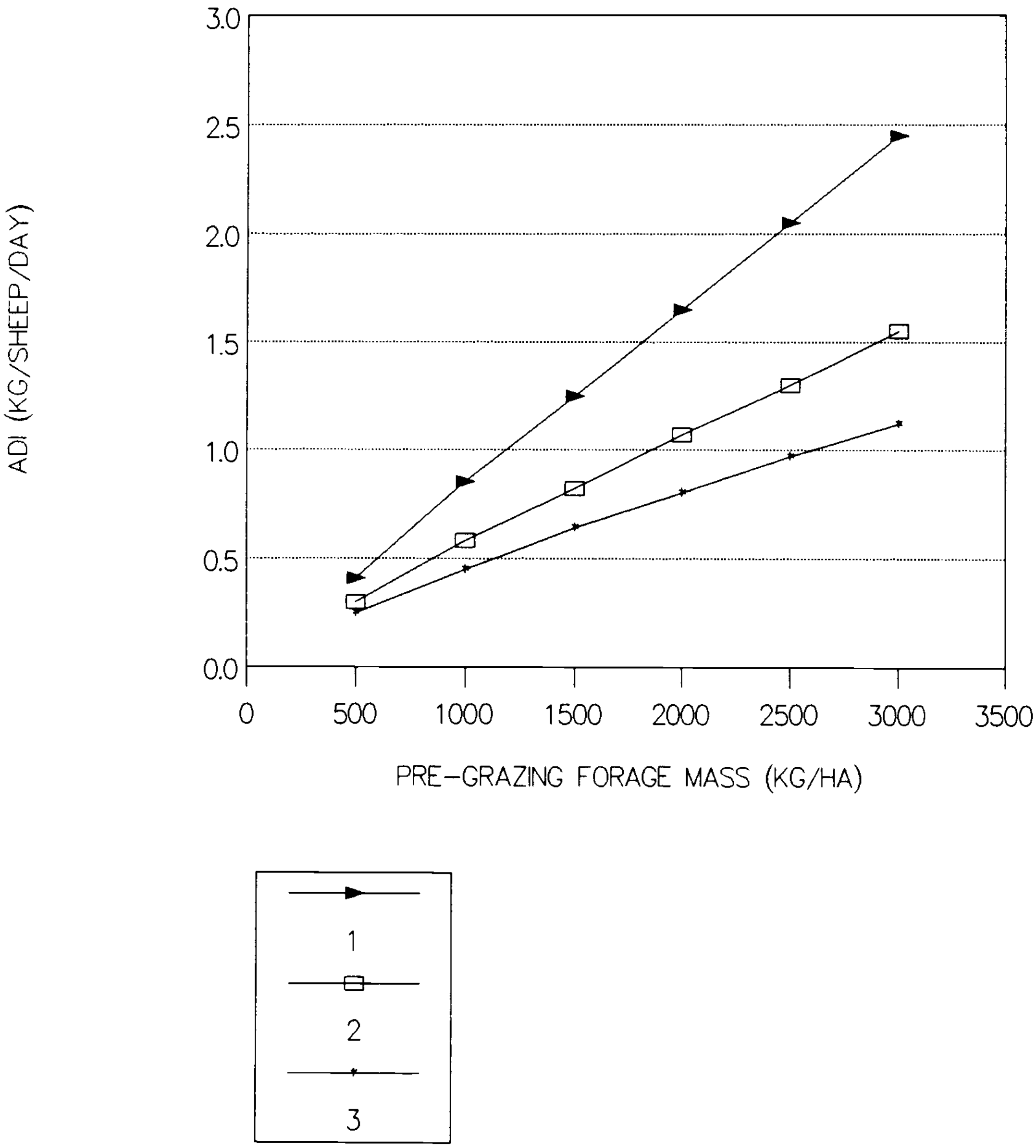


FIGURE 4.7 MODEL PREDICTIONS OF AVERAGE DAILY INTAKE (ADI, KG/SHEEP/DAY) OF TOTAL DRY MATTER (TDM, KG/HA) AND GREEN DRY MATTER (GDM, KG/HA) VS. PERCENT GREEN FORAGE OF TOTAL FORAGE MASS.



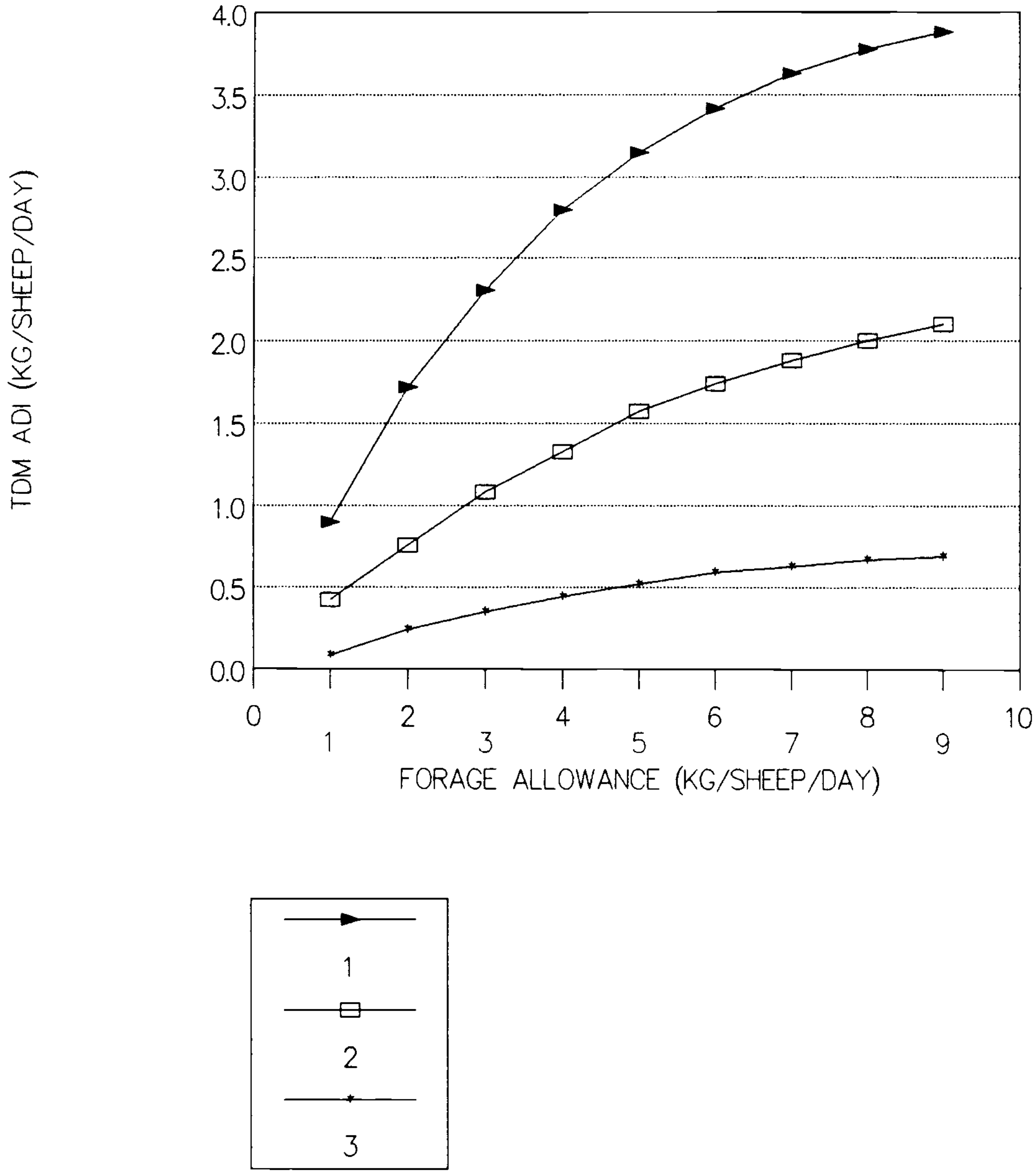
LEGEND : 1 - ADI OF TDM WITH K_d = 0.0006 per day (SUMMER)
2 - ADI OF TDM WITH K_d = 0.0002 per day (WINTER)
3 - ADI OF GDM IN SUMMER OR WINTER

FIGURE 4.8 EFFECT OF PRE-GRAZING FORAGE MASS (KG/HA) AND PERCENT GREEN FORAGE ON AVERAGE DAILY INTAKE OF TOTAL DRY MATTER (ADI, KG/SHEEP/DAY) OVER FIVE DAYS AT 200 SHEEP/HA.



LEGEND : 1 - ADI OF TDM WITH 90% GREEN FORAGE
2 - ADI OF TDM WITH 50% GREEN FORAGE
3 - ADI OF TDM WITH 10% GREEN FORAGE

FIGURE 4.9 EFFECT OF FORAGE ALLOWANCE (KG/SHEEP/DAY) AND FORAGE MASS (KG/HA, 90% GREEN FORAGE) ON AVERAGE DAILY INTAKE OF TOTAL DRY MATTER (ADI, KG/SHEEP/DAY).



LEGEND : 1 - ADI OF TDM WITH PRE-GRAZING MASS OF 2500 KG/HA
2 - ADI OF TDM WITH PRE-GRAZING MASS OF 1500 KG/HA
3 - ADI OF TDM WITH PRE-GRAZING MASS OF 500 KG/HA

REFERENCES

Arnold, G.W. 1981. Grazing Behaviour. In: F.H.W. Morley. (Ed.) Grazing Animals. pp: 79-104. Elsevier Scientific Publ. Co., New York.

Arnold, G.W., N.A. Campbell and K.A. Galbraith. 1977. Mathematical relationships and computer routines for a model of food intake, liveweight change and wool production in grazing sheep. Ag. Sys. 2:209-226.

Bircham, J.S. and G.W. Sheath. 1986. Pasture utilization in hill country 2. A general model describing pasture mass and intake under sheep and cattle grazing.

Christian, K.R., M. Freer, J.R. Donnelly, J.L. Davidson and J.S. Armstrong. 1978. Simulation of grazing systems. Centre for Ag. Publ. and Doc. Wageningen, Netherlands.

Clark, D.A., M.G. Lambert and D.F. Chapman. 1982. Pasture management and hill country production. Proc. N.Z. Grassland Assoc. 43:205-214.

France, J., N.R. Brockington and J.E. Newton. 1981. Modelling grazed grassland systems: wether sheep grazing perennial ryegrass. Applied Geography. 1:133-150.

Gibb, M.J. and T.T. Treacher. 1976. The effect of herbage allowance on herbage intake and performance of lambs grazing perennial ryegrass and red clover swards. J. Agr. Sci. 86:355-365.

Gibb, M.J. and T.T. Treacher. 1978. The effect of herbage allowance on herbage intake and performance of ewes and their twin lambs grazing perennial ryegrass. J. Ag. Sci. 90:139-147.

Guy, M.C., B.R. Watkin and D.A. Clark. 1981. Effect of season, stocking rate and grazing duration on diet selected by hoggets grazing mixed grass-clover pastures. N.Z. J. of Exp. Agr. 9:141-146.

L'Huillier, P.J., D.P. Poppi and T.J. Fraser. 1986. Influence of structure and composition of ryegrass and prairie grass-white clover swards on the grazed horizon and diet harvested by sheep. Grass and Forage Sci. 41:259-267.

McEwan, J.C., R.C. McDonald, P.F. Fennessy, K.F. Thompson, C.G. Hughson and K.G. Dodds. 1988. Pasture quality and nutrition in weaned lambs. Sheep and Beef Cattle Soc. N.Z. Vet. Assoc. 18:178-188.

McCall, D.G., R.J. Townsley, J.S. Bircham and G.W. Sheath. 1986. The interdependence of animal intake, pre- and post-grazing pasture mass and stock density. Proc. N.Z. Grassland Assoc. 47:255-261.

Penning, P.D., G.E. Hooper and T.T. Treacher. 1986. The effect of herbage allowance on intake and performance of ewes suckling twin lambs. Grass and Forage Sci. 41:199-208.

Pielou, E.C. 1974. Population and Community Ecology: Principles and Methods. Gordon and Breach Science Publ. New York.

Poppi, D.P., T.P. Hughes and P.J. L'Huillier. 1987. Intake of pastures by grazing ruminants. N.Z. Soc. Anim. Prod. Occ. Publ. No. 10: 55-63.

Rattray, P.V. and K.T. Jagusch. 1978. Pasture allowances for the breeding ewe. Proc. N.Z. Soc. Anim. Prod. 38:121-128.

Rattray, P.V., K.T. Jagusch and D.C. Smeaton. 1983. Interactions between feed quality, feed quantity, body weight and flushing. Proc. N.Z. Vet. Assoc. Sheep and Beef Cattle Soc. 13:21-34.

Rattray, P.V. and D.A. Clark. 1984. Factors affecting the intake of pasture. N.Z. Agr. Sci. 141-146.

Sharrow, S.H. 1983. Rotational vs. continuous grazing affects animal performance on annual grass-subclover pasture. J. Range Mngt. 36:593-595.

Sharrow, S.H. and W.C. Krueger. 1979. Performance of sheep under rotational and continuous grazing on hill pastures. J. Anim. Sci. 49:893-899.

White, D.H., P.J. Bowman, F.H.W. Morley, W.R. McManus and S.J. Filan. 1983. A simulation model of a breeding ewe flock. Ag. Sys. 10:149-189.

CHAPTER 5

SUMMARY

The objective of this study was to quantify the effects of pasture and management variables on forage intake by grazing sheep. The central hypothesis being tested was that in circumstances where pasture mass is limiting forage intake the total amount of forage consumed will increase (or residual pasture mass will decrease) at a diminishing rate during the grazing period. This concept was expressed mathematically using a negative exponential function in which the dependent variable was pasture residual and the independent variable the product of stock density and grazing duration, i.e. grazing pressure.

In all three grazing trials (summer, fall and winter) the regression coefficients describing the relationship between grazing pressure and residual pasture mass of green dry matter and total dry matter were highly significant ($P<.01$). While these results supported the above hypothesis, the estimated regression coefficients varied considerably between trials.

The lowest instantaneous rate of decline in green forage per stock day was recorded in the fall grazing trial. The value for the winter trial was intermediate between those for summer and fall. Differences in instantaneous rates between the summer and winter trials resulted most likely from seasonal changes in the vertical distribution of green forage. In summer green forage was elevated and easily accessible. In winter, only the green forage which had grown above the mat of weathered dead material was readily consumed. As green forage decreased in winter, foraging appeared to become rapidly more difficult and sheep appeared unable or unwilling to graze completely to ground level. The results of these two trials suggest that it is unlikely that either an instantaneous rate of forage decline or the minimum green forage residual are constant for all seasons.

In all trials, zero growth was assumed to occur during the grazing interval and no attempts were made to estimate forage growth. During the summer and winter trials this assumption appeared clearly plausible. However, during the fall trial new growth was visible in plots within five days post-clipping. Since more growth may have occurred in treatments with lower grazing pressures (due to higher average leaf area indices) the average daily intakes may have been biased downward for treatments of low relative grazing pressures. The occurrence of forage growth would also have reduced the estimate of the instantaneous rate of decline of green forage.

An assumption of the negative exponential hypothesis was that the effect of a particular grazing pressure on total intake in high density-short duration grazing systems was constant regardless of the combination of stock density and grazing duration used to achieve that grazing pressure. In the fall trial, designed to test this assumption, no significant differences or trends were found between combinations. However, these results only suggest that the assumption is valid. More research in this area is critical before such a conceptual model of grazing intake can be widely applied in simulation models.

The model developed to predict forage intake by grazing sheep used a function similar to the negative exponential to predict both green dry matter intake and potential dead dry matter intake. At low simulated allowances, predictions of the effects of forage allowance on average daily intake were consistent with reports from the literature. At high forage allowances most published studies of forage intake by non-lactating sheep have reported maximum values for average daily intake. The model predicted that average daily intake would continue to increase as allowance increased, but at a slower rate.

Why should average daily intake eventually reach a plateau as forage allowance increases? At low grazing pressures the rate of increase in total forage consumed may increase linearly as grazing pressure increases as is shown hypothetically in figure 1 for grazing pressures between 0 and 500 stock days. The linear increase, i.e. constant average daily intake, can occur due to two factors. Either forage mass is not limiting intake and animals are satiated, or forage mass is limiting intake but the amount of forage consumed at grazing pressures less than 500 stock days does not appreciably alter forage mass during grazing.

As grazing pressure increases beyond 500 stock days, forage mass is increasingly depressing intake. In this region, total forage intake is increasing at a decreasing rate as grazing pressure increases. This relationship, first linear then curvilinear, between total forage intake and grazing pressure (figure 5.1) can be used to describe the relationship between average daily intake and forage allowance (figure 5.2). The close qualitative agreement between this curve and results of forage allowance studies suggests that quantification of pasture and management variables on forage intake may best be accomplished by directly analyzing total forage intake (or pasture residual) as a function of grazing pressure rather than as a function of forage allowance.

FIGURE 5.1 CONCEPTUAL MODEL OF FORAGE CONSUMPTION (KG/HA) VS. GRAZING PRESSURE (STOCK DAYS).

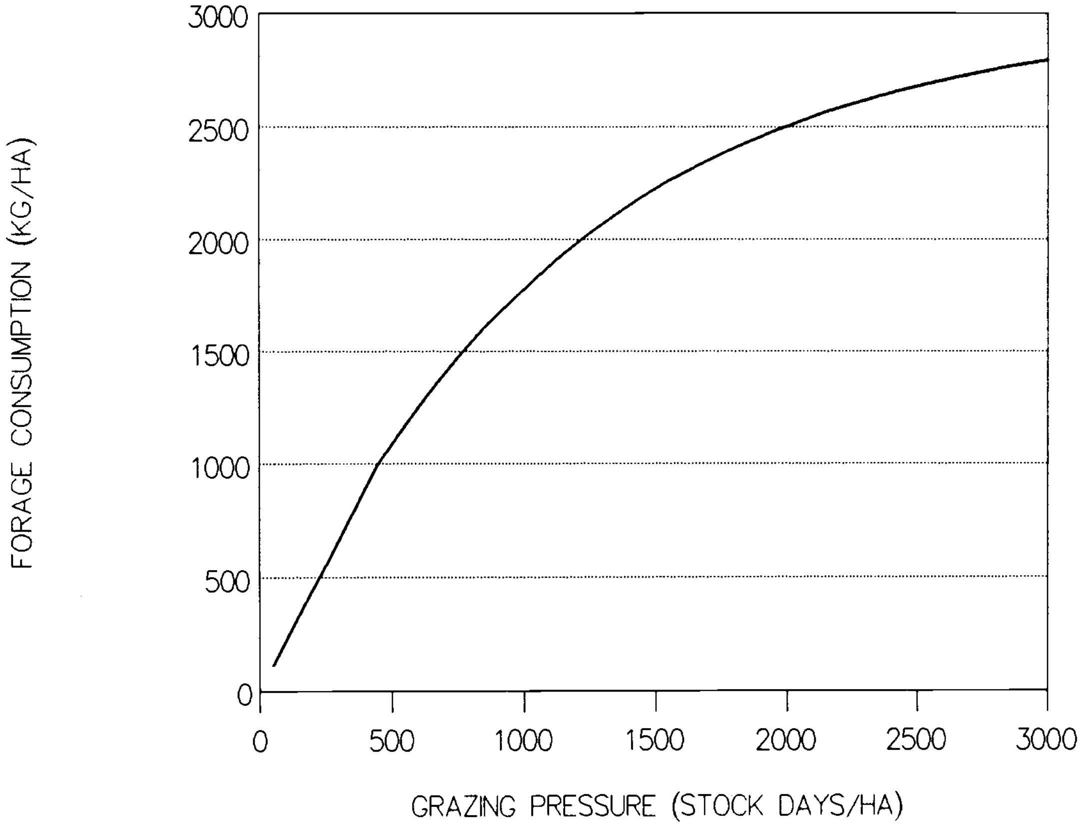
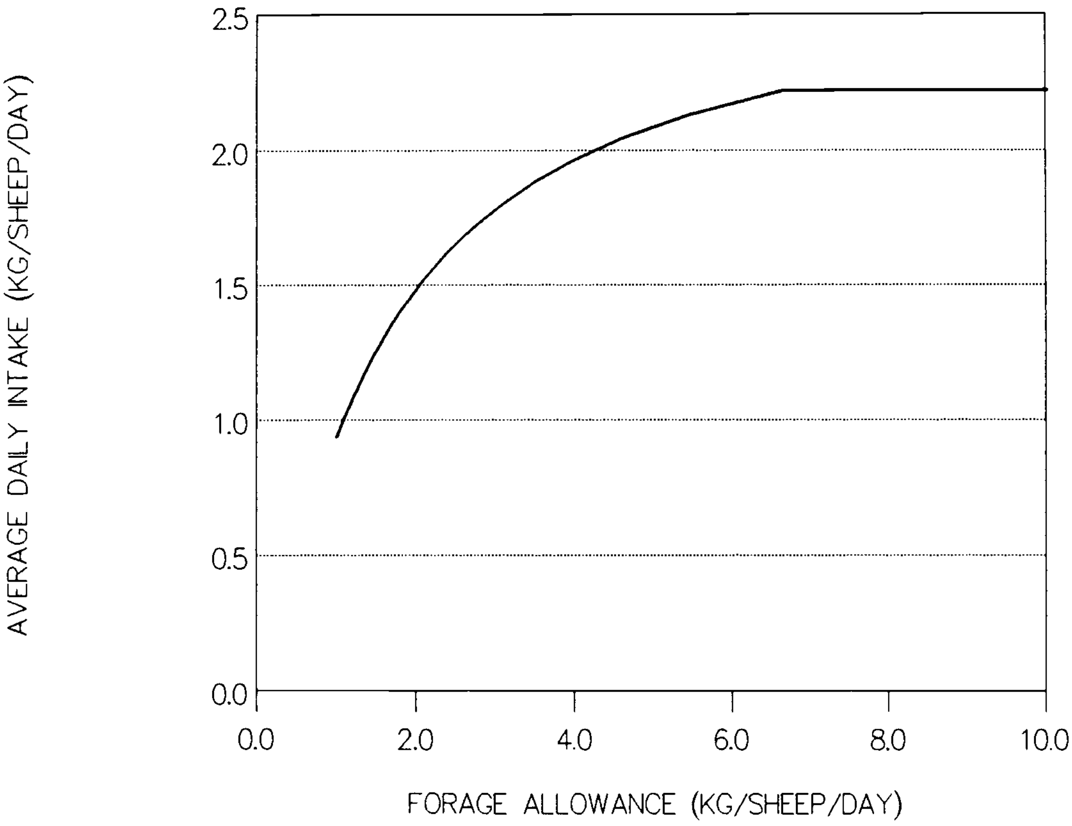


FIGURE 5.2 CONCEPTUAL MODEL OF AVERAGE DAILY INTAKE (ADI, KG/SHEEP/DAY) VS. FORAGE ALLOWANCE (KG/SHEEP/DAY).



BIBLIOGRAPHY

Allden, W.G. and I.A.M. Whittaker. 1970. The determinants of herbage intake by grazing sheep: the interrelationships of factors influencing herbage intake and availability. Aust. J. Ag. Res. 21:755-766.

Armstrong, R.H., T.G. Common and H.K. Smith. 1986. The voluntary intake and in vivo digestibility of herbage harvested from indigenous hill plant communities. Grass and Forage Sci. 41:53-60.

Arnold, G.W. 1964. Factors within plant associations affecting the behaviour and performance of grazing animals. In: D.J. Crisp. (Ed.) Grazing in Terrestrial and Marine and Environments. pp. 133-154. Blackwell Scientifics Press. London.

Arnold, G.W. 1975. Herbage intake and grazing behaviour in ewes of four breeds at different physiological states. Aust. J. Ag. Res. 26:1017-1024.

Arnold, G.W. 1981. Grazing Behaviour. In: F.H.W. Morley. (Ed.) Grazing Animals. pp: 79-104. Elsevier Scientific Publ. Co. New York.

Arnold, G.W. and Birrell. 1977. Food intake and grazing behaviour of sheep varying in body condition. Anim. Prod. 24:343-353.

Arnold, G.W., N.A. Campbell and K.A. Galbraith. 1977. Mathematical relationships and computer routines for a model of food intake, liveweight change and wool production in grazing sheep. Ag. Sys. 2:209-226.

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

Arnold, G.W. and M.L. Dudzinski. 1967b. Studies on the diet of the grazing animal. III. The effect of pasture species and pasture structure on the herbage intake of sheep. Aust. J. Ag. Res. 18:657-666.

Arnold, G.W. and M.L. Dudzinski. 1978. The Ethology of Free Ranging Domestic Animals. Elsevier Scientific Publ. Amsterdam.

Baile, C.A. and J.M. Forbes. 1974. Control of feed intake and regulation of energy balance in ruminants. Physio. Rev. 54:160.

Baldwin, R.L., L.J. Koong and M.J. Ulyatt. 1977. A dynamic model of ruminant digestion for evaluation of factors affecting nutritive value. Ag. Sys. 2:255-288.

Berggren-Thomas, B., 1984. Sheep breed evaluation: Grazing behavior, condition scores and lamb production. Masters Thesis. Oregon State Univ., Corvallis, Oregon.

Bircham, J.S. and G.W. Sheath. 1986. Pasture utilization in hill country 2. A general model describing pasture mass and intake under sheep and cattle grazing. N.Z. J. of Agr. Res. 29:639-648.

Black, J.L. and P.A. Kenney. 1984. Factors affecting diet selection by sheep. II. Height and density of pasture. Aust. J. Ag. Res. 35:565-578.

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

Blaxter, K.L., F.W. Wainman and J.L. Davidson. 1966. The voluntary intake of food by sheep and cattle in relation to their energy requirments for maintenance. Anim. Prod. 8:75-83.

Campling, R.C. 1970. Physical requlation of voluntary intake. In: A.T. Phillipson. (Ed.) Physiology of digestion and metabolism in the ruminant. Oriel Press Ltd. Newcastle upon Tyne, England. pp 226-234.

Chacon, E. and T.H. Stobbs. 1976. Influence of progressive defoliation of a grass sward on the eating behaviour of cattle. Aust. J. Ag. Res. 27:709-727.

Christian, K.R., M. Freer, J.R. Donnelly, J.L. Davidson and J.S. Armstrong. 1978. Simulation of grazing systems. Centre for Ag. Publ. and Doc. Wageningen, Netherlands.

Clark, D.A., M.G. Lambert and D.F. Chapman. 1982. Pasture management and hill country production. Proc. N.Z. Grassland Assoc. 43:205-214.

Clark, D.A. and M.J. Ulyatt. 1985. Utilization of forage legumes in ruminant livestock production on New Zealand. In: Forage legumes for energy-effecient animal production : proceedings of a trilateral workshop held in Palmerston North, N.Z. April 30-May 4, 1984. Ed: R.F. Barnes, R.P. Ball, R.W. Brougham, G.C. Marten and D.J. Minson. USDA Ag. Res. Serv. Washington, D.C. pp.197-203.

Cook, C.W., J.E. Mattox and L.E. Harris. 1961. Comparative daily consumption and digestibility of summer range forage by wet and dry ewes. J. Anim. Sci. 20:866-870.

Cooney, G.J. and K.F. Thompson. 1978. A farm grazing system in Southland - an advisor's recommendations. Proc. N.Z. Grassland Assoc. 40:60-69.

Demment, M.W., E.A. Laca and G.B. Greenwood. 1987. Intake in grazing ruminants: A conceptual framework. Symposium Proc. of Feed Intake by Beef Cattle. pp. 208-225. Oklahoma St. Univ. Agr. Exp. Station, Stillwater.

Dickerson, 1977. Crossbreeding evaluation of Finnsheep and some U.S. breeds for market lamb production. North Central Region Pub. No. 246. USDS and Univ of Nebraska, Lincoln.

Donnelly, J.R., J.L. Davidson and M. Freer. 1974. Effect of body condition on intake of food by mature sheep. Aust. J. Ag. Res. 25:813-823.

Drew, K.R. and J.T. Reid. 1975. Compensitory growth in immature sheep. III. Feed utilization by sheep subjected to feed deprivation followed by realimentation. J. Ag. Sci. 85:215-220.

During, C. and C.B. Dyson. 1980. The relationship of pasture to liveweight gain of hoggets on North Island hill country. Proc. N.Z. Soc. Anim. Prod. 40:98-105.

Edelsten, P.R. and J.E. Newton. 1977. A simulation model of a lowland sheep system. Ag. Sys. 2:17-32.

Forbes, J.M. 1969. The effect of pregnancy and fatness on the volume of rumen contents in the ewe. J. Ag. Sci. 72:119-121.

Forbes, J.M. 1977. Interrelationships between physical and metabolic control of voluntary intake in fattening pregnant and lactating mature sheep: A model. Anim. Prod. 24:91-101.

France, J., N.R. Brockington and J.E. Newton. 1981. Modelling grazed grassland systems: wether sheep grazing perennial ryegrass. Applied Geography. 1:133-150.

Freer, M. 1981. The control of food intake by grazing animals. In: F.H.W. Morley. (Ed.) Grazing Animals. pp. 105-124. Elsevier Scientific Publ. New York.

Freer, M., J.L. Davidson, J. Armstrong and J.R. Donnelly. 1970. Simulation of summer grazing. Proc. 11th Int. Grassland Cong. Surfers' Paradise, Queensland. pp. 913-917.

Geenty, K.G. and A.R. Sykes. 1982. Influence of herbage allowance on diet quality in lactating ewes. Proc. N.Z. Soc. Anim. Prod. 42:161-163.

Geenty, K.G. and A.R. Sykes. 1986. Effect of herbage allowance during pregnancy and lactation on feed intake, milk production, body composition and energy utilization of ewes at pasture. J. Ag. Sci. 106: 351-367.

Gibb, M.J. and T.T. Treacher. 1976. The effect of herbage allowance on herbage intake and performance of lambs grazing perennial ryegrass and red clover swards. J. Ag. Sci. 86:355-365.

Gibb, M.J. and T.T. Treacher. 1978. The effect of herbage allowance on herbage intake and performance of ewes and their twin lambs grazing perennial ryegrass. J. Ag. Sci. 90:139-147.

Gibb, M.J., T.T. Treacher and V.S. Shanmugalingan. 1981. Herbage intake and performance of grazing ewes and their lambs when weaned at 6, 8, 10 or 14 weeks of age. Anim. Prod. 33:223-232.

Graham, N.M., T.W. Searle and D.A. Griffiths. 1974. Basal metabolic rate in lambs and young sheep. Aust. J. Ag. Res. 25:957-971.

Graham, N.NcC., J.L. Black and G.J. Faichiney. 1976. Simulation of growth and production in sheep model 1: A computer program to estimate energy and nitrogen utilization, body composition and empty liveweight change, day by day for sheep of any age. Ag. Sys. 1:113-138.

Guy, M.C., B.R. Watkin and D.A. Clark. 1981. Effect of season, stocking rate and grazing duration on diet selected by hoggets grazing mixed grass-clover pastures. N.Z. J. of Exp. Agr. 9:141-146.

Hadjipieris, G., J.G.W. Jones and W. Holmes. 1965. The effect of age and liveweight on the feed intake of grazing wether sheep. Anim. Prod. 7:309-317.

Hadjipieris, G. and W. Holmes. 1966. Studies on feed intake and utilization by sheep. I. The volume of feed intake of dry, pregnant and lactating ewes. J. Ag. Sci. 66:217.

Hamilton, B.A., K.J. Hutchinson, P.C. Annis and J.B. Donnelly. 1973. Relationships between the diet selected by grazing sheep and the herbage on offer. Aust. J. Ag. Res. 24:271-277.

Harvey, W.R. 1975. Least-squares analysis of data with unequal subclass numbers. Publ. No. A-4, ARS, USDA. Washington, D.C.

Hawker, H., S.F. Crosbie and K.F. Thompson. 1982. Effects of season and pasture allowance on the wool growth of romney ewes. Proc. N.Z. Soc. Anim. Prod. 42:183-185.

Hawker, H., S.F. Crosbie, M. Barber and R.N. Andrews. 1985. Effects of shearing and herbage allowance on the intake, liveweight gain and wool growth of Romney ewe hoggets in spring-summer. Proc. N.Z. Soc. Anim. Prod. 45:141-145.

Hodgson, J. 1981. Variations in the surface characteristics of the sward and the short-term rate of herbage intake by calves and lambs. Grass and Forage Sci. 36:49-57.

Hodgson, J. 1982. Influence of sward characteristics on diet selection and herbage intake by the grazing animal. In: J.B. Hacker. (Ed.) Nutritional Limits to Animal Production from Pasture. Commonwealth Ag. Bureaux. London. pp. 153-166.

Hodgson, J. 1984. Sward conditions, herbage allowance and animal production: an evaluation of research results. Proc. N.Z. Soc. Anim. Prod. 44:99-104.

Hodgson, J. and T.J. Maxwell. 1984. Grazing studies for grassland sheep systems at the Hill Farming Research Organization, U.K. Proc. N.Z. Grassland Assoc. 45:184-189.

Hogan, J.R., R.H. Weston and J.R. Lindsay. 1969. The digestion of pasture plants by sheep. IV. The digestion of Phalaris tuberosa at different stages of maturity. Aust. J. Ag. Res. 20:925-940.

Hughes, T.P., D. Poppi and A.R. Sykes. 1980. Some implications of sward chemical and physical characteristicsfor the nutrition of grazing ruminants. Proc. N.Z. Soc. Anim. Prod. 40:68.

Hutchinson, K.J. and B.H. McRae. 1969. Some factors associated with the behaviour and survival of newly shorn sheep. Aust. J. Ag. Res. 20:513-521.

Jagusch, K.T., P.V. Rattray and K.S. MacLean. 1978. The dynamics of pasture production under sheep. Proc. N.Z. Soc. Anim. Prod. 38:129-138.

Jagusch, K.T., P.V. Rattray, T.W. Oliver and N.R. Cox. 1979. The effect of herbage yield and allowance on growth and carcass characteristics of weaned lambs. Proc. N.Z. Soc. Anim. Prod. 39:254-259.

Jagusch, K.T., J.F. Smith and P.V. Rattray. 1981. Principles of winter grazing practices with special reference to sheep management. Proc. N.Z. Vet. Assoc. Sheep and Beef Cattle Soc. 11:75-81.

Jamieson, W.S. and J. Hodgson. 1979. The effects of variation in sward characteristics upon the ingestive behaviour and herbage intake of calves and lambs under a continous stocking management. Grass and Forage Sci. 34:273-282.

Keenan, D.M., W.R. McManus and M. Freer. 1970. Voluntary intake of food by mature sheep following restricted feed. J. Ag. Sci. 74:477-485.

Langlands, J.P. 1968. The feed intake of grazing sheep differing in age, breed, previous nutrition and live weight change. J. Ag. Sci. 71:167-172.

Langlands, J.P. and B.A. Hamilton. 1969. Efficiency of wool production of grazing sheep 2. Differences between breeds and strains varying in age. Aust. J. Exp. Ag. and Anim. Husb. 9:254-257.

Langlands, J.P. and I.L. Bennet. 1973. Stocking intensity and pastoral production. II. Herbage intake of Merino sheep grazed at different stocking rates. J. Ag. Sci. 81:205-209.

Langlands, J.P. and J. Sanson. 1976. Factors affecting the nutritive value of the diet and the composition of rumen fluid of grazing sheep and cattle. Aust. J. Ag. Res. 27:691-707.

Laredo, M.A. and D.J. Minson. 1975. The voluntary intake and digestibility by sheep of leaf and stem fractions of Lolium perenne. J. Brit. Grassland Soc. 30:73-77.

L'Huillier, P.J., D.P. Poppi and T.J. Fraser. 1984. Influence of green leaf distribution on diet selection by sheep and the implications for animal performance. Proc. N.Z. Soc. Anim. Prod. 44:105-107.

L'Huillier, P.J., D.P. Poppi and T.J. Fraser. 1986. Influence of structure and composition of ryegrass and prairie grass-white clover swards on the grazed horizon and diet harvested by sheep. Grass and Forage Sci. 41:259-267.

McCall, D.G. 1984. A systems approach to research planning for North Island hill country. Ph.D. Dissertation. Massey Univ., New Zealand.

McCall, D.G., R.J. Townsley, J.S. Bircham and G.W. Sheath. 1986. The interdependence of animal intake, pre- and post-grazing pasture mass and stock density. Proc. N.Z. Grassland Assoc. 47:255-261.

McEwan, J.C., C.D. Mathieson and H. Hawker. 1985. Effect of herbage allowance on the productive performance of lactating and non-lactating hoggets. Proc. N.Z. Soc. of Anim. Prod. 45:147-150.

McEwan, J.C., R.C. McDonald, P.F. Fennessy, K.F. Thompson, C.G. Hughson and K.G. Dodds. 1988. Pasture quality and nutrition in weaned lambs. Proc. N.Z. Vet. Assoc. Sheep and Beef Cattle Soc. 18:178-188.

McMiniman, N.P., I.F. Beale and G.M. Murphy. 1986. Nutritional evaluation of south-west Queensland pastures. I. The botanical and nutrient content of diets selected by sheep grazing on Mitchell grass and mulga/grassland associations. Aust. J. Ag. Res. 37:289-302.

Mertens, A.R. and L.O. Ely. 1979. A dynamic model of fiber digestion and passage in the ruminant for evaluating forage quality. J. Anim. Sci. 49:1085-1095.

Meyer, H.H. and R.D. Lewis. 1988. Reproductive response of ewes to immunization with Fecundin (Ovandrotone). J. Anim. Sci. 66:2742-2749.

Milligan, K. 1983. Controlled Grazing. N.Z. Ministry of Ag. and Fisheries. New Zealand.

Milne, J.A., L. Bagley and S.A. Grant. 1979. Effects of season and level of grazing on the utilization of heather by sheep. 2. Diet selection and intake. Grass and Forage Sci. 34:45.

Minson, D.J. 1982. Effects of chemical and physical composition of herbage eaten upon intake. In: J.B. Hacker. (Ed.) Nutritional Limits to Animal Production from Pasture. Commonwealth Ag. Bureaux. London. pp. 167-182.

Minson, D.J., C.E. Harris, W.F. Raymond and R.J. Milford. 1964. The digestibility and voluntary intakes of S22 and H1 ryegrass, S170 Tall fescue, S48 Timothy, S215 Meadow fescue and Germinal cocksfoot. J. Brit. Grassland Soc. 19:298-305.

Munro, J.M. and K.G. Geenty. 1983. Influence of herbage allowance during suckling period on subsequent growth and carcass fatness of twin lambs weaned at 6 weeks of age. Proc. N.Z. Soc. Anim. Prod. 43:41-42.

Moss, R.A. 1987. Effects of herbage allowance on gummy ewe and sound mouthed ewe performances during early-mid lactation. N.Z. J. Ag. Res. 30-477-480.

Noy-Meir, I. 1976. Rotational grazing in a continuously growing pasture: A simple model. Ag. Sys. 1:87-112.

Osborn, D.F. 1980. The feeding value of grass and grass products. In: W. Holmes. (Ed.) Grass - its production and utilization. Blackwell Scientific Press. London. pp. 70-124.

Owen, J.B., R.F. Lee, P.M Lerman and E.L. Miller. 1980. The effect of reproductive state of ewes on their voluntary intake of diets varying in straw content. J. Ag. Sci. 94:637-644.

Penning, P.D. 1986. Some effects of sward conditions on grazing behaviour and intake by sheep. In: O. Gudmundsson (Ed.) Grazing research at northern latitudes. Plenum Press. New York. pp. 219-226.

Penning, P.D. and M.J. Gibb. 1979. The effect of milk intake on the intake of cut and grazed herbage by lambs. Anim. Prod. 29:53-67.

Penning, P.D., G.E. Hooper and T.T. Treacher. 1986. The effect of herbage allowance on intake and performance of ewes suckling twin lambs. Grass and Forage Sci. 41:199-208.

Pielou, E.C. 1974. Population and Community Ecology: Principles and Methods. Gordon and Breach Science Publ. New York.

Poppi, D.P., T.P. Hughes and P.J. L'Huillier. 1987. Intake of pastures by grazing ruminants. N.Z. Soc. Anim. Prod. Occ. Publ. No. 10: 55-63.

Rattray, P.V. 1978. Pasture constraints to sheep production. Proc. Agron. Soc. N.Z. 8:103-107.

Rattray, P.V., W.N. Garrett, N.E. East and N. Hinman. 1974. Efficiency of utilization of metabolizable energy during pregnancy and the energy requirement for pregnancy in sheep. J. Anim. Sci. 38:383-393.

Rattray, P.V. and K.T. Jagusch. 1978. Pasture allowances for the breeding ewe. Proc. N.Z. Soc. Anim. Prod. 38:121-126.

Rattray, P.V., K.T. Jagusch and K.S. MacLean. 1978. The effect of pasture allowance on the performance of different breeds of sheep. Proc. N.Z. Grassland Assoc. 40:89-103.

Rattray, P.V., K.T. Jagusch, J.F. Smith, G.W. Winn and K.S. MacLean. 1980. Flushing responses from heavy and light ewes. Proc. N.Z. Soc. Anim. Prod. 40:34-37.

Rattray, P.V., K.T. Jagusch, J.F. Smith, G.W. Winn and K.S. MacLean. 1981. Effects of genotype, liveweight, pasture type and feeding level on ovulation responses in ewes. Proc. N.Z. Soc. Anim. Prod. 41:174-182.

Rattray, P.V., K.T. Jagusch, D.M. Duganzich, K.S. MacLean and R.J. Lynch. 1982a. Influence of pasture allowance and mass during late pregnancy on ewe and lamb performance. Proc. N.Z. Grassland Assoc. 43:223-229.

Rattray, P.V., K.T. Jagusch, D.M. Duganzich, K.S. MacLean and R.J. Lynch. 1982b. Influence of feeding post-lambing on ewe and lamb performance at grazing. Proc. N.Z. Soc. Anim. Prod. 42:179-182.

Rattray, P.V., K.T. Jagusch and D.C. Smeaton. 1983. Interactions between feed quality, feed quantity, body weight and flushing. Proc. N.Z. Vet. Assoc. Sheep and Beef Cattle. Soc. 13:21-34.

Rattray, P.V. and D.A. Clark. 1984. Factors affecting the intake of pasture. N.Z. Ag. Sci. 18:141-146.

Rattray, P.V., K.F. Thompson, H. Hawker and R.M.W. Sumner. 1987. Pastures for sheep production. N.Z. Soc. Anim. Prod. Occ. Publ. No. 10. pp. 89-103.

Reid, R.L. and N.T. Hinks. 1962. Studies on the carbohydrates metabolism of sheep. Aust. J. Ag. Res. 13:1082-1111.

Searle, T.W. and N.McC. Graham. 1975. Studies of weaner sheep during and after a period of weight stasis II. Body composition. Aust. J. Ag. Res. 26:355-361.

Sharrow, S.H. 1983. Rotational vs. continuous grazing affects animal performance on annual grass-subclover pasture. J. Range Mngt. 36:593-595.

Sharrow, S.H. and W.C. Krueger. 1979. Performance of sheep under rotational and continuous grazing on hill pastures. J. Anim. Sci. 49:893-899.

Sheath, G.W. 1983. Pasture utilization in hill country. 1. Influence of grazing duration and land contour. N.Z. J. Exp. Ag. 11:309-319.

Sibbald, A.R., T.J. Maxwell and J. Eadie. 1979. A conceptual approach to the modelling of herbage intake by hill sheep. Ag. Sys. 4:119-134.

Smeaton, D.C. and T.W. Knight. 1981. Problems in flushing ewes on North Island hill country. Proc. N.Z. Soc. Anim. Prod. 41:183-188.

Smeaton, D.C., R.M. Sumner, T.W. Knight and T.K. Adams. 1983. Effects of time of weaning, pasture allowance and shearing time on ewe and lamb liveweight, wool growth and subsequent ovulation rate of the ewe. N.Z. J. Exp. Ag. 11:41-45.

Smith, L.W., H.K. Goering and C.H. Gordon. 1972. Relationships of forage compositions with rates of cell wall digestion and indigestibility of cell walls. J. Dairy Sci. 55:1140-1147.

Thompson, K.F., J.C. McEwan and W.H. Risk. 1980. Pasture allowance and lamb growth. Proc. N.Z. Soc. Anim. Prod. 40:92-97.

Thorton, R.F. and D.J. Minson. 1972. The relationship between the voluntary intake and mean apparent retention time in the rumen. Aust. J. Ag. Res. 23:871-877.

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

Troelsen, J.E. and J.B. Campbell. 1968. Voluntary consumption of forage by sheep and its relation to the size and shape of particles in the digestive tract. Anim. Prod. 10:289-296.

Ulyatt, M.J. 1971. Studies on the difference in pasture quality between perennial ryegras, short-rotation ryegrass and white clover. N.Z. J. Ag Res. 14:352-361.

Ulyatt, M.J. 1981. The feeding value of temperate pastures. In: D.J. Crisp. (Ed.) Grazing in Terrestrial and Marine and Environments. pp. 156-172. Blackwell Scientifics Press. London.

Ulyatt, M.J., R.L. Baldwin and L.J. Koong. 1976. The basis of nutritive value - a modelling approach. Proc. N.Z. Soc. Anim. Prod. 36:140-149.

Van Soest, P.J. 1965. Symposium on factors influencing the voluntary intake of herbage by ruminants: Voluntary intake in relation to chemical composition and digestibility. J. Anim. Sci. 24:834-843.

Vera, R.R. Morris, J.G. and L.J. Koong. 1977. A quantitative model of energy intake and partition in grazing sheep in various physiological states. Anim. Prod. 25:133-153.

Vona, L.C., G.A. Jung, R.L. Reid and W.C. Sharp. 1984. Nutritive value of warm-season grass hays for beef cattle and sheep; digestibility, intake and mineral untilization. J. Anim. Sci. 59:1582-1593.

Waldo, D.R. 1985. Regulation of forage intake in ruminants. In: R.F. Barnes, R.P. Ball, R.W. Brougham, G.C. Marten and D.J. Minson. (Eds.) Forage legumes for energy-effecient animal production : proceedings of a trilateral workshop held in Palmerston North, N.Z. April 30-May 4, 1984. USDA Ag. Res. Serv. Washington, D.C. pp. 220-224.

Weston, R.H. 1982. Animal factors affecting intake. In: J.B. Hacker. (Ed.) Nutritional Limits to Animal Production from Pasture. Commonwealth Ag. Bureaux. London. pp. 183-198.

Willoughby, W.M. 1959. Limitations to animal production imposed by seasonal fluctuations in pasture and by management procedures. Aust. J. Ag. Res. 10:248-268.

Wheeler, J.L., T.F. Reardon and L.J. Lambourne. 1963. The effect of pasture availability and shearing stress on herbage intake of grazing sheep. Austr. J. Ag. Res. 14:364-372.

White, D.H., P.J. Bowman, F.H.W. Morley, W.R. McManus and S.J. Filan. 1983. A simulation model of a breeding ewe flock. Ag. Sys. 10:149-189.

APPENDICES

APPENDICES

TABLE A1. AUTUMN PRE-GRAZING AND POST-GRAZING ESTIMATES OF FORAGE MASS (KG/HA) AND PERCENT GREEN FORAGE[a] BY STOCK TYPE (EWES OR LAMBS), STOCK DENSITY (SHEEP/HA), GRAZING DURATION (DAYS) AND REPLICATION (REP).

		Stock density (sheep/ha)								
		Rep 1			Rep 2			Rep 3		
	Days	270	540	810	270	540	810	270	540	810
Ewes										
Forage mass, kg/ha										
Pre-grazing:	1	3174	2982	3153	1807	2342	2085	2555	2919	2320
	2	3046	3816	3067	2556	2321	2299	3582	2876	2897
	3	2896	2811	3046	2513	3433	2492	2812	2876	2534
Post-grazing:	1	2650	2613	2549	1881	2102	1927	2778	2336	2151
	2	2788	2383	2199	2323	1890	1807	3054	2243	2022
	3	2346	2042	2346	1899	1788	1770	1976	2078	1912
Percent Green forage										
Pre-grazing:	1				41.6	39.5	40.1	32.6	25.3	30.1
	2				18.4	53.7	25.1	25.9	31.1	39.7
	3				26.1	36.1	24.3	53.0	26.9	34.4
Post-grazing:	1				38.9	28.3	37.3	21.2	25.4	20.6
	2				28.9	24.0	13.3	23.6	16.8	26.1
	3				26.3	32.4	24.1	27.3	11.7	25.7
Lambs										
Forage mass, kg/ha										
Pre-grazing:	1	3110	3196	3110	2920	2599	3369	2469	2833	3475
	2	2982	3089	3923	2470	2770	2235	2641	2641	2448
	3	3217	2682	2297	2748	-[b]	2727	2769	2598	3175
Post-grazing:	1	2641	2438	2631	2249	1963	2194	2557	2676	2732
	2	2622	2383	2641	2221	2046	1696	2179	2612	1820
	3	2392	2125	2208	2295	-	1890	2741	1801	2142
Percent Green forage										
Pre-grazing:	1				37.9	27.2	43.9	33.9	38.1	26.1
	2				32.8	44.2	22.9	33.8	22.9	37.6
	3				39.1	-	22.5	32.3	33.1	31.3
Post-grazing:	1				20.9	40.1	41.6	34.6	32.4	34.0
	2				26.3	34.4	23.6	30.1	28.2	29.3
	3				25.1	-	23.1	29.1	22.8	17.7

[a] Estimates of green forage for replication 1 were discarded due to damage to samples.

[b] Estimates of both forage mass and green forage were discarded due to flooding of paddock during grazing.

TABLE A2. SUMMER AND WINTER[a] ESTIMATES OF FORAGE MASS (KG/HA) AND GREEN FORAGE MASS (KG/HA) BY DAY OF GRAZING (DAY) AND REPLICATION (REP).

	Rep	Day 0	1	2	3	4	5	6	7	8
Summer										
Forage Mass, kg/ha										
	1	6524	5604	5127	3903	3561	2491	2438	2289	2190
	2	6443	5279	5110	4234	3286	3157	2648	2748	2201
	3	5297	4862	4576	3388	2755	2751	2649	2411	2160
Green Forage, kg/ha										
	1	393	227	139	123	79	43	37	51	15
	2	398	132	136	118	44	31	36	40	14
	3	161	86	67	75	30	22	28	13	2
Winter										
Forage Mass, kg/ha										
	1	1405	1130	865	870	1080				
	2	1325	1875	1315	1360	1445				
	3	1550	1110	1120	910	1210				
Green Forage, kg/ha										
	1	569	290	246	191	243				
	2	563	366	238	230	267				
	3	467	270	177	217	167				

[a] Animals were removed at the end of day 4.