AN ABSTRACT OF THE THESIS OF

Raymond G. Jaindl for the degree of Doctor of Philosophy in Rangeland Resources presented on April 22, 1988

Title: The Effect of Winter Grazing on Production and Dynamics of a *Lolium perenne* (L.) - *Trifolium repens* (L.) Pasture.

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Abstract approved: ______________________

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Perennial ryegrass (*Lolium perenne*) - white clover (*Trifolium repens*) hill-land pastures were grazed at different times in the winter to study the effect of time of winter grazing on plant response and forage production. The same pastures were grazed by sheep once in early December, January, February, March, or April and compared to an ungrazed control in each of three forage years (December 1983 to July 1986). Winter stock grazing densities were based on a three day grazing period and a 400 kg ha^{-1} dry matter residual.

Grazing in the winter reduced herbage mass but had relatively little effect on subsequent forage production. This is consistent with the poor conditions for growth (relatively cold and low light levels) during the winter. Rates of herbage accumulation on the ungrazed control treatment averaged 6, -9, 2, 13, and 53 kg dry matter ha^{-1} day^{-1} in December, January, February, March, and April,

respectively. Dead material accounted for more than 50% of the herbage mass in almost every month between December and March.

By May, herbage mass on grazed treatments was similar to the ungrazed control except for treatments grazed in December and April which averaged 20 and 47% less forage than the ungrazed control, respectively. In May of the third year the December grazed treatment had significantly less perennial ryegrass and numerically more annual grass than the ungrazed control, and the January, February, and March grazed treatments. Total annual forage production and forage harvested annually were highly variable but tended to be higher on the January, February, and March grazed treatments than on the ungrazed control, and the December and April grazed treatments.

Grazing management programs in temperate hill land pastures, such as are found in western Oregon, would require that forage grown in the fall be carried into the winter if pasture is to be used as a winter feed source. Date of winter grazing has minimal effect on subsequent spring production except for grazing in December which results in lower yields in May. Repeated annual grazing in December may reduce pasture production and increase annual grass dominance after several years.

The Effect of Winter Grazing on Production and Dynamics of a *Lolium perenne* (L.)-*Trifolium repens* (L.) Pasture

by

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A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Doctor of Philosophy

Completed April 22, 1988

Commencement June 1988

APPROVED:

Redacted for Privacy

Professor of Rangeland Resources in charge of major

Redacted for Privacy

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Date thesis is presented April 22, 1988

Typed by researcher for Raymond G. Jaindl

ACKNOWLEDGEMENTS

I extend my appreciation to the Oregon Agricultural Experiment Station for financial support throughout my graduate program.

To my major professor, Steve Sharrow, I offer my sincere appreciation for the time and energy you devoted to my development, execution of this study, and preparation of this thesis. Your constructive criticism was always thought provoking and always appreciated.

Thanks to my committee members, Drs. Tom Bedell, Howard Meyer, David Hannaway, and John Crawford for your help throughout my program. A special thanks to Dr. James Green for being the graduate council representative at my final defense.

I would also like to extend my appreciation to the staff and graduate students in the Department of Rangeland Resources.

To my parents, Otto and Catherine Jaindl, thanks. Your encouragement and support throughout my college education and my life have meant more to me than you will ever know.

And to you Lisa. I look forward to building a life together with you.

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INTRODUCTION

Historically, hill lands in western Oregon have been used as a grazing resource for livestock production. Though pasture growth occurs primarily in the spring and early summer, pastures are available for grazing throughout the year because of the mild winters. Maximizing utilization of the forage produced, however, is complicated by the seasonal differences in forage availability and the need to maintain a base flock throughout the year. While the rise in available forage in late spring typically surpasses the demand of ewes which lamb in late winter, other times of the year can be characterized by lack of abundant forage. This affects the number of ewes which can be carried over from one lambing season to the next. If flock size maximizes use of the spring forage, excess animals during the remainder of the year may lead to a deterioration of the pasture and/or to a large supplemental feed requirement. In contrast, if ewe numbers are regulated by forage availability during the low producing times of the year, a large amount of spring forage be unused.

In other areas of the world with climates similar to western Oregon (England, New Zealand, Ireland, and the Netherlands), management strategies have been evaluated in an effort to develop systems which maximize pasture production and quality. Until recently, these studies have concentrated primarily on the spring and summer periods when maximum growth occurs. The winter period, when little or no growth seems to occur, has received little attention. This stemmed from the philosophy that if a pasture does not increase substantially in biomass, then it has little use as a forage resource or is relatively unaffected by defoliation if it is grazed.

Historically, winter grazing has been of little concern in the United States. Low energy costs and inexpensive grain sources allowed winter feed requirements to be more economically obtained through conserved feeds or supplements than from pasture. Recently, the costs associated with conserving feeds as hay or silage or purchasing supplements have substantially increased. This has focused attention on the feasibility of meeting the majority of livestock winter feed requirements from efficiently produced and utilized pasture forage. This attention has initiated interest in the growth capabilities of pasture plants during the winter period, and the effect of winter grazing on the subsequent production and composition of a pasture. The objective of this thesis is to evaluate the growth of perennial ryegrass-white clover pastures during the winter and to determine the effect of winter grazing on subsequent pasture production and composition.

LITERATURE REVIEW

Production of perennial ryegrass - white clover pastures is primarily a function of physical parameters (climate, soils, topography and season), plant parameters (species composition, tiller density, leaf area, roots, and physiological status), and defoliation (intensity, frequency and timing). A variation in any one of these parameters can result in significant changes in pasture production and in the status of pasture plants. Studies on the relationship of these factors with pasture production have been conducted throughout the world.

Most global research on perennial ryegrass-white clover pastures, which is pertinent to western Oregon conditions, has been concerned with pasture growth in the spring and summer when the yearly production and composition of a pasture was assumed to be most influenced by management actions. Subjects of research included general pasture production (Cooper 1970, Hunt 1970), growth dynamics of individual plants (Anslow 1966, Keatinge et al. 1979a, Mitchell 1953, Peacock 1975b), effect of defoliation at both the pasture and individual plant level (Jacques 1941, Jones et al. 1982, Korte et al. 1985), the physical effect of an animal on pasture (Brown 1971, Edmond 1963), and the impact of grazing management strategies on both the pasture and the animal performance

(Gunn 1981, McMeekan 1956, Suckling 1966). Most of this research comes from England, Ireland, Netherlands, and New Zealand.

Topics of research conducted on Western Oregon pasture lands have varied from forage preference of sheep and cattle (Bedell 1968) to the impact of intensity and season of grazing on the carbohydrate reserves of perennial ryegrass (El Hassan and Krueger 1980). Most of the more recent studies, however, have been concerned with grazing systems and the effect of intensity and frequency of grazing in the spring and summer on hill pasture production (Motazedian 1983; Sharrow and Krueger 1979; Thetford 1976; Warner 1983).

Compared to the spring and summer seasons, relatively little research has been conducted on the development and growth of pasture in the fall and winter. Furthermore, the effects of grazing in the fall and winter on the subsequent production and composition of a perennial ryegrass-white clover pasture are poorly understood.

Developing winter grazing management strategies is a three step process. Firstly, pasture growth in the winter must be understood on the basis of the pasture as a whole (pasture yields and herbage accumulation rates) and at the level of individual plants (tiller development, leaf development, photosynthesis potential, and root, crown, and stolon development). Secondly, the effect of defoliation in the winter on the subsequent dynamics of a pasture must be evaluated. Thirdly, using this information, management strategies can be developed which optimize pasture longevity and production while maximizing livestock production and long term profits.

Winter Pasture Growth

Herbage Accumulation

Herbage accumulation during a growing season generally follows a sigmoid curve which varies with, among other things, stage of growth, plant phenology, and season (Brougham 1955, 1956a). In the winter, herbage accumulation in a perennial ryegrass-white clover pasture is low on average, but because of natural variation in climate variability from year to year may be quite high on any one site. On a lowland site in New Zealand, growth in a perennial ryegrass-white clover pasture varied from 12.9 kg DM ha^{-1} day^{-1} in mid-winter during an unusually warm year (air temperature=6.2°C, 5 cm soil temperature=4.6°C, and 19 days of ground frost) to no growth at all in a cold year (air temperature=4.6°C, 5 cm soil temperature=2.8°C, and 23 days of ground frost) (Hayman and Moss 1979). Similar results were reported for a high country site in Central Otago, New Zealand (Abrahamson and Talbot 1986).

Alberda (1965) suggested that temperature and light intensity interact in determining dry matter production. Thus, the optimum temperature is dependent on the light intensity, and the effect of light intensity is different at different temperatures. He suggested that this results from the fact that light intensity influences the rate of photosynthesis but not the rate of respiration while temperature influences both photosynthesis and respiration. Mitchell (1953) drew similar conclusions from a study of the influence of light and temperature on the development of young plants grown in a controlled chamber.

Deinum (1976) suggested that fall production from pasture is regulated by the photosynthetic efficiency of the individual leaves. He stated that efficiency in the fall is low due to the small demand for assimilate and the unfavorable conditions during leaf development; thus, potential herbage production is poor.

From a study using heating cables placed in the soil to control soil temperature and netting to regulate light on a pasture in England, Thomas and Norris (1981) concluded that temperature rather than light limited plant growth, especially from mid-February to mid-March. However, they found that mild, dull weather in winter is likely to induce tiller death as a result of a reduction in photosynthesis and an increase in plant respiration.

Raguse and Taggard (1979) estimated that the practical soil threshold temperature for overall growth in subterranean clover is near 5°C, though some cell activity may proceed at temperatures below that. Halliday and Sylvester (1950) found that the critical soil temperature for the grasses they evaluated was 5.6°C.

Ball et al. (1978) suggested that the rate of mobilization of soil organic nitrogen by plants was the factor which limited pasture production during the colder, wetter part of the year in New Zealand. They found that N recovery by plants was better during late winter to mid-spring than during the late autumn to mid-winter. Thus, they concluded that there was a greater risk of N loss during cool, wet conditions associated with the slow growth rates of the late autumn to mid-winter period.

Herbage accumulation is a function not only of growth but also senescence and death of leaves (Hunt 1970). In both England and New Zealand, forage grown in the fall and carried over into the winter has been shown to decline in yields due to decomposition losses (Halford 1972; Newton and Jackson 1985; Parmenter and Boswell 1983). At a high country station in New Zealand (elevation=490-920 m) Abrahamson and Talbot (1986) reported losses of green herbage by frosting or senescence ranged from 35 to 70% in an exceptionally cold winter. There was no difference between clovers, grasses, or other species in winter survival.

This loss of herbage in the winter can be associated with several factors (Smith 1964):

(1) Lack of frost hardiness (a metabolic change that occurs in the protoplasm of the cells during the fall).

(2) Low and alternating temperatures (alternating temperatures in particular are damaging because the rapid thawing of plant tissue causes damage to cells (Sprague 1955). A decrease in frost hardiness may also occur depending on the length of warm period and the temperatures reached).

(3) Desiccation (water loss from leaf surfaces on warm, windy days in the winter may not be replaced due to the inability of roots to absorb water from dry or frozen soil).

Results of a study by Brereton et al. (1985) showed that vernalization also can have an important effect on the balance between leaf growth and senescence for perennial ryegrass. They found that the senescence rate was greater than the extension rate when temperatures were less than 8°C for leaves on plants which had not reached a vernalized state, compared to 4°C for leaves on plants which had reached a vernalized state. This is of interest because it is in contrast to the readily accepted assumption, upon which many models are based, that the threshold temperature for net grass growth is about 5°C

(Brereton et al. 1985).

Because white clover is not considered a winter forage species, little research exists on its development in the winter. However, in a study of growth rates of white clover in England, Davies and Evans (1982) found clover continued to grow during a winter when temperatures averaged 6.6, 6.9, 4.5, 3.9 and 6.8°C in November, December, January, February and March, respectively. However, because the rate of leaf loss due to frost and cold temperatures was approximately equal to that of leaf formation, there was no net increase in herbage mass until the latter part of March.

Tiller dynamics

"In a grass sward the unit of growth is the tiller, and although the grass plant is perennial, the majority of the tillers are annual" (Garwood 1969). Since pastures are a dynamic population of short-lived tillers with half lives varying from 36-143 days (Korte 1986), herbage production is significantly affected by the amount of tillering which occurs in the perennial ryegrass component of the sward. Davies and Thomas (1983) stated that every tiller bud has the potential to develop into a viable tiller, irrespective of natural seasonal changes in temperature or radiation, as long as there is an adequate supply of nutrients. However, of interest here is the actual development of tiller buds and not the potential development. Numerous studies have been conducted to determine those factors which affect tillering in perennial ryegrass pastures.

A on tillering of perennial ryegrass was conducted by Garwood (1969) in a pure sward of perennial ryegrass and in a mixed perennial ryegrass-white clover sward in England. He reported that tiller numbers varied seasonally with the greatest number recorded in spring and early summer. From early summer until the September-November period, tiller numbers decreased, then increased steadily until the following spring.

In New Zealand, Chapman et al. (1983) found that the tiller appearance rate increased in the spring when the temperature of the top 10 cm of soil rose from 6.5 to 7.5°C. In England, Peacock (1975c) found tiller numbers remained the same from September to December and then increased to reach their maximum levels in April. The increase by April was associated with increased light intensities and day-length. Similar results were found by Lonsdale and Watkinson (1983) also from England, Spiertz and Ellen (1972) in the Netherlands, and Korte (1986) in New Zealand.

It is often suggested that radiation exercises a dominant influence on both tiller initiation and appearance (Brereton et al. 1985, Davies and Thomas 1983). Both Brown (1976) and Chapman et al. (1983) attributed lower tiller bud development in dense swards to mutual shading within the sward. Results of a growth chamber study by Deregibus et al. (1983) demonstrated that the phytochrome mechanism, which is recognized as the determinant of branching in dicotyledonous plants, also controls tillering in grasses. Thus, a reduction in tillering, which is encountered in swards where leaf area has increased so that the base of the plants are shaded, can be attributed to changes in light quality and not necessarily light intensity.

Ong and Marshall (1979) evaluated the effect of severe shading on the growth and survival of tillers of perennial ryegrass. They found that individually shaded tillers are able to survive prolonged intense shading as long as the rest of the plant receives adequate light. This is true both for large tillers with several expanded leaves and adventitious roots and for developing tillers with only a single expanding leaf. Thus, they concluded that although a plant is growing and producing many new tillers it displays a conservative organization. Individual tillers even under continued stress are not replaced by younger tillers. However, the initial support to a shaded tiller may not be sustained if the rest of the plant is also transferred to a lower light regime.

Like herbage accumulation, the number of tillers is a function of production and death. Garwood (1969) determined that tillers are produced and die during all months of the year at rates which vary with the variety of grass. For S23 perennial ryegrass he found a marked peak of tiller production occurred between March and April and a smaller peak occurred between September and October. There was no marked peak in tiller death rate, though the majority of tiller deaths (55%) occurred between July and September. In contrast, S24 perennial ryegrass had a marked peak in tiller production in October of the second year with a smaller peak occurring in April. For this variety a large number of dead tillers were recorded in June with a smaller peak occurring in September and October.

New tillers reach the same weight as old, established tillers 60-100 days after appearance (Korte et al. 1985). During this 60 to 110 day period tillers produce approximately 9 to 10 new leaves. Colvill and Marshall (1984) suggested that production and survival of tillers are influenced to a large degree by the competition for assimilate which increases at flowering.

Leaf Dynamics

While variation in tiller numbers can affect pasture yields, leaf extension rate and leaf size can overcome herbage yield differences which are a result of variation in tiller densities (Jones et al. 1982). Thus, in addition to evaluating the tiller dynamics, evaluating leaf dynamics can also contribute significantly to understanding pasture development. Leaf dynamics have been evaluated on the basis of the average number of leaves per tiller, leaf length and width, leaf growth rate, leaf photosynthetic potential, and leaf appearance rate. Each of these parameters has distinct yearly cycles of development and respond differently to changing climatic conditions.

In an intensive study of seasonal leaf growth of perennial ryegrass in England, Peacock (1975c) found the number of days between the appearance of successive leaves increased from 9.2 days in September to 32.7 days in December and decreased from 33.6 days in January to 7.9 days in May (soil surface temperatures during this study averaged 16, 3, 2, and 17°C in September, December, January, and May, respectively). While Anslow (1966) concluded from a review of the literature that temperature has an important effect on the rate of appearance of leaves on tillers, Patel and Cooper (1961) concluded from a study of seedling perennial ryegrass plants grown in a greenhouse that the rate of leaf appearance is limited primarily by light energy.

While white clover growth is minimal in the winter, seasonal leaf appearance rates have been measured in Wales by Davies and Evans (1982). They found the rate of leaf appearance for white clover declined from 0.09 leaves stolon^{-1} day^{-1} in early November to 0.02 leaves stolon^{-1} day^{-1} at the beginning of February. After this time, the leaf extension rate increased at a fairly steady rate until June, the end of sampling. The average number of leaves produced per stolon during a 28 day period was strongly related to mean air temperature.

A second component of seasonal leaf development of perennial ryegrass is leaf extension rate. In a study of the development of individual leaves, Peacock (1975a) found that laminal length decreased from September to February and increased from March to May, while laminal width remained the same from September to December but increased from January to May. At similar temperatures the rates of leaf extension in the spring were significantly higher than those in the autumn by 20% at 5°C, 50% at 10°C, and 100% at 14°C. He suggests that these results indicate that a plant developmental factor rather than an environmental factor underlies the seasonal differences in the rate of leaf extension in response to temperature. This may be linked with the fact that the spring plants are in a reproductive phase while the autumn plants are in a vegetative phase.

Parsons and Robson (1980) intensively studied the response of perennial ryegrass leaf extension to temperature during the transition from vegetative to reproductive growth. In simulated swards which were sown in the fall and over-wintered in an open, unheated glasshouse, they found that leaf extension rates decreased at a decreasing rate as temperatures approached 3 to 4°C. At that point, extension rates averaged less than 3 to 4 mm day^{-1}. However, the potential extension rates varied seasonally, falling from 15 to 20 mm day^{-1} in November to 10 mm day^{-1} by early January when held at similar temperatures (15°C). The response in January, however, was very variable with some plants maintaining autumn rates and others showing no growth. By mid-February potential rates of leaf extension increased three fold (30 mm day^{-1}). This quick change suggests that a physiological change took place in mid-January though the effects of this change on stem elongation did not become apparent until early March when climatic conditions improved. Thus, while potential growth in February rose three fold, the actual rate of leaf extension in the field varied far less because of low temperatures which typically occur at that time.

From a study of the influence of temperature on leaf extension rate of perennial ryegrass in Northern Ireland, Keatinge et al. (1979b) developed a model for predicting leaf extension rates (LER) based on daily mean temperatures (TM) for the October to March period

$$LER = 0.35 + 0.51\ TM \qquad r=.9$$

Based on this model, LER approaches 0 at about 1°C.

They concluded that air temperature, on a day-to-day basis, had a highly significant influence on the productivity of perennial ryegrass swards through control of LER. Brereton et al. (1985) also showed that leaf extension is significantly affected by temperature, while being little affected by radiation.

Photosynthesis in a plant can be affected by a change in the photosynthetic potential of a leaf and by climatic conditions. Temperate climate species increase photosynthetic rate as light energy increases (Langer 1973). However at 1/3 to 1/4 summer light intensities, no further response is recorded and the plant is light saturated.

The rate of net photosynthesis of leaves of both ryegrass and white clover increases substantially as temperatures increase from 3 to 23°C (Woledge and Dennis 1982). Dennis and Woledge (1983) found, however, that shaded white clover plants which received 25% of normal light levels produced leaves with photosynthetic capacities 30% lower than those on unshaded plants.

With a decline in temperature in autumn, perennial ryegrass leaves are produced less frequently and extend more slowly. This leads to an increase in the average age of the photosynthetic surface of the canopy, thus a decline in potential photosynthesis (Parsons and Robson 1981). Photosynthetic potential of winter pasture is further compounded by a 60% decrease in the maximal photosynthetic rates of leaves which are produced in

December and early January compared to those produced in October (Parsons and Robson 1981). October rates were re-established by March of the following spring. Brereton et al. (1985) found that the efficiency of radiation use at similar temperatures was approximately two times greater after mid-winter than before mid-winter.

Root and crown dynamics

Root systems of pasture can contribute a significant proportion to the total organic matter in a pasture (approximately 33% of total dry matter) (Walker et al. 1954). For this reason and because of the importance of roots in plant growth, it is important to understand the root dynamics of perennial ryegrass plants (Caradus and Evans 1977; Garwood 1968; Jacques 1941; Jacques and Edmond 1952; Jacques and Schwass 1956; Yates and Jacques 1952).

While the months of minimum and maximum growth of roots in perennial ryegrass vary with location, the patterns of development are similar. In the summer when air temperatures are high and soil moisture low, little root development occurs. Low root production in the summer has been attributed to high soil temperatures even when there is adequate soil water (Garwood 1968; Stuckey 1941). As temperatures decline in the fall and soil moisture becomes available, rooting activity increases, reaching maximum growth by late fall.

Alberda (1965) suggested that root development is a result of a change in the ratio of photosynthate production to the rate of leaf development. As temperatures decline the rate of leaf development declines faster than the rate of photosynthesis. Thus, the rate of production exceeds the use of photosynthate for leaf development and the excess photosynthate becomes available for root development. Thomas and Davies (1978) suggested that the shoot bases act as the buffer between herbage production and the environment. The bases accumulate reserves when conditions are favorable and provide material for leaf growth when conditions are unfavorable, such as during relatively warm but cloudy days in the winter or after defoliation.

Based on the number of new white roots per unit area or per plant, the optimum soil temperature for maximum root development in perennial ryegrass has been estimated to be approximately 5°C (Garwood 1968; Jacques and Schwass 1956). In temperate climates where temperatures decline below 5°C in the winter, there are two peaks of root development. One peak occurs in the fall as temperatures decline, and the other in late winter or early spring as soil temperatures begin to increase (Caradus and Evans 1977; Garwood 1968). However, based on the presence of cell division, Stuckey (1941) showed that root tips continued to divide even as temperatures approached 0°C.

While the length of life of a perennial ryegrass main root averages 365 days (Troughton 1981), the average length of active life of adventitious roots is much less and more variable depending on season of initiation. If initiated in the fall, an adventitious root is active for from 154 to 188 days, for 95 to 111 days if initiated in the winter, and for 61 to 79 days if initiated in the spring or summer (Garwood 1967).

White clover root development also follows a seasonal fluctuation (Garwood 1968). The number of new roots increases from July until September, remains relatively unchanged in October and November, declines in December and then increases to reach a peak in March. Caradus and Evans (1977) suggested that production of new roots by white clover is much more rapid than grasses, largely as a result of new lateral formation on old roots which essentially does not occur in grasses. This allows white clover to absorb more nutrients than grasses in the autumn.

Plant carbohydrate reserves, which are found primarily in the roots and crowns of plants, have also been used to evaluate plant growth. El Hassan and Krueger (1980) showed root carbohydrate reserve accumulation for perennial ryegrass followed a pattern similar to that described for root development. Carbohydrate concentrations increased during the fall regrowth period and then declined gradually during winter and early spring. Replenishment of crown reserves started around seed formation and continued through fall regrowth until December (except for a slight decline during the period between the end of seed shatter and the beginning of regrowth). In their study, crown biomass made up 28 to 39% of the average total biomass (mg plant^{-1}) of storage organs but contributed on average 44 to 56% of the total nonstructural carbohydrate reserves (mg plant^{-1}) in storage organs. Their results indicated that root and crown biomass were more important than carbohydrate concentrations in evaluating the magnitude of actual carbohydrates per plant. Baker (1957) also reported that quantitative determination of total available carbohydrate reserves gives a better indication of reserve distribution than estimates based only on percent concentration.

Stolon Dynamics

The amount of stoloniferous tissue in a pasture plays a significant role in the ability of white clover to survive and contribute to the total yield of the pasture. In New Zealand, Hay (1983) measured the amount of aerial stolon, surface stolon, and buried stolon from pasture and noted a pattern of seasonal change for each of the three classes. The amount of aerial stolons peaked in March and then decreased to very low levels in winter and spring; the amount of surface stolon peaked between summer and autumn and was at a minimum in winter and spring; and, the amount of buried stolon contributed a large proportion of total stolon weight at all times of the year, but varied markedly with season, ranging from a minimum of 30-40% in late summer to 87-99% in early spring. A sudden 50% decrease in the size of the buried-stolon class which occurred during the spring was attributed to decomposition of stolons which had died during the winter.

In a study of growth rates and developmental morphology of simulated swards of white clover, Davies and Evans (1982) found that seasonal changes in the amount of stolon varied with variety. In their study the number of stolons of Kent white clover tripled between December and the end of April while those of Katrina white clover remained steady throughout the winter. Numbers in both varieties declined during May and June.

Leaf Area Index and Pasture Growth

The capacity of a plant to produce dry matter is dependent on that factor which is most limiting, be it water, nutrients or light. Thus, Donald and Black (1958) stated "when light and light only, has become the limiting factor governing growth per unit area, the species has achieved the maximum production of which it is genetically capable." For this reason they felt that the inter-relationship of light, leaf area and production is likely to be significant in pasture production.

Brown and Blaser (1968) examined this interrelationship to help clarify the complex relationship of leaf area, light, and growth. From an evaluation of theoretical growth curves, they determined that growth rates increase until most of the incident light is intercepted. Eventually, an 'optimum Leaf Area Index' (Leaf Area Index or LAI refers to the ratio of leaf area to the soil area it occupies) would be reached at which time nearly all of the available light would be intercepted and photosynthesis to respiration ratio would be maximum. An increase beyond this point would result in such heavy shading of lower leaves that respiration would exceed photosynthesis in these leaves with a resultant drop in growth rate.

This concept has generated various studies to determine the validity of this theory. Myneni and Impens (1985) studied the effect of leaf angle on potential production from stands generated by a computer. Their results verified that erect-leaved canopies allowed relatively more non-parallel beam radiation to reach the lower layers of a canopy. Studies such as these help explain why the growth of clover is directly dependent on the level of radiation at the surface of the clover leaf canopy, and why growth is negative when radiation levels are below 60 to 80 cal cm^{-2} day^{-1} (Stern and Donald 1962).

From these studies, several key issues became apparent. Optimum LAI is dependent on season and species and should be considered to be a value which is associated with high annual yields, rather than a value which produces the highest growth rate (Brown and Blaser 1968). Furthermore, LAI measurements alone without light penetration or leaf angle estimates have little meaning in terms of growth rate. Results such as these led McCree and Troughton (1966) to conclude that an optimum Leaf Area Index for species such as white clover can not be predicted.

Effect of Fall and Winter Defoliation

Jagusch et al. (1981) estimated that winter pasture contributes from 7 to 15% of the total annual feed requirements for animal production in New Zealand. Thus, pasture in the winter can make an important contribution to the yearly feed requirement on a sheep ranch. The effect of defoliation in the fall and winter on pasture dynamics, however, appears to vary monthly and needs to be examined in detail.

Herbage Accumulation

Frame (1970) studied the effect of winter grazing by sheep on the subsequent spring and early summer production of a pasture in Scotland which was predominately perennial ryegrass. Treatments were different frequencies of grazing (once, twice or three times) between October and March on a study area where soil temperatures at 10 cm averaged 8.7, 5.5, 2.4, 1.9, 4.7, and 6.6°C in October, November, December, January, February, and March, respectively. Pastures grazed once in October, November, December, January, February, or March yielded an average of 57, 58, 65, 60, 81, and 40% of the ungrazed pasture by April 25, but 112, 108, 119, 121, 109, and 102% of the ungrazed pasture by May 25. Thus, though early spring yields were less on winter grazed pasture than on ungrazed pasture, yields on grazed pasture were similar to or more than the ungrazed pasture by May 25. Therefore, total annual forage production of winter grazed pasture will equal or may even surpass that of pasture which is not grazed in the winter.

On a simulated sward of perennial ryegrass in Wales, Davies and Simons (1979) found the weight of herbage produced in the spring was much less from plots which had been cut frequently in the fall and winter, or when the final cutting date in early spring was progressively delayed. The principle affect of later and more frequent cuttings in the autumn was a dramatic reduction in the length of subsequently produced leaves. The numbers of tillers and leaves were much less affected. Thus, more herbage was present in the spring on autumn and spring rested pasture compared to the autumn grazed pasture.

Defoliation during the hardening period in the autumn has also been shown to impede the development of frost hardiness, particularly in legumes (Smith 1964).

Broughham (1959) reported that herbage accumulation was less during the winter on pastures grazed hard (to 2.5 cm) in the autumn compared to pasture grazed hard in the winter. He attributed this to a considerable loss of herbage on the autumn grazed pasture due to tissue decomposition. From this and a later study (Brougham 1960), he suggested that one or more winter grazings would promote growth and tillering in grasses and growth in clovers. He attributed this to increased penetration of light to the ground and possible to higher soil temperatures on the grazed sites, at least on sunny days. Results of a study by Thomas and Norris (1981) suggest, however, that swards defoliated in the winter after periods of dull, mild weather will have slower regrowth due to a reduction in water-soluble carbohydrate reserves.

In addition to the defoliation effect of grazing, pasture production can be affected by the physical impact of treading from the individual animals. Edmond (1974) and Brown (1968) found that treading alone can result in a significant reduction in pasture production due to the lower vigor of a lesser number of grass tillers in trodden pastures. However, perennial ryegrass was found to be relatively tolerant of treading. The direct effects on plants, which appeared to be important, particularly on wet soils, were root damage, plant displacement, and burial in the mud (Edmond 1963).

Tillering

The effect of defoliation intensity on the tiller dynamics of a ryegrass sward in New Zealand during late autumn was studied by Korte et al. (1982a). After cutting to 1-2 cm or 5-6 cm, density of ryegrass tillers increased for two weeks and then declined after canopy reached full light interception. Tiller density was greater in the 1-2 cm cutting as a result of a higher tiller appearance rate in the first 2 weeks. Cutting height did not affect tiller death. Regrowth came primarily from the recovery of tillers present at the time of defoliation since newly emerged tillers were considerably smaller than the older tillers.

Infrequent defoliation can reduce the longevity of vegetative tillers to a greater extent during reproductive growth than vegetative growth (Korte et al. 1985). This is attributed to specific physiological effects involving light interception and transport of assimilates.

Davies and Simons (1979) found that production of new tillers in the spring increased when levels of prior utilization in the fall and winter were greater. This is substantiated by the correlation between tillering activity and radiation which was found by Brereton et al.

(1985). This provides an indication that defoliation in the fall and winter can influence the tiller densities of pastures in early spring.

Leaf Development

Nowak and Caldwell, (1984) in a study of several important semi-arid range species, determined that compensatory photosynthesis can occur after defoliation in some species (i.e. the photosynthetic rate of foliage on partially defoliated plants increases relative to foliage of the same age on undefoliated plants). Thus, after partial defoliation, production of these species may surpass that of undefoliated plants if grazed during periods of plant growth. The concept that grazing stimulates growth by increasing photosynthetic rates was also suggested by May (1960).

Brougham (1956b) found leaf efficiency (the rate of increase of herbage dry weight per unit area of leaf) to be initially lower following severe defoliation than following less severe defoliation treatments. However, the leaf efficiency of the severely defoliated plants increased rapidly to a maximum rate. This occurred when 95% of the incident light was intercepted. Thereafter, efficiency gradually declined. Brougham (1958) stated that the point where maximum leaf efficiency was reached in the spring and summer in New Zealand occurred when LAI equaled 7.1, 3.5, and 4.5 for perennial ryegrass, white clover, and a mixed stand, respectively.

Root and Crown Dynamics

One of the earlier studies on the effect of defoliation on root growth in perennial ryegrass was that of Roberts and Hunt (1936) of Wales. They determined that root weight, root growth (length), and seasonal growth rate decreased in varying amounts depending on the severity of cutting. Jacques and Edmond (1952) found that decreased root growth results from the priority of demand by a plant for photosynthetic tissue. Thus, until new leaf material is formed, an increase in the absorptive area of the roots is of secondary importance.

Greenhouse studies have established that defoliation depresses root growth of growing plants (Alberda 1966; Crider 1955; Evans 1973). However, the extent to which defoliation depresses root elongation in grasses is related to the percentage of leaf lamina remaining (Evans 1973). In a study by Crider (1955), a single clipping which removed at least one-half of the foliage of grass plants caused a cessation of root growth for periods ranging from 6 to 18 days. In addition, Troughton (1981) showed that the length of life of individual main roots was reduced from a mean of 365 days to 191 days when the plant was defoliated to a 3 cm height 12 times during the life of the root. However, while the frequent defoliation of the perennial ryegrass plants resulted in a decreased root weight per plant, root weight per unit area was unaffected. Thus, there were more plants and tillers per unit area than in uncut swards.

Since root development varies seasonally, the effects of defoliation on root development varies with the time of year. Baker (1957) found that herbage growth in February and March was decreased if defoliation occurred in the previous late summer or fall. He attributed this to the plants beginning the winter with a smaller amount of root and stubble than undefoliated plants. Plants, which were treated leniently in the previous fall, had the highest yields in the early spring. Motazedian (1983) established that root biomass is sensitive to defoliation frequency but not intensity in the spring.

Complete protection of perennial ryegrass from grazing does not result in a greater accumulation of carbohydrate reserves when compared to grazed treatments (El Hassan and Krueger 1980). In fact reserves found in ungrazed plants are sometimes significantly lower than for grazed treatments. However, fall grazing decreased biomass of roots when compared to complete protection and fall protection (El Hassan and Krueger 1980). Thus, protection from very heavy fall grazing should be beneficial for maintenance of the perennial ryegrass. From these results, El Hassan (1977) also suggested that winter grazing may be potentially harmful to perennial ryegrass plants since growth and respiration are primarily dependent on the reserve pool during this period.

May (1960) published an extensive review of the effect of defoliation on the carbohydrate reserves in pasture plants. He suggested that the time of cutting in relation to climate is as important as the number of cuts on plant development after defoliation. He further stated that "a specific role for carbohydrate reserves in initiating regrowth, and in determining the rate of ultimate extent of regrowth, cannot yet be considered as firmly established."

Pasture Composition

Hard grazing and treading in winter increase the dominance of perennial ryegrass (Halford 1972). In a study on the effect of continuous winter grazing by ewes at five stocking rates, Black (1975) found recovery of pasture was extremely rapid even at a stocking rate of 59.3 ewes ha^{-1}. This effect was partially attributed to the increased proportion of perennial ryegrass following winter stocking in a sward originally dominated by *Poa trivialis*.

One of the main effects of grazing by sheep on pasture may be a result of the physical impact of treading. In a review of the work of Edmond in New Zealand, Brown and Evans (1973) indicated that high treading rates rapidly moved pasture to pure perennial ryegrass stands since velvet grass (Holcus lanatus) is not tolerant of grazing and bentgrass (Agrostis tenuis) is only moderately tolerant. This was also attributed to perennial ryegrass' high tolerance to compaction as long as puddling (i.e. treading of soil to such a degree that moisture can not penetrate the soil surface) doesn't occur. Brown (1968 and 1971) also showed that treading at high stocking rates during the autumn and winter, and possibly spring and summer, can severely damage Agrostis tenuis. White clover yields were reduced in the summer when treading was heavy and in the winter at all rates of treading according to Brown (1968).

Wilman and Griffiths (1978) noted that, in the short run, winter grazing has little effect on pasture composition. However, they suggest that possible botanical composition effects could only be determined after a pasture has been grazed in the winter over a number of years.

Winter Grazing Management Strategies

Grazing Strategies

The total harvestable yield produced by any fall/winter defoliation regimen depends on the advantage of higher mass and any associated increase in growth rate in early spring, and the disadvantage of increased tiller death in dense swards in winter (Davies and Simons 1979). Davies and Simons (1979) suggested that gains and losses counterbalance one another to a very large extent. Therefore, there is considerable flexibility in possible defoliation practices without loss of total production from swards which are not specifically required for early spring use. Similar conclusions were drawn by Lockhart et al. (1969) from a study on the effects of winter grazing on subsequent production from pasture.

The basic grazing strategies used on pasture involve either set-stocking or rotational grazing. Set-stocking is a simple management strategy in which a fixed number of animals is allowed unrestricted access to a fixed area of land for a substantial part of a grazing season (Hodgson 1979). In Wales, Edward and Morgan (1962) found that set stocking at light levels (5 ewes per hectare) from November 30 to March 13 resulted in a significant reduction in the quantity of spring growth. With this form of management they concluded that resting a sward over winter may allow the accumulation of an appreciable quantity of dry matter for spring use if conditions are favorable.

Rotational grazing is a system of pasture utilization involving short periods of heavy stocking followed by periods of rest during the same season to allow plant recovery (Kothman 1974). Studies comparing set-stocking and rotational grazing frequently report conflicting results (Clark et al. 1982, Lambert et al.1983). Chapman et al. (1983) measured the components of growth, defoliation, and senescence of individual ramets of perennial ryegrass, Agrostis spp., and white clover to try to determine causes for these conflicting results. After five years of grazing, they found that grazing management produced distinctly different swards in regard to leaf and tiller size, and leaf extension rates. However, because these were inversely related to tiller density, they concluded that leaf production was similar under both strategies.

In general, rotational grazing is the strategy most often recommended for use on perennial ryegrass-white clover pastures (Cooney and Thompson 1978), and is the strategy which has been researched the most in regard to winter grazing. Rotationally grazing breeding ewes on pasture in the winter is often used in New Zealand (Halford 1972). This management strategy involves slowly rotating ewes from some time after breeding up to lambing through permanent or temporary paddocks. Each paddock is grazed 1-4 days. When forage is short the animals can be supplemented with hay as needed. The rotation can involve low animal concentrations and infrequent shifts or high animal concentrations and frequent shifts. The higher the concentrations, the greater the labor requirement, but there will be a gain in efficiency of pasture use and less pasture damage.

Brown and Harris (1972) recommended all-grass wintering as a winter management system because it attempts to keep pasture growing to the limits set by weather, and it ideally avoids the high leaf death and loss of nutritive value found in systems where pasture is ungrazed for 90 or more days in the winter. However, maximum winter production is dependent on management during the whole year. Pasture fully utilized in the summer limits the invasion of annuals and weeds and minimizes the number of dead seed stalks carried into the winter. Thus, perennial ryegrass and white clover vigor and production will be improved. In the autumn, pasture must be managed to minimize the effect of summer producing plants, and to regulate leaf area according to radiation levels of that period. This will limit the death and decay at the base of the plants which would otherwise occur, and will improve conditions for tiller production. A similar strategy was recommended by Baars et al. (1981).

Hunt and Brougham (1967) suggested that their research emphasized the need for 'autumn clean-up' (hard grazing) in systems where lax grazing during the summer results in an accumulation of dead and sheath material. Hard grazing will result in enhanced tiller development and survival, and increased leaf production as a result of the more favorable light conditions. Defoliation of pastures in late autumn may also prevent premature development of inflorescence in autumn and improve uniformity of flowering in spring (Harris 1978).

El Hassan (1977) suggested that winter grazing may be potentially harmful to plants, especially at high stocking densities, since growth and respiration are primarily dependent on the reserve pool during this period. Thus, careful attention should be given to stocking intensity and/or deferment during one or two grazing seasons when winter grazing is used.

Parker and Willis (1973) suggested that the advantages of rotational grazing in the winter are: (1) increased flexibility, (2) increased ease of management, (3) relatively stable, high, and controllable levels of nutrition, and (4) some pasture improvement. They attributed this to the intensive but brief treading effect, the quick, hard grazing followed by a long resting spell and the concentration of dung and urine on each paddock.

For a winter rotational grazing system to be successful, Duffy (1970), a farm advisor in New Zealand, recommended: (1) pastures must be prepared for winter growth by suitable grazing in the fall (i.e. no seed heads), (2) suitable sacrifice areas must be available for adverse conditions (i.e. snow, excessive wet ground), (3) fencing must be good and drainage reasonable, (4) stock must be shifted at the right time to allow pasture recovery, and (5) lambing has to be timed to follow spring growth.

Theoretically, good management would require that a pasture be defoliated such that the LAI of the stubble remaining would intercept most of the incoming radiation. Practically, this has little usefulness because:

(1) defoliation heights would have to be excessively high,

(2) shaded leaves are less efficient, at least initially, once exposed to light,

(3) a considerable part of the herbage mass would have to remain unharvested, and

(4) tiller production would be decreased and the ability of young basal leaves to produce new active leaves would be reduced (Brown and Blaser 1968).

Korte, Watkin, and Harris (1982b) suggested that light interception can be used as a criterion for grazing in the fall when plants are vegetative but not in late spring when plants are reproductive. In the fall, they recommended that grazing be delayed until 2 weeks after 95% light interception is reached. Studies done by the Hill Farming Organization in Scotland demonstrated that little advantage is gained in terms of net herbage production when continuously stocked swards are maintained at a LAI above 3 (an herbage mass of 1200-1500 kg dry matter ha^{-1})

(Gunn 1981).

From a study in which swards were cut at weekly intervals to five levels of LAI (from 1 to 4.5), King et al. (1984) concluded that once swards had equilibrated to the cutting regimen, growth rates increased with LAI. However, since tiller density and the partitioning of growth between herbage harvested and that lost by senescence also changed with LAI, net growth rate was constant over the LAI range 2 to 4.5. Maximum rate of herbage harvested was between LAI 2 and 3.

Grazing Frequency and Intensity

In rotational grazing, the intervals between grazing should be adjusted to provide adequate feed at all times while achieving maximum growth rates (Smetham 1973). Smetham (1973) suggested that in the winter these intervals can last up to 40 or 50 days. This would result in: (1) undisturbed growth during the intervals, (2) enhanced turnover of minerals, and (3) decreased loss of herbage due to rotting and accelerated senescence.

The choice of length of grazing cycle in a rotational grazing system may not be as critical as was previously thought (Orr and Newton 1984). Morley (1968) developed theoretical limits for frequency of grazing in a rotational grazing management system for perennial ryegrass pastures. He stated that the period between grazings would need to be approximately 9 weeks in winter and 6 weeks in the spring and summer. Frequent adjustment of intervals is not likely to contribute significantly to production. He further stated that the optimum number of subdivisions would be nine, since theoretically little advantage is derived if it is increased beyond this number. From these values and the rate of growth, the optimum length of grazing period can be calculated.

Brougham (1956a) suggested that to achieve maximum production in the winter the intervals between defoliations should not exceed 6 weeks when defoliated to approximately 2.5 cm. This would maintain a good balance between the grasses and the clovers, thus insuring vigorous growth in the early spring.

After several more years of study, Brougham (1959, 1960) suggested that the most favorable management system combines lower grazing intensity in the spring, summer, and early autumn with hard grazing in late autumn and winter. This would result in a rapid change in pasture composition to grass dominance which would give higher yields over the winter. In addition, losses of herbage through tissue decomposition would be avoided. However, Brown and Evans (1973) suggested that moving stock before heavy defoliation occurs may be more advantageous because the cushioning effect of the herbage would reduce potential treading damage.

From studies on rotational grazing in the winter in

New Zealand, Parmenter and Boswell (1983) found: (1) rotation length and timing of shorter regrowth periods early or late in winter had little effect on winter production, (2) large herbage mass (greater than 2000 kg dry matter ha^{-1}) have net losses of dry matter during cold winter conditions, and (3) spring production was 10 to 20 kg dry matter ha^{-1} day^{-1} greater in pasture grazed 4 or 5 times during the winter than in pasture grazed only twice. Thus, they suggested that early spring production might be improved by winter rotation lengths shorter than those currently favored for all grass wintering, even though these shorter rotations might necessitate more supplemental feeding in the winter. A similar observation was made by Scott (1973).

Jagger (1977) suggested that the number of paddocks needed on all-grass sheep farms using rotational grazing can be determined from: (1) length of winter, (2) length of rotation, (3) flock grazing intensity per area, (4) stocking rate, and (5) number of flocks of sheep on each farm. The necessary number of paddocks for each mob, the area required for each mob and the average size of each paddock can be estimated from this information.

Animal Performance

Of major concern to producers is the effect of winter grazing management on ewe survival and lamb production. Results of a study by Rattray et al. (1982) indicates the great buffering capacity of ewes 6 weeks prepartum. They state that strict rationing, which occurs with rotational grazing, is not detrimental to the ewe or her lamb and can continue right up to lambing. This would allow pasture to be conserved for the much more important period immediately post-lambing. Hayman and Moss (1979) also found that lamb birth weights were not affected by winter grazing management in New Zealand. However, ewe live-weight gain in the winter increased as grazing duration increased from 2 to 7 day shifts. Jagusch et al. (1981) also agreed that strict rationing and mob stocking, when feed is short in early spring, can be conducted right up to lambing without any detrimental effects on lamb production. Thus, mid-pregnancy and pre-partum feeding may have been over-emphasized in the past.

Sharrow and Krueger (1979) suggested, that for a perennial grass/subterranean clover pasture (Trifolium subterraneum), rotational grazing is most effective in improving animal performance during the green feed period when the plants are actually growing, and continuous grazing is the better strategy during the summer drought when plants are dormant. Brown (1976) showed that autumn deferment resulted in increased liveweight of sheep during the winter months.

A study by Chopping et al. (1978) in Australia on continuous vs. rotational grazing in the winter using dairy cows found that rotational grazing did not reduce milk yield $head^{-1}$ day^{-1} nor did it affect milk composition or liveweight even when available forage was low. Parsons et al. (1983) found, that in pasture continuously grazed in the winter, animal intake was greater in hard grazed swards than on leniently-grazed swards. This was attributed to more of the shoot produced in the hard grazed sward being harvested, leaving less unharvested or lost to death. Thus, maximum intake per area can be achieved when a sward is maintained at an LAI which is substantially below the optimum for photosynthesis.

Conclusions

Maximizing profit from pasture for sheep production is dependent on the amount of pasture grown, the proportion of pasture eaten, and the efficiency of feed conversion by sheep. Therefore, maximum production depends on high stocking rates which requires greater management skill and the ability to adjust sheep numbers to match seasonal pasture growth (Edgar 1973). However, intensifying management to increase production and profitability per hectare increases the risks of making costly errors in feeding and management (Parker 1973).

Parker (1973) suggested that for producers to minimize the risks involved they must accurately estimate the availability and quality of feed and the requirements of livestock throughout the year. Furthermore, he stated that consistent improvements can be made in winter feed practices if farmers are "continuously aware of the total quantities of feed they have available, the manner and rate at which these are changing, and how these quantities can be used most effectively in both the short and long term."

Thus, while numerous systems such as the autumn/winter slow rotation system (Smetham 1973) and all grass wintering (Brown and Harris 1972) have been defined, success in pasture management and animal production is not dependent on using 'the system'. Rather, success is dependent on understanding the dynamics of the plant components of pasture as related to the climatic conditions of the area and year, on understanding animal needs, and on managing both the plants and the animals to maximize pasture production and longevity, livestock production and long term profitability.

DATE OF WINTER GRAZING EFFECT ON YIELD COMPONENTS OF A *LOLIUM PERENNE* (L.) - *TRIFOLIUM REPENS* (L.) HILL PASTURE

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Abstract

Perennial ryegrass-white clover pastures were grazed at different times in the winter to study the effect of time of grazing on plant response and forage production. Pastures were grazed to a 400 kg dry matter ha^{-1} residual by sheep once in early December (D), January (J), February (F), March (M) or April (A) and compared to an ungrazed control (C) in each of three forage years. Grazing in the winter reduced herbage mass but had relatively little effect on forage production in the winter. This is consistent with the relatively poor conditions for growth (cold and low light levels) during the winter. Rates of herbage accumulation on C in the winter were low averaging 6, -9, and 2 kg dry matter ha^{-1} in December, January, and February, respectively. By May, herbage mass on grazed treatments was similar to C except for D and A which averaged 20 and 47% less forage than C, respectively ($p<0.01$). By May 1986, D yielded less perennial ryegrass compared to C ($p<0.05$). Total annual forage production and forage harvested annually were highly variable but tended to be greater on J, F, and M than on C, D, and A.

Introduction

During the winter and early spring, a conflict exists between the need to graze pasture as a low-cost means of feeding livestock and the effect that defoliation will have on the subsequent production and composition (Wilman and Griffiths 1978). Wintering of sheep on improved pasture has been established as a cost-effective management system in New Zealand (Parmenter and Boswell 1983). However, winter grazing has been reported (Edwards and Morgan 1962, Lockhart et al. 1969, Frame 1970, and Newton and Jackson 1985) to reduce the herbage mass of pasture in the spring in Wales and England. While Frame (1970) reported that grazing between January and March reduced spring yields the most, El Hassan and Krueger (1980) suggested that fall grazing may be more demanding on plants, especially at high stocking rates.

Most studies of the effect of winter grazing on pasture have involved a series of two or more short periods of grazing or continuous grazing during part of the winter and have primarily evaluated early spring and total annual pasture production. This study was designed to determine the effect of a single grazing event at different times during the winter period on the subsequent growth and composition of a perennial ryegrass (Lolium perenne) - white clover (Trifolium repens) pasture.

Materials and Methods

The study area was located 6 km north-west of Corvallis, Oregon on a north facing rolling hillside averaging 9% slope. Elevation was approximately 200 m. The area has a maritime climate with cool, rainy winters and warm, dry summers. Mean annual precipitation is 1080 mm, approximately 80% of which falls as rain from October through March (Redmond 1987). Typically, temperatures are relatively mild with average daily maximum/minimum temperatures ranging between 7.2/0.6°C in January and 27.2/10.6°C in July. The soil is a Philomath silty clay (clayey, montmorillonitic, mesic, shallow, Vertic Haploxeroll) (Soil Conservation Service 1975).

Prior to reseeding in 1982 the pasture composition was approximately 40% tall fescue (Festuca arundinacea), 20% perennial ryegrass, 10% subterranean clover (Trifolium subterraneum) and 20% annual grasses (Warner and Sharrow 1984). In the summer of 1982 the area was prepared for seeding by spraying with Roundup (glophosate) and then rototilling to a depth of 15 cm. In October of that year 7 kg ha^{-1} white clover and 16 kg ha^{-1} perennial ryegrass were seeded. Reserves of subterranean clover seeds were present in the soil. The pasture was fertilized with 37, 37, 48, 18 and 0.6 kg ha^{-1} N, P_2O_5, K_2O, S, and Mo, respectively, at seeding. In each year of the study an additional 37 kg ha^{-1} P_2O_5 and 18 kg ha^{-1} S were applied in October. In October 1984, 27 kg ha^{-1} K_2O was applied after tests indicated low levels of K in the soil.

The study was conducted for three forage years (September to August), 1983-84, 1984-85, and 1985-86. The experimental design was a randomized, complete block with three blocks; each block contained six paddocks randomly assigned to five dates of grazing between December and May plus a control, which was not grazed during the winter. Date of winter grazing was repeated on the same paddock in each block throughout the three years of the study. Blocking was based on initial pasture yield estimates and a visual inspection of the study area which suggested differences due to hill location. Each paddock was 0.1 ha in area.

Winter grazing consisted of a single grazing event on each paddock in the first week of December, January, February, March, or April. Stock grazing densities were based on an allowance of 1.4 kg DM ewe^{-1} day^{-1}, a two to three day grazing period, and a 400 kg DM ha^{-1} residual remaining after grazing. Ewes were used to graze paddocks during this period. All paddocks including the control were grazed as a single pasture by ewes with lambs once in May and once in July of each year of the study and once in June 1984. Each grazing event continued until target residual dry matter levels of 1200 kg DM ha^{-1} in May and

June and 900 kg DM ha^{-1} in July were reached. Generally, this was accomplished with 5 to 9 days of grazing.

Monthly herbage mass and grazing residual were estimated by clipping one 0.2 m^2 circular plot to ground level at each of ten points in each paddock to be sampled. The 10 sampling points were randomly located in each paddock at the beginning of each forage year. A new unclipped portion of ground near each point was sampled each sampling date so that no one spot was sampled more than once in any year.

Control paddocks were sampled every month beginning in December until growth ended in the summer. Grazed paddocks were sampled within 7 days prior to the grazing event to estimate number of animals needed, and sampled each month thereafter until growth ended in the summer. Paddocks were also sampled immediately after grazing to determine the amount of residue remaining. Herbage samples were dried for 48 hours at 50°C and then weighed. Net rate of herbage accumulation was calculated as the difference between the total herbage DM at a sampling date (or the residual remaining after grazing) and the total herbage DM present at the next sampling, divided by the number of days between sampling. Forage consumption was calculated as the differences between the herbage mass before grazing and the residual remaining after grazing. Annual herbage production was calculated by summing the incremental accumulation during the year.

Species composition was estimated by hand sorting a 25 g subsample (wet weight) taken from each of 3 plots in each paddock sampled. Samples were sorted into perennial ryegrass, other perennial grasses, annual grasses, white clover, subterranean clover, forbs, and dead material. The number of tillers of perennial ryegrass was estimated from counts of tillers in each of the subsamples. Average number of leaves per perennial ryegrass tiller was estimated by counting the total number of leaves and dividing by the number of tillers in that subsample.

Density and basal area of the perennial ryegrass plants were estimated once at the beginning of the forage year (September) and once at the end of the winter period (May) in 1985-86. The length and width of the base of all perennial ryegrass plants found inside ten randomly located 0.2 m^2 plots in each paddock were recorded. Basal area of each individual plant was calculated using the formula for the area of an ellipse,

$$\text{Area} = \pi\ (1/2L)\ (1/2W),$$

where L was the longer diameter and W was the shorter diameter.

Root mass of perennial ryegrass was measured in September, December, March, and July 1985-86 by excavating four soil cores in each paddock to a depth of 30 cm. Each core contained one plant and was 15 cm in diameter. Soil cores of this size have been found to yield 80 to 99.5% of perennial ryegrass root biomass (El Hassan and Krueger 1980, Motazedian 1983). Plants were selected for sampling based on two criteria: (1) the basal area was near the population average, 20 cm^2, which was determined in September 1985, and (2) the nearest neighbor was no closer than 9 cm. After soaking cores in water for several hours, the roots were washed free of soil on a 6 mm^2 mesh screen. The main root mass, which remained on the screen after washing, was separated from the rest of the plant at the junction of the root and crown. The root material, dirt, and water which moved through the 6 mm^2 mesh were collected in a bucket. The root material which floated on the surface of the water was also collected on a 1 mm^2 mesh screen. The root material was oven dried at 50°C for 48 h and then weighed to estimate root dry matter.

Data were analyzed using analysis of variance, with grazing times as main plots and years as subplots in a split-plot-in-time, randomized complete block design with three replications. Differences between means were separated using Waller and Duncan's BLSD mean separation procedure (Steel and Torrie, 1980) at $p<0.05$.

Results and Discussion

Weather measured at the site (Figure 1) indicated that fall rains began approximately 1 month later than usual in 1983 but then were above normal levels in May and June, 1984. The 1984-85 forage year was wetter and cooler than average in October and November, drier and colder than average in December and January, and drier but warmer than average in the spring. Winter weather started unusually early in 1985-86. Temperatures fell below freezing in late November and stayed low throughout most of December. The ground temperature was 0°C in the top 5 cm of soil for a total of 28 days between November 24 and December 31. By January, temperatures and precipitation were to average levels.

Annual dry matter production averaged over all treatments was 5530 kg DM ha^{-1} $year^{-1}$ and did not differ between years ($p>0.05$). Of this approximately 10% was produced in the fall-winter (before April) and 90% in the spring and early summer (after March). Rates of herbage accumulation (Table 1) declined from December to a low in January then increased to maximum rates by May. Herbage accumulation in January was negative representing a net loss of forage during that month. Winter herbage accumulation rates in this study are lower than those reporte for other areas with maritime limates (Hume and Lucas

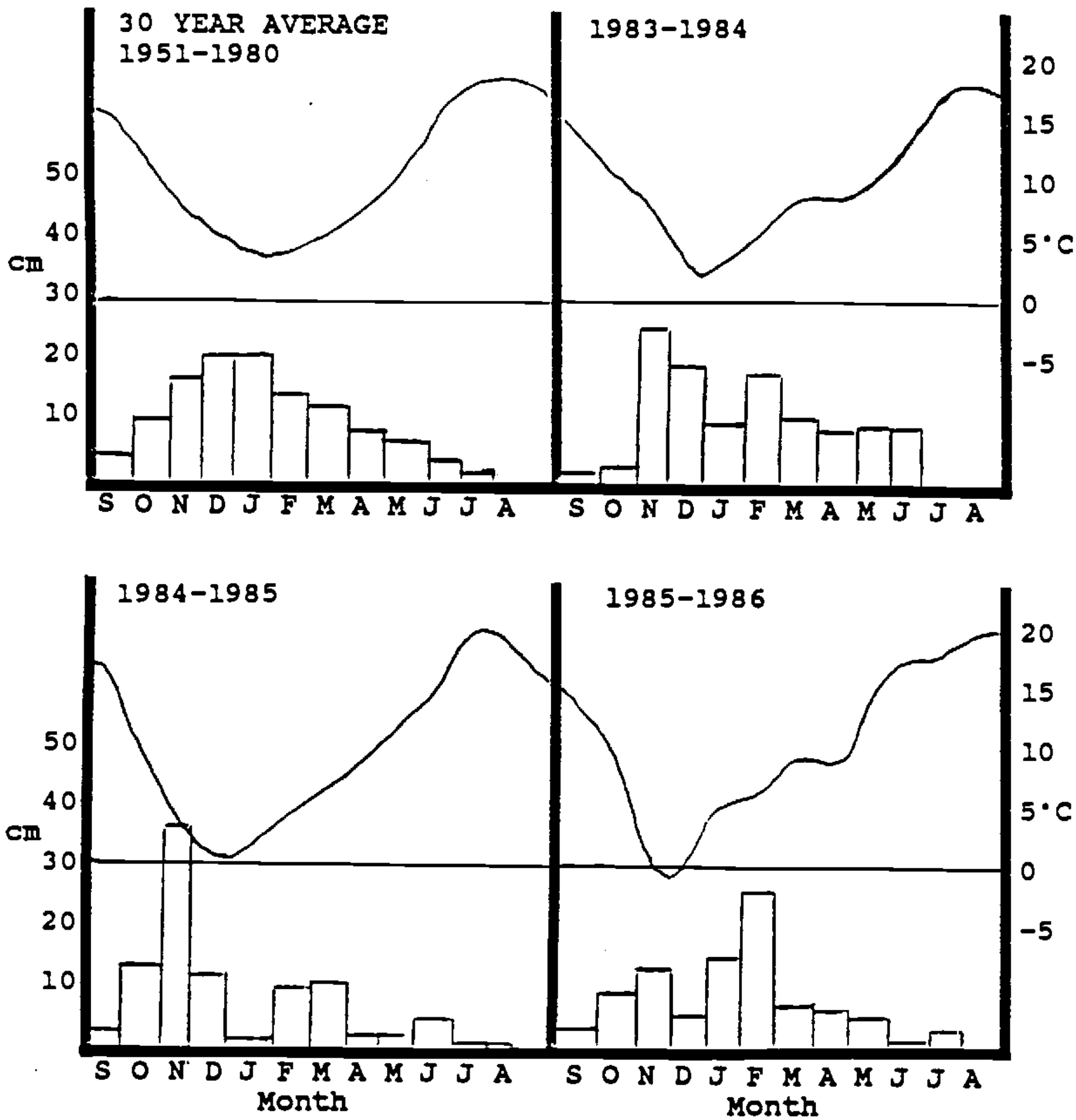

Figure 1. Monthly precipitation and mean air temperature for the study area in the 1983-84, 1984-85, and 1985-86 forage years. The 30 year average precipitation and air temperature for the site are estimated from data collected at a US weather station 10 km north-east of the study area (Redmond 1987).

Table 1. December through July herbage accumulation rates (kg DM ha^{-1} day^{-1}) for six winter grazing treatments. Treatments are ungrazed control (C) and grazed in December (D), January (J), February (F), March (M) or April (A). Data are averaged over three forage years.

Winter Grazing Treatment	Month					
	Dec.	Jan.	Feb.	Mar.	Apr.	May-Jul.
C	6a[1]	-9a	2a	13a	53a	47a
D	0a	-3a	5ab	12a	47ab	48a
J	-	-5a	9b	15a	59a	49a
F	-	-	5ab	18a	61a	52a
M	-	-	-	12a	58a	55a
A	-	-	-	-	36b	56a
S.E.	1.1	1.7	1.2	2.1	4.2	5.2

[1] Means in a column not sharing a common letter differ ($p<0.05$).

1987, Parmenter and Boswell 1983). These differences are probably related to differences in climate, natural soil fertility, or the amount of N applied as fertilizer during the study. Newton and Jackson (1985) in England also reported a net loss of herbage mass between November and March when more than 1000 kg DM ha^{-1} was present on 31 October while Brougham (1956) in New Zealand reported a net loss only if herbage mass exceeded approximately 2000 kg DM ha^{-1}. A decrease in winter herbage mass to approximately 1000 kg DM ha^{-1} in our study suggested that our conditions were more similar to those of Newton and Jackson (1985) than that of Brougham (1956).

The herbage mass on all paddocks before grazing was similar to C. Sheep removed an average of 664 kg DM ha^{-1} of forage in the winter (December to March) (Table 2) ($p>0.05$). Since relatively little or no pasture production occurred during this period, herbage consumed by sheep was not replaced until spring. Thus, grazing depressed subsequent herbage mass but not herbage accumulation compared to C during the winter. Herbage mass on all grazing treatments after grazing was similar until growth began in the spring (Figure 2).

Approximately 50% of the herbage mass during the winter period was composed of dead material (this included litter and parts of leaves which were brown) (Figure 2). Because of the higher herbage mass on C compared to the

Table 2. Forage consumed by sheep (kg DM ha^{-1}) in the winter, spring, and summer from six winter grazing treatments. Treatments are ungrazed control (C) and grazed in December (D), January (J), February (F), March (M) or April (A). Data are averaged over three forage years.

Winter Grazing Treatment	Season			Annual Total
	Winter	Spring	Summer	
C	-	1811a[1]	2539a	4350a
D	534a	1334b	2363a	4231a
J	735a	1800a	2675a	5210a
F	666a	1861a	2896a	5423a
M	723a	1273b	2859a	4855a
A	1063b	534c	2446a	4043a
S.E.	87	129	304	401

[1] Means in a column not sharing a common letter differ ($p<0.05$).

Figure 2. Monthly total herbage mass, live herbage, and dead material after the winter grazing event for six winter grazing treatments. Treatments are ungrazed control (C) and grazed in December (D), January (J), February (F), March (M) or April (A). Closed symbols differ ($p<0.05$) from C.

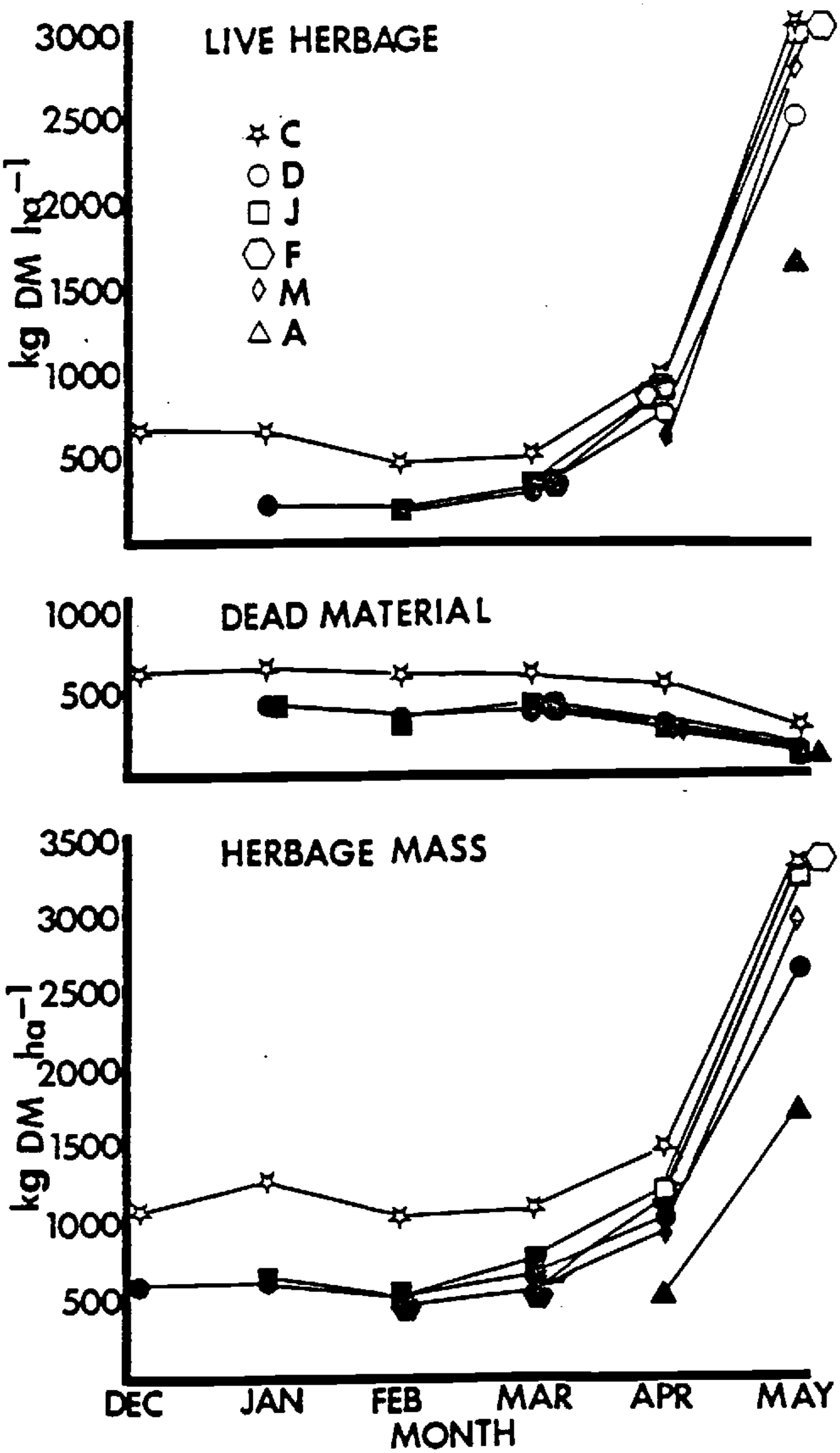
LIVE HERBAGE
C
D
J
F
M
A
kg DM ha⁻¹
3000
2500
2000
1500
1000
500
DEAD MATERIAL
1000
500
HERBAGE MASS
3500
3000
2500
2000
1500
1000
500
kg DM ha⁻¹
DEC
JAN
FEB
MAR
APR
MAY
MONTH

Figure 2.

grazed paddocks, C had a greater total quantity of dead material than the grazed paddocks ($p<0.05$). The amounts of dead material on the grazing treatments were similar and varied relatively little during the winter ($p>0.05$). Dead material averaged approximately 630 and 400 kg DM ha^{-1} on C and the grazed paddocks, respectively, between December and March. Similar results have been reported by Parmenter and Boswell (1983) who attributed differences in amounts of dead material between grazed and ungrazed pastures to either the reduction in herbage mass available to be killed by adverse climatic conditions or to increased rates of decomposition as a result of grazing.

The quantity of live herbage was less on the grazed treatments than C ($p<0.05$) and varied relatively little during the winter months (Figure 2). Since there was little change in the amount of live tissue, loss of tissue by death and decomposition of older leaves was either minimal or was offset by formation of new tissue. Brougham (1956) suggested that the moist conditions at the bottom layer of a pasture provide a favorable environment for decomposition. Thus, loss of leaves and formation of new tissue in the winter essentially offset each other once the ceiling level of herbage accumulation for a site is achieved.

In February, the rate of herbage accumulation on J was greater than on C ($p<0.05$) presumably due to differences in the senescence and decomposition rate of leaves. Rates of herbage accumulation in February also differed between years ($p<0.05$), averaging 1, 12, and 3 kg DM ha^{-1} day^{-1} in 1984, 1985, and 1986, respectively. Differences in production among years may be a result of different levels of snowfall in February (0, 5, and 2.5 cm of snow in 1984, 1985, and 1986, respectively).

Rates of herbage accumulation during March and April averaged 14 and 52 kg DM ha^{-1} day^{-1}, respectively. The effect of winter grazing treatment on herbage accumulation in March differed among years ($p<0.05$), however, because rates of herbage accumulation were relatively low in March, spring and total herbage production were relatively unaffected. In March and April the quantity of live herbage increased and the quantity of dead material decreased. By the first of May, dead material averaged less than 10% of total herbage mass for all treatments. The quantity of dead material was still greater on C than on the grazed paddocks; 290 vs. 170 kg DM ha^{-1}, respectively ($p<0.01$).

On the first of May, herbage mass on D and A treatments was less than C while J, F, and M had replaced herbage mass consumed by sheep to become similar to C. Brougham (1960) reported increased growth on winter grazed pasture and attributed this to better penetration of light to the ground and possibly to higher soil temperatures.

Brown (1976) and Chapman et al. (1983) suggested that increased growth on winter grazed pastures is a result of reduced dead material which allows better distribution of radiation and improved conditions for the initiation of new tillers.

Slopes of the herbage mass line presented in Figure 2 suggest that generally little production occurred in the month immediately after winter grazing but then increased sufficiently to overcome the difference in herbage mass with that of C by spring. Lower rates of herbage accumulation in A during April compared to C are consistent with this pattern. While herbage accumulation on A was depressed in April compared to C ($p<0.05$), rates of herbage accumulation did not differ in May and June ($p>0.05$).

Responses to D appeared to be somewhat unique among our grazing treatments. During March and April, the difference in herbage mass between D and C was not overcome. By the first of May, D was the only grazing treatment other than A whose herbage mass differed from C ($p<0.05$). Less forage removed from D compared to C during the May grazing by sheep ($p<0.01$) (Table 2) reflect this difference in herbage mass.

Subsequent herbage accumulation after the May grazing did not differ ($p>0.05$) between treatments, and by July herbage mass averaged over all treatments was 4380 kg DM

ha^{-1} ($p>0.05$). Frame (1970), Lockhart et al. (1969), and Laws and Newton (1987) also reported that winter defoliation only temporarily delays early spring growth.

Of the total production between December and July on our pastures approximately 79 to 90% was consumed by sheep. Neither total annual forage production nor total forage consumed annually differed significantly between treatments ($p>0.05$). However, numerically C, D, and A tended to average less annual production (Figure 3) and less total forage consumed (Table 2) than J, F, and M.

Differences in seasonal production and between treatments were also accompanied by differences in species composition. Treatments differences were most apparent in May.

White clover was abundant only during the first year when it contributed 840 kg DM ha^{-1} in May. By the third year it averaged less than 150 kg DM ha^{-1} in all treatments. These results suggest that loss of white clover was unrelated to grazing treatment.

Annual grass was present on every sampling date but averaged less than approximately 200 and 100 kg DM ha^{-1} on C and the grazed treatments, respectively, during the winter. In May annual grass averaged 490 kg DM ha^{-1}. The amount of annual grass increased in all grazed treatments from the first to the third year ($p<0.05$). Although not significantly different ($p>0.05$), the increase in D was

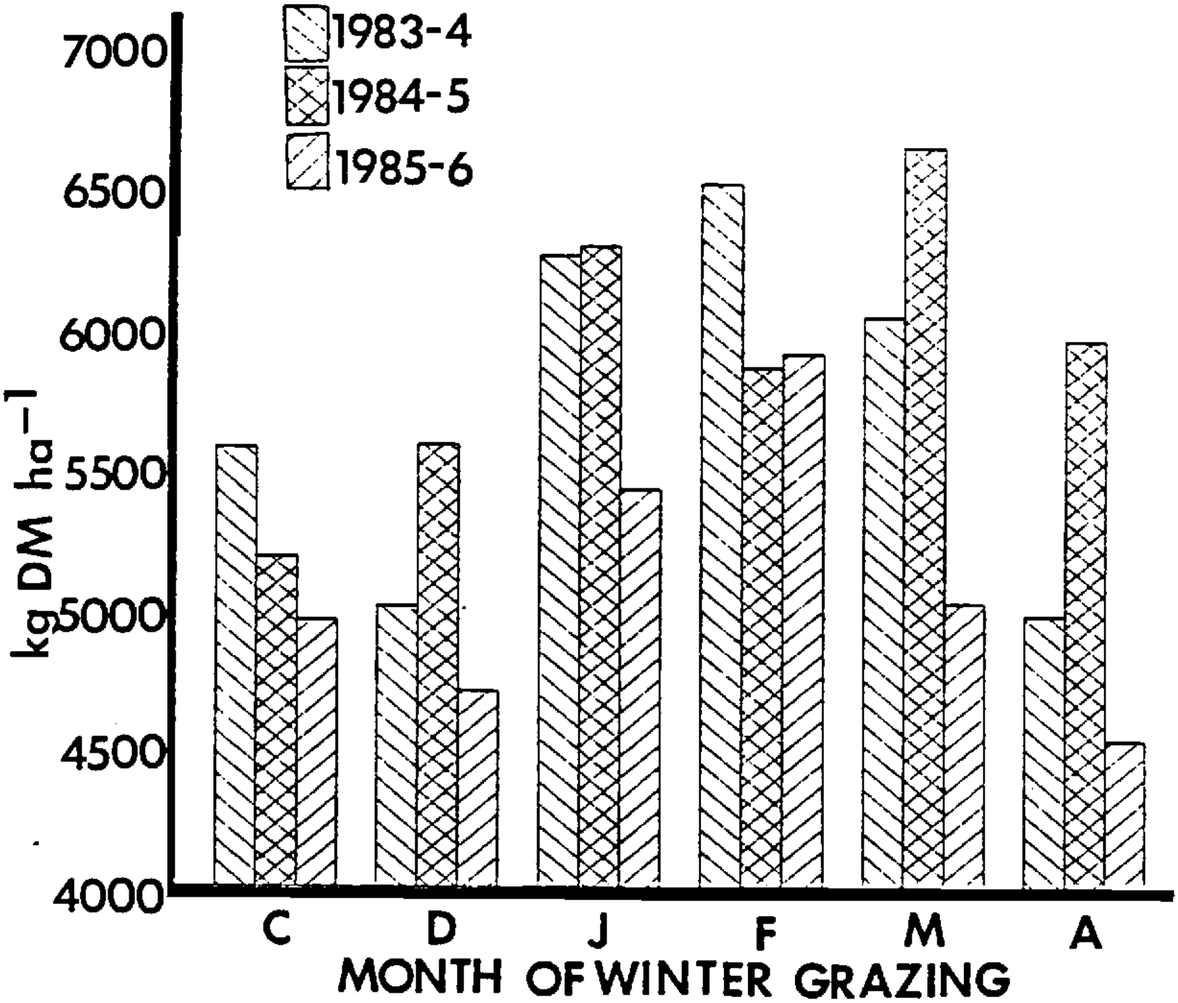

Figure 3. Annual production for the 1983-84, 1984-85, and 1985-86 forage years for six winter grazing treatments. Treatments are ungrazed control (C) and grazed in December (D), January (J), February (F), March (M) or April (A).

numerically greater than in the other grazing treatments. By May of the third year D averaged 1120 kg DM ha^{-1} annual grass compared to an average of 665 kg DM ha^{-1} in the other grazing treatments.

Perennial ryegrass was the major pasture component in all treatments. The number of tillers of perennial ryegrass per square meter on C changed seasonally. Tillers increased from an average of 2,210 tillers per m^2 during the winter period to 3430 tillers per m^2 by the first of April. There was little difference between tiller numbers in April, May, or July. This trend in tiller development in late winter and early spring has been reported by Brereton et al. (1985) and Peacock (1975), however, the number of tillers per area on our study is lower than what they have reported.

The effect of date of winter grazing on amount of perennial ryegrass in the spring varied among years (Table 3) ($p<0.05$). In 1984, C, D, and A had less perennial ryegrass in May than did J, F, and M. In 1985, yields of perennial ryegrass in almost all of the treatments were greater than in 1984 and there was little difference due to winter grazing treatment ($p>0.05$). By May 1986, yields of perennial ryegrass from D and A were less than the other treatments ($p<0.05$). Reduction in the amount of perennial ryegrass on December-grazed pastures has also been reported by Davies and Simons (1979), Brougham

Table 3. Yields of perennial ryegrass (kg DM ha^{-1}) in May of three years for six winter grazing treatments. Treatments are ungrazed control (C) and grazed in December (D), January (J), February (F), March (M) or April (A).

Winter Grazing Treatment	Year		
	1984	1985	1986
C	559a[1]	1708efg	1950efg
D	738ab	1785efg	848abcd
J	1374cdef	2232g	1861efg
F	1437defg	1989fg	1557efg
M	1630efg	1699efg	1396def
A	715ab	1317bcde	745abc
Yearly $\bar{X}$	1075a	1788b	1393a

S.E.: Winter Grazing 222; Year 80; Grazing*Year 188.
$p>0.05$ $p<0.05$ $p<0.05$

[1] Means not sharing a common letter differ ($p<0.05$).

(1959) and Baker (1957).

Baker (1957) and El Hassan and Krueger (1980) suggested that grazing in early December reduces the ability of perennial ryegrass to rebuild root mass useful for regrowth the following spring. Perennial ryegrass root mass measured in the beginning of the forage year (September), the end of the fall growth period (December), the end of winter (March), and the end of the growing season (July) in the third year of our study did not differ among the winter grazing treatments ($p>0.05$). Averaged over all winter grazing treatments, main root mass declined from 5.55 g per plant in September to 3.38 g per plant in December, changed relatively little from December to March, and increased to 4.6 g per plant by July ($p<0.01$).

Variation in the number of tillers of perennial ryegrass between treatments and among years tended to follow a similar pattern to those described for perennial ryegrass yields. In May 1984, 1985, and 1986, they averaged 2105, 5300, and 3990 tillers per m^2, respectively. While not significantly different ($p>0.05$), the number of tillers present in May 1986 were numerically lower on D. Tillers averaged 3372, 2946, 4245, 4111, 4113, and 4015 tillers per m^2 in C, D, J, F, M, and A, respectively, in May 1986.

The number of leaves per tiller of perennial ryegrass varied seasonally. Leaves per tiller decreased between December and January and then did not increase until after March. A similar trend in leaf number per tiller for this period has been reported for monocultures of perennial ryegrass (Brereton et al. 1985, Thomas and Norris 1981).

Grazing reduced the number of leaves per tiller (Table 4) compared to C for 1 to 2 months immediately after grazing. Thereafter, grazed paddocks had the same number or more leaves per tiller than in C. Thus, similar yields of perennial ryegrass in May from C compared to J, F, and M result from a fewer number of larger, but more sparsely leaved tillers. Similar compensation between leaf and tiller number and size under different grazing management treatments have been reported by Chapman et al. (1983) and Davies and Simons (1979).

Mean basal area per perennial ryegrass plant, not including juvenile plants (plants with basal areas less than 2 cm^2), did not differ ($p>0.05$) among winter grazing treatments and was similar between the fall and spring averaging 20 cm^2 in September and 17 cm^2 in May. Although density of perennial ryegrass plants did not vary ($p>0.05$) between winter grazing treatments, it did increase from an average of 57 to 86 plants per m^2 between September and May ($p<0.01$). This increase in adult plants is accounted for by a decline in the number of juvinile plants by May.

Table 4. Number of leaves per tiller of perennial ryegrass in the December to May period for six winter grazing treatments. Treatments are ungrazed control (C) and grazed in December (D), January (J), February (F), March (M) or April (A). Data are averaged over three forage years.

Winter Grazing Treatment	Month					
	Dec.	Jan.	Feb.	Mar.	Apr.	May
C	2.3	2.1a[1]	2.0a	2.1a	2.4a	2.7b
D	-	1.6b	1.7b	2.1a	2.4a	2.8ab
J	-	-	1.7b	2.1a	2.4a	2.8ab
F	-	-	-	1.7b	2.3a	2.9a
M	-	-	-	-	2.1b	2.8ab
A	-	-	-	-	-	2.4c
S.E.	-	0.06	0.05	0.05	0.04	0.04

[1] Means in a column not sharing a common letter differ ($p<0.05$).

Management Implications

Winter accounted for less than 2% of the total annual production but 12 to 15% of the total annual forage consumed from our paddocks. Because there was little growth during the winter period, these pastures did not have enough forage available to allow regrazing until spring.

The effect of winter grazing on the subsequent spring production and pasture composition varied with the time grazing occurred in the winter. Although pasture grazed between January and March had an increased rate of forage production and decreased leaf death of perennial ryegrass during this period compared to the control, relatively little available forage was present in April when there may be a high demand for forage. December grazing lowered yields in May and decreased the amount of perennial ryegrass by the third year. Varying date of winter grazing on a paddock from one year to the next may allow pasture to overcome effects of grazing from the previous year. Following grazing in May there was little difference in rates of herbage accumulation between winter grazing treatments.

References

Baker H.K. 1957. Studies on the root development of herbage plants. 2. The effect of cutting on the root and stubble development, and herbage production of spaced perennial ryegrass plants. J. Br. Grassl. Soc. 12:116-26.

Brereton, A.J., O.T. Carton, and W.F. O'Keefe. 1985. Tissue turnover in perennial ryegrass (Lolium perenne L.) during winter. Irish J. Agric. Res. 24:49-62.

Brougham, R.W. 1956. The rate of growth of short rotation ryegrass pastures in the late autumn, winter and early spring. N.Z. J. Sci. and Tech. 38:78-87.

Brougham, R.W. 1959. The effects of frequency and intensity of grazing on the productivity of a pasture of short-rotation ryegrass and red and white clover. N.Z. J. Agric. Res. 2:1232-1248.

Brougham, R.W. 1960. The effects of frequent hard grazings at different times of the year on the productivity and species yields of a grass-clover pasture. N.Z. J. Agric. Res. 3:125-136.

Brown, T.H. 1976. Effect of deferred autumn grazing and stocking rate of sheep on pasture production in a Mediterranean-type climate. Aust. J. Exp. Agric. Anim. Husb. 16:181-185.

Chapman, D.F., D.A. Clark, C.A. Land, and N. Dymock. 1983. Leaf and tiller growth of Lolium perenne and Agrostis spp. and leaf appearance rates of Trifolium repens in set stocked and rotationally grazed hill pastures. N.Z. J. Agric. Res. 26:156-168.

Davies, A., and R.G. Simons. 1979. Effect of autumn cutting regime on developmental morphology and spring growth of perennial ryegrass. J. Agric. Sci. 92:457-69.

Edward, R., and J. Morgan. 1962. The influence of winter management of grassland on subsequent spring growth. J. Agric. Soc. Univ. Coll. Wales Aberyst. 43:16-20.

El Hassan, B.A., and W.C. Krueger. 1980. Impact of intensity and season of grazing on carbohydrate reserves of perennial ryegrass. J. Range Manage. 33:200-203.

Frame, J. (1970). The effect of winter grazing by sheep on spring and early summer pasture production. J. Br. Grassl. Soc. 25:167-171.

Hume D.E., and R.J. Lucas. 1987. Effects of winter cutting management on growth and tiller numbers of six grass species. N.Z. J. Exp. Agric. 15:17-22.

Laws, J.A., and J.E. Newton. 1987. The effect of stocking rate and grazing management of sheep during winter on liveweight performance and herbage production. Res. and Development in Agric. 4:141-146.

Lockhart, D.A.S., J.B.D. Herriott, J.M.M. Cunningham, and R.G. Heddle. 1969. The effects of winter grazing on subsequent production from pasture. J. Br. Grassl. Soc. 24:146-150.

Motazedian, I. 1983. Effect of defoliation treatments on forage quality, quantity, and species composition of a Lolium perenne (L.)-Trifolium subterraneum (L.) pasture. Ph.D. diss. Oregon State Univ., Corvallis. 203p.

Newton, J.E., and C. Jackson. 1985. The effects of management and duration of grazing by sheep during the autumn and winter on subsequent grass production. J. Agric. Sci. 105:199-203.

Parmenter, G.A., and C.C. Boswell. 1983. Effect of number and timing of winter grazings on winter and spring pasture production. N.Z. J. Exp. Agric. 11:281-287.

Peacock, J.M. 1975. Temperature and leaf growth in Lolium perenne. 3. Factors affecting seasonal differences. J. Appl. Ecol. 12:685-697.

Redmond, K.T. 1987. Local climatological data for Corvallis, Oregon. 1986 summary. Agric. Exp. Stat. Spec. Rep. 809. 26 pp.

Soil Conservation Service (SCS). 1975. Soil survey of Benton County area, Oregon. USDA, Wash. D.C.

Steel, R.G.D., and J.H. Torrie. 1980. Principles and Procedures of Statistics. 2nd edn. New York:McGraw-Hill.

Thomas, H., and I.B. Norris. 1981. The influence of light and temperature during winter on growth and death in simulated swards of Lolium perenne. Grass Forage Sci. 36:107-116.

Warner, J.R., and S.H. Sharrow. 1984. Set stocking, rotational grazing and forward rotational grazing by sheep on western Oregon hill pastures. Grass Forage Sci. 39:331-338.

Wilman, D., and P.O. Griffiths. 1978. Effect of winter and early spring grazing by sheep on subsequent sward production. J. Agric. Sci. 90:471-477.

LITERATURE CITED

Abrahamson, M., and J. Talbot. 1986. Quantity and quality changes of autumn-saved pasture in a high county winter. N.Z. J. Exp. Agric. 14:247-256.

Alberda, T. 1965. The influence of temperature, light intensity, and nitrate concentration on dry matter production of Lolium perenne L. Neth. J. Agric. Sci. 13:335-360.

Alberda, T. 1966. The influence of reserve substances on dry-matter production after defoliation. Proc. Int. Grassl. Congr. 10th. p.140-147.

Anslow, R.C. 1966. The rate of appearance of leaves on tillers of the gramineae. Herb. Abstr. 36:149-55.

Baars, J.A., K.T. Jagusch, C.B. Dyson, and P.A. Farguhar. 1981. Pasture production sward dynamics under sheep grazing. Proc. N.Z. Soc. Anim. Prod. 41:101-111.

Baker H.K. 1957a. Studies on the root development of herbage plants. 2. The effect of cutting on the root and stubble development, and herbage production of spaced perennial ryegrass plants. J. Br. Grassl. Soc. 12:116-26.

Baker, H.K., 1957b. Studies on the root development of herbage plants. III. the influence of cutting treatment on the root, stubble, and herbage production of a perennial ryegrass sward. J. Br. Grassl. Soc. 12:197-208.

Ball, R., L.F. Molloy, and D.J. Ross. 1978. Influence of fertilizer nitrogen on herbage dry matter and nitrogen yields, and botanical composition of a grazed grass-clover pasture. N.Z. J. Agric. Res. 21:47-55.

Bedell, T.E. 1968. Seasonal forage preferences of grazing cattle and sheep in Western Oregon. J. Range Manage. 21:291-297.

Black, W.J.M. 1975. Winter grazing of pasture by sheep. 1. Some effects of sheep stocking density on permanent pasture, including sward recovery, botanical composition, and animal performance assessment. Irish J. Agric. Res. 14:275-284.

Brereton, A.J., O.T. Carton, and W.F. O'Keefe. 1985. Tissue turnover in perennial ryegrass (Lolium perenne L.) during winter. Irish J. Agric. Res. 24:49-62.

Brougham, R.W. 1955. A study in rate of pasture growth. Aust. J. Agric. Res. 6:804-812.

Brougham, R.W. 1956a. The rate of growth of short rotation ryegrass pastures in the late autumn, winter and early spring. N.Z. J. Sci. and Tech. 38:78-87.

Brougham, R.W. 1956b. Effect of intensity of defoliation on regrowth of pasture. Aust. J. Agric. Res. 7:377-387.

Brougham, R.W. 1958. Interception of light by the foliage of pure and mixed stands of pasture plants. Aust. J. Agric. Res. 9:39-52.

Brougham, R.W. 1959. The effects of frequency and intensity of grazing on the productivity of a pasture of short-rotation ryegrass and red and white clover. N.Z. J. Agric. Res. 2:1232-1248.

Brougham, R.W. 1960. The effects of frequent hard grazings at different times of the year on the productivity and species yields of a grass-clover pasture. N.Z. J. Agric. Res. 3:125-136.

Brown, K.R. 1968. Some effects of sheep treading on the herbage and seed yield of four grasses grown in association with white clover. N.Z. J. Agric. Res. 11:883-890.

Brown, K.R. 1971. Changes in a browntop-perennial ryegrass-white clover pasture trodden by sheep from October to March 1966-67. N.Z. J. Agric. Res. 14:828-834.

Brown, K.R., and A.J. Harris. 1972. Wintering without crops-the problems involved. Proc. N.Z. Grassl. Assoc. 34:49-56.

Brown, K.R., and P.S. Evans. 1973. Animal treading: A review of the work of the late D.B. Edmond. N.Z. J. Exp. Agric. 1:217-226.

Brown, R.H., and R.E. Blaser. 1968. Leaf area index in pasture growth. Herb. Abstr. 38:1-9.

Brown, T.H. 1976. Effect of deferred autumn grazing and stocking rate of sheep on pasture production in a Mediterranean-type climate. Aust. J. Exp. Agric. Anim. Husb. 16:181-185.

Caradus, J.R., and P.S. Evans. 1977. Seasonal root formation of white clover, ryegrass, and cocksfoot in New Zealand. N.Z. J. Agric. Res. 20:337-342.

Chapman, D.F., D.A. Clark, C.A. Land, and N. Dymock. 1983. Leaf and tiller growth of Lolium perenne and Agrostis spp. and leaf appearance rates of Trifolium repens in set stocked and rotationally grazed hill pastures. N.Z. J. Agric. Res. 26:156-168.

Chopping, G.D., R.J. Moss, I.K. Goodchild, and P.K. O'Rourke. 1978. The effect of grazing systems and nitrogen fertilizer regimes on milk production from irrigated pangola-couch pastures (Digitaria decumbens). Proc. Aust. Soc. Anim. Prod. 12:229.

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

Colvill, K.E., and C. Marshall. 1984. Tiller dynamics and assimilate partitioning in Lolium perenne with particular reference to flowering. Ann. Appl. Biol. 104:543-557.

Cooney, G.J., and K.F. Thompson. 1978. A farm grazing system in Southland - An advisors recommendations. Proc. N.Z. Grassl. Assoc. 39:60-69.

Cooper, J.P. 1970. Potential production and energy conversion in temperate and tropical grasses. Herb. Abstr. 40:1-15.

Crider, F.J. 1955. Root-growth stoppage resulting from defoliation of grasses. USDA Tech. Bull. 1102, 22 p.

Davies, A., and R.G. Simons. 1979. Effect of autumn cutting regime on developmental morphology and spring growth of perennial ryegrass. J. Agric. Sci. 92:457-69.

Davies, A., and M.E. Evans. 1982. The pattern of growth in swards of two contrasting varieties of white clover in winter and spring. Grass Forage Sci. 37:199-207.

Davies, A., and H. Thomas. 1983. Rates of leaf and tiller production in young spaced perennial ryegrass plants in relation to soil temperature and solar radiation (Lolium perenne). Ann. Bot. 51:591-597.

Deinum, B. 1976. Photosynthesis and sink size: An explanation for the low productivity of grass swards in autumn. Neth. J. Agric. Sci. 24:238-246.

Dennis, W.D., and J. Woledge. 1983. The effect of shade during leaf expansion on photosynthesis by white clover leaves. Ann. Bot. 511:111-118.

Deregibus, V.A., R.A. Sanchez, and J.J. Casal. 1983. Effects of light quality on tiller production in Lolium spp. (L. perenne, L. multiflorum). Plant Physiol. 72:900-902.

Donald, C.M., and J.N. Black. 1958. The significance of leaf area in pasture growth. Herb. Abstr. 28:1-6.

Duffy, R. 1970. Wintering on pasture in South Otega. N.Z. J. Agric. Res. 121:38-43.

Edgar, D.G. 1973. New frontiers in sheep production. Proc. Ruakura Farmers Conf. Week 25th, N.Z. p.286-288.

Edmond, D.B. 1963. Effects of treading perennial ryegrass (Lolium perenne) and white clover (Trifolium repens) pastures in winter and summer at two soil moisture levels. N.Z. J. Agric. Res. 6:265-276.

Edmond, D.B. 1974. Effects of sheep treading on measured pasture yield and physical condition of four soils. N.Z. J. Exp. Agric. 2:39-43.

Edward, R., and J. Morgan. 1962. The influence of winter management of grassland on subsequent spring growth. J. Agric. Soc. Univ. Coll. Wales Aberyst. 43:16-20.

El Hassan, B.A. 1977. The impact of three stocking intensities and four grazing treatments on the carbohydrate reserves of perennial ryegrass (Lolium perenne L.). Ph.D. diss. Oregon State Univ., Corvallis. 91 p.

El Hassan, B.A., and W.C. Krueger. 1980. Impact of intensity and season of grazing on carbohydrate reserves of perennial ryegrass. J. Range Manage. 33:200-203.

Evans, P.S. 1973. The effect of repeated defoliation to three different levels on root growth of five pasture species. N.Z. J. Agric. Res. 16:31-34.

Frame, J. 1970. The effect of winter grazing by sheep on spring and early summer pasture production. J. Br. Grassl. Soc. 25:167-171.

Garwood, E.A. 1967. Seasonal variation in appearance and growth of grass roots. J. Br. Grassl. Soc. 22:121-130.

Garwood, E.A. 1968. Some effects of soil water conditions and soil temperature on the roots of grasses and clover. III Effects of variation in the soil-water content and in soil temperature on growth. J. Br. Grassl. Soc. 23:117-128.

Garwood, E.A. 1969. Seasonal tiller population of grass and grass/clover swards with and without irrigation. J. Br. Grassl. Soc. 24:333-344.

Gunn, R.G. 1981. Hill farming research organization biennial report 1979-81. Bush Estate, Penicuik, Midlothian, Scotland. p. 71-75.

Halford, R.E. 1972. Grass wintering and its implications in Southland. Proc. N.Z. Grassl. Assoc. 34:42-48.

Halliday, D.J., and J.B. Sylvester. 1950. Nitrogen for grass: A survey of the response of grass to nitrogen fertilizers. Bull. Jealots Hill Res. Stn. 9:1-30.

Harris, W. 1978. Defoliation as a determinant of the growth, persistence and composition of pasture. p. 67-85. In J.R. Wilson (ed.) Plant Relations in Pasture. CSIRO, East Melbourne, Aust.

Hay, M.J.M. 1983. Seasonal variation in the distribution of white clover (Trifolium repens) stolons among three horizontal strata in two grazed swards. N.Z. J. Agric. Res. 26:29-34.

Hayman, J.M., and R.A. Moss. 1979. Grazing irrigated pasture with sheep: effect of winter management on pasture regrowth. N.Z. J. Exp. Agric. 7:277-280.

Hodgson, J. 1979. Nomenclature and definitions in grazing studies. Grass and Forage Sci. 34:11-18.

Hunt, L.A., and R.W. Brougham. 1967. Some changes in the structure of a perennial ryegrass sward frequently but leniently defoliated during the summer. N.Z. J. Agric. Res. 10:397-404.

Hume, D.E., and R.J. Lucas. 1987. Effects of winter cutting management on growth and tiller numbers of six grass species. N.Z. J. Exp. Agric. 15:17-22.

Hunt, W.F. 1970. The influence of leaf death on the rate of accumulation of green herbage during pasture regrowth. J. Appl. Ecol. 7:41-50.

Jacques, W.A. 1941. Root-development in some common New Zealand pasture plants . I Perennial ryegrass (Lolium perenne). A. Effect of time of sowing and taking a hay crop in the first harvest year. N.Z. J. Sci. Tech. 22:237-247.

Jacques, W.A., and D.B. Edmond. 1952. Root development in some common New Zealand pasture plants. V The effect of defoliation and root pruning on cocksfoot (Dactylus glomerata) and perennial ryegrass (Lolium perenne). N.Z. J. Sci. Tech. 34:231-248.

Jacques, W.A., and R.H. Schwass. 1956. Root development in some common New Zealand pasture plants. VII Seasonal root replacement in perennial ryegrass (Lolium perenne), Italian ryegrass (L. multiflorum), and tall fescue (Festuca arundinacea). N.Z. J. Sci. Tech. 38:569-583.

Jagger, H.J. 1977. A formula for rotational grazing: determining the number of paddocks needed on all grass sheep farms. N.Z. J. Agric. Sci. 11:49-50.

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

Jones, M.B., B. Collett, and S. Brown. 1982. Sward growth under cutting and continuous stocking managements: sward canopy structure, tiller density and leaf turnover. Grass Forage Sci. 37:67-73.

Keatinge, J.D.H., M.S. Camlin, and R.H. Stewart. 1979. The influence of climatic factors on physiological development in perennial ryegrass. Grass Forage Sci. 34:55-59.

Keatinge, J.D.H., R.H. Stewart, and M.K. Garrett. 1979. The influence of temperature and soil water potential on the leaf extension rate of perennial ryegrass in Northern Ireland. J. Agric. Sci. 92:173-183.

King, J., S.A. Grant, L. Torvell, and E.M. Sim. 1984. Growth rate, senescence and photosynthesis of ryegrass swards cut to maintain a range of values for leaf area index. Grass Forage Sci. 39:371-380.

Korte, C.J. 1986. Tillering in 'Grasslands Nui' perennial ryegrass swards. (2) Seasonal pattern of tillering and age of flowering tillers with two mowing frequencies. N.Z. J. Agric. Res. 29:629-638.

Korte, C.J., J.G. Spall, and A.C.P. Chu. 1982a. Pattern of autumn tillering in a Grassland 4708 tetraploid hybrid ryegrass sward following two heights of mowing. N.Z. J. Agric. Res. 25:157-161.

Korte, C.J., B.R. Watkin, and W. Harris. 1982b. Use of residual leaf area index and light interception as criteria for spring grazing management of a ryegrass dominant pasture. N.Z. J. Agric. Res. 25:309-319.

Korte, C.J., B.R. Watkin, and W. Harris. 1985. Tillering in "Grasslands Nui" perennial ryegrass swards. (1) Effect of cutting treatments on tiller appearance and longevity, relationship between tiller age and weight, and herbage production. N.Z. J. Agric. Res. 28:437-447.

Kothman, M.M. ed. 1974. A glossary of terms used in range management. Soc. Range Manage., Denver, CO. 36 pp.

Lambert, M.G., D.A. Clark, D.A.Grant, D.A. Costell, and R.W. Fletcher. 1983. Influence of fertiliser and grazing management on North Island moist hill country. I. Herbage accumulation. N.Z. J. Agric. Res. 26:95-108.

Langer, R.R.M. 1973. Pasture and pasture plants. A.H. & A.W.Reed Ltd., Sydney. p.41-84.

Laws, J.A., and J.E. Newton. 1987 The effect of stocking rate and grazing management of sheep during winter on liveweight performance and herbage production. Res. and Development Agric. 4:141-146.

Lockhart, D.A.S., J.B.D. Herriott, J.M.M. Cunningham, and R.G. Heddle. 1969. The effects of winter grazing on subsequent production from pasture. J. Br. Grassl. Soc. 24:146-150.

Lonsdale, W.M., and A.R. Watkinson. 1983. Tiller dynamics and self thinning in grassland habitats (UK). Oecologia. 60:390-395.

May, C.H. 1960. The utilization of carbohydrate reserves in pasture plants after defoliation. Herb. Abstr. 30:239-245.

McCree, K.J., and J.A. Troughton. 1966. Non-existence of an optimum Leaf Area Index for the production rate of white clover under constant conditions. Plant Physiol. 41:1615-1622.

McMeekan, C.P. 1956. Grazing management and animal production. Proc. Int. Grassl. Congr., 7th. p. 146-156.

Mitchell, K.J. 1953. Influence of light and temperature on the growth of ryegrass (Lolium spp.). I Pattern of vegetative development. Physiologia Pl. 6:21-46.

Morely, F.H.W. 1968. Pasture growth curves and grazing management. Aust. J. Exp. Agric. Anim. Husb. 8:40-45.

Motazedian, I. 1983. Effect of defoliation treatments on forage quality, quantity, and species composition of a Lolium perenne (L.)-Trifolium subterraneum (L.) pasture. Ph.D. diss. Oregon State Univ., Corvallis. 203p.

Myneni, R.B., and I. Impens. 1985. A procedural approach for studying the radiation regime of infinite and truncated foliage spaces. Part III. Effect of leaf size and inclination distribution on nonparallel beam radiation penetration and canopy photosynthesis. Agric. and Forest Meteorol. 34:183-194.

Newton, J.E., and C. Jackson. 1985. The effects of management and duration of grazing by sheep during the autumn and winter on subsequent grass production. J. Agric. Sci. 105:199-203.

Nowalk, R.S., and M.M Caldwell. 1984. A test of compensatory photosynthesis in the field; implications for herbivory tolerance. Oecologia. 61:311-318.

Ong, C.K., and C. Marshall. 1979. The growth and survival of severely shaded tillers in Lolium perenne L. Ann. Bot. 43:147-155.

Orr, R.J., and J.E. Newton. 1984. Grazing cycle length and silage supplementation: effects on the performance of lactating ewes with twin lambs. Grass Forage Sci. 39:323-328.

Parker, B.W., and B.H. Willis. 1973. Improved pasture by winter management. Proc. N.Z. Grassl. Assoc. 34:195-198.

Parker, O.F. 1973. The need for precision feed budgeting as a farming tool. Proc. N.Z. J. Grassl. Assoc. 34:205-211.

Parmenter, G.A., and C.C. Boswell. 1983. Effect of number and timing of winter grazings on winter and spring pasture production. N.Z. J. Exp. Agric. 11:281-287.

Parsons, A.J., and M.J. Robson. 1980. Seasonal changes in the physiology of S24 perennial ryegrass (Lolium perenne) (1) Response of leaf extension to temperature during the transition from vegetative to reproductive growth. Ann. Bot. 46:435-444.

Parsons, A.J., and M.J. Robson. 1981. Seasonal changes in the physiology of S24 perennial ryegrass (Lolium perenne L.) (2) Potential leaf and canopy photosynthesis during the transition from vegetative to reproductive growth. Ann. Bot. 47:249-258.

Parsons, A.J., E.L. Leafe, B. Collett, P.D. Penning, and J. Lewis. 1983. The physiology of grass production under grazing. II Photosynthesis, crop growth and animal intake of continuously-grazed swards. J. Appl. Ecol. 20:127-139.

Patel, A.S., and J.P. Cooper. 1961. The influence of seasonal changes in light energy on leaf and tiller development in ryegrass, timothy and meadow fescue. J. Br. Grassl. Soc. 16:299-308.

Peacock, J.M. 1975a. Temperature and leaf growth in Lolium perenne 1. The thermal microclimate: its measurement and relation to crop growth. J. Appl. Ecol. 12:99-114.

Peacock, J.M. 1975b. Temperature and leaf growth in Lolium perenne. 2. The site of temperature perception. J. Appl. Ecol. 12:115-123.

Peacock, J.M. 1975c. Temperature and leaf growth in Lolium perenne. 3. Factors affecting seasonal differences. J. Appl. Ecol. 12:685-697.

Raguse, C.A., and K.L. Taggard. 1979. Growth of subterranean clover in a range soil as affected by microclimate and phosphorus availability. III. Comparative growth of subterranean and rose clovers at cold soil temperatures. Agron. J. 71:523-528.

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

Redmond, K.T. 1987. Local climatological data for Corvallis, Oregon. 1986 summary. Agric. Exp. Stat. Spec. Rep. 809. 26 pp.

Roberts, R.H., and I.V. Hunt. 1936. The effect of shoot cutting on the growth of root and shoot of perennial ryegrass (Lolium perenne) and of timothy (Phleum pratense). Welsh J. Agric. 12:158-174.

Scott, R.S. 1973. Effects of autumn applied nitrogen and method and frequency of defoliation on a ryegrass/white clover sward. Proc. N.Z. Grassl. Assoc. 34:242-252.

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.

Smetham, M.L. 1973. Grazing management. p.179-228. In R.H.M. Langer (ed.) Pastures and pasture plants. A.H. & A.W. Reed Ltd., Sydney.

Smith, D. 1964. Winter injury and survival of forage plants. A review. Herb. Abstr. 34:203-209.

Soil Conservation Service (SCS). 1975. Soil survey of Benton County area, Oregon. USDA, Wash. D.C.

Spiertz, J.H.J., and J. Ellen. 1972. The effect of light intensity on some morphological and physiological aspects of the crop perennial ryegrass (Lolium perenne L. var. 'Cropper') and its effect on seed production. Neth. J. Agric. Sci. 20:232-246.

Sprague, M.A. 1955. The influence of rate of cooling and winter cover on the winter survival of ladino clover and alfalfa. Plant Physiol. 30:447-451.

Steel, R.G.D., and J.H. Torrie. 1980. Principles and Procedures of Statistics. 2nd edn. New York:McGraw-Hill.

Stern, W.R., and C.M. Donald. 1962. Light relationships in grass-clover sward. Aust. J. Agric. Res. 13:599-614.

Stuckey, I.H. 1941. Seasonal growth of grass roots. Amer. J. Bot. 28:486-491.

Suckling, F.E.T. 1966. Hill pasture improvement. Newton King Group of Companies in collaboration with the New Zealand Dept. of Scientific and Industrial Research. 58 p.

Thetford, F.O. 1976. Responses of vegetation and sheep to three grazing pressures. Ph.D. diss. Oregon State Univ., Corvallis. 157 p.

Thomas, H., and A. Davies. 1978. Effects of shading on the regrowth of _Lolium perenne_ swards in the field. Ann. Bot. 42:705-715.

Thomas, H., and I.B. Norris. 1981. The influence of light and temperature during winter on growth and death in simulated swards of _Lolium perenne_. Grass Forage Sci. 36:107-116.

Troughton, A. 1981. Length of life of grass roots. Grass Forage Sci. 36:117-120.

Walker, T.W., H.D. Orchiston, and A.F.R. Adams. 1954. The nitrogen economy of grass legume associations. J. Br. Grassl. Soc. 9:249-274.

Warner, J.R. 1983. Evaluation of three sheep grazing systems on Western Oregon hill pastures. M.S. thesis, Oregon State Univ., Corvallis. 124 p.

Warner, J.R., and S.H. Sharrow. 1984. Set stocking, rotational grazing and forward rotational grazing by sheep on western Oregon hill pastures. Grass Forage Sci. 39:331-338.

Wilman, D., and P.O. Griffiths. 1978. Effect of winter and early spring grazing by sheep on subsequent sward production. J. Agric. Sci. 90:471-477.

Woledge, J., and W.D. Dennis. 1982. The effect of temperature on photosynthesis of ryegrass and white clover leaves. Ann. Bot. 50:25-35.

Yates, M.E., and W.A. Jacques. 1952. Root development in some common New Zealand pasture plants. VI Importance of various roots, particularly the seminal roots of perennial ryegrass (_Lolium perenne_). N.Z. J. Sci. Tech. 34:249-257.

APPENDICES

APPENDIX A. Climatic data collected at the Wilson Tract, February 1984 through July 1986.

CLIMATE

The equipment used to collect the climatic data, the dates the data were collected, and the information collected are summarized below. The hygrothermograph and LICOR LI 1776 were kept in a standard weather station box at the site. The rain gauge was mounted on a metal post 4 m from the weather station. The PTC recording thermometer was placed on the ground beneath the rain gauge. The pocket case thermometers were pushed into the ground to the desired depth and the thermometers were removed from the cases as needed. The Taylor Weather-Hawk recording thermometers were housed 0.5 km from the study plots with leads buried 5 m from the hut under open pasture.

Equipment	Time Period	Parameters Measured	Frequency
Hygrothermograph	2/28/84 - 7/7/86	Max. and Min. air temp.	daily
		Max. and Min. humidity	daily
PTC Recording Thermometer	3/19/84- 9/27/84	Max. and Min. 10 cm soil temp.	daily
Taylor Weather-Hawk Recording Thermometer	9/28/84 - 7/7/86	Max. and Min. 10 cm soil temp.	daily
	9/7/84 - 7/7/86	Max. and Min. 5 cm soil temp.	daily
	11/16/84 -8/30/84	Max. and Min. 20 cm soil temp.	daily
Pocket Case Thermometers	9/6/85 - 6/29/86	Plot 5 cm soil temp.	weekly
	1/20/85 - 8/29/85	Plot 10 cm soil temp.	weekly
All Weather Rain Gauge	2/28/84 - 7/7/86	Precipitation	weekly
LI-COR LI-1776 Solar Monitor	9/21/84 - 7/7/86	Photosynthetically active radiation (400-700 nm) in einsteins (6.023x10 3 photons)	daily integration

Table A1. Average monthly climatic data for Wilson Tract.[1]

	Month											
	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Rainfall (mm)												
30 yr	40	100	180	220	220	140	130	70	60	30	10	20
83-4	-	-	-	210	90	200	130	90	110	100	0	0
84-5	30	140	410	130	10	111	120	30	30	60	10	10
85-6	40	110	150	60	160	280	90	70	60	10	-	-
Maximum Air Temperature (°C)												
30 yr	22	16	9	6	5	8	10	13	17	20	25	24
83-4	-	-	-	3	7	9	12	11	14	18	25	25
84-5	22	13	8	4	5	8	11	15	17	22	29	25
85-6	19	15	4	2	8	9	13	13	17	23	-	-
Minimum Air Temperature (°C)												
30 yr	8	5	2	1	0	1	2	3	6	9	10	10
83-4	-	-	-	-1	2	2	6	4	6	8	10	10
84-5	9	5	2	-2	-2	1	1	4	6	8	11	11
85-6	8	5	-2	-4	2	3	4	3	6	10	-	-
Average Maximum 10 cm Soil Temperature (°C)												
83-4	-	-	-	5	6	8	10	11	15	18	21	22
84-5	19	12	7	3	3	5	10	14	17	20	25	23
85-6	18	14	6	2	7	8	13	14	15	21	-	-

[1] Data from the cooperative Oregon State University - U.S. Weather Bureau Station at Hyslop Crop Science Farm ten km north-east of Corvallis, Oregon (Redmond 1987) were used to estimate 30 year average using regression equations developed from available data at the study area.

Table A1. (continued)

	Month											
	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Average Minimum 10 cm Soil Temperature (°C)												
83-4	-	-	-	5	5	2	7	8	12	15	16	16
84-5	16	11	7	2	2	4	7	12	15	18	22	20
85-6	17	13	6	1	6	7	11	12	14	19	-	-
Average Maximum 5 cm Soil Temperature (°C)												
85-6	20	14	6	2	8	8	13	15	18	24	-	-
Average Minimum 5 cm Soil Temperature (°C)												
85-6	13	9	4	1	6	6	9	10	14	18	-	-
Photosynthetically Active Radiation												
30 yr	30	18	9	7	9	13	21	29	38	43	47	39
84-5	31	16	8	7	13	18	25	33	42	51	57	44
85-6	30	20	10	11	7	11	25	33	38	48	-	-

Table A2. Hyslop Crop Science Farms 10 km, NE of the study area collects on a daily basis max/min air temperature at 1 m height above the ground, precipitation, minimum humidity, max/min 5 and 10 cm soil temperature, and total solar radiation (langleys). Data reported for Hyslop were paired with data from OSU Wilson Farm to develop models for predicting Wilson Farm climatic information from Hyslop data.

Y = Wilson Farms
X = Hyslop Crop Science Farms

<u>Maximum Temperature</u> (data in °C)

1983-84	Y=-3.45+1.03X	r^2=.95	n=185
1984-85	Y=-1.57+0.97X	r^2=.98	n=351
1985-86	Y=-2.07+0.98X	r^2=.97	n=309
All Years	Y=-1.95+0.98X	r^2=.97	n=842

<u>Minimum Temperature</u> (data in °C)

1983-84	Y=0.88+0.89X	r^2=.80	n=185
1984-85	Y=0.35+1.00X	r^2=.89	n=350
1985-86	Y=-0.36+0.98X	r^2=.88	n=309
All Years	Y=-0.25+0.99X	r^2=.88	n=844

<u>Humidity</u> (minimum %)

1983-84	Y=19.1+0.86X	r^2=.65	n=172
1984-85	Y=9.6+0.96X	r^2=.81	n=349
1985-86	Y=6.0+0.95X	r^2=.75	n=829
All Years	Y=12.9+0.89X	r^2=.75	n=829

<u>10 cm Maximum Soil Temperature</u> (°C)

1983-84	Y=1.67+0.73X	r^2=.88	n=152
1984-85	Y=0.38+0.85X	r^2=.97	n=360
1985-86	Y=2.13+0.75X	r^2=.94	n=309
All Years	Y=1.30+0.79X	r^2=.95	n=821

<u>10 cm Minimum Soil Temperature</u> (°C)

1983-84	Y=2.66+0.71X	r^2=.75	n=152
1984-85	Y=0.35+1.03X	r^2=.95	n=360
1985-86	Y=1.59+0.97X	r^2=.93	n=309
All Years	Y=1.27+0.93X	r^2=.90	n=821

<u>5 cm Maximum Soil Temperature</u> (°C)

1985-86	Y=1.48+0.74X	r^2=.96	n=303

Table A2. (continued)

5 cm Minimum Soil Temperature (°C)

1985-86	Y=1.29+0.94X	r^2=.91	n=303

Photosynthetically Active Radiation
(X=langleys per day, Y=Einsteins per m^2 per day)

1984-85	Y=1.081+0.083X	r^2=.96	n=312
1985-86	Y=2.051+0.079X	r^2=.80	n=280
All Years	Y=0.878+0.082X	r^2=.95	n=590

The models for monthly records are:

Precipitation (cm)

Mar. 1984 to Jun. 1986 Y=0.015+1.1126X r^2=.97 n=28

Maximum Temperature (°C)

Mar. 1984 to Jun. 1986 Y=-1.96+0.98X r^2=.99 n=28

Minimum Temperature (°C)

Mar. 1984 to Jun. 1986 Y=-0.58+1.04X r^2=.93 n=28

Minimum Humidity (%)

Mar. 1984 to Jun. 1986 Y=14.77+0.86X r^2=.85 n=28

10 cm Maximum Soil Temperature (°C)

Mar. 1984 to Jun. 1986 Y=1.10+0.803X r^2=.98 n=28

10 cm Minimum Soil Temperature (°C)

Mar. 1984 to Jun. 1986 Y=1.11+0.95X r^2=.93 n=28

5 cm Maximum Soil Temperature (°C)

Sep. 1985 to Jun. 1986 Y=1.57+.74X r^2=.99 n=10

5 cm Minimum Soil Temperature (°C)

Sep. 1985 to Jun. 1986 Y=1.00+0.99X r^2=.95 n=10

Photosynthetically Active Radiation
(X=Langleys per day, Y=Einsteins per m^2 per day)

Oct. 1984 to Jun. 1986 Y=0.866+.0.083X r^2=.99 n=21

Appendix B. Summary of Analysis of Variance evaluating winter grazing treatment and year effects on pasture.

Table B1. Mean annual forage production (kg DM ha^{-1} day^{-1}) for six winter grazing treatments in three forage years.

Month of Winter Grazing	Forage Year 1983-84	1984-85	1985-86	Three year Average
Control	5527	5147	4928	5201
December	4980	5537	4682	5066
January	6194	6227	5383	5934
February	6440	5803	5853	6031
March	5977	6570	4986	5844
April	4944	5900	4514	5119
$\overline{X}$	5676	5864	5058	

SE: Winter Grazing 443; Year 308; Grazing*Year 416.

$p>0.05$ $p>0.05$ $p>0.05$

No means differ ($p<0.05$).

Table B2. Monthly herbage accumulation rates (kg DM ha^{-1} day^{-1}) for six winter grazing treatments. Data are averaged over three forage years.

Month of Winter Grazing	Month					
	Dec.	Jan.	Feb.	Mar.	Apr.	May-Jul.
Control	6x[1]	-9x	2x	13x	53x	47x
December	0x	-3x	5xy	12x	47xy	48x
January	-	-5x	9y	15x	59x	49x
February	-	-	5xy	18x	61x	52x
March	-	-	-	12x	58x	55x
April	-	-	-	-	36y	56x
SE	1.1	1.7	1.2	2.1	4.2	5.2

[1] Means in a column not sharing a common letter differ ($p<0.05$).

Table B3. Monthly herbage accumulation rates (kg DM ha^{-1} day^{-1}) for three forage years.

Year	Month Dec.	Jan.	Feb.	Mar.	Apr.	May-Jul.
1983-84	4x[1]	-9x	1x	13x	49x	49x
1984-85	7x	-11x	12y	14x	58x	54x
1985-86	-1y	3y	3x	16x	50x	51x
SE	0.9	2.8	1.8	2.3	4.2	3.9

[1] Means in a column not sharing a common letter differ ($p<0.05$).

Table B4. Herbage Accumulation Rates (kg DM ha^{-1} day^{-1}) for March for winter grazing treatments in three years.

Month of Winter Grazing	Forage Year 1984	1985	1986
Control	14bcde[1]	12bcd	12bcd
December	12bcd	9ab	16bcde
January	15bcde	11abc	19de
February	18cde	17cde	20e
March	4a	20e	11abc

SE: Winter Grazing 2.1; Year 2.3; Grazing*Year 2.2.

$p>0.05$ $p>0.05$ $p<0.01$

[1] Means not sharing a common letter differ ($p<0.05$).

Table B5. Monthly herbage mass (kg DM ha^{-1}) for six winter grazing treatments. Data are averaged over three forage years.

Month of Winter Grazing	Month							
	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.[1]	Jul.
Control	1085	1304x[2]	1072x	1130x	1537x	3363x	3508x	4133x
December	-	648y	561y	701y	1084y	2681y	3369x	4159x
January	-	-	548y	802y	1263xy	3301xy	3331x	4465x
February	-	-	-	619y	1190y	3276xy	3955x	4247x
March	-	-	-	-	977y	2961xy	4093x	4779x
April	-	-	-	-	-	1787z	3951x	4496x
SE	-	86	86	70	96	210	252	430
p	-	<0.05	<0.05	<0.01	<0.05	<0.01	>0.05	>0.05

1 Means are for the June 1984 only.

2 Means in a column not sharing a common letter differ ($p<0.05$)

Table B6. Monthly herbage mass (kg DM ha^{-1}) for three forage years.

Year	Month							
	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.
1983-84	1015x[1]	1001xy	620x	578x	931x	2844x	3701	3944x
1984-85	1222x	1173y	743xy	1014y	1441y	3066x	-	4834x
1985-86	1016x	754x	819y	848y	1258y	2774x	-	4360x
SE	51	66	123	47	49	147	-	242
p	>0.05	<0.05	<0.05	<0.01	<0.01	>0.05	-	>0.05

[1] Means in a column not sharing a common letter differ ($p<0.05$).

Table B7. Forage consumed (kg DM ha^{-1}) from six winter grazing treatments. Data are averaged over three forage years.

Winter Grazing Treatment	Month				
	Dec.-Apr.	May	Jun.[1]	Jul.	Total
Control	0	1811x[2]	1005x	2204x	4350x
December	534x	1334y	631x	2153x	4231x
January	735x	1800x	353x	2557x	5210x
February	666x	1861x	1214x	2493x	5423x
March	723x	1273y	981x	2532x	4855x
April	1063y	534z	703x	2210x	4043x
SE	87	129	180	313	401
p	<0.05	<0.01	>0.05	>0.05	>0.05

1 Means are for June 1984 only.

2 Means in a column not sharing a common letter differ ($p<0.05$)

Table B8. Forage consumed (kg DM ha^{-1}) from pasture in three forage years.

Year	Month				Total
	Dec.-Apr.	May	Jun.	Jul.	
1983-84	515x[1]	1440x	814	854x	3624x
1984-85	722x	1614x	-	3804z	6140y
1985-86	623x	1252x	-	2417y	4292x
SE	86	206	-	269	406
p	>0.05	>0.05	-	<0.01	<0.05

[1] Means in a column not sharing a common letter differ ($p<0.05$)

Table B9. Forage consumed (kg DM ha^{-1}) during the December to April period from winter grazing treatments in three forage years.

Month of Winter Grazing	Forage Year		
	1983-84	1984-85	1985-86
December	283a[1]	667abc	653abc
January	938c	647abc	620abc
February	696abc	641abc	660abc
March	368ab	892bc	908c
April	807abc	1487d	896bc

SE: Winter Grazing 87; Year 86; Grazing*Year 149.

$p<0.01$ $p>0.05$ $p<0.05$

[1] Means not sharing a common letter differ ($p<0.05$).

Table B10. Monthly yields of live herbage (kg DM ha^{-1}) for six winter grazing treatments. Data are averaged over three forage years.

Month of Winter Grazing	Month							
	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.[1]	Jul.
Control	659	647a[2]	460x	508x	988x	3071x	3263x	3130x
December	-	206y	194y	301y	752xy	2497x	3189x	3370x
January	-	-	181y	339y	936xy	3095x	3062x	3327x
February	-	-	-	241y	880xy	3091x	3791x	3456x
March	-	-	-	-	622y	2812y	3903x	3701x
April	-	-	-	-	-	1652y	3778x	3634x
SE	-	62	44	42	92	377	250	384
p	-	<0.05	<0.05	<0.05	>0.05	<0.01	>0.05	>0.05

[1] Means are for June 1984 only.

[2] Means in a column not sharing a common letter differ ($p<0.05$).

Table B11. Monthly yields of live herbage (kg DM ha^{-1}) in three forage years.

Year	Month							
	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.
1983-84	1015a[1]	487a	259a	275a	717a	2696a	3498	2447b
1984-85	451b	493a	288a	414b	815b	2888a	-	4225a
1985-86	512b	300b	288a	352ab	975c	2525a	-	3637a
SE	98	39	31	27	13	166	-	234
p	<0.05	<0.05	>0.05	=0.05	<0.01	>0.05	-	<0.05

[1] Means in a column not sharing a common letter differ ($p<0.05$).

Table B12. Monthly yields of dead material (kg DM ha^{-1}) for six winter grazing treatments. Data are averaged over three forage years.

Month of Winter Grazing	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.[1]	Jul.
Control	630	657x[2]	612x	622x	548x	292x	245x	969x
December	-	442y	367y	400y	331y	185yz	181x	789x
January	-	-	367y	463y	328y	206y	269x	1138x
February	-	-	-	378y	309y	185yz	163x	791x
March	-	-	-	-	355y	149z	190x	1078x
April	-	-	-	-	-	135z	172x	862x
SE	-	34	46	34	35	18	47	10
p	-	<0.05	<0.05	<0.01	<0.01	<0.01	>0.05	>0.05

[1] Means are for June 1984 only.

[2] Means in a column not sharing a common letter differ ($p<0.05$).

Table B13. Monthly yields of dead material (kg DM ha^{-1}) in three forage years.

Year	Month							
	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.
1983-84	NA	514x[1]	361x	303x	214x	148x	203	1481x
1984-85	755x	681x	454y	600y	626y	178x	-	609y
1985-86	504y	454x	531z	496y	283x	249x	-	724y
SE	41	60	85	47	42	36	-	62
p	<0.05	>0.05	<0.01	<0.05	<0.01	>0.05	-	<0.01

[1] Means in a column not sharing a common letter differ ($p<0.05$).

Table B14. Monthly yields of perennial ryegrass (kg DM ha^{-1}) for six winter grazing treatments. Data are averaged over three forage years.

Month of Winter Grazing	Month							
	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.[1]	Jul.
Control	336	350	288	309	565	405	915	1582
December	-	100	98	164	354	1124	1404	1491
January	-	-	125	224	570	1822	974	1539
February	-	-	-	166	528	1661	1101	1797
March	-	-	-	-	337	1575	1051	1777
April	-	-	-	-	-	926	1148	1785
SE	-	71	49	41	74	222	246	424
p	-	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05

[1] Means are for June 1984 only.

No means differ (<0.05)

Table B15. Mean monthly yields of perennial ryegrass (kg DM ha^{-1}) for three forage years.

Year	Month							
	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.
1983-84	287x[1]	131x	129x	162x	312x	1075x	1099	948x
1984-85	315x	350y	195x	266x	524y	1788y	-	2505y
1985-86	356x	194x	188x	220x	576y	1393x	-	1633xy
SE	44	37	23	28	27	97	-	780
p	>0.05	<0.05	>0.05	>0.05	<0.01	<0.05	-	<0.05

[1] Means in a column not sharing a common letter differ ($p<0.05$).

Table B16. Monthly yields of annual grass (kg DM ha^{-1}) for six winter grazing treatments. Data are averaged over three forage years.

Month of Winter Grazing	Month							
	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.[1]	Jul.
Control	223	206	131	132	218	639	628	741
December	-	81	78	107	275	629	623	1154
January	-	-	37	57	195	423	451	666
February	-	-	-	37	180	438	846	623
March	-	-	-	-	186	446	1040	968
April	-	-	-	-	-	367	868	1135
SE	-	47	22	30	34	93	281	189
p	-	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05

[1] Means are for June 1984 only.

No means in a column differ ($p<0.05$).

Table B17. Monthly yields of annual grass (kg DM ha^{-1}) in three forage years.

Year	Month							
	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.
1983-84	413x[1]	245x	92x	48x	142x	320x	742	117x
1984-85	105x	99x	87x	85y	166x	431x	-	952y
1985-86	99x	86x	66x	117y	324y	720y	-	1574z
SE	77	45	15	8	11	57	-	71
p	>0.05	>0.05	>0.05	<0.05	<0.01	<0.05	-	<0.01

[1] Means in a column not sharing a common letter differ ($p<0.05$).

Table B18. Monthly number of perennial ryegrass tillers per m^2 for six winter grazing treatments. Data are averaged over three forage years.

Month of Winter Grazing	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.[1]	Jul.
Control	2171	2213	2244	2723	3470	3372	1330	3437
December	-	894	935	1690	2841	2946	3362	3047
January	-	-	1328	2594	4472	4245	2166	3780
February	-	-	-	2313	3872	4111	1619	4091
March	-	-	-	-	3739	4113	1724	3791
April	-	-	-	-	-	4015	1971	3371
SE	-	613	454	549	697	665	620	769
p	-	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05

[1] Means are for June 1984 only.

No means in a column differ ($p<0.05$).

Table B19. Monthly number of perennial ryegrass tillers per m^2 in three forage years.

Year	Month							
	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.
1983-84	NA	526x[1]	644x	1088x	1684x	2106x	2029	2139x
1984-85	2151x	2914y	1849y	3136y	5448y	5302x	-	4977y
1985-86	2190x	1220y	2014y	2766y	3905y	3992y	-	3642xy
SE	348	418	260	370	273	142	-	397
p	>0.05	<0.05	<0.05	<0.05	<0.01	<0.01	-	<0.05

[1] Means in a column not sharing a common letter differ ($p<0.05$).

Table B20. Monthly number of leaves per tiller of perennial ryegrass for six winter grazing treatments. Data are averaged over three forage years.

Month of Winter Grazing	Month							
	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.[1]	Jul.
Control	2.3	2.1x[2]	2.0x	2.1x	2.4x	2.7y	2.8x	2.4x
December	-	1.6y	1.7y	2.1x	2.4x	2.8xy	2.8x	2.4x
January	-	-	1.7y	2.1x	2.4x	2.8xy	2.5x	2.5x
February	-	-	-	1.7y	2.3x	2.9x	2.4x	2.5x
March	-	-	-	-	2.1y	2.8xy	2.6x	2.4x
April	-	-	-	-	-	2.4z	2.6x	2.5x
SE	-	0.06	0.05	0.05	0.04	0.04	0.16	0.08
p	-	<0.05	<0.05	<0.01	<0.01	<0.01	>0.05	>0.05

[1] Means are for June 1984 only.

[2] Means in a column not sharing a common letter differ ($p<0.05$).

Table B21. Monthly number of leaves per tiller of perennial ryegrass for three forage years.

Year	Month							
	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.
1983-84	NA	1.9y[1]	2.0x	2.0x	2.3x	2.8x	2.6	2.5y
1984-85	2.4x	2.1z	1.7y	2.0x	2.3x	2.7x	-	2.7x
1985-86	2.2y	1.6x	1.7y	1.9x	2.3x	2.7x	-	2.2z
SE	0.02	0.03	0.03	0.04	0.02	0.03	-	0.03
p	<0.05	<0.01	<0.01	>0.05	>0.05	>0.05	-	<0.01

[1] Means in a column not sharing a common letter differ ($p<0.05$).

Table B22. Mean basal area (cm^2) per plant (BA), basal area per m^2 (cm^2 per m^2), and density (plants per m^2) of adult perennial ryegrass plants (plants with basal area >2 cm^2) in September and May of the third study year for six winter grazing treatments.

Month of Winter Grazing	BA		BA m^{-2}		Density	
	Sep.	May	Sep.	May	Sep.	May
Control	17	16	986	1335	61	81
December	19	13	988	1100	50	83
January	22	20	1318	1614	61	83
February	22	20	1290	1654	63	87
March	23	17	1214	1489	52	88
April	16	17	931	1523	56	91
$\bar{X}$	20	17	1121	1453	57	86

SE: BA: Grazing 2.3; Month 1.1; Grazing*Month 2.0.

$p>0.05$ $p>0.05$ $p>0.05$

BA m^{-2}: Grazing 184; Month 36; Grazing*Month 135.

$p>0.05$ $p<0.05$ $p>0.05$

Density: Grazing 4.4; Month 1.0; Grazing*Month 4.4.

$p>0.05$ $p<0.01$ $p>0.05$

Table B23. Mean main root weight (g $plant^{-1}$) from perennial ryegrass plants in September, December, March and July 1985-86 for six winter grazing treatments.

Month of Winter Grazing	Month Sep.	Dec.	Mar.	Jul.
Control	5.98x[1]	3.39z	3.52z	4.12y
December	5.20x	3.44z	3.23z	5.16y
January	5.30x	3.77z	3.25z	4.59y
February	5.32x	3.01z	3.96z	4.16y
March	5.54x	3.68z	2.94z	4.71y
April	5.93x	2.99z	2.77z	4.86y

SE: Grazing 0.23; Month 0.21; Grazing*month 0.35.

$p>0.05$ $p<0.01$ $p>0.05$

[1] Means in a row not sharing a common letter differ ($p<0.05$).

Appendix C. Data summaries.

Table C1. Monthly herbage accumulation rates (kg DM ha^{-1} day^{-1}).

Forage Year	Block	Tmt.	Dec	Jan	Feb	Mar	Apr	May-July
			Month					
1	A	C	11	-8	-1	9	48	44
1	B	C	9	-21	3	19	73	46
1	C	C	12	-10	-11	15	37	44
1	A	D	-8	2	1	14	40	53
1	B	D	4	-22	9	8	44	46
1	C	D	-7	-3	-5	15	42	42
1	A	J	.	1	1	17	41	40
1	B	J	.	-7	11	16	78	45
1	C	J	.	-12	0	12	55	51
1	A	F	.	.	4	13	50	44
1	B	F	.	.	3	25	67	55
1	C	F	.	.	-6	17	67	51
1	A	M	.	.	.	10	44	47
1	B	M	.	.	.	2	73	51
1	C	M	.	.	.	1	60	58
1	A	A	.	.	.	.	21	43
1	B	A	.	.	.	.	28	68
1	C	A	.	.	.	.	22	48
2	A	C	4	-3	1	11	24	43
2	B	C	10	-21	5	20	86	67
2	C	C	4	-17	13	6	52	31
2	A	D	8	-8	17	8	41	65
2	B	D	5	-11	13	10	51	44
2	C	D	8	-8	9	8	56	47
2	A	J	.	0	9	9	48	57
2	B	J	.	-15	25	14	69	78
2	C	J	.	-20	21	11	64	32
2	A	F	.	.	8	4	46	41
2	B	F	.	.	20	27	74	59
2	C	F	.	.	7	19	70	45
2	A	M	.	.	.	21	22	38
2	B	M	.	.	.	25	76	95
2	C	M	.	.	.	14	92	49
2	A	A	.	.	.	.	19	38
2	B	A	.	.	.	.	81	65
2	C	A	.	.	.	.	64	74
3	A	C	6	-7	-3	21	39	38
3	B	C	7	4	9	10	68	60
3	C	C	-6	5	3	6	53	47
3	A	D	-6	11	-4	18	38	46
3	B	D	-4	1	6	16	55	38
3	C	D	-2	9	-1	14	56	51
3	A	J	.	2	3	27	51	51
3	B	J	.	-2	13	13	75	49
3	C	J	.	8	1	16	53	41
3	A	F	.	.	1	20	38	54
3	B	F	.	.	4	20	74	52
3	C	F	.	.	7	19	60	68
3	A	M	.	.	.	15	42	48
3	B	M	.	.	.	8	51	54
3	C	M	.	.	.	11	60	52
3	A	A	.	.	.	.	19	29
3	B	A	.	.	.	.	33	59
3	C	A	.	.	.	.	34	76

Table C2. Mean monthly herbage mass (kg DM ha^{-1}).

Forage year	Block	Tmt	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Annual Yields
1	A	C	637	1033	831	812	1061	2971	2572	3112	5390
1	B	C	1342	1665	1107	1195	1719	4642	4462	5048	6450
1	C	C	1067	1472	1193	883	1293	2780	3490	3194	4740
1	A	D	637	380	429	448	817	2430	3127	3778	5440
1	B	D	1342	816	231	491	724	2475	3911	4078	4950
1	C	D	1067	638	546	414	825	2498	3070	3340	4550
1	A	J	.	1047	383	416	893	2517	2606	3730	5310
1	B	J	.	1838	524	837	1275	4398	3963	4888	7130
1	C	J	.	1686	336	348	677	2888	3424	3275	6140
1	A	F	.	.	809	402	756	2763	2890	3009	5690
1	B	F	.	.	1159	448	1153	3833	4421	4544	7000
1	C	F	.	.	1158	236	712	3376	4553	3334	6620
1	A	M	.	.	.	862	682	2424	3028	3412	5450
1	B	M	.	.	.	1110	624	3551	4504	5059	6320
1	C	M	.	.	.	875	754	3138	4748	4348	6160
1	A	A	.	.	.	.	1014	1267	2472	3194	4180
1	B	A	.	.	.	.	1638	1764	4977	5584	6220
1	C	A	.	.	.	.	1459	1480	4403	4078	4432
2	A	C	939	1104	1020	1057	1452	2203	.	3704	3960
2	B	C	1492	1843	1275	1411	2154	4831	.	6187	7630
2	C	C	1236	1407	956	1302	1524	3123	.	3266	3850
2	A	D	995	667	448	910	1212	2470	.	5637	6220
2	B	D	1598	959	654	1009	1385	2973	.	4609	5000
2	C	D	1248	1060	843	1094	1405	3129	.	4450	5390
2	A	J	.	1138	549	780	1110	2599	.	4809	5780
2	B	J	.	1515	488	1158	1662	3815	.	6652	8260
2	C	J	.	1716	452	1016	1419	3411	.	3345	4640
2	A	F	.	.	813	705	850	2278	.	3536	4440
2	B	F	.	.	1277	1045	2034	4334	.	5186	7350
2	C	F	.	.	1333	678	1368	3552	.	4388	5620
2	A	M	.	.	.	768	1428	2112	.	3660	3980
2	B	M	.	.	.	1822	1517	3888	.	8404	9220
2	C	M	.	.	.	1902	1102	3953	.	4675	6510
2	A	A	.	.	.	.	1048	999	.	3126	3460
2	B	A	.	.	.	.	2379	3022	.	5514	7320
2	C	A	.	.	.	.	2476	2500	.	5868	6920
3	A	C	839	1000	816	734	1366	2599	.	3197	3885
3	B	C	1220	1409	1512	1759	2052	4217	.	5547	6364
3	C	C	990	804	941	1018	1210	2901	.	3941	4536
3	A	D	1429	368	676	563	1110	2317	.	3602	4332
3	B	D	1236	455	494	673	1144	2911	.	3574	4474
3	C	D	976	490	731	703	1130	2929	.	4360	5241
3	A	J	.	881	614	697	1505	3138	.	4429	5590
3	B	J	.	1873	818	1176	1559	3971	.	5040	6036
3	C	J	.	1083	772	789	1271	2971	.	4020	4524
3	A	F	.	.	855	536	1138	2367	.	4047	4858
3	B	F	.	.	1447	799	1399	3781	.	4797	6268
3	C	F	.	.	1400	726	1298	3202	.	5381	6432
3	A	M	.	.	.	946	844	2194	.	4010	4385
3	B	M	.	.	.	2062	1066	2696	.	5197	5400
3	C	M	.	.	.	1406	779	2694	.	4244	5172
3	A	A	.	.	.	.	1056	1001	.	2454	2779
3	B	A	.	.	.	.	1902	1860	.	4700	5188
3	C	A	.	.	.	.	2033	2190	.	5947	5575

Table C3. Mean monthly yields of live harbage (kg DM ha^{-1}).

Forage			Month							
year	Block	Tmt	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
1	A	C	637	568	423	401	714	2558	2330	1976
1	B	C	1342	859	518	605	1325	4377	4163	3293
1	C	C	1067	886	460	464	959	2513	3295	1118
1	A	D	637	169	170	139	574	2272	2899	2826
1	B	D	1342	255	82	204	542	2374	3778	2369
1	C	D	1067	185	196	228	682	2341	2889	2381
1	A	J	.	667	147	212	629	2376	2463	1858
1	B	J	.	913	206	327	1148	4279	3705	3573
1	C	J	.	1079	129	142	523	2810	3017	1844
1	A	F	.	.	366	182	550	2539	2737	2281
1	B	F	.	.	447	260	1018	3772	4262	3204
1	C	F	.	.	785	135	590	3227	4375	2410
1	A	M	.	.	.	387	434	2252	2765	1921
1	B	M	.	.	.	597	405	3491	4306	3116
1	C	M	.	.	.	542	656	3016	4639	1857
1	A	A	.	.	.	.	783	1229	2378	2354
1	B	A	.	.	.	.	1137	1711	4743	3278
1	C	A	.	.	.	.	1067	1390	4214	2390
2	A	C	403	531	532	426	723	1936	.	3267
2	B	C	564	962	590	858	1335	4647	.	5308
2	C	C	386	532	363	542	728	2870	.	2854
2	A	D	566	304	190	444	737	2282	.	4887
2	B	D	789	279	207	398	712	2801	.	4171
2	C	D	524	348	262	427	763	2982	.	3969
2	A	J	.	512	146	212	679	2430	.	4011
2	B	J	.	786	229	610	1095	3624	.	5355
2	C	J	.	541	77	246	729	3220	.	2796
2	A	F	.	.	374	198	577	2137	.	3257
2	B	F	.	.	714	460	1204	4195	.	4299
2	C	F	.	.	569	148	825	3421	.	4050
2	A	M	.	.	.	322	681	1818	.	3159
2	B	M	.	.	.	937	755	3701	.	7572
2	C	M	.	.	.	915	687	3830	.	3941
2	A	A	.	.	.	.	584	782	.	2848
2	B	A	.	.	.	.	1330	2919	.	5078
2	C	A	.	.	.	.	1451	2390	.	5234
3	A	C	467	424	262	275	825	2350	.	2766
3	B	C	702	741	675	636	1499	3832	.	4256
3	C	C	368	322	316	364	786	2556	.	3335
3	A	D	794	58	157	169	845	2141	.	3134
3	B	D	677	183	230	371	928	2499	.	3160
3	C	D	539	73	256	325	988	2779	.	3431
3	A	J	.	450	235	347	1212	2938	.	3679
3	B	J	.	1058	324	611	1352	3657	.	3800
3	C	J	.	423	137	340	1056	2517	.	3030
3	A	F	.	.	337	180	875	2239	.	3312
3	B	F	.	.	697	400	1188	3342	.	3708
3	C	F	.	.	811	206	1096	2946	.	4580
3	A	M	.	.	.	466	574	2100	.	3465
3	B	M	.	.	.	1077	784	2547	.	4608
3	C	M	.	.	.	581	623	2557	.	3671
3	A	A	.	.	.	.	729	841	.	2186
3	B	A	.	.	.	.	1299	1669	.	4238
3	C	A	.	.	.	.	1732	1940	.	5103

Table C4. Mean monthly yields of dead material (kg DM ha^{-1}).

Forage year	Block	Tmt	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
1	A	C	N/A	465	408	411	347	413	242	1136
1	B	C	N/A	806	589	590	394	265	299	1454
1	C	C	N/A	586	733	419	334	267	195	2076
1	A	D	N/A	211	259	309	243	158	228	952
1	B	D	N/A	561	149	287	182	101	133	1709
1	C	D	N/A	453	350	186	143	157	181	959
1	A	J	.	380	236	204	264	141	143	1872
1	B	J	.	925	318	510	128	119	258	1315
1	C	J	.	607	207	206	154	78	407	1431
1	A	F	.	.	443	220	206	224	153	728
1	B	F	.	.	712	188	135	61	159	1340
1	C	F	.	.	373	101	122	149	178	924
1	A	M	.	.	.	475	248	172	263	1491
1	B	M	.	.	.	513	219	60	198	1943
1	C	M	.	.	.	333	98	122	109	2491
1	A	A	.	.	.	.	231	38	94	840
1	B	A	.	.	.	.	501	53	234	2306
1	C	A	.	.	.	.	392	90	189	1688
2	A	C	536	573	488	631	729	267	.	437
2	B	C	878	881	685	553	819	184	.	879
2	C	C	850	875	593	760	796	253	.	412
2	A	D	429	363	258	466	475	188	.	750
2	B	D	809	680	447	611	673	172	.	438
2	C	D	724	712	581	667	642	147	.	481
2	A	J	.	626	403	568	431	169	.	798
2	B	J	.	729	259	548	567	191	.	1297
2	C	J	.	1175	375	770	690	191	.	549
2	A	F	.	.	439	507	273	141	.	279
2	B	F	.	.	563	585	830	139	.	887
2	C	F	.	.	764	530	543	131	.	338
2	A	M	.	.	.	446	747	294	.	501
2	B	M	.	.	.	885	762	187	.	832
2	C	M	.	.	.	987	415	123	.	734
2	A	A	.	.	.	.	464	217	.	278
2	B	A	.	.	.	.	049	103	.	436
2	C	A	.	.	.	.	025	110	.	634
3	A	C	372	576	555	459	541	249	.	431
3	B	C	518	668	837	123	553	385	.	1291
3	C	C	622	482	625	654	424	345	.	606
3	A	D	635	310	519	394	265	176	.	468
3	B	D	559	272	264	302	216	412	.	414
3	C	D	437	417	475	378	142	150	.	929
3	A	J	.	431	379	350	293	200	.	750
3	B	J	.	815	494	565	207	314	.	1240
3	C	J	.	660	635	449	215	454	.	990
3	A	F	.	.	518	356	263	128	.	735
3	B	F	.	.	750	399	211	439	.	1089
3	C	F	.	.	589	520	202	256	.	801
3	A	M	.	.	.	480	270	94	.	545
3	B	M	.	.	.	985	282	149	.	589
3	C	M	.	.	.	825	156	137	.	573
3	A	A	.	.	.	.	327	160	.	268
3	B	A	.	.	.	.	603	191	.	462
3	C	A	.	.	.	.	301	250	.	844

Table C5. Mean monthly yields of annual grass (kg DM ha^{-1}).

Forage			Month							
year	Block	Tmt	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
1	A	C	165	156	247	68	196	778	543	51
1	B	C	677	398	78	213	266	376	287	86
1	C	C	492	684	302	190	312	978	1054	2
1	A	D	165	49	52	10	146	318	588	31
1	B	D	677	128	12	1	73	318	574	114
1	C	D	492	55	38	1	106	253	708	74
1	A	J	.	239	38	49	121	276	463	84
1	B	J	.	245	38	1	42	145	119	4
1	C	J	.	746	26	15	99	323	772	112
1	A	F	.	.	101	8	134	109	517	5
1	B	F	.	.	165	11	178	385	673	29
1	C	F	.	.	440	11	91	168	1347	94
1	A	M	.	.	.	108	126	248	478	67
1	B	M	.	.	.	178	69	297	2054	240
1	C	M	.	.	.	170	176	268	589	71
1	A	A	.	.	.	.	227	220	846	527
1	B	A	.	.	.	.	193	238	436	266
1	C	A	.	.	.	.	128	60	1323	241
2	A	C	44	67	105	31	83	182	.	856
2	B	C	69	47	80	171	280	957	.	37
2	C	C	162	200	169	147	235	847	.	1370
2	A	D	87	44	60	55	150	173	.	298
2	B	D	224	128	78	193	248	770	.	2745
2	C	D	57	107	52	167	220	465	.	1508
2	A	J	.	76	5	39	109	279	.	1179
2	B	J	.	18	26	27	119	33	.	102
2	C	J	.	144	24	85	214	605	.	856
2	A	F	.	.	10	29	118	201	.	186
2	B	F	.	.	57	56	166	369	.	464
2	C	F	.	.	102	24	145	766	.	705
2	A	M	.	.	.	125	191	354	.	673
2	B	M	.	.	.	75	106	366	.	924
2	C	M	.	.	.	105	108	165	.	709
2	A	A	.	.	.	.	257	259	.	1566
2	B	A	.	.	.	.	92	523	.	1437
2	C	A	.	.	.	.	68	444	.	1528
3	A	C	66	121	14	57	123	351	.	656
3	B	C	193	101	75	137	288	743	.	1561
3	C	C	112	74	105	172	181	535	.	2049
3	A	D	406	28	63	50	375	925	.	1708
3	B	D	471	169	183	303	510	1403	.	2154
3	C	D	155	23	161	187	651	1036	.	1751
3	A	J	.	279	120	196	590	1319	.	1642
3	B	J	.	122	21	21	193	299	.	764
3	C	J	.	35	38	81	267	529	.	1250
3	A	F	.	.	83	61	248	535	.	876
3	B	F	.	.	149	78	261	755	.	1573
3	C	F	.	.	36	59	280	657	.	1678
3	A	M	.	.	.	255	244	736	.	1750
3	B	M	.	.	.	285	390	834	.	2549
3	C	M	.	.	.	166	262	746	.	1729
3	A	A	.	.	.	.	318	405	.	1489
3	B	A	.	.	.	.	401	505	.	1806
3	C	A	.	.	.	.	669	650	.	1351

Table C6. Mean monthly yields of other perennial grasses (kg DM ha^{-1}).

Forage			Month							
year	Block	Tmt	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
1	A	C	0	5	2	9	36	69	0	0
1	B	C	27	31	14	39	81	814	0	26
1	C	C	4	17	8	16	112	400	346	13
1	A	D	0	4	1	12	13	80	0	6
1	B	D	27	4	3	6	125	280	0	0
1	C	D	4	3	5	5	46	159	113	0
1	A	J	.	12	0	0	10	76	0	2
1	B	J	.	20	4	14	42	90	0	4
1	C	J	.	35	3	10	20	222	97	0
1	A	F	.	.	1	6	8	3	19	0
1	B	F	.	.	33	1	81	449	0	3
1	C	F	.	.	57	7	35	513	35	55
1	A	M	.	.	.	19	22	77	0	2
1	B	M	.	.	.	32	18	175	0	3
1	C	M	.	.	.	39	41	169	0	0
1	A	A	.	.	.	.	7	17	0	0
1	B	A	.	.	.	.	126	250	0	128
1	C	A	.	.	.	.	95	129	0	0
2	A	C	39	1	1	14	1	23	.	0
2	B	C	0	0	4	1	11	139	.	462
2	C	C	1	0	0	1	0	17	.	160
2	A	D	0	1	0	9	16	0	.	54
2	B	D	0	0	0	3	0	67	.	4
2	C	D	0	1	0	2	0	78	.	500
2	A	J	.	0	0	0	1	34	.	68
2	B	J	.	0	0	13	0	0	.	0
2	C	J	.	2	0	4	10	0	.	0
2	A	F	.	.	25	4	17	45	.	1
2	B	F	.	.	12	0	0	71	.	288
2	C	F	.	.	32	0	26	157	.	466
2	A	M	.	.	.	0	0	45	.	38
2	B	M	.	.	.	30	8	711	.	212
2	C	M	.	.	.	81	32	870	.	2
2	A	A	.	.	.	.	5	2	.	3
2	B	A	.	.	.	.	25	18	.	2
2	C	A	.	.	.	.	36	0	.	2
3	A	C	4	9	0	27	11	2	.	2
3	B	C	3	79	41	2	36	163	.	45
3	C	C	0	0	0	0	1	76	.	52
3	A	D	104	0	0	0	79	146	.	71
3	B	D	5	0	0	1	0	71	.	235
3	C	D	31	0	0	6	0	47	.	2
3	A	J	.	0	0	0	20	107	.	19
3	B	J	.	0	0	1	3	216	.	296
3	C	J	.	0	1	1	1	2	.	0
3	A	F	.	.	61	0	0	25	.	0
3	B	F	.	.	0	1	31	211	.	1
3	C	F	.	.	0	0	130	81	.	321
3	A	M	.	.	.	1	0	40	.	34
3	B	M	.	.	.	142	14	56	.	398
3	C	M	.	.	.	1	4	29	.	94
3	A	A	.	.	.	.	1	43	.	1
3	B	A	.	.	.	.	29	273	.	102
3	C	A	.	.	.	.	13	60	.	66

Table C7. Mean monthly yields of white clover (kg DM ha^{-1}).

Forage year	Block	Tmt	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
			Month							
1	A	C	147	67	3	18	56	568	753	451
1	B	C	208	231	48	106	445	2145	2585	2203
1	C	C	179	0	23	25	120	256	656	427
1	A	D	147	47	49	42	130	1047	1223	1797
1	B	D	208	28	4	6	97	563	491	706
1	C	D	179	54	16	13	126	1051	968	1331
1	A	J	.	40	15	22	189	744	1000	973
1	B	J	.	136	45	127	391	2127	2245	2158
1	C	J	.	2	5	2	68	436	769	856
1	A	F	.	.	42	71	137	1107	1204	1166
1	B	F	.	.	68	69	276	1090	2263	1983
1	C	F	.	.	23	18	60	807	1374	1574
1	A	M	.	.	.	12	47	507	995	645
1	B	M	.	.	.	79	77	1061	1008	1627
1	C	M	.	.	.	26	115	507	2500	832
1	A	A	.	.	.	.	308	398	863	1262
1	B	A	.	.	.	.	263	505	2386	1606
1	C	A	.	.	.	.	174	158	1251	574
2	A	C	20	28	10	13	16	219	.	137
2	B	C	36	87	80	87	260	497	.	892
2	C	C	2	44	2	17	10	149	.	106
2	A	D	18	4	10	52	43	57	.	161
2	B	D	95	3	9	11	8	123	.	209
2	C	D	76	32	22	22	34	182	.	214
2	A	J	.	7	15	12	71	180	.	505
2	B	J	.	129	15	124	65	156	.	75
2	C	J	.	26	2	13	28	399	.	305
2	A	F	.	.	4	41	47	291	.	488
2	B	F	.	.	81	62	90	323	.	529
2	C	F	.	.	48	16	115	664	.	255
2	A	M	.	.	.	8	16	316	.	300
2	B	M	.	.	.	106	46	222	.	356
2	C	M	.	.	.	70	22	329	.	772
2	A	A	.	.	.	.	18	49	.	236
2	B	A	.	.	.	.	279	671	.	965
2	C	A	.	.	.	.	97	76	.	555
3	A	C	1	1	1	1	4	42	.	317
3	B	C	0	1	0	1	5	6	.	36
3	C	C	0	1	1	1	2	3	.	92
3	A	D	2	2	1	1	8	76	.	236
3	B	D	1	0	1	0	2	0	.	1
3	C	D	0	1	0	1	1	0	.	128
3	A	J	.	2	1	1	8	134	.	259
3	B	J	.	5	1	3	18	219	.	134
3	C	J	.	1	1	0	2	0	.	2
3	A	F	.	.	1	4	4	117	.	332
3	B	F	.	.	1	2	1	0	.	38
3	C	F	.	.	1	1	3	120	.	28
3	A	M	.	.	.	1	5	47	.	78
3	B	M	.	.	.	4	2	4	.	36
3	C	M	.	.	.	1	0	8	.	4
3	A	A	.	.	.	.	6	2	.	20
3	B	A	.	.	.	.	0	3	.	0
3	C	A	.	.	.	.	2	0	.	3

Table C8. Mean monthly yields of subterranean clover (kg DM ha^{-1}).

Forage year	Block	Tmt	Month: Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
1	A	C	6	40	6	4	46	350	68	2
1	B	C	64	2	7	4	9	250	0	0
1	C	C	42	3	0	14	11	23	132	13
1	A	D	6	2	0	1	0	0	9	6
1	B	D	64	8	0	0	0	21	64	2
1	C	D	42	3	1	0	4	0	142	10
1	A	J	.	14	5	0	0	0	32	9
1	B	J	.	2	1	0	0	0	11	0
1	C	J	.	21	0	4	1	14	471	52
1	A	F	.	.	2	1	3	74	14	5
1	B	F	.	.	1	1	46	4	4	6
1	C	F	.	.	1	1	1	36	96	17
1	A	M	.	.	.	9	14	140	11	4
1	B	M	.	.	.	4	1	0	323	56
1	C	M	.	.	.	1	31	211	83	67
1	A	A	.	.	.	.	2	20	2	5
1	B	A	.	.	.	.	53	26	66	20
1	C	A	.	.	.	.	80	13	535	0
2	A	C	3	2	2	7	4	107	.	3
2	B	C	2	0	4	11	3	307	.	5
2	C	C	4	16	5	6	11	92	.	3
2	A	D	0	0	0	0	1	0	.	5
2	B	D	2	1	2	1	0	8	.	0
2	C	D	12	1	3	8	14	81	.	0
2	A	J	.	5	1	0	2	17	.	12
2	B	J	.	3	0	1	3	4	.	0
2	C	J	.	5	2	16	60	241	.	3
2	A	F	.	.	2	0	1	17	.	3
2	B	F	.	.	11	10	28	63	.	4
2	C	F	.	.	3	5	16	82	.	20
2	A	M	.	.	.	2	5	91	.	9
2	B	M	.	.	.	1	1	0	.	8
2	C	M	.	.	.	33	27	157	.	8
2	A	A	.	.	.	.	4	2	.	3
2	B	A	.	.	.	.	1	6	.	5
2	C	A	.	.	.	.	128	10	.	16
3	A	C	10	7	2	2	6	5	.	145
3	B	C	1	1	1	4	8	35	.	89
3	C	C	31	3	2	5	15	617	.	10
3	A	D	0	0	0	0	1	0	.	0
3	B	D	13	2	6	0	3	176	.	6
3	C	D	37	1	4	1	10	321	.	127
3	A	J	.	5	1	4	63	61	.	12
3	B	J	.	9	1	0	0	0	.	24
3	C	J	.	1	6	23	23	198	.	7
3	A	F	.	.	4	0	1	225	.	274
3	B	F	.	.	8	0	3	155	.	7
3	C	F	.	.	3	1	23	576	.	525
3	A	M	.	.	.	20	8	53	.	48
3	B	M	.	.	.	2	0	10	.	4
3	C	M	.	.	.	2	1	82	.	26
3	A	A	.	.	.	.	53	74	.	3
3	B	A	.	.	.	.	35	82	.	7
3	C	A	.	.	.	.	62	6	.	0

Table C9. Mean monthly yields of forbs (kg DM ha^{-1}).

Forage year	Block	Tmt	Month: Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
1	A	C	73	1	11	25	71	238	117	55
1	B	C	38	23	4	1	8	201	0	0
1	C	C	55	93	14	48	183	307	488	122
1	A	D	73	1	5	0	62	259	148	57
1	B	D	38	0	0	0	22	123	181	107
1	C	D	55	0	14	1	34	82	124	86
1	A	J	.	29	13	2	50	107	91	247
1	B	J	.	5	1	0	9	13	15	0
1	C	J	.	51	9	21	63	627	175	205
1	A	F	.	.	1	0	28	117	181	46
1	B	F	.	.	1	1	24	98	30	3
1	C	F	.	.	6	1	73	245	293	84
1	A	M	.	.	.	12	36	54	323	451
1	B	M	.	.	.	7	25	91	181	93
1	C	M	.	.	.	0	26	48	0	136
1	A	A	.	.	.	.	12	47	24	59
1	B	A	.	.	.	.	48	46	95	23
1	C	A	.	.	.	.	119	51	51	0
2	A	C	1	3	4	1	4	76	.	131
2	B	C	8	3	10	62	138	539	.	42
2	C	C	13	16	0	3	19	164	.	251
2	A	D	13	13	1	8	32	180	.	259
2	B	D	4	1	6	19	14	358	.	50
2	C	D	28	2	3	9	29	152	.	79
2	A	J	.	4	1	7	43	175	.	505
2	B	J	.	27	22	32	13	47	.	5
2	C	J	.	25	3	13	106	396	.	162
2	A	F	.	.	3	4	42	316	.	101
2	B	F	.	.	1	3	19	197	.	4
2	C	F	.	.	4	1	40	205	.	401
2	A	M	.	.	.	12	114	229	.	1087
2	B	M	.	.	.	92	54	100	.	553
2	C	M	.	.	.	24	25	280	.	83
2	A	A	.	.	.	.	26	43	.	128
2	B	A	.	.	.	.	13	23	.	41
2	C	A	.	.	.	.	4	5	.	5
3	A	C	0	1	5	7	39	70	.	209
3	B	C	5	1	24	4	32	106	.	129
3	C	C	16	12	31	4	14	132	.	270
3	A	D	14	2	1	0	36	286	.	31
3	B	D	2	0	0	1	92	277	.	27
3	C	D	1	1	4	8	4	105	.	21
3	A	J	.	5	1	5	74	125	.	867
3	B	J	.	11	0	0	3	43	.	0
3	C	J	.	29	1	23	42	268	.	451
3	A	F	.	.	25	8	37	251	.	185
3	B	F	.	.	2	0	2	20	.	1
3	C	F	.	.	3	0	76	123	.	46
3	A	M	.	.	.	5	33	330	.	394
3	B	M	.	.	.	3	3	16	.	33
3	C	M	.	.	.	6	11	24	.	20
3	A	A	.	.	.	.	2	28	.	99
3	B	A	.	.	.	.	4	25	.	87
3	C	A	.	.	.	.	6	52	.	23

Table C10. Mean monthly yields of perennial ryegrass (kg DM ha^{-1}).

Forage			Month							
year	Block	Tmt	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
1	A	C	242	300	153	277	308	550	848	1413
1	B	C	326	174	367	240	514	582	1282	971
1	C	C	293	89	111	171	219	545	616	539
1	A	D	242	67	63	73	221	361	925	930
1	B	D	326	85	62	191	224	1063	2460	1436
1	C	D	293	68	123	207	365	789	826	874
1	A	J	.	331	77	138	257	1171	869	540
1	B	J	.	477	118	185	661	1895	1308	1404
1	C	J	.	222	86	89	271	1056	745	614
1	A	F	.	.	220	94	238	1127	796	1056
1	B	F	.	.	179	177	410	1735	1283	1172
1	C	F	.	.	257	97	330	1449	1225	581
1	A	M	.	.	.	227	189	1220	951	747
1	B	M	.	.	.	297	215	1860	741	1091
1	C	M	.	.	.	304	264	1809	1461	748
1	A	A	.	.	.	.	226	527	635	497
1	B	A	.	.	.	.	450	641	1755	1232
1	C	A	.	.	.	.	467	977	1053	1214
2	A	C	295	429	411	360	614	1326	.	2130
2	B	C	448	824	411	525	641	2198	.	3530
2	C	C	202	256	185	368	452	1599	.	956
2	A	D	447	242	118	319	495	1867	.	4115
2	B	D	463	146	111	169	441	1470	.	1159
2	C	D	351	205	182	218	464	2018	.	1659
2	A	J	.	420	124	153	452	1740	.	1733
2	B	J	.	607	165	411	893	3381	.	5167
2	C	J	.	337	46	115	309	1574	.	1465
2	A	F	.	.	330	119	352	1265	.	2475
2	B	F	.	.	550	327	900	3163	.	3005
2	C	F	.	.	380	102	482	1539	.	2195
2	A	M	.	.	.	173	354	776	.	1047
2	B	M	.	.	.	632	538	2298	.	5437
2	C	M	.	.	.	602	472	2022	.	2361
2	A	A	.	.	.	.	272	426	.	908
2	B	A	.	.	.	.	916	1673	.	2626
2	C	A	.	.	.	.	1115	1852	.	3114
3	A	C	384	288	238	181	640	1881	.	1429
3	B	C	489	552	536	475	1124	2773	.	2403
3	C	C	195	235	182	182	567	1193	.	862
3	A	D	258	28	93	119	345	706	.	1089
3	B	D	183	13	37	64	308	567	.	755
3	C	D	315	44	88	118	321	1271	.	1404
3	A	J	.	163	114	131	437	1188	.	878
3	B	J	.	909	305	580	1138	2878	.	2531
3	C	J	.	352	91	209	714	1516	.	1316
3	A	F	.	.	82	107	585	1085	.	1654
3	B	F	.	.	148	321	871	2204	.	2050
3	C	F	.	.	36	148	584	1382	.	1980
3	A	M	.	.	.	184	279	894	.	1186
3	B	M	.	.	.	634	376	1625	.	1587
3	C	M	.	.	.	413	344	1668	.	1785
3	A	A	.	.	.	.	347	279	.	578
3	B	A	.	.	.	.	832	782	.	2234
3	C	A	.	.	.	.	975	1172	.	3659

Table C11. Mean monthly number of perennial ryegrass tillers per m^2.

Forage year	Block	Tmt	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
			Month							
1	A	C	N/A	1045	928	1508	1315	1478	2173	3548
1	B	C	N/A	497	1095	1253	1603	705	785	1100
1	C	C	N/A	468	480	775	858	733	1032	1885
1	A	D	N/A	275	393	652	1132	1082	2057	3000
1	B	D	N/A	278	345	1503	1072	1838	5693	2015
1	C	D	N/A	592	745	1228	1718	1657	2037	2450
1	A	J	.	822	420	1317	1760	2087	2393	2155
1	B	J	.	1645	762	1150	3960	3555	2547	1538
1	C	J	.	1045	627	782	1202	1137	1558	2490
1	A	F	.	.	1092	832	1558	1785	2411	4822
1	B	F	.	.	898	1305	2707	1982	1310	2692
1	C	F	.	.	1270	750	1912	2608	1135	2253
1	A	M	.	.	.	1498	1405	2798	3242	2133
1	B	M	.	.	.	1833	1540	3747	923	1247
1	C	M	.	.	.	1415	1522	2352	1008	1337
1	A	A	.	.	.	.	1468	2362	2325	933
1	B	A	.	.	.	.	1445	2608	2203	1643
1	C	A	.	.	.	.	2132	3402	1385	1253
2	A	C	2222	3077	4558	4233	7039	5180	.	5026
2	B	C	2557	7180	3385	4947	4558	3713	.	3975
2	C	C	1675	1613	1015	2823	3253	2973	.	2307
2	A	D	2378	2038	1155	3740	5031	6254	.	6401
2	B	D	2460	1553	962	1503	4220	3354	.	2200
2	C	D	3190	2025	1763	2337	5470	6225	.	3771
2	A	J	.	3083	1082	2540	5140	5785	.	3644
2	B	J	.	4805	2163	6020	10918	8898	.	9803
2	C	J	.	2092	557	1034	2315	4212	.	3868
2	A	F	.	.	2165	2113	3781	5213	.	4188
2	B	F	.	.	4398	4778	7539	7687	.	4912
2	C	F	.	.	2425	1562	4221	4679	.	5158
2	A	M	.	.	.	1423	5538	3268	.	2992
2	B	M	.	.	.	6962	6562	6973	.	6054
2	C	M	.	.	.	5462	6127	4674	.	9481
2	A	A	.	.	.	.	2826	3650	.	2283
2	B	A	.	.	.	.	5503	5351	.	6268
2	C	A	.	.	.	.	8930	7347	.	7263
3	A	C	1793	1550	2861	2728	4284	7536	.	4524
3	B	C	3581	3196	4420	4756	5293	5287	.	6591
3	C	C	1197	1289	1452	1481	3028	2740	.	1975
3	A	D	2158	420	1144	1811	2636	1777	.	2775
3	B	D	1626	157	576	629	1796	1232	.	1313
3	C	D	2059	707	1333	1809	2497	3095	.	3498
3	A	J	.	1098	1572	1896	4228	3335	.	2353
3	B	J	.	6395	3603	6797	6709	5176	.	4243
3	C	J	.	1943	1165	1808	4012	4019	.	3928
3	A	F	.	.	2038	2190	4585	3604	.	5065
3	B	F	.	.	4532	4808	5615	5298	.	4050
3	C	F	.	.	3792	2479	2934	4147	.	3677
3	A	M	.	.	.	2242	4127	3860	.	2958
3	B	M	.	.	.	6717	2950	4107	.	2747
3	C	M	.	.	.	3991	3879	5238	.	5169
3	A	A	.	.	.	.	2436	2032	.	1383
3	B	A	.	.	.	.	5225	4047	.	4147
3	C	A	.	.	.	.	4889	5334	.	5163

Table C12. Mean monthly number of leaves per perennial ryegrass tiller.

Forage year	Block	Tmt	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
1	A	C	N/A	N/A	2.0	2.0	2.4	2.4	2.5	2.5
1	B	C	N/A	2.0	2.3	2.1	2.4	2.7	3.3	2.2
1	C	C	N/A	2.0	2.0	2.0	2.2	2.8	2.7	2.7
1	A	D	N/A	N/A	2.0	2.0	2.2	2.8	2.6	2.8
1	B	D	N/A	1.8	2.0	2.1	2.4	3.0	3.0	2.6
1	C	D	N/A	1.8	2.0	2.2	2.4	2.7	2.8	2.4
1	A	J	.	N/A	1.9	2.1	2.5	2.8	2.5	2.4
1	B	J	.	N/A	2.0	2.3	2.3	2.9	2.3	2.6
1	C	J	.	2.0	1.9	2.1	2.4	2.9	2.8	2.7
1	A	F	.	.	2.2	1.8	2.3	2.9	2.5	2.5
1	B	F	.	.	2.2	2.1	2.3	3.4	2.4	2.5
1	C	F	.	.	2.0	1.8	2.3	2.8	2.3	2.5
1	A	M	.	.	.	2.0	2.0	3.0	3.0	2.4
1	B	M	.	.	.	2.2	2.1	2.8	2.6	2.8
1	C	M	.	.	.	2.1	2.0	3.1	2.3	2.2
1	A	A	.	.	.	.	2.6	2.7	2.6	2.9
1	B	A	.	.	.	.	2.3	2.4	2.5	2.4
1	C	A	.	.	.	.	2.4	2.4	2.6	2.2
2	A	C	2.4	2.4	2.1	2.2	2.7	2.9	.	2.6
2	B	C	2.5	2.4	2.2	2.4	2.5	2.5	.	2.5
2	C	C	2.4	2.2	2.1	2.3	2.3	2.7	.	2.6
2	A	D	2.7	1.7	1.5	1.9	2.4	2.9	.	2.8
2	B	D	2.4	1.9	1.3	2.0	2.4	3.0	.	2.4
2	C	D	2.5	1.8	1.6	2.2	2.4	2.9	.	2.7
2	A	J	.	2.3	1.6	1.6	2.3	2.9	.	2.7
2	B	J	.	2.4	1.6	2.2	2.4	3.0	.	2.9
2	C	J	.	2.3	1.5	2.1	2.4	2.6	.	2.7
2	A	F	.	.	2.2	1.6	2.4	3.0	.	2.9
2	B	F	.	.	2.4	2.1	2.2	2.9	.	2.6
2	C	F	.	.	2.3	1.4	2.4	2.7	.	2.8
2	A	M	.	.	.	1.9	2.2	2.8	.	2.5
2	B	M	.	.	.	2.2	2.1	2.8	.	2.6
2	C	M	.	.	.	2.4	2.1	2.7	.	2.5
2	A	A	.	.	.	.	2.5	2.3	.	2.8
2	B	A	.	.	.	.	2.4	2.4	.	2.8
2	C	A	.	.	.	.	2.2	2.4	.	2.8
3	A	C	2.2	1.9	1.8	2.0	2.3	2.8	.	2.0
3	B	C	2.3	2.1	2.0	2.0	2.3	3.0	.	2.3
3	C	C	2.1	2.0	1.9	1.9	2.2	2.8	.	2.3
3	A	D	2.2	1.1	1.5	1.9	2.4	3.0	.	2.1
3	B	D	1.4	1.3	1.5	2.2	2.4	2.6	.	2.0
3	C	D	2.2	1.3	1.7	2.1	2.3	2.6	.	2.0
3	A	J	.	2.0	1.6	2.1	2.4	2.7	.	2.2
3	B	J	.	2.0	1.7	2.2	2.4	2.6	.	2.1
3	C	J	.	2.0	1.6	2.0	2.2	2.8	.	2.1
3	A	F	.	.	1.8	1.6	2.5	2.9	.	2.3
3	B	F	.	.	2.0	1.5	2.3	2.7	.	2.2
3	C	F	.	.	1.9	1.6	2.3	2.7	.	2.2
3	A	M	.	.	.	2.1	2.2	2.7	.	2.3
3	B	M	.	.	.	1.9	2.2	2.8	.	2.4
3	C	M	.	.	.	2.1	2.2	2.6	.	2.0
3	A	A	.	.	.	.	2.3	2.4	.	2.3
3	B	A	.	.	.	.	2.3	2.2	.	2.3
3	C	A	.	.	.	.	2.6	2.1	.	1.9

Table C13. Mean root mass (g per plant) in September, December, March and July, 1985-86 (roots which passed through a 4 mm^2 mesh are small roots).

Tmt	Block	Month	Main Root	Small Root
C	A	SEP	6.44	5.47
C	B	SEP	5.29	4.97
C	C	SEP	6.22	2.67
D	A	SEP	4.42	-
D	B	SEP	5.48	5.59
D	C	SEP	5.71	2.82
J	A	SEP	5.26	1.87
J	B	SEP	5.36	2.75
J	C	SEP	5.27	3.14
F	A	SEP	4.65	1.57
F	B	SEP	5.67	4.58
F	C	SEP	5.64	3.19
M	A	SEP	6.33	5.21
M	B	SEP	5.87	4.14
M	C	SEP	4.41	3.87
A	A	SEP	5.68	1.75
A	B	SEP	6.49	4.69
A	C	SEP	5.62	3.68
C	A	DEC	4.09	1.96
C	B	DEC	3.37	3.42
C	C	DEC	2.72	2.86
D	A	DEC	3.35	3.17
D	B	DEC	3.97	5.54
D	C	DEC	3.00	2.84
J	A	DEC	5.02	4.81
J	B	DEC	3.30	3.79
J	C	DEC	3.01	2.40
F	A	DEC	2.51	2.19
F	B	DEC	2.77	2.07
F	C	DEC	3.77	4.39
M	A	DEC	3.84	4.40
M	B	DEC	4.57	5.09
M	C	DEC	2.64	2.67
A	A	DEC	2.75	3.09
A	B	DEC	3.43	4.61
A	C	DEC	2.81	3.36
C	A	MAR	3.66	3.98
C	B	MAR	3.93	2.76
C	C	MAR	2.95	2.99
D	A	MAR	2.76	3.57
D	B	MAR	3.05	3.92
D	C	MAR	3.89	2.38
J	A	MAR	2.89	3.30
J	B	MAR	4.61	2.66
J	C	MAR	2.25	3.24
F	A	MAR	3.80	1.29
F	B	MAR	4.04	2.28
F	C	MAR	4.04	2.97
M	A	MAR	2.71	2.05
M	B	MAR	3.84	2.66
M	C	MAR	2.28	2.98
A	A	MAR	2.11	4.97
A	B	MAR	3.10	3.29
A	C	MAR	3.10	2.74

Tmt	Block	Month	Main Root	Small Root
C	A	JUL	4.60	3.36
C	B	JUL	4.32	2.04
C	C	JUL	3.44	1.52
D	A	JUL	6.38	2.53
D	B	JUL	4.76	2.57
D	C	JUL	4.34	2.73
J	A	JUL	4.66	2.39
J	B	JUL	5.90	4.16
J	C	JUL	3.22	1.86
F	A	JUL	4.32	3.61
F	B	JUL	4.59	2.95
F	C	JUL	3.57	1.63
M	A	JUL	5.14	5.09
M	B	JUL	4.74	2.88
M	C	JUL	4.25	1.92
A	A	JUL	5.35	6.04
A	B	JUL	5.66	1.83
A	C	JUL	3.58	1.23

Table C14. Mean basal area (cm^2), density (plants per m^2), and basal area per m^2 in September and May with and without plants <2 cm^2 in basal area (juviniles).

			Without plants <2 cm			With plants <2 cm		
Month	Block	Tmt	Basal Area	cm /m	Density	Basal Area	cm /m	Density
SEP	A	C	9	961	114	13	894	72
SEP	B	C	17	1228	79	21	1187	53
SEP	C	C	13	910	79	17	878	59
SEP	A	D	17	1460	89	23	1413	59
SEP	B	D	12	916	77	18	873	50
SEP	C	D	11	730	75	16	678	42
SEP	A	J	12	992	86	17	938	53
SEP	B	J	27	2122	84	34	2093	66
SEP	C	J	12	950	83	14	922	65
SEP	A	F	14	1431	104	22	1364	62
SEP	B	F	17	1274	79	26	1227	49
SEP	C	F	14	1306	95	17	1280	78
SEP	A	M	11	884	75	16	842	49
SEP	B	M	30	1906	64	36	1888	52
SEP	C	M	12	960	82	17	915	54
SEP	A	A	7	600	81	10	548	49
SEP	B	A	16	1282	83	18	1259	68
SEP	C	A	15	1011	67	19	985	51
MAY	A	C	14	1369	96	15	1379	88
MAY	B	C	20	1616	86	20	1605	79
MAY	C	C	12	1039	88	13	1020	76
MAY	A	D	13	1540	116	16	1509	96
MAY	B	D	11	907	80	11	907	80
MAY	C	D	10	912	90	12	885	73
MAY	A	J	17	1483	91	17	1475	86
MAY	B	J	24	1997	86	25	1988	80
MAY	C	J	15	1402	96	17	1380	83
MAY	A	F	15	1390	91	17	1379	84
MAY	B	F	20	1921	96	22	1912	90
MAY	C	F	18	1689	98	20	1672	87
MAY	A	M	13	1356	102	14	1342	93
MAY	B	M	18	1626	92	19	1617	87
MAY	C	M	16	1522	93	17	1507	83
MAY	A	A	9	811	91	10	790	78
MAY	B	A	21	2025	95	22	2023	94
MAY	C	A	17	1778	112	18	1756	100