Pasture production, nitrogen responses and sheep liveweight gain from Caucasian and white clover pastures

A dissertation
submitted in partial fulfilment
of the requirements for the Degree of
Bachelor of Agricultural Science
with Honours
at
Lincoln University
by

Elliot P. Scott

Lincoln University
2001

Abstract

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The autumn pasture production and liveweight gain (LWG) from Caucasian and white clover / ryegrass pastures, maintained at high and low soil fertility, were measured in a grazing experiment at Lincoln University, Canterbury. Caucasian clover pastures had 10% greater autumn / early winter dry matter production than white clover pastures (7840 c.f. 7120 kg DM ha^{-1}, P = 0.006). Total clover production from Caucasian clover pastures (total 2300 kg DM ha^{-1}) was 2.15 times greater than white clover pastures (P < 0.000). Although when compared to white clover, Caucasian clover pastures offered to lambs contained a greater pre-grazing clover content (20.5 c.f. 10.1%, P = 0.006), LWG $head^{-1}$ was similar on both pastures (Caucasian clover 109 g hd^{-1} d^{-1}, white clover 80 g hd^{-1} d^{-1}, P = 0.373). A higher stocking rate was sustained on high compared to low fertility farmlets (39.9 c.f. 37.5 lambs ha^{-1}, P = 0.058), also there were 24 more grazing days (490 c.f. 466 grazing days, p = 0.034) on high fertility pastures even though LWG ha^{-1} was similar (high fertility 3.76 kg ha^{-1} d^{-1}, low fertility 3.56 kg ha^{-1} d^{-1}, P = 0.871).

In another experiment, the response of Caucasian and white clover based pastures, at high and low soil fertility, to the autumn application of nitrogen (120 kg N ha^{-1}) was evaluated to establish the suitability of Caucasian clover in dairy pastures. The application of N increased pasture production by 3.5-3.9 kg DM ha^{-1} kg N^{-1} (P = 0.285, 0.228), less than the commonly expected response of 10 kg DM ha^{-1} kg N^{-1}. Pasture clover content was not affected by N application at any harvest (0.283 < P < 0.786). However, total clover production was 2.15 times greater in Caucasian clover compared to white clover pastures (2300 c.f. 1080 kg DM ha^{-1}, P < 0.000). Chemical analysis of the grass components indicated that the application of 420 kg N ha^{-1} over the previous 12 months had increased the mean N content in ryegrass (3.98 c.f. 3.70%, P < 0.000) and annual grass (4.48 c.f. 4.16%, P = 0.026) compared to plots that did not receive N. The lack of response to the applied N was attributed to a number of factors including the short defoliation interval (22 days), the availability of mineralised N from the fertile soil after four years of N_2 fixation, annual grass content of the pasture (22-28%) and mealy bug infestation in ryegrass.

In a third experiment, the success of transplantation of Caucasian clover seedlings into two dairy pastures in autumn 1998, three years previously, was evaluated to determine whether Caucasian clover can survive and spread under dairy farm management and N inputs. Of the Caucasian clover plants that were transplanted, approximately 30% had survived until autumn 2001. The mean plant diameter of the surviving plants was 106 mm and 182 mm in paddocks with and without regular N fertiliser application, respectively. Total visual clover cover in early May was 19-47% where Caucasian clover seedlings had been transplanted and 15-31% at an adjacent site.

These short-term studies were inconclusive in showing that increased legume content and total dry matter production from Caucasian clover pastures will lead to increased animal productivity. However, even in a high N environment (420 kg N ha^{-1} yr^{-1}), Caucasian clover pastures produced more total legume than white clover pastures, and a long-term study to determine the suitability of Caucasian clover for dairy pastures is warranted.

Keywords: annual grass, autumn pastures, Caucasian clover, ewe lambs, liveweight gain, *Lolium perenne*, nitrogen fertiliser, pasture production, pasture composition, ryegrass, soil fertility, *Trifolium ambiguum*, *T. repens*, white clover.

Table of Contents

List of Figures

List of Tables

List of Plates

1 Introduction

New Zealand pastures typically have a clover content of less than 20% (Moss, 1987; Ettema and Ledgard, 1992). This is lower than that required for maximum nitrogen (N) fixation and animal performance (Widdup, Purves, Black, Jarvis and Lucas, 2001; Chapman, Parsons and Schwinning, 1996; Harris, 1997). The dominance of grass in pastures to the detriment of the legume component is undesirable, as it both lowers the nutritional quality of the pasture and N inputs from legume N_2 fixation. Increasing (white and / or red) clover content has been shown to increase animal productivity (Caradus, Harris and Johnson, 1996; Harris, 1997; Thom, Burggraf, Waugh and Clark, 2001).

In the past, research on the legume content of New Zealand pastures has focused on white clover (*Trifolium repens*), as it has been considered the most important forage legume in New Zealand (Brock, Caradus and Hay, 1988; Hay and Hunt, 1989; Langer, 1990), which can be used over a range of environmental conditions (Caradus, Hay and Woodfield, 1996). However, in dry conditions, or where fertiliser input is less than recommended in more intensive production systems, in more humid environments, other clovers may be more suitable.

Recently, research on Caucasian clover (*Trifolium ambiguum* M. Bieb.), an alternative to white clover, has increased (e.g. Watson, Neville, Bell and Harris, 1997; Black, Pollock, Lucas, Amyes, Pownall and Sedcole, 2000). Caucasian clover has been introduced to high fertility lowland sites as a means of increasing legume content and pasture quality in irrigated (Moss, Burton and Allan, 1996; Black *et al.,* 2000) and dryland environments (Watson, Neville, Bell and Harris, 1996b; Watson Neville and Bell 1998; Black and Lucas, 2000).

Caucasian clover was shown to have a similar nutritive value to white clover (Allinson, Speer, Taylor and Guillard, 1985) and it has therefore been suggested as a possible alternative legume on intensive dairy farms (Watson *et al.,* 1997). On such farms, competition between white clover and N-stimulated grass typically results in pastures with a low clover content (Harris, Clark, Waugh and Clarkson, 1996). There is a possibility that the morphology of Caucasian clover will enable it to compete more successfully with perennial ryegrasses than white clover, particularly in high fertility soils where N fertiliser is used, as the underground growing points and taproot retention of Caucasian clover appear to facilitate better pasture clover production during summer (Watson *et al.,* 1997).

Lamb liveweight gain (LWG), pasture production and composition are being compared on white and Caucasian clovers at two levels of soil fertility in an ongoing grazing experiment at Lincoln University. In this experiment, Black *et al.* (2000) showed that LWG were similar in the second year after sowing. However, in the third year, lambs grazing Caucasian clover based pasture had a LWG greater than on white clover (139 g hd^{-1} d^{-1} c.f. 118 g hd^{-1} d^{-1}). Production ha^{-1} was also found to be higher in Caucasian clover based pastures (2.70 kg ha^{-1} d^{-1}) compared to white clover based pastures (3.22 kg ha^{-1} d^{-1}).

In addition to the above experiment, Maw (2000) attempted to determine the effect of defoliation frequency and autumn and late winter N fertiliser applications on the dry matter yield and botanical composition of Caucasian clover / ryegrass and white clover / ryegrass pastures. The results from the experiment showed a response of 7.9 kg DM ha^{-1} kg N^{-1} in autumn, with no difference in dry matter yield between fertility or clover treatments. There was a higher clover content in Caucasian clover plots (13.5%) compared to white clover plots (9.1%, $P < 0.155$). However, pasture composition was not affected by the application of N.

A review of literature in Chapter Two of this dissertation focuses on competition in pasture swards. The interactions between white clover and other legumes, and white clover and ryegrass and N in a pastoral environment are also covered. Caucasian clover is reviewed as an option to increase the legume content of lowland pastures. Chapter Three reports the findings of the grazing experiment in its fourth autumn. Liveweight gain, pre-grazing pasture mass and composition and post-grazing pasture mass were measured. Chapter Four reports on a subsequent second year in the study of the effect of N on Caucasian and white clover at high and low soil fertility in the grazing experiment, the first year was reported by Andrew Maw in his B. Agr. Sci. Hons dissertation (Maw, 2000). The effect of N fertiliser on the production of Caucasian clover, white clover and ryegrass in the plots was assessed, along with the N content of pasture components. Chapter Five reports the clover content of two dairy farm pastures where individual plants of Caucasian clover had been transplanted three years previously. Chapter Six is a general discussion of the autumn LWG of ewe lambs on the Lincoln University grazing experiment and on the use of Caucasian clover in lowland New Zealand pastures.

The objectives of this study were to:

1. Compare pasture production and subsequent lamb liveweight gain from Caucasian and white clover pastures under high and low phosphate and sulphur soil fertility in the fourth autumn of an ongoing grazing experiment.

2. Conclude the study of the interaction between N-stimulated grass, and two clover species (Caucasian and white) in a grazed experiment.

3. Report the survival and spread of Caucasian clover that was transplanted to dairy pastures three years previously.

4. Compile and discuss the liveweight gain data for four successive autumn grazing periods from the grazing experiment.

5. Discuss the place and value of Caucasian clover as an alternative to white clover in temperate lowland pastures.

2 Literature review

2.1 Introduction

The competition between plants in a pasture sward is difficult to evaluate as both intra- and inter-specific forces are present. The ability of individual plants to capture light nitrogen (N) and water in the "dynamic equilibrium" of grass / legume mixtures is an important determinant in the effect of competition on each plant. Grime (1974) developed a model of plant strategies in response to varying levels of stress and disturbance and attempted to classify individual species according to their strategy.

This review of literature will cover aspects of competition in pastures and will attempt to use the model of Grime (1974) to classify the strategies of ryegrass, Caucasian and white clover in pastures. The competition between white clover and red and subterranean clovers and between white clover and ryegrass will also be covered. The ability of Caucasian clover to increase the legume content N_2 fixation ability and animal production from of New Zealand pastures is also discussed. It should be noted that there is a lack of literature on Caucasian clover competition with white clover and ryegrass and the interaction with N fertiliser.

2.2 Pasture dynamics

When considering the forces that drive pasture dynamics, both in relation to productivity and botanical composition, it is necessary to distinguish between:

1. Environmental stresses that directly limit plant growth and survival,
2. Plant interactions that may be beneficial by reducing environmental stresses, but are more often competitive where adjacent plants interfere with each others growth and survival, and
3. Disturbances such as cultivation and grazing, which modify interactions among plants, competitive and otherwise (Harris, 1990).

2.3 Competition

Competition between plants can be defined as "the interactions between individuals due to the necessity to share limited resources, leading to a decline in the number of surviving plants and

/ or a reduction in their growth" (Begon, Harper and Townsend, 1986, cited in Lemaire, 2001). In the exact sense, two plants do not compete with each other as long as water, nutrients, oxygen, carbon dioxide (CO_2) and light are in excess, and there is adequate heat. It is generally accepted that the more similar the needs of the two organisms, the more intense the contest (Haynes, 1980).

The intensity of competition is difficult to evaluate. In practice, the intensity of competition has been evaluated only through its observed effects on the two competitors by the measurement of the reduction in performance relative to performance in the absence of competition. In theory, "for each condition of competition (nature of the limiting resource) the intensity of the competition should be proportional to the deficiency relative to the individual requirement for the limiting resource of the two competitors" (Lemaire, 2001). However, it is difficult to evaluate the level of availability of the same resource shared between two competitors.

In a sward, plants experience both intra- and inter-specific competition. Intuitively, competition between plants of the same species is expected to be much greater, because they have the same demands for resources on both a temporal and spatial basis (Lemaire, 2001). However, in mixed swards, the effects of both forms of competition interact. As stressed by Turkington (1983), the dynamic aspects of competition have rarely been studied.

2.3.1 Light / Nitrogen

To understand the competitive relationships among individual plants, it is necessary to know the hierarchies between the different requirements for plant growth and development under different environmental constraints (Lemaire, 2001). In natural environments, the source of CO_2 is continuously renewed with a more or less constant concentration. However, the level of light capture determines the use of CO_2 by a plant. Carbon dioxide assimilated by plants provides not only carbon skeletons for plant growth, but also energy for maintenance and activation of all metabolic functions. This greatly determines the uptake capacity of the plant for N and minerals. So, the level of light capture by a single plant should also determine its ability to take up N and minerals. Therefore, competition for N and mineral resources in the soil between two plants should depend on their specific ability to capture these resources (root architecture and absorption properties of the root tissues), but should also be greatly influenced by their own hierarchical position within the plant population in relation to light capture (Lemaire, 2001).

In an established pasture, a "dynamic equilibrium" operates. It is brought about through increased grass growth from the transferred N, which results in grass becoming more competitive for other factors, which are in limited supply. This has consequential increases in the shading of neighbouring clover plants (Harris, 1990). So, as a plant population develops, competition for light between dominant and dominated plants increases, and the more shaded plants become unable to absorb soil N due to the lack of energy provided to their roots (Lemaire, 2001). In consequence, small initial differences in light interception among individuals within a plant population are progressively emphasised by the inability of the shaded plants to satisfy their N demand for maximising leaf expansion for light capture.

The interaction between light capture and N uptake plays a critical role in the dynamics of grass / legume mixtures. The sharing of N resources among grasses and legumes is constrained by interactions for light capture that implies that "any advantage taken by one species in N acquisition provokes a corresponding disadvantage for the other species so that the "average plant" dynamics at the whole plant population level is maintained" (Lemaire, 2001).

A series of experiments by Blackman (1934; 1938) and Blackman and Templeman (1938) involving different N formulations, associate grasses and shading led to the conclusion that the balance between legumes and grasses in swards depends largely on the competition for light. As the density and height of grasses was positively correlated with N supply, additional N depressed white clover by increasing shading, rather than by any direct effect of N on the clover.

The ability of legumes to obtain their N from two sources (i), N_2 fixation and (ii) soil mineral N, gives them a competitive advantage over grasses when soil N supply is low (Lemaire, 2001). However, when a large supply of N occurs in soil, legumes are disadvantaged for light capture and light use efficiency. Additionally their ability to fix N_2 declines. As a result, changes in the balance between grasses and legumes in swards will cause fluctuations in soil mineral N concentration. This, combined with selective grazing of clover (Chapman *et al.*, 1996), results in the complex dynamics of grass / legume populations characterised by cyclic dominance of one species over the other at patch levels as stated in the models of Thornley, Bergelson and Parsons (1995) and Schwinning and Parsons (1996a; 1996b).

White clover has an optimum temperature for growth of about 24°C compared with 20°C for ryegrass (Mitchell, 1956). Also, the horizontal orientation of white clover leaves allow it to recover the capacity for light interception more rapidly following defoliation. It follows that closer or more frequent grazing in autumn, winter and early spring generally increases the white clover content of swards, but the opposite response occurs from late spring and through the summer months (Valentine and Matthew, 1999).

2.3.2 Water

The amount of water that is absorbed and transpired by a single plant is in proportion to the amount of solar energy intercepted. So, as for N and mineral resources, competition for water among plants within a population is largely driven by the competition for light (Lemaire, 2001). Water is not only a "resource" for plant growth, but also is a means for dissipating the excess of solar energy received by leaves in order to avoid plant tissue desiccation through the cooling effect of transpiration. Therefore, in some circumstances, plants can derive some benefit from shading by their neighbours through a decrease in their own water demand, although this cannot be maintained after the soil water resources are depleted.

Radcliffe (1974) found in standardised measurements of grazed pastures at 11 geographically dispersed sites that year-to-year variation in clover content at several sites was greater than site-to-site variation. Between year variation was least for the high rainfall sites, which suggests that much of the year-to-year variation in clover content may be principally associated with rainfall. Harris (1987) also found that white clover content usually rises in years, and especially summers, with adequate soil moisture.

2.4 C – S – R model of competition

Grime (1973) defined competition between plants as the tendency of neighbouring plants to utilise the same quanta of light, ions of mineral nutrients, molecules of water or volume of space. Competition has led to the evolution of strategies that are different from those which enable plants to withstand extremes of environmental stress or predation. Grime (1974) developed a model of three plant strategies: competitive (C), stress-tolerant (S) and disturbance tolerator or ruderal (R) to describe the primary growth of plants (Figure 2.1).

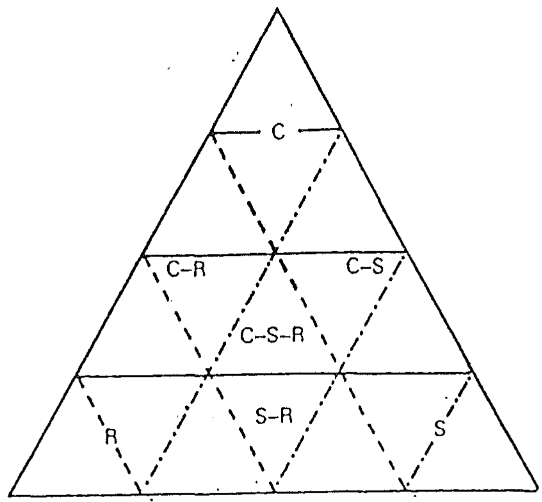

Figure 2.1 A model describing the various intermediates between competition, stress and disturbance (ruderal) in vegetation, and the location of primary and secondary strategies. C, competitor; S, stress-tolerator; R, ruderal; C – R, competitive ruderal; S – R, stress-tolerant ruderal; C – S, stress tolerant competitor; and C – S – R strategist.

(Adapted from Grime, Hodgson and Hunt, 1990).

Stress and disturbance together comprise the stimulus which prevent the resolution of competition. Combinations of environments with high and low stress and disturbance give rise to the three plant strategies (Table 2.1). The C – S – R balance is not constant and in any community it varies both spatially and temporally.

Table 2.1 The basis for the evolution of three strategies in plants.

Intensity of disturbance	*Intensity of stress*	
	High	Low
Low	Competitors	Stress-tolerators
High	Ruderals	(No viable strategy)

(From Grime *et al.*, 1990).

2.4.1 Pastures

Pastures are located near the centre of the C – S – R triangle i.e. competition, stress and disturbance are all important, but none is overwhelming (McIvor, 2001). The relative importance of the different forces can vary markedly between seasons, for example, tolerance of drought stress during infrequent drought may be critical for the long-term persistence of plants. Management can be viewed as manipulation of competition (species selection for sowing in mixtures), stress (fertiliser application, drainage, irrigation), disturbance (grazing, mowing, herbicide application) and their interactions (changes to stress and disturbance levels can change the competitive relationships between species).

In many pasture situations, farmers are aiming for low species numbers (often only two or three). However, efforts are often frustrated as other species establish and persist sometimes to the point of dominance. A general conclusion from Grime's model is that species diversity is greatest at intermediate levels of disturbance (McIvor, 2001). At high levels of disturbance most species cannot tolerate the disturbance regime, and, at low disturbance, the vegetation is dominated by a few competitive species. Disturbance levels are intermediate in many pastures, favouring more species rather than the two or three in ideal pasture.

2.4.2 Ryegrass

The strategy of ryegrass has been described by Grime *et al.* (1990) as being between C – R and C – S – R. Ruderal characteristics include limited lateral spread, a short establishment phase, production of flowers early in life history, seasonal regeneration in vegetation gaps and a rapid curtailment of vegetative growth in response to resource depletion with the diversion of resources into flowering (Grime *et al.,* 1990). Competitive characteristics include well-defined peaks of leaf production coinciding with periods of maximum potential productivity, production of flowers after these periods and a high relative growth rate. Ryegrass will also establish at cooler temperatures and lower soil water contents than most other potential competitors. The ability to avoid some of the more severe effects of defoliation with vertically orientated leaves and by remaining closely packed together in dense tufts or clumps is a stress tolerating characteristic of ryegrass (Brock and Hay, 2001).

2.4.3 White clover

Grime *et al.* (1990) also described white clover growth strategy as being between C – S – R and C – R, similar to that of ryegrass. In the New Zealand environment, with the occurrence of drought and frost, white clover does not appear to display many stress tolerant features (Dodd, Sheath, Wedderburn and Tarbotton, 2001). However, it does show strong competitive and ruderal characteristics. Competitive characteristics include rapid attainment of light interception by horizontal leaf arrangement and canopy adjustments arising from changes of petiole length, presence of dormant buds on stolons and high relative growth rate with the ability to spread widely by stolon growth. The ability to explore both the soil and aerial environment, the use of fixed atmospheric N_2 rather than mineral N from the soil and storage of mineral nutrients in stolons to boost next seasons growth are also competitive strategies used by white clover (Harris, 1987; Grime *et al.,* 1990; Brock and Hay, 2001). Ruderal characteristics include flowering in early life history, high frequency of flowering, a proportion of annual production devoted to seed production and the production of a large dormant seed bank.

2.4.4 Caucasian clover

Caucasian clover could be described as being more of a C – S than a C – S – R. Competitive characteristics include a high, dense canopy of leaves, in a rapidly ascending monolayer and extensive lateral spread above and below ground. Forde, Hay and Brock (1989) described Caucasian clover as a 'guerilla' species, which uses considerable resources in rhizome production (as opposed to investment in the parent plant). It has well defined seasonal production coinciding with periods of maximum potential productivity, low input into seed production, regenerates mostly via dormant buds on rhizomes rather than dormant seed and uses fixed atmospheric N_2 rather than mineral N from the soil. Stress tolerant characteristics include long-lived roots, with storage in both rhizomes and roots (Strachan, Nordmeyer and White, 1994) and adaptation to changes in mineral nutrition and seasonal changes in temperature, light and moisture supply (Byrant, 1974; Dear and Zorin, 1985). These stress tolerant characteristics can result in a very persistent phase of up to at least 20 years in a high country environment (Yates, 1993).

The underground growth habit of Caucasian clover rhizomes confers protection from frequent and intensive defoliation (Peterson, Sheaffer, Jordan and Christians, 1994). During winter, up to 90% of the white clover stolon mass can be buried through treading by stock and the activity of earthworms (Hay, Chapman, Hay, Pennell, Woods and Fletcher, 1987). Lateral spread of individual Caucasian clover plants is therefore often greater than white clover, since new white clover plants slough off from parent plants as surviving stolon segments, thus displaying a completely different survival strategy.

Caucasian clover is not well adapted to colonising new sites. Although it does produce hard seed that is capable of surviving passage through the grazing animal to germinate in the dung, there is little or none of the specific rhizobia that is required to effectively nodulate the clover plants in New Zealand soils (Pryor, Lowther and Trainor, 1996). As the rhizobia are absent from New Zealand soils, the nodulation of seedlings and rhizome roots is dependent on the spread of specific rhizobia in the soil. In their study, lateral movement of rhizobia in the soil did not exceed 6 cm per year, which was slightly less than recorded rates of rhizome expansion. So although 'natural reseeding' has the ability to 'thicken-up' swards of Caucasian clover, the slow spread of rhizobia indicates that nodulation failures will limit the extent of spread into areas not previously sown in Caucasian clover.

2.4.5 Weed invasion

In agricultural terms, weed invasion is the colonisation by an undesirable species that interferes with human activities (McIvor, 2001). Many weeds are R or C – R strategists with rapid growth rates, high seed production, seed dormancy and wide dispersal. Grant and Ball (1970) studied the location of barley grass (*Hordeum murinum*) and goose grass (*Bromus mollis*) in pastures. They found they were usually located along ridge tops in terrace areas and in flat land on small humps, or where the pasture had been disturbed around haystack sites or tile drain backfill, indicating the ruderal strategies of both species.

Since weed invasion is greater where competition is less, the use of competitive species can be a satisfactory control measure, particularly if combined with other management practices. However, while perennial grasses can limit weed invasion, they can also limit legume regeneration. Black and Lucas (2000) found that when white clover was sown with cocksfoot, both clover and weed content were reduced, compared to the less competitive species ryegrass, grazing brome, phalaris or tall fescue.

2.5 White clover and red clover

In studies of short rotation ryegrass in association with red and white clover Brougham (1959), found that the prostrate growing stoloniferous characteristics of white clover resulted in greater production than ryegrass or red clover under a frequently grazed pasture. This was in direct contrast to the other two species where they produced most under infrequent grazing. It was concluded that frequent grazing allowed light to get into the base of the sward and gave white clover a competitive advantage over red clover. Harkess, Hunt and Frame (1970), also concluded that white clover when sown in pasture mixtures was under greater competitive stress under infrequent as opposed to frequent cutting regimes.

Under long spelling summer conditions, Brougham (1965) observed marked reductions in the numbers of white clover leaves present, and leaf numbers unit area^{-1} were much lower where red clover dominated. In addition, the white clover leaves that did develop were much more etiolated than those that developed in pure stands of white clover. These effects were attributed to the different light environments under which the white clover leaves had developed, which were of a consequence of shading from red clover plants.

Brougham (1965) followed by stating that in the mixed stands, the taller growing canopy of red clover leaves would intercept most of the incoming radiation so that both the intensity and spectral composition of light reaching the white clover leaves would be reduced and markedly altered. Following successful establishment of both species, when red clover is allowed to dominate white clover over the summer, leaf growth and consequently the current N_2 fixing capacity of white clover are markedly affected. However, as red clover will also be fixing N_2 this will not be a major concern. When the red clover population declines after three or four years, white clover is then able to exploit gaps left by red clover and it maintains total clover production through its 'guerilla' growth habit.

2.6 White clover and subterranean clover

When white and subterranean clovers were sown in replacement mixtures, Hill and Gleeson (1990) observed that they interfere competitively with one another in different ways and at different times, depending on whether white clover regenerates as an annual, from seed, or as a perennial from surviving stolons. Hafia white clover produced large fully expanded leaves beneath which only a few young expanding leaves were present. This resulted in a sward made up of large, heavy, tall leaves with a relatively low vertical leaf density. Seaton Park subterranean clover on the other hand, tended to have a slightly shorter canopy made up of a series of fully expanded or almost fully expanded leaves. When the two species were combined, Seaton Park tended to maintain the same canopy structure, while Hafia was able to elongate petioles and position large leaves above the dense Seaton Park canopy. They explained this over yielding (greater production of mixtures relative to monocultures) as morphological complementarity.

In contrast, Smith and Crespo (1979) found that as the level of competition from white clover increased, there was a marked decline in subterranean clover plant size, flowers plant^{-1}, seeds burr^{-1} and total seed production plant^{-1}. No effects on seed dormancy or hard-seededness were apparent.

Hill and Gleeson (1988) found after eight weeks under a frequent cutting regime, subterranean clover was a more aggressive competitor when sown as the minor component, but white clover was the most aggressive competitor when sown as the major component of the mixture. After 12 weeks, subterranean clover was the most aggressive when sown as the major or minor component. Under infrequent cutting, subterranean clover was also more competitive than white clover.

2.7 White clover and grasses

White clover has a distinct range of competitive strategies available to it, all of which can be employed in particular situations to great effect. Perhaps the most important strategy is the 'guerrilla' growth habit where it uses its stoloniferous character to rapidly establish in sward spaces (Hay and Hunt, 1989). It then employs its superior light interception (horizontal arrangement of laminae with phototrophic movement resulting in a low critical leaf area index

(Harris, 1987)), and different growth rhythm, to successfully combat vigorous grass competition in areas of N deficiency.

With some exceptions, white clover yields are generally inversely related to yields of associated species (Harris, 1977; Hay and Hunt, 1989). Studies have indicated that white clover can coexist more successfully with tufted rather than stoloniferous or rhizomatous grasses (Chestnutt and Lowe, 1970; Hay and Hunt, 1989).

Differences between white clover genotypes in their ability to compete with associate grasses, and their response to the modifying effects of N fertilisation and defoliation management have been related largely to differences in petiole length and leaf size (Harris, 1987). Genotypes which form canopies of large leaves on long petioles are able to avoid shading from associate species, and differ in strategy from those genotypes that form dense networks of well rooted stolons bearing small leaves on short petioles, and are better able to stand frequent and close defoliation (Hay and Hunt, 1989).

In dryland plots, Black and Lucas (2000) found that Caucasian clover based ryegrass or cocksfoot pastures had a greater legume content than white clover based pastures (21% c.f. 1%) after a five-year establishment period, indicating the weakness of white clover to grass competition during periods of summer drought.

2.7.1 Defoliation

The defoliation of herbage has two components, frequency or time between defoliations, and severity, the proportion of herbage removed defoliation^{-1} (Brock and Hay, 2001). This determines the degree of physiological stress placed on the plant at each defoliation. As white clover must elevate its leaf blades into the upper levels of the canopy to intercept light, defoliation leaf^{-1} is therefore usually severe. Consequently, defoliation frequency is the more important aspect of defoliation controlling white clover growth. For ryegrass, with vertically orientated leaves, severity is of equal importance, as it determines the proportion of leaf blade removed, hence light interception and regrowth potential, depending on stocking rate and grazing duration.

Harris (1987) explained the varied response of white clover content to defoliation frequency in mixed swards obtained by Brougham (1959), Harris and Thomas (1973) and Harris (1974), by viewing frequent defoliation as especially prejudicial to erect grass species. The stoloniferous habit of white clover means that a smaller proportion of its total biomass is removed in any defoliation. Therefore, where white clover is at a competitive disadvantage for light interception, frequent cutting may increase clover content. Infrequent defoliation could be expected to increase white clover where it is already at a competitive advantage, or at least actively growing and able to take advantage of the longer defoliation intervals in moist temperate pastures, or where infrequent defoliation is prejudicial to the associated species growth (Hay and Hunt, 1989).

2.7.2 Nitrogen

Nitrogen in the readily available mineral form released through mineralisation is usually in the shortest supply for plant growth. Legumes such as white clover are able to fix atmospheric N_2 to substitute for mineral N in times of N deficiency in the plant (Brock and Hay, 1996). Assuming the necessary nutrients are supplied (in particular P, sulphate, K and molybdenum (Brock and Hay, 2001)) at the correct pH, N from legume N_2 fixation will accumulate in the soil organic matter. As soil fertility and nutrient supply increase, competitive grasses begin to dominate and legumes are suppressed. In this way, building soil fertility through fixed N inputs becomes self-regulatory and, eventually, an equilibrium is reached where N inputs via white clover are needed only to balance N losses from the system (Ball, 1982; Field and Ball, 1982). As competition for light increases from the more erect grass species, white clover growth and N_2 fixation is decreased until a new equilibrium balance is attained (Brock and Hay, 2001). This equilibrium level is far below that which would sustain maximum white clover production. However, the aggregated pattern of high N return in urine patches by the grazing animal results in high losses through ammonia volatilisation and nitrate leaching (Ball, 1982), creating a mosaic of patches of variable N status allowing the white clover population to be maintained.

Many New Zealand white clover based pastures have average annual clover production of less than 20% of the total (Moss, 1987; Ettema and Ledgard, 1992), with N inputs from fixation too low to support the full production potential of ryegrass / white clover pastures (Clark and Harris, 1996), especially when white clover is not contributing adequately to N inputs. To correct this N deficiency (Ball and Field, 1982) it has become necessary to apply N fertiliser if maximum dry matter production (not necessarily maximum profitability or pasture nutritive value) is to be achieved on farms where white clover is the sole legume. However, in the absence of clover, N fertiliser applied to grass swards consistently increases the N content of the herbage (Wilman and Wright, 1983).

Clark and Harris (1996) summarised the advantages and disadvantages of clover and fertiliser N. White clover based systems have lower costs since there is no N fertiliser requirement. Systems based on N fertiliser, despite being more costly, are usually a more reliable means of providing increased pasture production at critical periods for dairy farms. Although application of N fertiliser increases total herbage production, the clover content of pastures declines with increasing amounts of N fertiliser (Ball and Field, 1982; O'Connor, 1982; Harris and Clark, 1996; Harris *et al.,* 1996). This is due to increased competition (particularly for light, but also water and nutrients) from N stimulated ryegrass, which is more efficient at taking up fertiliser N from the soil than legumes (Murphy and Ball, 1985).

'Tactical' use of N fertiliser to reduce the impact on the grass / legume balance can include restricting the use to a limited number of areas on the farm, stimulating growth from what may become predominantly all grass areas in times of feed shortage, while sustaining a predominantly unfertilised grass / legume system elsewhere. Harris and Clark (1996) demonstrated how close-grazing management can reduce competition between the grass and clover components following fertiliser N input. They suggested that some clover content, and even N_2 fixation can be retained if all additional pasture is utilised when up to 200 kg N ha^{-1} yr^{-1} is applied. If N fertiliser is applied in late winter and mid – late autumn when soil temperatures are above 4 and 7 °C, respectively and pasture production is often lower than demand, the effect on white clover will be minimised due to its low growth at this time (Murphy and Ball, 1985).

2.8 Clover content

White clover pastures in New Zealand generally have a clover content of 10-20% (Chapman *et al.,* 1996; Harris, 1997), lower than that required for maximum animal performance and N_2 fixation (Widdup *et al.,* 2001; Chapman *et al.,* 1996; Harris, 1997). Increasing clover content has been shown to increase animal intakes and production. Under either *ad libitum* or restricted feeding levels, cows fed pure white clover had higher intakes and superior production to those fed ryegrass (Rogers, Porter and Robinson, 1982). Harris (1997) has since shown milk production (kg MS cow^{-1}) to be greatest at pasture clover contents of 60 – 75%. Using a farm simulation model (UDDER), Clark and Harris (1996) showed that maximum gross margin ha^{-1} and a high level of milksolids production ha^{-1} and cow^{-1} can be best achieved by combining N inputs from white clover and N fertiliser. The model predicts best results would be achieved with clover contents of 30-40% for pasture on offer and N fertiliser rates of 100-200 kg N ha^{-1} yr^{-1}.

2.8.1 Caucasian clover

Caucasian clover is an exciting prospect for New Zealand agriculture. Initially, research focused on its ability to colonise low-input high country grassland where its rhizomatous habit has enabled it to persist and spread while white clover typically fails to persist (Allan and Keoghan, 1994; White, 1995; Moorhead, 1997). However, recent research has focused on the introduction of Caucasian clover to high fertility lowland sites as a means of increasing legume content and pasture quality in irrigated (Moss *et al.*, 1996; Black *et al.,* 2000) and dryland environments (Watson *et al.*, 1996b; Watson *et al.*, 1998; Black and Lucas, 2000). Caucasian clover has shown an ability to increase pasture production and clover content (Watson *et al.,* 1997), while showing greater resistance to both abiotic (Moss *et al.,* 1996; Watson *et al.,* 1996b; Black and Lucas, 2000) and biotic (Watson, Neville and Bell, 1996a) stress compared to white clover.

Caucasian clover has also shown an ability to fix more total N_2 than white clover in irrigated ryegrass / clover pastures. The N_2 fixation ability of Caucasian and white clovers are directly related to the amount of clover dry matter produced in the sward (Widdup *et al.,* 2001). In their study, Caucasian clover produced up to four times the dry matter yield of white clover and there was up to four times the amount of N_2 fixed in the herbage. The increased N input from Caucasian clover increased grass N content and N uptake from the soil, resulting in higher total pasture production compared with white clover pastures by year three (15.7 c.f. 14.2 t DM ha^{-1}).

However, despite the likelihood of increasing pasture clover content, farmers have not readily included Caucasian clover in pasture mixes. Although initial *rhizobium* problems have been corrected (Pryor, Lowther, McIntyre and Ronson, 1998), the slow establishment of Caucasian clover, especially when sown with ryegrass (Hurst, Black, Lucas and Moot, 2000) may still be an issue. Slow establishment and low initial herbage production may be due to the early emphasis on development of a large underground biomass (Strachan *et al.*, 1994; Genrich, Sheaffer and Ehlke, 1998). Farmers must be patient during establishment. The suggestion that Caucasian clover be sown alone in spring ryegrass drilled in the following autumn is probably not acceptable to many commercial farmers, but, sowing with a less aggressive species such as timothy or tall fescue may a be more popular option to decrease competition during the establishment phase (Hurst *et al.*, 2000). Ryegrass can normally be over-drilled later if the less aggressive grass declines in productivity.

2.9 Gaps in literature

- White clover competition with Caucasian clover

Although total clover content has been shown to increase when Caucasian clover is sown in pastures, due to the hard seed content of the soil, white clover is also likely to grow and has been shown to be complementary to Caucasian clover (e.g. Moss *et al.*, 1996; Watson *et al.*, 1996b; Black *et al.* 2000; Black and Lucas 2000). White clover productivity is greater in the early spring and late autumn, while Caucasian clover productivity is greater from late spring to early autumn (Black and Lucas, 2000). In year three of the Caucasian clover grazing experiment at Lincoln University white clover made up 39% of the total legume content of the pasture (19%) (Black *et al.*, 2000). When the two clovers are grown together, the result is not only a greater total clover yield, but also a wider seasonal spread of clover production than would be possible if Caucasian clover was the sole legume.

To date there is no published literature on the competition between white and Caucasian clover. However, from laboratory evidence, Elliot, McIntyre, Challis, Pryor, Lowther and Ronson (1998) promoted the possibility of poor sociability between the two clovers because of rhizobial incompatibility. The Caucasian clover rhizobia formed nodules on white clover that did not fix N_2. There is little or no evidence of this or any other competition in the field in the literature.

- Caucasian clover competition with ryegrass (and effect of N fertiliser)

Maw (2000) attempted to determine the effect of defoliation frequency and autumn and late winter N fertiliser applications on the dry matter yield and botanical composition of Caucasian clover / ryegrass and white clover / ryegrass pastures. However, the results from the experiment gave inconclusive results. The results showed a response of 7.9 kg DM ha^{-1} kg N^{-1} with no difference between soil fertility or clover treatments in dry matter yield. There was a higher autumn clover content in Caucasian clover plots (13.5%) compared to white clover plots (9.1%, $P < 0.155$).

It was suggested that the potentially taller growth habit and larger leaves of Caucasian clover will allow it to be more competitive than white clover against ryegrass stimulated by N fertiliser. This could indirectly lead to a greater total yield of clover as a reduction in ryegrass in Caucasian clover pastures may ultimately allow for greater establishment of white clover from hard seed in the soil.

In a pot experiment at Lincoln University, the competition between Caucasian clover and ryegrass was studied. Herbage, rhizome and root biomass for Caucasian clover at four grass : clover ratios (0:1, 1:1, 2:1 and 4:1) were measured at high and low N fertility. At 177 days after sowing, while there was little effect of N, Caucasian clover herbage and root biomass were dramatically reduced with grass competition while rhizome mass was unaffected. Furthermore, at 287 days after sowing, a similar effect was evident with Caucasian clover herbage, rhizome and root biomass reduced with grass competition, with the effect being greater at high N fertility (A. D. Black, unpublished data). This effect needs to be further studied in large plots in the field with the influence of the grazing animal.

2.10 Conclusions

- The competition between plants in a sward depends on their ability to capture light, N and water.

- The primary growth of plants can be related to the use of competitive, ruderal or stress tolerating strategies in environments of varying disturbance and / or stress.

- The dynamic aspects of competition in mixed swards, especially for Caucasian clover, have rarely been studied.

- Caucasian clover has been shown to increase the legume content N_2 fixation ability and animal productivity from a range of New Zealand pasture environments.

- To date, the limited amount of work on the effect of applied N to Caucasian clover / ryegrass pastures has been inconclusive. Due to the potential suitability of Caucasian clover to dairy pastures, and the continued use of N fertiliser, this needs to be determined.

3 Pasture production and composition and autumn liveweight gain of lambs grazing Caucasian or white clover based pastures at high and low soil fertility

3.1 Introduction

Pastures in New Zealand generally have a clover content of 10-20% (Chapman *et al.,* 1996; Harris, 1997), lower than that required for maximum nitrogen (N) fixation and animal performance (Harris, 1997; Widdup *et al.*, 2000). Recent research has focused on the introduction of Caucasian clover to high fertility lowland sites as a means of increasing legume content and pasture quality in irrigated environments (Moss *et al.*, 1996; Black *et al.,* 2000). Caucasian clover has shown an ability to increase pasture production and clover content (Watson *et al.,* 1997), while showing greater resistance to both abiotic (Moss *et al.,* 1996; Watson *et al.,* 1996b; Black and Lucas, 2000) and biotic (Watson *et al.*, 1996a) stress compared to white clover. There is limited published animal productivity data from Caucasian clover based pastures, although initial reports have shown it to be superior to white clover in autumn (Maw, 2000) and annually (Black *et al.*, 2000).

This chapter reports on the fourth autumn of an ongoing grazing experiment at Lincoln University where pasture production, composition and nutritive value and lamb liveweight gain (LWG) was measured from Caucasian and white clovers at high and low soil fertility.

3.2 Materials and methods

3.2.1 Site

The experimental site was located in research plot D2F of the Soil, Plant and Ecological Sciences Division research area at Lincoln University, Canterbury (43°39'S, 172°28'E, 11 m.a.s.l.). The soil, a Templeton silt loam, a gley soil of variable depth (600-1500 mm), was developed over gravel on the lower terraces of the Canterbury plains. It is a medium to free-draining soil with a moderate capacity to retain moisture.

3.2.1.1 Experimental design

The grazing experiment used a 2×2 factorial design laid out in a Latin Square arrangement with two pasture species, two soil fertility levels and eight replicates (a total of 32 plots). Pastures were sown with either hexaploid Endura Caucasian clover (*Trifolium ambiguum* M. Bieb, 6 kg ha^{-1}) or Grasslands Demand white clover (*Trifolium repens* L., 2 kg ha^{-1}) in December 1996 into 0.04 ha plots. In March 1997, Grasslands Ruanui zero endophyte ryegrass (*Lolium perenne* L., 15 kg ha^{-1}) was direct drilled into the clover turf. The design allowed for two animal replicates of four farmlets of each treatment. Each farmlet consisted of four 0.04 ha plots of the same pasture treatment (white clover – low fertility, white clover – high fertility, Caucasian clover – low fertility, Caucasian clover – high fertility).

The grazing experiment plots (separately fenced since the beginning of the experiment) were supplied with water via troughs placed to supply two plots. Races ran between strips of eight main plots to allow easy access.

A soil "Quick test" before sowing in December 1996 indicated moderate soil fertility over the entire site (pH 5.9, Olsen P 11, K 10, and S 6). Following sowing, 1 t ha^{-1} superphosphate (0-9-0-12) was applied to the 16 high fertility plots and 1 t ha^{-1} basal lime was applied to all 32 plots. Since establishment, high fertility treatments have received an annual application of 250 kg ha^{-1} of sulphur super. Subsequent soil tests taken annually in May have shown an increase in soil fertility (P and S) in the fertilised plots and lower fertility in the unfertilised plots (Table 3.1).

Table 3.1 Soil Quick test means for each May sampling to 75 mm of the grazing experiment from 26/5/1998 until 7/5/2001 for high and low fertility treatments.

	pH	Ca	K	Olsen P	Mg	Na	SO_4^{2-}-S
26/05/1998							
Low fertility	6.3	10	15	10	27	13	9
High fertility	6.1	10	13	22	23	10	14
19/05/1999							
Low fertility	6.0	8	11	13	20	10	6
High fertility	6.0	8	10	18	19	10	7
19/05/2000							
Low fertility	5.8	6	9	9	17	9	5
High fertility	5.7	7	9	16	17	10	9
07/05/2001							
Low fertility	6.2	7	16	11	27	15	9
High fertility	6.1	7	15	22	27	15	20

3.2.2 Climate

The climate experienced in the area was typical of the Canterbury plains with warm dry summers and cool winters. Mean data from Broadfields Meteorological Station (43°38'S, 11 m.a.s.l.) indicated that there was 172 mm less rainfall, air temperatures that were 0.5-0.9 °C higher, 29 mm more evapotranspiration and soil temperatures that were similar to the 40 year mean for the duration of the experiment (February to June 2001, Table 3.2). Plots were irrigated regularly using a soil water budget based on weekly rainfall and evapotranspiration data. Irrigation on the experimental area was adequate until mid autumn 2001 when due to unforeseen circumstances, the usual regime could not be continued.

Table 3.2 Climate data for January to August 2001 and 40 year means (40 YM) from Broadfields Meteorological Station, Lincoln, Canterbury.

	Mean daily air temperature (°C)		Mean daily 10 cm soil temperature (°C)		Rainfall (mm)		Evapotranspiration (mm)	
Month	2001 actual	40 YM	2001 actual	40 YM	2001 actual	40 YM	2001 actual	40 YM
Jan	14.9	16.6	15.0	17.6	55.0	50.3	142.5	153.0
Feb	**17.3**	16.4	**16.0**	17.1	**10.2**	51.3	**118.2**	117.6
Mar	**15.3**	14.8	**14.3**	14.6	**4.2**	58.9	**108.8**	96.8
Apr	**12.8**	12.0	**11.1**	10.9	**5.0**	51.8	**77.4**	62.2
May	9.5	9.0	7.9	7.4	40.6	50.4	37.0	43.7
Jun	7.0	6.3	4.0	4.6	37.2	63.0	39.0	33.0
Jul	4.7	6.0	3.7	4.1	64.0	73.7	38.5	37.0
Aug	8.1	7.2	6.9	5.2	35.6	68.1	51.4	50.7
Sept	10.0	9.2	9.9	7.8	15.2	40.1	75.6	68.6
Oct	12.2	11.4	13.1	11.0	63.2	54.9	89.5	104.6
Nov	*	13.1	*	14.0	*	55.7	*	142.7
Dec	*	15.2	*	16.8	*	61.3	*	142.7
Total					330	680	778	1053

Nb. Bolded data are for experimental period.

3.2.3 Animals

Since autumn 1998, eight separate ewe lamb flocks have been used to rotationally graze pastures of the same treatment for the duration of the experiment (Plate 3.1). Every autumn in February (1998-2001) 80, seven-month-old Coopworth ewe lambs were selected for uniformity and soundness. Prior to their allocation to the eight treatment flocks, the lambs were weighed (in 2001 range 31.4 kg to 38.6 kg, mean 35.2 kg) and blocked into ten groups, each consisting of eight animals of similar liveweight. One lamb from each liveweight block was then randomly allocated to a treatment flock, so each treatment group consisted of one animal from each liveweight block. This gave ten measurement animals flock^{-1} , balanced on a liveweight basis.

Plate 3.1 Overview of part of the grazing experiment looking east in October 2000 when ewe lambs were grazing the plots. Note caged area (bottom left) where dry matter production is measured and eight flocks of sheep grazing the plots according to their rotation.

3.2.4 Management

In 2001, the hoggets from the previous year left the experimental area on 29 January. Ewe lambs rotationally grazed the farmlets for two autumn rotations when liveweight gain (LWG) was measured: 12 February to 13 March and 13 March to 11 April. A third rotation from 11 April to 1 May was used as a clean up graze, and grazing days were recorded, before animals were removed from the experiment.

Flock size for each farmlet was determined by feed budgets, which estimated total available pasture mass (kg DM ha^{-1}). Where necessary, at the start of each rotation, stocking rate was adjusted using the "put and take" method (Bransby and Maclaurin, 2000) to maintain a similar pasture allowance in all farmlets.

At the beginning and end of each rotation, both measurement and spare animals were fasted and weighed. Measurement animals removed from treatment flocks and spare animals were maintained on ryegrass / clover pasture in raceways around treatment flocks, with the aim of reducing stock camping on experimental plots (Corbett, 1978), and to create a familiar and more realistic grazing environment. In the past these lambs were used occasionally to 'clean up' excess pasture to a similar post-grazing mass in under-grazed plots and also to maintain pasture quality. However, when there were differences in post-grazing pasture mass in autumn 2001, animals were kept in a paddock for an extra day for ease of management. Longer grazing duration and the addition and / or removal of stock was recorded and included in the sum of grazing days farmlet^{-1}.

In the first rotation, pre-grazing pasture mass ranged from 2280 to 2610 kg DM ha^{-1} (average 2390) and post-grazing pasture mass from 1290 to 1470 kg DM ha^{-1} (average 1360). In the second rotation, pre-grazing pasture mass ranged from 2220 to 2640 kg DM ha^{-1} (average 2430) and post-grazing pasture mass from 1140-1310 kg DM ha^{-1} (average 1220). In the third rotation, pre-grazing pasture mass ranged from 1140-1350 kg DM ha^{-1} (average 1200) and post-grazing pasture mass from 520-810 kg DM ha^{-1} (average 610). At the stocking rates used this gave average pasture allowances of 2.1, 2.2 and 1.5 kg DM lamb^{-1} day^{-1} in rotations 1, 2 and 3 respectively. The mean grazing duration was 7.1 days (range 7 to 8 days) and the mean spelling period prior to grazing in the first rotation was 34 days (range 32-36) and between the first and second rotation was 21 days.

3.2.5 Measurements

3.2.5.1 Dry matter production

Dry matter production and legume content were measured independently of the grazing sheep within one caged area plot^{-1} (Black *et al.*, 2000). New areas to be excluded from grazing were mown to 30 mm at the start of each 28-day period. After each period, the herbage within one 0.2 m^2 quadrat plot^{-1} was cut to 30 mm above ground level. Pasture components were separated by quantitative pasture dissection. Mixing, quartering and discarding reduced the sample mass to a suitably sized but representative sub-sample of approximately 400 pieces (Boswell, 1974). Sub-samples were sorted into components of ryegrass (*Lolium perenne*), annual grass (predominantly barley grass (*Hordeum murinum* L.), annual poa (*Poa annua*) and goose grass (*Bromus mollis*)), white clover (*Trifolium repens*), Caucasian clover (*Trifolium ambiguum*), dicotyledon weeds (predominentely dock (*Rumex obtusifolius*), chickweed (*Stellaria media*) and dandelion (*Taraxacum officinale*)) and dead material. Components were dried at 80°C for 48 hours, weighed and the contribution of each component to total pasture mass calculated (Cayley and Bird, 1996).

3.2.5.2 Pasture mass

Pre- and post-grazing pasture masses were measured using a capacitance meter, which was calibrated against five dry matter cuts of both pre- and post-grazing pasture mass treatment^{-1} at the beginning of autumn according to L'Huillier and Thomson (1988).

3.2.5.3 Pre-grazing pasture composition and feeding value

Four sample cuts were taken systematically within each of the five strata in each plot to obtain a representative sample from twenty sites plot^{-1}. The pasture samples were hand cut to 50 mm stubble height and bulked for each plot. Pasture components were separated by quantitative pasture dissection, and were dried, weighed and the contribution of each component to total pasture mass calculated (3.2.5.1). Clover (white or Caucasian and volunteer white) petiole and leaf and ryegrass leaf were then bulked for each treatment for each of the two sheep replicates for chemical analysis.

3.2.5.4 Grazing days

Total grazing days for each farmlet rotation^{-1} were determined using the following equation: (mean number of lambs plot^{-1}) × (mean number of days on each plot) × 4. These were then summed for each treatment and expressed as total grazing days farmlet^{-1} for the autumn period.

3.2.5.5 Allowance

Pasture allowances (kg DM hd^{-1} d^{-1}) for animals in each flock were estimated from the available pasture mass (as determined from corrected capacitance readings, kg DM ha^{-1}) divided by the stocking rate (lambs ha^{-1}) divided by the grazing duration (days) divided by 4.

3.2.5.6 Apparent intake

Apparent dry matter intakes (kg DM hd^{-1} d^{-1}) for animals in each flock were estimated from the difference between available and residual pasture mass (as determined from corrected capacitance readings) divided by the stocking rate (lambs ha^{-1}) divided by the grazing duration (days) divided by 4.

3.2.5.7 Liveweight gain

Liveweight gain (g hd^{-1} d^{-1}) was calculated as the difference between the fasted liveweight at the beginning and end of each rotation divided by the number of days of the experiment.

3.2.6 Statistical analysis

Significant ($P < 0.05$) differences in dry matter production and legume content in the caged areas were analysed using two way analysis of variance with Genstat 5, release 4.1 according to the Latin Square design and eight agronomic replicates. Significant ($P < 0.05$) agronomic and liveweight treatment differences relating to lamb LWG were analysed using the General Linear Model using MINITAB version 11 according to the 2 clover × 2 soil fertility level factorial design for the two animal replicates.

3.3 Results

3.3.1 Caged areas

3.3.1.1 Dry matter production

Total production from caged areas averaged 7480 kg DM ha^{-1} from the beginning of February until the end of June 2001. Total autumn production was 10% greater for Caucasian clover plots than white clover plots (7840 c.f. 7120 kg DM ha^{-1}, P = 0.006). However, production was only greater for Caucasian clover compared to white clover plots in February (P = 0.025) and April (P = 0.003, Table 3.3). There was a trend for high fertility plots to have a greater total autumn production than low fertility plots (7690 c.f. 7260 kg DM ha^{-1}, P = 0.073). This was evident in March when high fertility plots produced 13% more dry matter than low fertility plots (P = 0.010).

Table 3.3 Total and monthly dry matter production (kg DM ha^{-1}) from caged areas of Caucasian and white clover pastures at high and low fertility at the Lincoln University grazing experiment from February until June 2001.

Treatment	February	March	April	May	June	Total
White clover	**2610**	1710	**1400**	818	584	**7120**
Caucasian clover	**2940**	1800	**1620**	914	560	**7840**
P	***0.025***	*0.194*	***0.003***	*0.140*	*0.697*	***0.006***
Low fertility	2730	**1650**	1500	842	539	7260
High fertility	2810	**1860**	1530	890	604	7690
P	*0.555*	***0.010***	*0.621*	*0.444*	*0.295*	*0.073*
s.e.m.	*94.6*	*49.6*	*45.2*	*43.4*	*42.2*	*158*

3.3.1.2 Clover content and production

Autumn clover content was high and averaged 22.4% of the total dry matter produced in the caged areas (Table 3.4). On average, there was 29.3% clover in Caucasian clover pastures, almost double that in white clover pastures (15.2%, $P < 0.000$) from February until June. Total autumn clover production was 2.15 times greater for Caucasian clover than white clover (3200 c.f. 1080 kg DM ha^{-1}, $P < 0.000$) with production in each month 1.54 to 3.41 times greater for Caucasian clover than white clover.

Table 3.4 Total clover content (%) of caged areas of Caucasian and white clover pastures at high and low fertility at the Lincoln University grazing experiment from February until June 2001. Volunteer white clover as a percentage of total Caucasian clover content in brackets.

Treatment	February	March	April	May	June	Average
White clover	**20.0**	**22.4**	**7.8**	**4.4**	3.0	**15.2**
Caucasian clover	**41.4 (37.1)**	**32.8 (34.7)**	**23.0 (29.0)**	**10.0 (42.9)**	4.9 (56.9)	**29.3 (35.7)**
P	*0.001*	*0.001*	*0.001*	*0.004*	*0.060*	*0.000*
Low fertility	31.9	26.4	17.4	7.92	3.12	22.7
High fertility	29.6	28.8	13.4	6.44	4.78	20.8
P	*0.612*	*0.305*	*0.161*	*0.372*	*0.105*	*0.238*
s.e.m.	*3.14*	*1.65*	*1.88*	*1.13*	*0.674*	*1.63*

3.3.2 Pasture mass

Pre-grazing pasture mass for the first two autumn rotations averaged 2410 kg DM ha^{-1} over all treatments. Pasture mass was 160 kg DM ha^{-1} higher on Caucasian clover plots (2490 kg DM ha^{-1}) than white clover plots (2330 kg DM ha^{-1}, $P = 0.016$, Table 3.5) and was 120 kg DM ha^{-1} greater on high compared to low fertility plots (2470 c.f. 2350 kg DM ha^{-1}, P =

Table 3.5 Mean pre- and post-grazing pasture mass (kg DM ha^{-1}), average stocking rate (lambs ha^{-1}), allowance (kg DM hd^{-1} d^{-1}), apparent intake (kg DM hd^{-1} d^{-1}), total grazing days $farmlet^{-1}$ and sheep liveweight gain (LWG), $hectare^{-1}$ day^{-1} and $head^{-1}$ day^{-1} from Caucasian and white clover pastures at high and low soil fertility for two rotations during autumn 2001 (12 February to 11April). Total grazing days for all three autumn 2001 rotations (78 days) in brackets.

Treatment	Pre-grazing mass	Post-grazing mass	Stocking rate	Allowance	Apparent intake	Total grazing days	LWG (kg ha^{-1} d^{-1})	LWG (g hd^{-1} d^{-1})
				2001 (58 days)				
White clover	**2330**	1270	38.3	**2.1**	**0.96**	349 (474)	3.06	80
Caucasian clover	**2490**	1300	39.1	**2.2**	**1.1**	357 (481)	4.25	109
P	***0.016***	*0.207*	*0.391*	***0.014***	***0.021***	*0.391(0.347)*	*0.365*	*0.373*
Low-fertility	**2350**	1260	37.5	2.2	1.0	342 **(466)**	3.56	95
High-fertility	**2470**	1310	39.9	2.1	1.0	364 **(490)**	3.76	94
P	***0.035***	*0.083*	*0.058*	*0.422*	*0.835*	*0.058* ***(0.034)***	*0.871*	*0.955*
s.e.m.	*23*	*14*	*0.57*	*0.013*	*0.016*	*5.1 (4.6)*	*0.79*	*20*
F × C interaction	*0.173*	*0.061*	*0.391*	*0.718*	*0.452*	*0.347 (0.347)*	*0.789*	*0.731*

0.035). Post-grazing pasture mass averaged 1290 kg DM ha^{-1} and was similar for both clover and fertility treatments.

3.3.3 Stocking rate

Stocking rate was similar for clover treatments (38.7 lambs ha^{-1}) and slightly more for high fertility (39.9 lambs ha^{-1}) than low fertility plots (37.5 lambs ha^{-1}, P = 0.058, Table 3.5).

3.3.4 Grazing days

Grazing days $farmlet^{-1}$ (0.16 ha) for the 78 days of the autumn 2001 experimental period ranged from 466 on low fertility plots to 497 on high fertility Caucasian clover plots (Table 3.5). For the three autumn rotations, there were 24 more grazing days on high fertility compared to low fertility plots (490 c.f. 466 grazing days, P = 0.034). However, there were a similar number of grazing days on Caucasian clover plots (481 grazing days) and white clover plots (474 grazing days, P = 0.347). A similar trend was evident for the 58 days that liveweight was measured (the first two rotations).

3.3.5 Allowance

The pasture allowance averaged 2.2 kg DM hd^{-1} d^{-1} over all treatments for the first two autumn rotations. Sheep grazing Caucasian clover plots had a 5% greater (P = 0.014) allowance than those on white clover (2.2 c.f. 2.1 kg DM hd^{-1} d^{-1}, Table 3.5). There was no difference between the allowances of sheep grazing low and high fertility plots (2.1 & 2.2 kg DM hd^{-1} d^{-1}, P = 0.422).

3.3.6 Apparent intake

Apparent intake averaged 1.0 kg DM hd^{-1} d^{-1} and was greater on Caucasian clover plots than white clover plots (1.1 c.f. 0.96 kg DM hd^{-1} d^{-1}, P = 0.021, Table 3.5). There was no difference (P = 0.835) between the allowance on high and low fertility plots (1.0 kg DM hd^{-1} d^{-1}).

3.3.7 Liveweight gain

Sheep autumn LWG were low in all plots and averaged 209 kg ha^{-1} and 95 g hd^{-1} d^{-1} for the 58 days of the experiment. Liveweight gain $hectare^{-1}$ ranged from 160 kg ha^{-1} on white clover low fertility plots to 247 kg ha^{-1} on Caucasian clover low fertility plots (Table 3.5). There were no differences between clover (Caucasian clover 243 kg ha^{-1}, white clover 175 kg ha^{-1}, P = 0.365) or fertility treatments (low fertility, 203 kg ha^{-1}, high fertility 214 kg ha^{-1}, P = 0.871). Liveweight gain $head^{-1}$ ranged from 75 g hd^{-1} d^{-1} on white clover low fertility plots to 116 g hd^{-1} d^{-1} on Caucasian clover low fertility plots. Caucasian and white clover based pastures supported a similar rate of LWG hd^{-1} (109 g hd^{-1} d^{-1} and 80 g hd^{-1} d^{-1}, respectively, P = 0.373, Table 3.5). There were no differences between fertility treatments (low fertility 95 kg hd^{-1} d^{-1}, high fertility 94 kg hd^{-1} d^{-1}, P = 0.955).

3.3.8 Pre-grazing pasture composition

The pre-grazing clover content averaged 15.3% of the dry matter on offer. In Caucasian clover plots there was twice the amount of clover on offer as there was in white clover plots (20.5 c.f. 10.1%, P = 0.006, Table 3.7). Ryegrass averaged 45.0% of the pre-grazing pasture mass and was greater in white clover (48.8%) than in Caucasian clover (41.2%) pastures (P = 0.043). Neither clover nor fertility affected the annual grass or dead material content of the pasture , which averaged 15.6 and 23.0%, respectively over all treatments. Dicotyledon weed content was low and averaged 1.1%. However, there was an interaction between fertility and clover (Table 3.6) as, in low fertility Caucasian clover plots there was a greater dicotyledon weed content than in high fertility plots (2.69 c.f. 0.53%, P = 0.032), but the dicotyledon content of white clover plots was not affected by fertility.

Table 3.6 Interaction (P = 0.032) between Caucasian and white clover and high and low soil fertility for pre-grazing dicotyledon weed content (%).

Clover	Fertility	
	Low	High
White	0.48	0.67
Caucasian	2.69	0.53

s.e.m. 0.310

Table 3.7 Botanical composition (%) of herbage on offer and crude protein content (%), *in vitro* organic matter digestibility (OMD, %) and metabolisable energy content (ME, MJME kg DM^{-1}) of clover petiole and leaf and ryegrass leaf for Caucasian and white clover pastures at high and low soil fertility for two rotations during autumn 2001 (12 February to 11 April).

Treatment	Total clover	Ryegrass	Annual grass	Dicotyledon weeds	Dead	Clover crude protein	Ryegrass crude protein	Clover OMD	Ryegrass OMD	Clover ME	Ryegrass ME
White clover	**10.1**	**48.8**	16.4	**0.6**	24.2	30.1	22.6	86.2	81.0	12.4	11.5
Caucasian clover	**20.5**	**41.2**	14.9	**1.6**	21.8	29.8	23.0	86.6	81.9	12.5	11.6
P	***0.006***	***0.043***	*0.448*	***0.045***	*0.214*	*0.739*	*0.371*	*0.626*	*0.079*	*0.500*	*0.219*
Low-fertility	15.3	45.6	14.8	**1.6**	22.7	30.3	22.5	*	81.3	*	11.6
High-fertility	15.3	44.4	16.4	**0.6**	23.4	29.6	23.0	*	81.5	*	11.6
P	*0.975*	*0.622*	*0.422*	***0.050***	*0.691*	*0.533*	*0.244*	*	*0.581*	*	*0.495*
s.e.m.	*1.04*	*1.58*	*1.22*	*0.219*	*1.09*	*0.629*	*0.269*	*0.424*	*0.229*	*0.071*	*0.046*
F × C interaction	*0.355*	*0.136*	*0.894*	***0.032***	*0.409*	*0.295*	*0.322*	*	*0.581*	*	*1.00*

* Due to small samples, high and low fertility treatments bulked for clover OMD and ME analysis.

3.3.9 Pre-grazing pasture nutritional value

Crude protein levels in clover petiole and leaf and ryegrass leaf were not affected by clover species or soil fertility ($0.244 < P < 0.739$) and averaged 22.8% and 30.0%, respectively (Table 3.7). Clover *in vitro* organic matter digestibility (OMD) averaged 86.4% and was not affected by clover species ($P = 0.626$). Ryegrass OMD was not affected by fertility ($P = 0.581$) but there was a trend ($P = 0.079$) for higher OMD of ryegrass from Caucasian clover pastures (81.9%) than white clover pastures (81.0%). Metabolisable energy in clover and ryegrass leaf were not affected by clover species or soil fertility ($0.219 < P < 0.500$) and averaged 12.5 and 11.6 MJ ME kg DM^{-1}, respectively.

3.4 Discussion

3.4.1 Liveweight gain

The rate of autumn lamb LWG head^{-1} was relatively slow across all treatments and averaged only 95 g hd^{-1} d^{-1} (Table 3.5). However, LWG ha^{-1} reflected the high stocking rate and averaged 209 kg ha^{-1} for the 58 day autumn period. Lambs grazing Caucasian clover had similar LWG head^{-1} and hectare^{-1} day^{-1} to those on white clover ($P = 0.373$ and $P = 0.365$, respectively). These small differences in LWG may be expected with lambs grazing pre-grazing pasture masses that differ by only 160 kg DM ha^{-1} (Caucasian clover, 2490 c.f. white clover, 2330 kg DM ha^{-1}, $P = 0.016$). Pasture allowances were 5% more and apparent intakes 9% greater on Caucasian clover pastures.

The increased clover content on Caucasian clover pastures (20.5 c.f. 10.1% in white clover pastures) did not lead to LWG that were higher than those on white clover pastures. This short-term experiment was inconclusive in confirming the value of Caucasian clover in increasing clover content as a means of improving animal performance. Differences in LWG between treatments would be difficult to determine at such low clover contents (~15%). Hyslop, Fraser, Smith, Knight, Slay and Moffat (2000) studied the effect of changing white clover content on LWG of ewe lambs in spring and autumn. In autumn (unlike spring), young sheep grazing ryegrass or tall fescue based swards showed no association in LWG to increasing levels of clover. The authors could not suggest a definitive reason for this apparent anomaly.

Lambs on high fertility soils were offered a greater pre-grazing pasture mass (2470 c.f. 2350 kg DM ha^{-1}, $P = 0.035$) but a similar allowance (2.1 c.f. 2.2 kg DM hd^{-1} d^{-1}, $P = 0.422$) to similar lambs grazing low fertility pastures, due to the higher stocking rate (40 c.f. 38 lambs ha^{-1}, $P = 0.058$). Consequently, lamb LWG head^{-1} day^{-1} was similar on high and low fertility plots with lambs being offered similar allowances with similar clover contents leading to similar apparent intakes. Liveweight gain ha^{-1} d^{-1} was similar (low fertility 3.56, high fertility 3.76 kg ha^{-1} d^{-1}, $P = 0.871$) on high and low fertility farmlets. The higher stocking rate on high fertility pastures did lead greater number of grazing days when compared to low fertility pastures for the 58 day period when liveweight was measured (364 c.f. 342 grazing days, $P = 0.058$) and for the whole autumn (490 c.f. 466 grazing days, $P = 0.034$).

3.4.1.1 Stocking rate

The high stocking rate (average 39 lambs ha^{-1}) on the experiment reduced the potential for high LWG hd^{-1}. Assuming similar conditions throughout the year, the stocking rate used gave LWG ha^{-1} equivalent to 1350 kg liveweight ha^{-1} $year^{-1}$ for the 58-day duration of the experiment. However, as stocking rate increases, more feed is required to maintain animals and less feed is used for daily LWG of each animal, which decreases with increasing stocking rate (Jones and Sandland, 1974).

The high stocking rate used meant that pasture allowances ranged from 2.1-2.2 kg DM hd^{-1} d^{-1} and intakes from 0.95-1.1 kg DM hd^{-1} d^{-1}. With the given pre- and post-grazing pasture masses, pasture utilisation ranged from 43-50% of the feed on offer. If the utilisation of the pasture had been lower, the opportunity for selection of pasture components would have been greater, especially if the clover content of the intake was increased by the reduced grazing pressure (Penning Parsons, Orr, Harvey and Campion, 1995).

At the midpoint of the experiment, the lambs weighed an average of 38 kg and gained 95 g hd^{-1} d^{-1}. According to AFRC (1993) the dry matter intake required for maintenance and growth of 40 kg lambs gaining 100 g d^{-1} would be 1.11 kg DM d^{-1} if the pasture contained 10 MJME kg DM^{-1} and 0.95 kg DM d^{-1} if the pasture contained 11 MJME kg DM^{-1}. As Ulyatt, Fennessy, Rattray and Jagusch, (1980) state the energy value of ryegrass / white clover dominant autumn pasture to be 10.8 MJME kg DM^{-1}, the apparent intakes of the lambs in this experiment were adequate to meet this requirement. In this experiment, the clover component averaged 12.5 MJ ME kg DM^{-1} and the ryegrass averaged 11.5 MJ ME kg DM^{-1}. However, there was a high content of dead material (23.0%) in the autumn 2001 pasture, which would reduce the overall quality of the pasture.

3.4.1.2 Pasture production

For the 58-day duration of the experiment (12 February to 11 April), pasture production from the caged areas was estimated to be 3900 kg DM ha^{-1} at a mean rate of 67 kg DM ha^{-1} d^{-1} (Table 3.3). This is greater than three year average of 48 kg DM ha^{-1} d^{-1} for December to March periods given by Moss, Fraser, Daly, Knight and Carson (2000) for irrigated ryegrass based pastures. The LWG over this period was 209 kg ha^{-1} (0.054 kg LWG kg DM^{-1}), similar to the 0.0529 kg LWG kg DM^{-1} found by Black (1998) on the same pastures.

3.4.1.3 Pasture composition

The total clover content in pre-grazing pasture for the duration of the experiment was low in all treatments and averaged 15.3% of the dry matter on offer. This was lower than the average clover content in the caged areas (22.4%, Table 3.4), even though there were similar intervals between grazings of the main plots and harvests of the caged areas. Mowing the caged areas prior to placing the cages may have helped increase the clover content, as it would have allowed more light to reach the clover plants. The trim was done with a lawnmower to 30 mm leaving around 500 kg DM ha^{-1}. However, this height can be very variable and sometimes resulted in scalping the pasture to ground level. Also as Caucasian clover rhizomes are underground and white clover stolons are on the soil surface, the trim would probably have decreased the regrowth potential of the elevated ryegrass clumps, as a greater proportion of the plant would be removed than the two clover species. The regrowth potential of clover in the caged areas was therefore increased in comparison with the pasture post-grazing. Residual dead material would also be removed, increasing the contribution of other components to the total yield.

Hyslop *et al.* (2000) developed a model incorporating pasture mass, green : dead ratio, and grass : clover ratio and used it to explore the effect of clover after adjusting for other effects including season. The predictive model suggests that small changes in clover content of pre-grazing masses between the levels of 10-20% in the sward makes a large difference to LWG. Although, in the present experiment, the changes in clover content were in this range (white clover 10.1%, Caucasian clover 20.5%, P = 0.006), there was no measurable difference in LWG (white clover 80 g hd^{-1} d^{-1}, Caucasian clover 109 g hd^{-1} d^{-1}, P = 0.373). However, in their results, there was little correlation between autumn clover content and LWG. The results of Hyslop *et al.* (2000) also suggest that clover content would have to be 40% of sward mass or greater before LWG of over 250 g hd^{-1} d^{-1} were achieved. This clover content was achieved over the 1998 / 99 summer period in the Caucasian clover treatments at the present experimental site (Black *et al.*, 2000).

Longer-term experiments with more replication are required to show valid differences between treatments. A longer experimental grazing period would require that differences in gut fill or short-term changes in liveweight would have less effect on final LWG for a specific period. Another option would be to have a larger area with the ability to run more sheep in each flock to reduce the effect of individual animal variation on the final result. Unfortunately, this option would introduce further spatial variation. Increasing the number of animal replicates would also reduce the effect of individual animal variation, although the cost involved would negate this option.

The clover content in all pastures was lower than the legume content that lambs prefer. Penning *et al.* (1995) determined that sheep prefer a mixed diet of about 70% clover. Therefore, when sheep graze a pasture sward that contains less than 70% clover, they will be inclined to preferentially graze the clover component of the sward in an attempt to reach their desired dietary balance. The increased apparent intake of lambs grazing Caucasian clover is likely to be due to two factors. The allowance for lambs grazing Caucasian clover was higher than that for white clover (2.2 c.f. 2.1 kg DM hd^{-1} d^{-1}), but the greater clover content of Caucasian clover pastures may have also been an issue. Poppi, Hughes and L' Huillier (1987) reported that an important factor in the reduction of intake was the reduction in bite size and therefore pasture intake, due to the difficulties experienced by the animal selecting the preferred pasture components.

Another reason for the low LWG during the autumn could be the high content of annual grass in the experimental plots. During the two autumn rotations, annual grass content averaged 15.6%, similar to the average clover content. There is no recent New Zealand literature on LWG of animals grazing annual grasses such as goose and barley grass. However, it was presumed that animals would have lower gains on annual grasses than on the perennial ryegrass used in this experiment, possibly due to a greater amount of fungal infection present.

Even though there was up to 5.6 times more dicotyledon weeds in low fertility Caucasian clover pastures than the other treatments (Table 3.6) this was considered unlikely to affect the results as the weed content was still a very low component of the sward (0.48-2.69%).

3.4.1.4 Nutritive value

The components of the pasture that were analysed showed high energy and crude protein contents (11.5-12.5 MJ ME kg DM^{-1}, 22.5-30.3% crude protein, Table 3.7) compared to generalised values for autumn pasture (10.8 MJME kg DM^{-1} and 25% crude protein, Ulyatt *et al.*, 1980). The crude protein and metabolisable energy of the pasture measured in both ryegrass and clover was similar to previous autumns (A. D. Black, unpublished data). However, in autumn 2001, these components only made up to 60% of the feed on offer, the remainder being a small amount of ryegrass reproductive stem (data not presented), dead material (23%) and annual grass (15.6%), decreasing the overall quality of the pasture. The bulking of fertility treatments that was required due to the small sample size was unlikely to cause a major difference as there has been no difference in clover OMD or metabolisable energy content between high and low soil fertility treatments in the past (A.D. Black, *pers. comm.*).

3.4.1.5 Class of animal

The use of Coopworth ewe lambs of an unknown genetic base as measurement animals was less than ideal to achieve maximum LWG. It is likely that if animals with a greater growth potential were used, such as ram lambs from a breed with a large mature body size (Nicol, 1983), then overall LWG would have been greater. Animals such as these would be more responsive to changes in pasture quality than animals with a low growth potential, allowing differences between pasture treatments to be expressed as differences in LWG.

3.4.2 Grazing days

3.4.2.1 Stocking rate

Over the 78 day experimental period, there were 24 more grazing days on high fertility compared to low fertility plots ($P = 0.034$). This was predominantly caused by the stocking rate, which was higher on high fertility than low fertility pastures (40 c.f. 38 lambs ha^{-1}, $P = 0.058$) due to the greater pre-grazing pasture mass (2470 c.f. 2350 kg DM ha^{-1}, $P = 0.035$). The difference in pre-grazing pasture mass between the clover treatments (Caucasian clover 2490, white clover 2330 kg DM ha^{-1}, $P = 0.016$) was not compensated for by an increased stocking rate. Due to the small differences in pre-grazing pasture mass (160 kg DM ha^{-1}), the small farmlet area (0.16 ha) and the short experimental period, adjusting the stocking rate by 17% (one animal) on Caucasian clover pastures would have had a much greater effect than tolerating the small difference in pre-grazing mass. Pasture allowances and apparent intakes for Caucasian clover would have been significantly reduced compared to white clover with the increased stocking rate. Therefore, the difference in pre-grazing pasture masses between Caucasian and white clover was expressed as a difference in allowance (Caucasian clover 2.2 c.f. white clover 2.1 kg DM hd^{-1} d^{-1}, $P = 0.014$) and apparent intake (Caucasian clover 1.0 c.f. white clover 0.96 kg DM hd^{-1} d^{-1}, $P = 0.391$). Consequently, the stocking rate (Caucasian clover 39.1 c.f. white clover 38.3 lambs ha^{-1}) or number of grazing days did not differ between Caucasian (357) and white clover pastures (349, $P = 0.391$) as it did for the soil fertility treatments.

Coniffe, Browne and Walshe (1970) state production at the optimum stocking rate is the only valid measure of treatment effect and treatment comparisons should be based on this criterion. This would suggest that treatments should be tested over a range of stocking rates so that an optimum rate can be estimated for each treatment. After combining the results from stocking rate experiments over a wide range of environments, Jones and Sandland (1974) found the relationship between stocking rate and production animal^{-1} remained linear over a wide range of stocking rates. By using this relationship in a known production system, stocking rate can be adjusted to an optimum to allow meaningful comparisons between treatments. The experimental protocol allowed for differences in pre-grazing pasture mass by using the "put and take" method of grazing. The aim was for allowances over all treatments to be similar so that differences in LWG between treatments could be attributed to differences in pasture quality (e.g. clover content). Despite its inadequacies (Bransby, 1989) the put and take system has proved to be relatively successful in the past (Black *et al.*, 2000; Maw, 2000).

3.5 Conclusions

- Despite increased dry matter production (10%) of Caucasian clover / ryegrass pastures, slightly higher allowances and apparent intakes and a clover content twice that of white clover / ryegrass pastures, with the experimental design and size and length of the autumn grazing period, the differences between treatments in autumn LWG of Coopworth ewe lambs were not statistically significant.

- The high utilisation of autumn pasture of declining quality and the use of Coopworth ewe lambs with a relatively low growth potential at high stocking rates are possible reasons for the low LWG (80-109 g hd^{-1} d^{-1}).

- The higher pre-grazing pasture mass of high fertility farmlets allowed a higher stocking rate (39.9 c.f. 37.5 lambs ha^{-1}, $P = 0.058$) and, although LWG ha^{-1} was similar (low fertility 3.56 kg ha^{-1} d^{-1}, high fertility, 3.76 kg ha^{-1} d^{-1}, $P = 0.871$), high fertility farmlets also had 24 more grazing days than low fertility farmlets during the autumn period ($P = 0.034$).

4 Nitrogen fertiliser responses of Caucasian and white clover based pastures at high and low soil fertility

4.1 Introduction

Nitrogen (N) fertilisers have been shown to decrease the white clover content of New Zealand pastures (Harris, Penno and Bryant, 1994). The increased vigour of N-stimulated ryegrass is likely to shade clover, particularly if the additional feed produced is not utilised (Harris *et al.*, 1996). Caucasian clover pastures have been shown to have a greater clover content than white clover pastures and the increased competitiveness of Caucasian clover against ryegrass (Black and Lucas, 2000) may make it a suitable companion legume in dairy pastures where N fertiliser is frequently used.

Maw (2000) attempted to determine the effect of defoliation frequency and autumn and late winter N fertiliser applications on the dry matter yield and botanical composition of Caucasian clover / ryegrass and white clover / ryegrass pastures. However, the results from the experiment were inconclusive. The results showed a response of 7.9 kg DM ha^{-1} kg N^{-1} with no difference between fertility or clover treatments in dry matter yield. There was a higher autumn clover content in Caucasian clover plots (13.5%) compared to white clover plots (9.1%, $P < 0.155$).

This chapter reports the second autumn of this experiment where the defoliation treatment was abandoned and 120 kg N ha^{-1} was applied. Pasture production and composition are assessed from February until June 2000.

4.2 Materials and methods

4.2.1 Climate

The climate for the area is discussed in Chapter 3 (Table 3.2). Approximately 60 mm irrigation was applied to the 16 main plots in the N experiment (plots 9 to 24) between 21/4/2001 and 30/4/2001. During this period, there was 0 mm rain and 17 mm evapotranspiration.

4.2.2 Experimental design

As described by Maw (2000), the original experiment, a clover species × fertility (P and S) × N fertiliser × defoliation frequency experiment was set up in autumn 2000 as a (2 × 2) × (2 × 2) split plot factorial replicated four times. The work was conducted in 16 main plots (plots 9-24) of the 32 plot grazing experiment (3.2.1.1).

4.2.2.1 Treatments

Main plot treatments were two clover species each sown with perennial ryegrass at two fertility levels (Table 3.1). Sub-plot treatments were two N treatments (equivalent to + / – 420 kg N ha^{-1} yr^{-1}) and frequent (14 day) or infrequent (28 day) defoliation. On 21/2/2000, within each of the selected 0.04 ha main plots, one 16 m^2 area was selected for uniformity, a minimum of two metres from fence lines and free from any obvious grass grub damage (Plate 4.1). This 16 m^2 area provided four subplots for the autumn / early spring N and defoliation treatments (0 kg N ha^{-1} and infrequent defoliation, 0 kg N ha^{-1} and frequent defoliation, 100 kg N ha^{-1} and infrequent defoliation, 100 kg N ha^{-1} and frequent defoliation).

In 2001, the defoliation frequency treatment was discontinued leaving the two N treatments, each with two subplots. A total of 420 kg N ha^{-1} was applied over the 14 months of the experiment N as fertiliser (Table 4.1). Nitrogen was usually applied as urea granules by hand if rainfall or irrigation was imminent, or dissolved in water, and applied with a watering can if not.

Plate 4.2 View of grazing trial looking south in August 2001. Note nitrogen subplots identified with white fibreglass poles and caged areas where dry matter production is measured.

Table 4.1 Nitrogen fertiliser application timing, amount (kg N ha^{-1}) and form to subplots on the grazing experiment from 1/3/2000 to 20/4/2001.

Treatment	-N	+N	Form
01/03/2000	0	100	Urea
01/08/2000	0	100	Urea
21/11/2000	0	50	C.A.N.*
17/01/2001	0	50	Urea
15/02/2001	**0**	**50**	**Urea**
20/04/2001	**0**	**70**	**Urea**

Nb. Bold represents autumn 2001 application of N.

* Calcium Ammonium Nitrate

Soil tests on 7 May 2000 showed no consistent differences between N treatments (Table 4.2). The sulphur value for the low fertility plot that did not receive N was higher than expected.

Table 4.2 Soil Quick test means for fertility main plot and nitrogen (N) sub plots on the clover species × fertility (P and S) × N experiment sampled to 75 mm on 7 May 2001.

	pH	Ca	K	Olsen P	Mg	Na	SO_4^{2-}-S
07/05/2001							
Low fertility	6.2	6	14	12	23	14	11
Low fertility plus N	6.2	7	13	10	22	12	6
High fertility	6.2	7	13	22	22	14	16
High fertility plus N	6.2	7	10	20	21	13	15

4.2.2.2 Grazing

Ewe hoggets on the grazing experiment grazed the plots in accordance with their rotation, with the N subplots harvested immediately prior to grazing. Due the grazing rotation and layout of the + / - N subplots, blocks 1 & 2 and blocks 3 & 4 of the N experiment were grazed alternately. The time of pasture harvests, regrowth period and grazing duration are shown in Table 4.3.

Table 4.3 Grazing time, duration of grazing and regrowth period since last grazing of the + / - nitrogen (N) investigation subplots.

Harvest	Blocks	Date grazed	Duration (days)	Regrowth period (days)
1	3 & 4	03/03/2001	10	36
2	1 & 2	13/03/2001	9	21
3	3 & 4	04/04/2001	7	21
4	1 & 2	11/04/2001	5	21
5	3 & 4	24/04/2001	6	13
6	1 & 2	14/6/2001*	N / A	60
7	3 & 4	14/6/2001*	N / A	45

*Time of harvest only. The sheep did not graze at this time.

After grazing, + / - N subplots were mown with a rotary lawn mower to 30 mm to remove excess reproductive ryegrass and annual grass material. Lambs were removed from the experiment on 1/5/01.

4.2.3 Measurements

4.2.3.1 Dry matter yield and pasture composition

Dry matter cuts of blocks 1 & 2 and 3 & 4 were taken prior to animals entering the plots. One 0.2 m^2 quadrat cut was taken by hand from each of the four subplots to a constant stubble height of 30 mm. The 2 × + N and 2 × – N samples were bulked in the field, and pasture components were separated by quantitative pasture dissection, dried with the remaining unsorted part of each sample, weighed and total pasture mass and the contribution of each component to total pasture mass calculated (3.2.5.1). Ryegrass and annual grass sub-samples for each treatment were bulked for the early and late autumn harvests in blocks 3 & 4 so that there were two replicates within time for chemical analysis.

4.2.4 Statistical analysis

Analysis of variance was used to detect significant ($P < 0.05$) differences between treatments using MINITAB version 11. Data were analysed as a split plot factorial with clover species × fertility level as the main plot treatments and N level as the subplot treatment. A covariate (1 = adequate watering, 2 = dry) was included in harvests 2, 4 & 6 in an attempt to eliminate the variation caused by uneven watering in 10 subplots. However, this proved unsuccessful, so was excluded in the final analysis.

4.3 Results

4.3.1 Autumn production

Due to the rotational grazing management of the ewe hoggets (4.2.2.2), results for blocks 1 & 2 and blocks 3 & 4 are presented separately. Total autumn dry matter production ranged from 2930 kg DM ha^{-1} in low fertility white clover plots without N to 4600 kg DM ha^{-1} in high fertility white clover plots with N in blocks 1 & 2. In blocks 3 & 4 dry matter production ranged from 3280 kg DM ha^{-1} in low fertility Caucasian clover plots without N to 4480 kg DM ha^{-1} in high fertility Caucasian clover plots with N. Dry matter production in blocks 1 & 2 was affected by uneven irrigation on some plots causing plants to have a wilted appearance, start to "brown off" and these plots produced 920 kg DM ha^{-1} less than the average of the plots not affected. The average autumn production rate (blocks 1 & 2, 114 days; blocks 3 & 4, 137 days) was 31 kg DM ha^{-1} d^{-1}.

4.3.1.1 Total dry matter

Total autumn dry matter production was increased by 3.5-3.9 kg DM ha^{-1} kg N^{-1} ($P = 0.280$, 0.228) with the application of 120 kg N ha^{-1} although neither this nor the cumulative yield at any time were significantly different from plots not receiving N (Figure 4.1, Figure 4.2, Table 4.4 and Table 4.6). Production was similar in Caucasian and white clover plots in blocks 1 & 2 and blocks 3 & 4 ($P = 0.482$, 0.928). Production was also similar in high fertility and low fertility plots (3670 c.f. 3400 kg DM ha^{-1}, $P = 0.473$ in blocks 1 & 2 and 4310 c.f. 3850 kg DM ha^{-1}, $P = 0.233$ in blocks 3 & 4).

Total autumn dry matter production for blocks 1 & 2 was affected by the interaction ($P = 0.015$) between the fertility and clover treatments (Table 4.4 and Table 4.5). This effect was not evident in blocks 3 & 4 ($P = 0.633$).

Table 4.4 Contribution to total dry matter production (kg DM ha^{-1}) of pasture components for Caucasian and white clover at high and low soil fertility + / - 120 kg N ha^{-1} from 20 February until 14 June 2001 for blocks 1 & 2 (three harvests) (contribution of volunteer white clover to total Caucasian clover in brackets).

Treatment	Ryegrass	Annual grass	Total clover	Dead material	Dicotyledon weeds	Total
White clover	1430	854	161	1220	9.1	3670
Caucasian clover	1390	707	277 (152)	1000	28	3410
P	*0.834*	*0.170*	*0.230*	*0.312*	*0.197*	*0.482*
Low fertility	1270	785	286	1030	25	3400
High fertility	1550	777	151	1190	12	3670
P	*0.155*	*0.940*	*0.168*	*0.466*	*0.325*	*0.473*
No N	1380	**619**	240	1060	25	3330
120 kg N ha^{-1}	1440	**943**	198	1160	12	3750
P	*0.764*	***0.012***	*0.643*	*0.635*	*0.377*	*0.285*
s.e.m.	*122*	*68.0*	*62.0*	*138*	*9.2*	*251*
Interactions	-	**F × C****	-	-	-	**f × c***

* P < 0.05, ** P < 0.01

Table 4.5 Interaction ($P = 0.015$) between total autumn dry matter yield (kg DM ha^{-1}) for Caucasian and white clover and high and low soil fertility in blocks 1 & 2.

Clover	Fertility		
	Low	High	Mean
White	2960	4380	3670
Caucasian	3840	2970	3410
Mean	3400	3670	3540

s.e.m. = 355

High fertility white clover plots produced 48% more dry matter than low fertility white clover plots (4380 c.f. 2960 $kgDMha^{-1}$). However, in Caucasian clover plots, dry matter production decreased from 3840 kg DM ha^{-1} in low fertility plots to 2790 kg DM ha^{-1} in high fertility plots.

Table 4.6 Contribution to total dry matter production (kg DM ha^{-1}) of pasture components for Caucasian and white clover at high and low soil fertility + / - 120 kg N ha^{-1} from 29 January until 14 June 2001 for blocks 3 & 4 (four harvests) (contribution of volunteer white clover to total Caucasian clover in brackets).

Treatment	Ryegrass	Annual grass	Total clover	Dead material	Dicotyledon weeds	Total
White clover	1510	1100	**240**	**1250**	6.3	4100
Caucasian clover	1320	1190	**640 (401)**	**865**	51	4060
P	*0.460*	*0.556*	***0.000***	***0.041***	*0.142*	*0.928*
Low fertility	1410	**937**	439	1030	29	3850
High fertility	1420	**1350**	441	1080	28	4310
P	*0.971*	***0.031***	*0.982*	*0.777*	*0.957*	*0.233*
No N	1410	966	436	1000	34	3850
120 kg N ha^{-1}	1420	1320	443	1110	22	4320
P	*0.961*	*0.054*	*0.908*	*0.499*	*0.667*	*0.228*
s.e.m.	*169*	*108*	*41.9*	*109*	*19*	*252*
Interactions	-	-	-	-	-	-

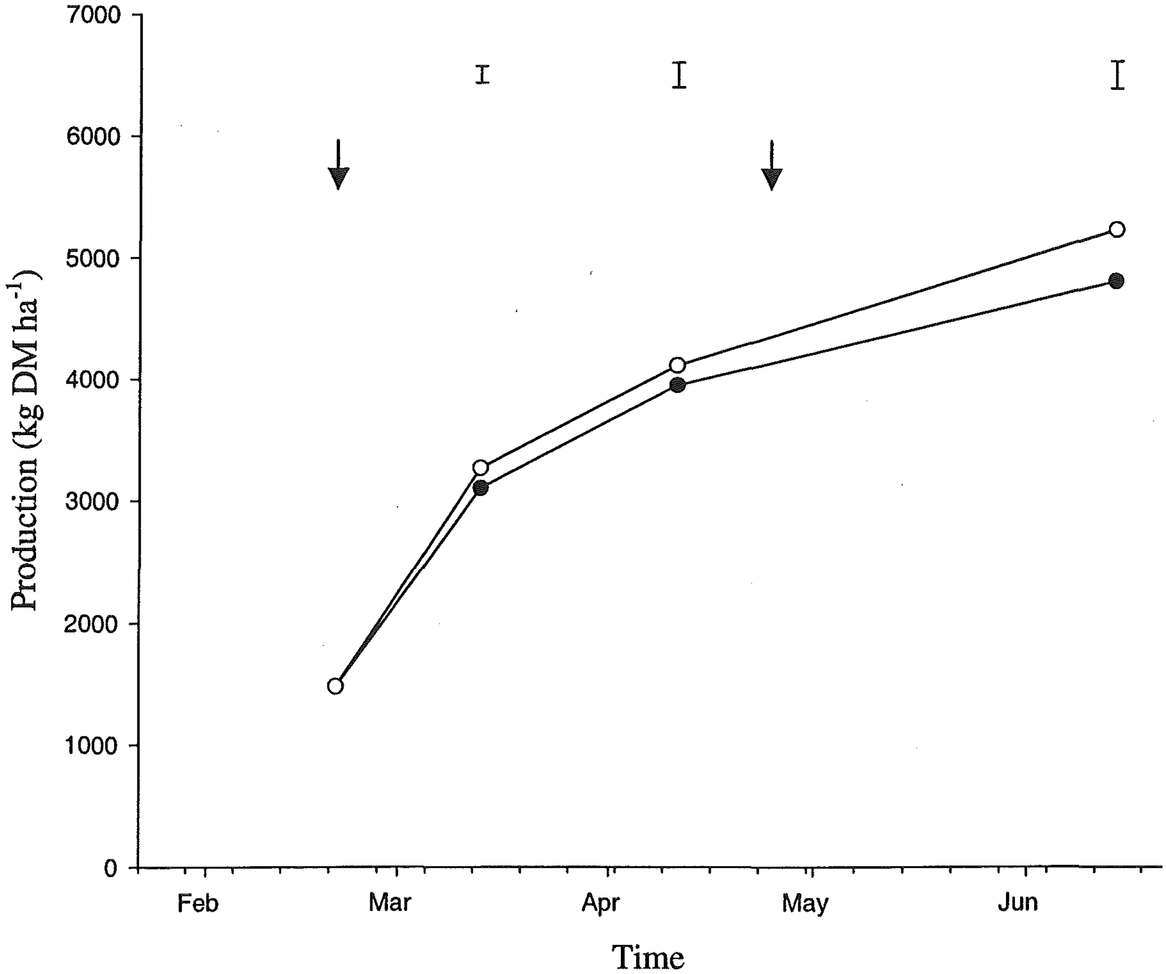

Figure 4.1 Cumulative dry matter production (kg DM ha^{-1}) + (○) / - (●) 120 kg N ha^{-1} from 20 February until 14 June 2001 for blocks 1 & 2. Arrows indicate time of nitrogen application and error bars represent s.e.m..

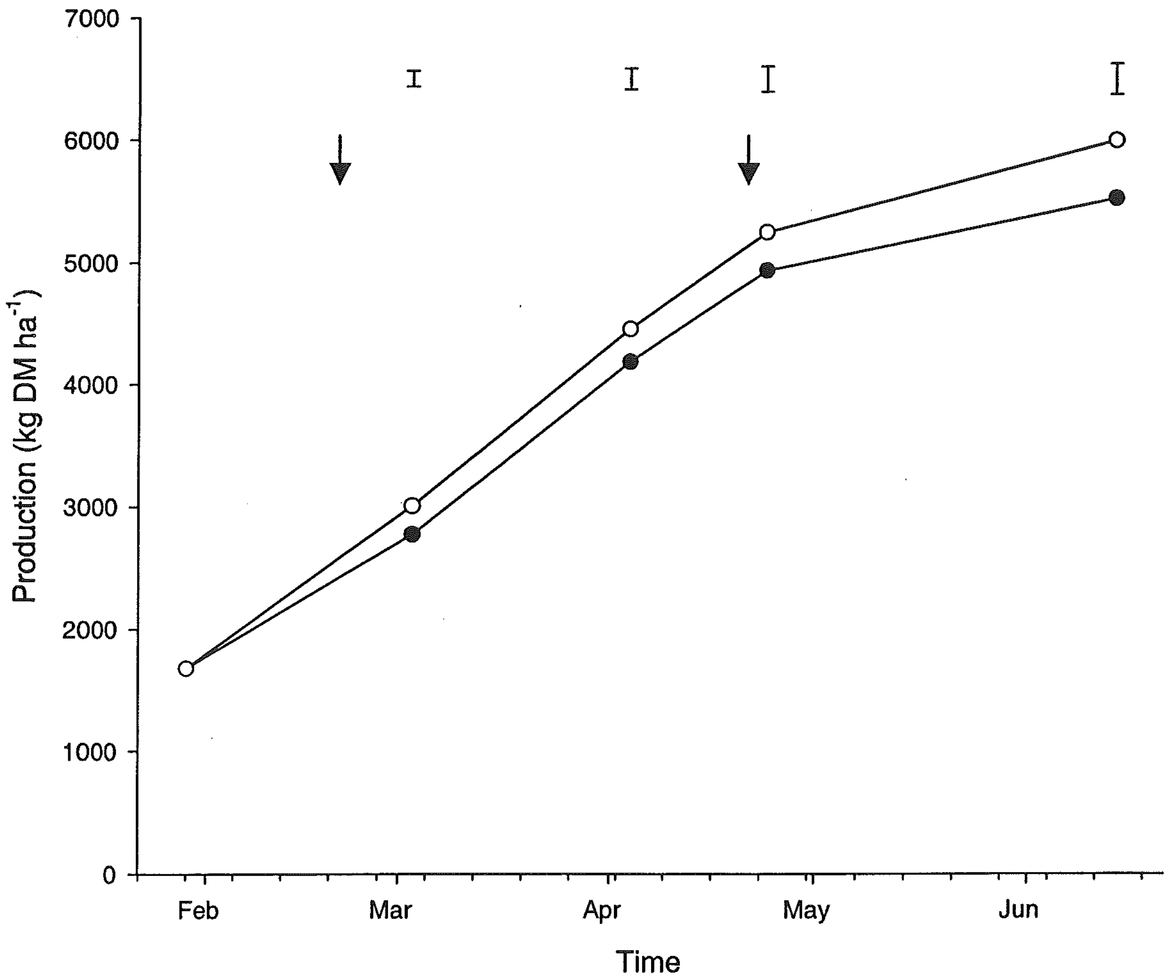

Figure 4.2 Cumulative dry matter production (kg DM ha^{-1}) + (○) / - (●) 120 kg N ha^{-1} from 29 January until 14 June 2001 for blocks 3 & 4. Arrows indicate time of nitrogen application and error bars represent s.e.m..

4.3.1.2 Dry matter components

Ryegrass, annual grass and clover comprised 58 and 78% (blocks 1 & 2 and blocks 3 & 4 respectively) of the total dry matter harvested (Table 4.4 and Table 4.6). The remainder included dead material and dicotyledon weeds (mainly dandelion and chickweed).

Total autumn ryegrass production in the experiment ranged from 1020 kg DM ha^{-1} in low fertility white clover plots with N to 1760 kg DM ha^{-1} in high fertility white clover plots with N in blocks 1 & 2. In blocks 3 & 4 total autumn ryegrass production ranged from 1160 kg DM ha^{-1} in low fertility Caucasian clover plots with N to 1700 kg DM ha^{-1} in low fertility white clover plots with N. There were no interactions or main effects of clover or fertiliser or subplot effect of N on total autumn ryegrass dry matter production.

Of the total dry matter produced in autumn, annual grass comprised 14-29% in blocks 1 & 2 and 18-35% in blocks 3 & 4. In blocks 1 & 2 there was an interaction ($P < 0.000$) between fertility and clover main plots for total autumn annual grass yields of fertility and clover (Table 4.7).

Table 4.7 Interaction ($P < 0.000$) between Caucasian and white clover at high and low soil fertility for total autumn annual grass production (kg DM ha^{-1}) in blocks 1 & 2.

Clover	Fertility		
	Low	High	Mean
White	635	1070	854
Caucasian	934	481	707
Mean	785	777	781

s.e.m. = 96.1

In white clover plots, total autumn annual grass dry matter production increased from 635 kg DM ha^{-1} in low fertility plots to 1070 kg DM ha^{-1} in high fertility plots. However, the high fertility Caucasian clover plots produced less annual grass than low fertility plots (481 c.f. 934 kg DM ha^{-1}).

In blocks 1 & 2 there was also a significant subplot effect of N on total autumn annual grass production (Table 4.4). Annual grass production from subplots that received 120 kg ha^{-1} N was greater ($P = 0.012$) than from those with no N (943 c.f. 619 kg DM ha^{-1}). This effect was also evident in blocks 3 & 4 where there was a trend for 37% greater annual grass production in plots that received 120 kg N ha^{-1} than those that did not receive N (1320 c.f. 966 kg DM ha^{-1}, $P = 0.054$). Although there were no interactions in total autumn annual grass production in blocks 3 & 4, annual grass production from high fertility plots (1350 kg DM ha^{-1}) was greater ($P = 0.031$) than low fertility plots (937 kg DM ha^{-1}, Table 4.6).

Total autumn clover production from Caucasian clover plots was 72% ($P = 0.230$) and 167% ($P = 0.000$) that of white clover plots in blocks 1 & 2 and blocks 3 & 4, respectively (Table 4.4 and Table 4.6). In the Caucasian clover plots, volunteer white clover comprised 55-63% of the total clover production. There was no effect of fertility or N on total autumn clover yield.

Dead material composed 31% of dry matter in blocks 1 & 2 and 26% in blocks 3 & 4. Total contribution to dry matter production in autumn from dead material was 45% greater in white clover compared with Caucasian clover in blocks 3 & 4 ($P = 0.041$). However, there was no difference in blocks 1 & 2 ($P = 0.312$). Dicotyledon weed production was generally higher in Caucasian clover plots (blocks 1 & 2, 28 c.f. 9, $P = 0.197$ and blocks 3 & 4, 51 c.f. 6 kg DM ha^{-1}, $P = 0.142$).

4.3.2 Production at each harvest

Due to the rotational grazing management of the ewe hoggets (4.2.2.2) results for blocks 1 & 2 and blocks 3 & 4 are presented separately. In blocks 1 & 2, production dropped from 81 kg DM ha^{-1} d^{-1} in the 21 days prior to the harvest on 13 March to 15 kg DM ha^{-1} d^{-1} in the 45 days prior to the final harvest on 14 June. In blocks 3 & 4, production increased from 34 kg DM ha^{-1} d^{-1} prior to 3 March to 68 kg DM ha^{-1} d^{-1} between then and 4 April and then dropped to 59 and 15 kg DM ha^{-1} d^{-1} prior to harvests on 24 April and 14 June, respectively.

4.3.2.1 Dry matter (individual harvests)

Dry matter production in blocks 1 & 2 for the 21 days to 13 March and 21 days to 11 April was affected by an interaction between fertility and clover ($P = 0.026$ and $P = 0.006$ respectively, Table 4.8 and Table 4.9).

Table 4.8 Interaction between Caucasian and white clover at high and low soil fertility for the dry matter production (kg DM ha^{-1}) during the 21 days prior to 13 March (s.e.m. 194, $P = 0.026$) and the 21 days prior to 11 April (s.e.m. 118, $P = 0.006$) in blocks 1 & 2.

Period of production	20 February to 13 March		20 March to 11 April	
	Fertility			
Clover	Low	High	Low	High
White	1390	2240	674	1080
Caucasian	1710	1470	1080	558

Dry matter production in white clover plots was 60-61% greater in high fertility than low fertility plots at harvests on 13 March and 11 April. However, in high fertility Caucasian clover plots dry matter production was less than low fertility plots at both harvests (14 and

48%, respectively). There were no main effects of fertiliser or clover or subplot effects of N at any harvest (Table 4.9).

Table 4.9 Dry matter production (kg DM ha^{-1}) for Caucasian and white clover at high and low soil fertility + / - 120 kg N ha^{-1} prior to 13 March, 11 April and 14 June (a) 2001 (blocks 1 & 2) and 3 March, 4 and 24 April and 14 June (b) 2001 (blocks 3 & 4).

Treatment	3 March	13 March	4 April	11 April	24 April	14 June (a)	14 June (b)
White clover	1310	1820	1360	878	753	976	670
Caucasian clover	1110	1590	1500	819	793	995	665
P	*0.298*	*0.287*	*0.242*	*0.631*	*0.674*	*0.912*	*0.965*
Low fertility	1110	1550	1340	877	795	973	605
High fertility	1310	1850	1530	820	751	998	730
P	*0.311*	*0.164*	*0.124*	*0.645*	*0.633*	*0.876*	*0.320*
No N	1090	1620	1410	849	752	857	588
120 kg N ha^{-1}	1330	1790	1450	848	794	1110	747
P	*0.240*	*0.428*	*0.748*	*0.996*	*0.650*	*0.150*	*0.214*
s.e.m.	*129*	*137*	*76*	*84*	*64*	*113*	*82*
Interactions	-	**f × c***	-	**F × C****	-	-	-

* P < 0.05, ** P < 0.01

4.3.2.2 Components at each harvest

In blocks 1 & 2, ryegrass, annual grass and clover comprised 65, 52 and 88% of dry matter at harvests on 13 March, 11 April and 14 June, respectively. However, in blocks 3 & 4, the same components comprised 68% of dry matter in harvests on 3 March, 79% on 4 April, 62% on 24 April and 83% on 14 June. The remainder included dicotyledon weeds and dead material. Ryegrass production ranged between 30 and 41% of total production at all harvests and production tended to decline toward late autumn (Table 4.11). In blocks 3 & 4 on 3 March, ryegrass production was affected by the interaction between fertility and clover (Table 4.10 and Table 4.11).

Table 4.10 Interaction (P = 0.044) between the ryegrass production (kg DM ha^{-1}) of Caucasian and white clover and high and low soil fertility main plots on 3 March (blocks 3 & 4).

Clover	Fertility		
	Low	High	Mean
White	552	426	489
Caucasian	256	434	345
Mean	404	430	417

s.e.m. = 62.1

Prior to 3 March at low fertility, ryegrass production from white clover (552 kg DM ha^{-1}) was 2.2 times that from Caucasian clover (256 kg DM ha^{-1}). However, at high fertility ryegrass production from white clover and Caucasian clover plots was similar (~430 kg DM ha^{-1}).

In blocks 1 & 2, annual grass increased from 15 and 10% of dry matter produced prior to harvests on 13 March and 11 April, respectively, to 45% prior to the harvest on 14 June (Table 4.13). Annual grass production was generally higher in blocks 3 & 4 and increased from 19% of dry matter produced prior to 3 March to 29% prior to 4 April, 22% prior to 24 April, then increased to 50% of dry matter at the 14 June harvest. Prior to harvests on 13 March and 11 April (blocks 1 & 2) annual grass production was affected by the interaction between fertility and clover (Table 4.12 and Table 4.13).

Table 4.11 Ryegrass dry matter production (kg DM ha^{-1}) for Caucasian and white clover at high and low soil fertility + / - 120 kg N ha^{-1} prior to 13 March, 11 April and 14 June (a) 2001 (blocks 1 & 2) and 3 March, 4 and 24 April and 14 June (b) 2001 (blocks 3 & 4).

Treatment	3 March	13 March	4 April	11 April	24 April	14 June (a)	14 June (b)
White clover	489	694	544	340	260	394	211
Caucasian clover	345	694	486	305	296	392	192
P	*0.054*	*0.995*	*0.611*	*0.531*	*0.605*	*0.984*	*0.728*
Low fertility	404	618	518	330	298	625	188
High fertility	430	77	512	315	258	462	216
P	*0.692*	*0.129*	*0.961*	*0.791*	*0.561*	*0.152*	*0.614*
No N	393	670	554	340	265	373	195
120 kg N ha^{-1}	442	719	477	305	291	413	209
P	*0.455*	*0.597*	*0.508*	*0.537*	*0.707*	*0.655*	*0.797*
s.e.m.	*43.9*	*62.7*	*77.6*	*37.8*	*45.9*	*60.2*	*37.3*
Interactions	**f × c***	-	-	-	-	-	-

* P < 0.05

Table 4.12 Interaction between Caucasian and white clover and high and low soil fertility for annual grass production (kg DM ha^{-1}) prior to harvests on 13 March (P = 0.006, s.e.m. 50.0) and 11 April (P = 0.009, s.e.m. 26.9) in blocks 1 & 2.

Period of production	20 February to 13 March		20 March to 11 April	
	Fertility			
Clover	Low	High	Low	High
White	154	492	46	119
Caucasian	217	134	157	34

High fertility increased annual grass production in white clover plots prior to harvests on 13 March (219%) and 11 April (159%), whereas, in Caucasian clover plots, high fertility decreased annual grass production prior to both harvests (38 and 78%, respectively). Annual grass production was also increased with increased fertility prior to the harvest on 4 April (70%, P = 0.028) (blocks 3 & 4) and on 14 June (a) with the application of N (58%, P = 0.044, blocks 1 & 2, Table 4.13).

Table 4.13 Annual grass dry matter production (kg DM ha^{-1}) for Caucasian and white clover at high and low soil fertility + / - 120 kg N ha^{-1} prior to 13 March, 11 April and 14 June (a) 2001 (blocks 1 & 2) and 3 March, 4 and 24 April and 14 June (b) 2001 (blocks 3 & 4).

Treatment	3 March	13 March	4 April	11 April	24 April	14 June (a)	14 June (b)
White clover	225	**323**	388	82.4	148	449	336
Caucasian clover	233	**175**	434	95.4	187	437	337
P	*0.914*	***0.029***	*0.570*	*0.644*	*0.196*	*0.886*	*0.979*
Low fertility	192	**185**	**305**	101	146	498	294
High fertility	266	**313**	**517**	76.5	188	388	379
P	*0.356*	***0.050***	***0.028***	*0.389*	*0.172*	*0.217*	*0.235*
No N	174	192	357	83.1	154	**343**	281
120 kg N ha^{-1}	284	306	465	94.6	180	**542**	392
P	*0.184*	*0.073*	*0.200*	*0.682*	*0.385*	***0.044***	*0.132*
s.e.m.	*52.4*	*38.2*	*54.2*	*19.1*	*19.3*	*57.5*	*46.2*
Interactions	-	**F × C****	-	**F × C****	-	-	-

** P < 0.01

Total clover production was up to five times greater on Caucasian clover than white clover plots prior to harvests in blocks 3 & 4 on 4 ($P = 0.000$) and 24 April ($P = 0.000$) and 14 June (b) ($P = 0.032$ Table 4.14). Total clover production on 11 April (blocks 1 & 2) in high fertility plots was 62% less than low fertility plots ($P = 0.019$). Total clover production was not affected by the application of N.

Table 4.14 Total clover dry matter production (kg DM ha^{-1}) for Caucasian and white clover at high and low soil fertility + / - 120 kg N ha^{-1} prior to 13 March, 11 April and 14 June (a) 2001 (blocks 1 & 2) and 3 March, 4 and 24 April and 14 June (b) 2001 (blocks 3 & 4) (contribution of volunteer white clover to total Caucasian clover production in brackets).

Treatment	3 March	13 March	4 April	11 April	24 April	14 June (a)	14 June (b)
White clover	151	119	**66.8**	22.4	**10.0**	19.6	**13.0**
Caucasian clover	211 (137)	196 (114)	**348 (212)**	44.4 (20.1)	**49.3 (29.8)**	36.0 (17.5)	**31.6 (22.5)**
P	*0.162*	*0.355*	***0.000***	*0.062*	***0.000***	*0.082*	***0.032***
Low fertility	181	202	207	**48.5**	33.5	35.5	17.4
High fertility	180	113	208	**18.3**	25.8	20.1	27.3
P	*0.982*	*0.289*	*0.997*	***0.019***	*0.315*	*0.098*	*0.199*
No N	189	171	200	36.4	27.6	32.5	19.8
120 kg N ha^{-1}	172	144	215	30.4	31.6	23.1	24.9
P	*0.659*	*0.735*	*0.786*	*0.565*	*0.593*	*0.283*	*0.486*
s.e.m.	*27.1*	*54.9*	*39.4*	*7.02*	*5.06*	*5.70*	*4.92*
Interactions	-	-	-	-	-	-	-

The contribution of dead material to dry matter harvested decreased in June and was generally higher for blocks 1 & 2 than for blocks 3 & 4 (35, 47 and 12% c.f. 31, 20, 38 and 16% of dry matter produced). The contribution of dead material to dry matter production on 11 April was affected by the interaction between fertility and clover in blocks 1 & 2 (Table 4.15 and Table 4.16).

Table 4.15 The interaction (P = 0.009) between Caucasian and white clover at high and low soil fertility between 20 March and 11 April (blocks 1 & 2) for contribution of dead material to dry matter production (kg DM ha^{-1}).

Clover	Fertility		
	Low	High	Mean
White	310	553	431
Caucasian	470	264	367
Mean	390	408	399

s.e.m. 63.4

In white clover plots, the contribution of dead material to dry matter production increased from 310 kg DM ha^{-1} at low fertility to 553 kg DM ha^{-1} at high fertility. However, in Caucasian clover plots, the contribution to dry matter production of dead material from 470 kg DM ha^{-1} in low fertility plots to 264 kg DM ha^{-1} in high fertility plots.

Contribution to dry matter production on 4 April (blocks 3 & 4) from dead material was 84% greater in white clover plots compared with Caucasian clover plots (P = 0.012, Table 4.16).

Table 4.16 Contribution of dead material to dry matter production (kg DM ha^{-1}) for Caucasian and white clover at high and low soil fertility + / - 120 kg N ha^{-1} prior to 13 March, 11 April and 14 June (a) 2001 (blocks 1 & 2) and 3 March, 4 and 24 April and 14 June (b) 2001 (blocks 3 & 4).

Treatment	3 March	13 March	4 April	11 April	24 April	14 June (a)	14 June (b)
White clover	442	673	**363**	431	335.0	112	111.0
Caucasian clover	309	514	**197**	367	259	123.0	101
P	*0.262*	*0.256*	***0.012***	*0.341*	*0.068*	*0.700*	*0.756*
Low fertility	326	536	289	390	315	109	105
High fertility	424	652	271	408	279	125	106
P	*0.396*	*0.399*	*0.737*	*0.776*	*0.343*	*0.572*	*0.982*
No N	330	575	279	384	302	102	92.9
120 kg N ha^{-1}	421	612	281	414	292	133	119
P	*0.431*	*0.786*	*0.959*	*0.653*	*0.803*	*0.296*	*0.368*
s.e.m.	*77.1*	*91.4*	*35.2*	*44.8*	*25.2*	*19.40*	*18.8*
Interactions	-	-	-	**F × C****	-	-	-

** P < 0.01

4.3.3 Percent total clover

Total clover percent was 2 to 18 percentage units higher in Caucasian clover plots than white clover plots in blocks 3 & 4, viz, P = 0.026, 0.000, 0.000 and 0.003 for harvests on 3 March, 4 and 24 April and 14 June (b) respectively (Figure 4.4). This effect was not evident in blocks 1 & 2 (Figure 4.3). There were no interactions between the percent total clover in fertility or clover main plot treatments or N subplot treatment, nor was it affected by fertility or N at any harvest.

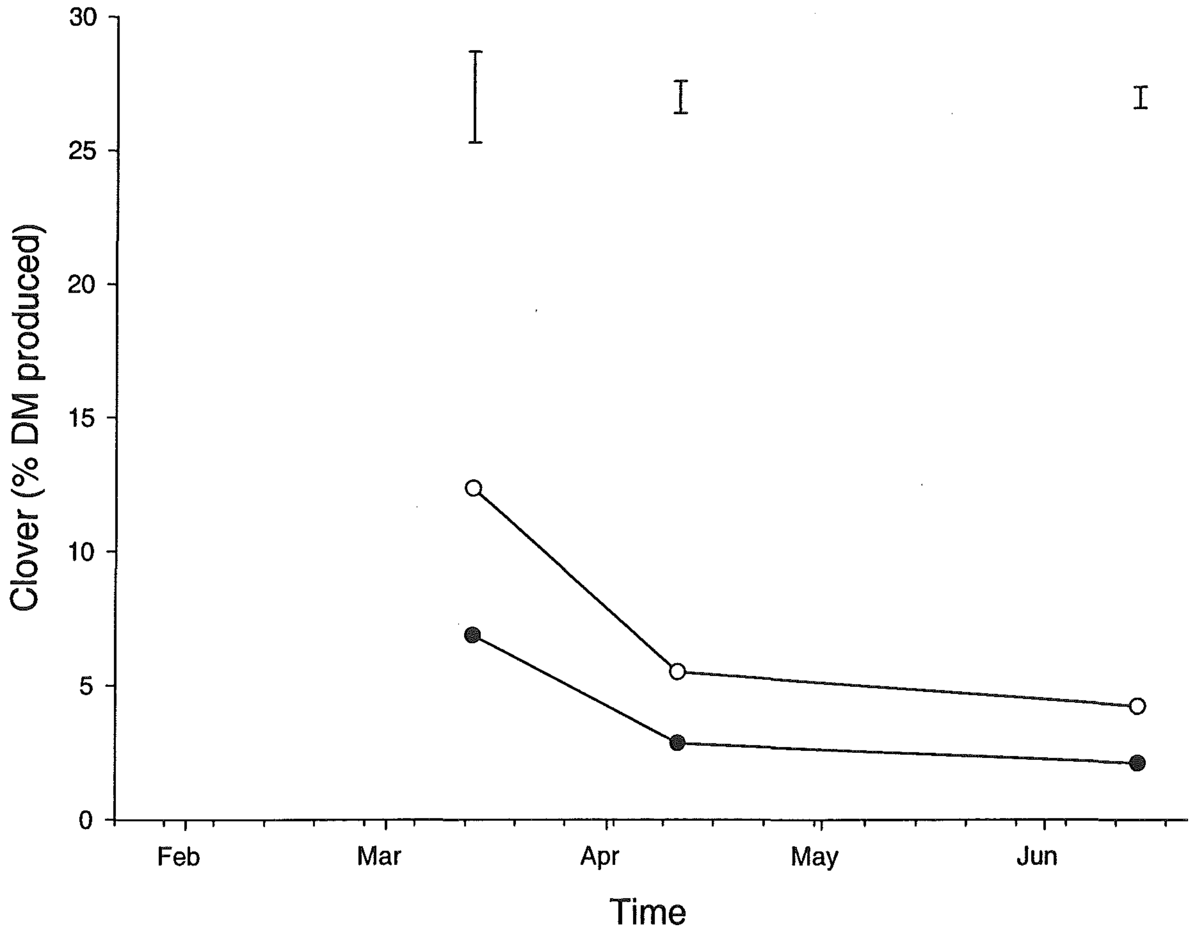

Figure 4.3 Total clover percent of dry matter produced for blocks 1 & 2 at three autumn 2001 harvests for white clover (●) and Caucasian clover (○). Bars represent s.e.m. at each harvest.

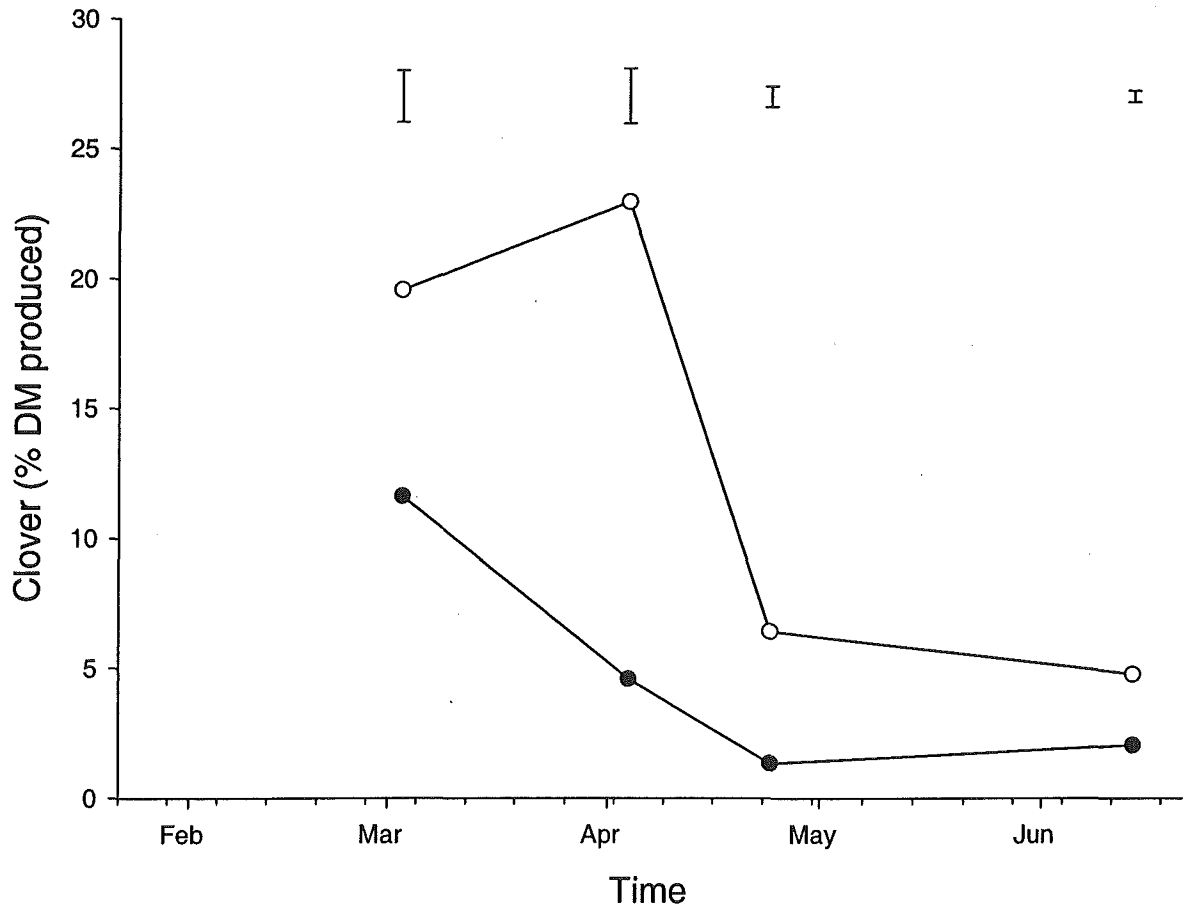

Figure 4.4 Total clover percent of dry matter produced for blocks 3 & 4 at four autumn 2001 harvests for white clover (●) and Caucasian clover (○). Bars represent s.e.m. at each harvest.

4.3.4 Herbage nitrogen content

Nitrogen content of ryegrass averaged 3.84% and was lower than annual grass, which averaged 4.32% ($P < 0.001$). The application of N fertiliser increased herbage N content from 3.70 to 3.98% in ryegrass ($P < 0.000$) and from 4.16 to 4.84% in annual grass ($P = 0.026$) (Table 4.17).

Table 4.17 Herbage nitrogen (N) content (%) of ryegrass and annual grass for Caucasian and white clover at high and low soil fertility + / - 120 kg N ha^{-1} during autumn 2001.

Treatment	Ryegrass	Annual grass
White clover	3.84	4.26
Caucasian clover	3.84	4.39
P	*0.982*	*0.295*
Low fertility	3.84	4.23
High fertility	3.84	4.42
P	*0.164*	*0.137*
No N	**3.70**	**4.16**
120 kg N ha^{-1}	**3.98**	**4.48**
P	***0.000***	***0.026***
s.e.m.	*0.04*	*0.08*

4.4 Discussion

4.4.1 Pasture production

4.4.1.1 Nitrogen response

The response to autumn applied N (Table 4.1) across fertility and clover treatments was low, and ranged from 3.5 kg DM ha^{-1} kg N^{-1} on blocks 1 & 2 to 3.9 kg DM ha^{-1} kg N^{-1} on blocks 3 & 4 (Table 4.4, Table 4.6, Figure 4.1 and Figure 4.2) and was not different at any harvest (Table 4.9). This response is less than the commonly expected response of 10 kg DM ha^{-1} kg N^{-1} (Clark and Harris, 1996) and also less than the 7.9 kg DM ha^{-1} kg N^{-1} response measured on the same site the previous autumn (Maw, 2000).

However, Roberts and Thomson (1989) were able to show responses to autumn applied N are often variable and lower than 10 kg DM ha^{-1} kg N^{-1}. O'Connor (1982) reviewed the results of a large number of field experiments throughout New Zealand and reported that responses to autumn applications of 100 kg N ha^{-1} (1.2-9.8 kg DM ha^{-1} kg N^{-1}) were often smaller and less reliable than spring responses (2.1-12.6 kg DM ha^{-1} kg N^{-1}). Roberts, Morton and Edmeades (1994) went a step further by stating that the probability of a achieving a 10:1 response is 0.2 to 0.4 in autumn increasing to 0.8 to 1.0 in spring and early summer. The variability in N response can be attributed to the prevailing climatic conditions, the ability of pasture to respond to N fertiliser, low soil moisture status, high soil nitrate levels, variation in mineral N levels following summer drought and often poor botanical composition resulting from drought or insect pest attack (Field and Ball, 1978; O'Connor, 1982).

The small response may have been a reflection of the previous N application to the plots. Over the previous 12 months, 420 kg N ha^{-1} has been applied in varying amounts from 50-100 kg N ha^{-1} at each application. It is well documented that as N application rate increases, the efficiency of the response declines (Ball and Field, 1982; Roberts and Thomson, 1989). Many authors have suggested rates of between 25-50 kg N ha^{-1} for single applications, depending on the N fertility of the site and pasture composition, because of the decline in efficiency at higher rates (O'Connor and Cumberland, 1973; Steele, O'Connor and Ledgard, 1981).

Kemp, Condron and Matthew, (1999) stated that the size of the response to N fertiliser depends on the current level of N deficiency, the suitability of other environmental conditions for pasture growth and the growth potential of the pasture. Unlike in 2000, when soil available N appeared to be adequate in the low N plots (as measured in the N content of the herbage, average 4%), in 2001, there was a deficiency of N in the same plots resulting in ryegrass containing 3.70% N. The application of N increased the ryegrass N concentration to 3.98%, close to 4%, below which, ryegrass is deficient (McLaren and Cameron, 1996). However, when N stress is relieved by fertiliser application, a period of luxury N uptake precedes the response in terms of herbage dry matter. Thus the efficiency of N use by the plant will be determined, to some extent, by the length of time the pasture is spelled after the N application (Ball and Field, 1982).

The defoliation interval in this experiment averaged 22 days for the first five harvests, then stretched out to 45-60 days for the last harvest. Roberts and Thomson (1989) found that a defoliation interval of six weeks gave the greatest response to applied N over a three-year period. However, for a reason unknown to the authors, the shortest defoliation interval (two weeks) gave greater responses than the intermediate interval (three weeks). Other workers have advocated defoliation intervals ranging from six to nine weeks depending as optimum for N responses (McKenzie, 1970; O'Connor and Cumberland, 1973; Ball and Field, 1982). However, this will depend on temperature, as plants will reach ceiling yield in a shorter period of time at warmer temperatures.

On the same site Maw (2000) also studied the effect of defoliation interval on N response. Frequent defoliation (14 days) reduced autumn dry matter yield by 28% compared to infrequent (28 day) defoliation. The increase in N content of the herbage and small dry matter response measured in 2001 may be a reflection of the relatively short defoliation interval.

The monthly air temperatures remained above 7 °C for the duration of the trial (Table 3.2). However, from late May until the last harvest (approximately 30 days later in June), the 10 cm soil temperature was below 7 °C. As well as going onto a low pasture mass, air and soil temperature were decreasing to below 7 °C at the second application of N (70 kg ha^{-1}), reducing the potential for pasture growth (Kemp *et al*, 1999). The N would have been applied earlier if irrigation had been adequate. However, the application was only one week after 80 kg N ha^{-1} was applied to the old Lincoln University dairy farm (A.C.W. Whatman, *pers. comm.*). Furthermore, on one set of blocks, there was only one harvest after N application.

When 25 kg N ha^{-1} was applied in trials in the South Island (O'Connor, 1982), 54% of the response has been in the first defoliation (39 day interval) and 46% of the response in the second defoliation (62 day interval). In addition, autumn applications of N have been found to have an influence on winter and early spring growth rates (McLaren and Cameron, 1996). This may be particularly beneficial since it is in late winter / early spring when feed is normally in short supply. It is thought that autumn applied N fertiliser becomes immobilised in the warm soil at this time of the year and is thus protected from winter leaching. If a subsequent harvest was taken with a longer defoliation interval, a larger dry matter response may have been evident.

The response to N may also have been restricted by the pasture mass that the N was applied to. Nitrogen was applied to all plots on the same day, regardless of when sheep had grazed or were due to graze them (Table 4.3). The first application (50 kg N ha^{-1} on 15 February) was onto an average pasture mass of 1790 kg DM ha^{-1}. However, the second application (70 kg N ha^{-1} on 20 April) was onto a much lower and variable pasture mass (average 777, range 546-1030 kg DM ha^{-1}). Roberts and Thomson (1989) also found that responses to a 50 kg ha^{-1} application of N decreased from 10.6 to 5.9 kg DM ha^{-1} kg N^{-1} when the herbage mass at application dropped from 2800 to 1500 kg DM ha^{-1}. These arguments are supported by Kemp *et al.* (1999), who reported that yield responses to nitrogen will be reduced if applied when leaf area is low (< 1000 kg DM ha^{-1}) and the pasture canopy is unable to intercept all available solar radiation during the lag growth phase following defoliation. As the pasture was a rotationally grazed sheep pasture, the pasture mass in this experiment was much lower than recommended for maximum N response, particularly at the second application.

In the past, grass grub has limited the response of the same pastures to N (Maw, 2000). Although grass grub was not perceived to be a problem in 2001, a further reason for the low response may have been the high mealy bug population that was evident in the grazing experiment pastures during the very dry autumn 2001. A severe infestation of mealy bug was named as the likely cause of reductions of yield of ryegrass pastures, particularly low endophyte, at Lincoln in previous seasons (Popay, Hume, Baltus, Latch, Tapper, Lyons, Cooper, Pennell, Eerens and Marshall, 1999). It is likely that the presence of mealy bug limited the ability of the endophyte free Ruanui ryegrass to respond to the additional N fertiliser.

4.4.1.2 Fertility × clover interaction

The interaction between fertility and clover for total autumn dry matter production (Table 4.5), total autumn annual grass dry matter production (Table 4.4 and Table 4.7), dry matter and annual grass production between 20 February and 11 April (Table 4.8 and Table 4.12) and dead material accumulation between 20 March and 11 April (Table 4.15) in blocks 1 & 2 was probably caused by the uneven watering of some subplots. Ten subplots, including all eight of the Caucasian clover high fertility + / - 120 kg N ha^{-1} subplots and two of the low fertility white clover + 120 kg N ha^{-1} subplots were affected. These subplots had a wilted appearance, started to "brown off" and these subplots produced 920 kg DM ha^{-1} less than the average of the plots not affected. These subplots were in the centre of their respective main plots, meaning that, as the plots were irrigated by a gun irrigator for the duration of summer and early autumn, when water pressure was reduced due to other irrigators operating, the spray from the gun was not reaching the centre of the main plots. The subplots that were positioned at either end of the main plots were not affected. As the effect was on one whole treatment in each block (Caucasian clover high fertility), analysis of covariance was unsuccessful in removing the effect. As these plots came under water stress, dry matter production was reduced, particularly for annual grass at the first two harvests.

4.4.2 Pasture composition

Differences between the production and proportion of pasture components in the sward in relation to treatments were generally small and inconsistent at each harvest (Table 4.10, Table 4.11, Table 4.12, Table 4.13, Table 4.15 and Table 4.16), except for clover species on total clover production and content (Figure 4.3, Figure 4.4, Table 4.6 and Table 4.14).

4.4.2.1 Clover

In blocks 3 & 4, clover production was 2.7 times greater for Caucasian clover than white clover pastures (Table 4.6 and Table 4.14). The effect in blocks 3 & 4 was similar to both the caged areas and the pre-grazing pasture mass in autumn, where Caucasian clover pastures had greater clover content and clover production than white clover pastures. However, average clover content was lower on the N investigation subplots (8.6%) than either the pre-grazing pasture in the main plots (15.3%) or the caged areas where pasture production was measured (22.4%). As N application had no effect on the clover content in the pasture, or clover production, compared to control plots that did not receive N (Table 4.4 and Table 4.6), this difference cannot be ascribed to N fertiliser application unless there was significant lateral movement of N underground which is unlikely.

The lack of difference in clover content with or without applied N was in contrast to that found by Harris and Clark (1996) in an experiment comparing 0, 200 and 400 kg N ha^{-1} y^{-1} at low (3.24 cows ha^{-1}) and high (4.53 cows ha^{-1}) stocking rates. They found that as long as the additional dry matter produced with applied N was utilised by increasing the stocking rate, there was little difference in white clover content between 0 and 200 kg N ha^{-1} y^{-1} (15.4% and 14.9% of dry matter respectively). However, when 400 kg N ha^{-1} y^{-1} was applied (similar to the rate used in this experiment) clover content dropped to 6.8% of dry matter. The lack of difference over all treatments in clover content with applied N compared to plots that did not receive N was unexpected. If there were a difference between the competitive abilities of Caucasian and white clover, an interaction between clover and N for clover production or content would have been apparent. No such interaction was apparent with p values ranging between 0.625 and 0.902.

However, as Maw (2000) stated, other workers (Ball, 1978; Ledgard, Sprosen, Steele and West, 1995) have reported that significant reductions in white clover after the application of N fertiliser are not often apparent until the spring of the second year. In the present study, this would be spring 2001. Therefore, to determine the suitability of Caucasian clover to dairy pastures where N fertiliser is used, a longer-term study is recommended.

One reason for the apparent lack of difference may have been the short defoliation interval (average 22 days for the first five harvests). As it is the grass that responds to applied N, the proportion of clover in the herbage normally declines as the length of the spell after N application increases (Ball and Field, 1982). In late spring / early summer under favourable growth conditions, with three and five weeks regrowth, clover contents were 30 and 17%, respectively. On the N treated plots, the clover contents were 17 and 3% for the same regrowth period. The absolute yield of clover from the no N plots remained constant between the third and fifth weeks, but declined to half of this figure in the N treated swards. Ball and Field (1982) stated that only under conditions of favourable clover growth was there a significantly reduced clover content, with the effect more pronounced as the pasture regrowth period after application lengthened. The 22-day regrowth periods and high stocking rate (39 lambs ha^{-1}) may have negated any effect of N application on clover production or content.

4.4.2.2 Ryegrass

Ryegrass dry matter production was similar in all treatments at almost every harvest (Table 4.11). The interaction between clover and fertility at the harvest on 3 March (Table 4.10) was not repeated at any further harvest. Averaged over all plots, ryegrass (which comprised 39% and 35% of dry matter produced in low and high N plots, respectively) dry matter production increased by 0.29 kg DM ha^{-1} kg N^{-1}. The inability of ryegrass to convert the additional N to dry matter suggests that production may not have been limited by the N content of the ryegrass herbage in the low N plots (3.70%). However, the mealy bug infestation may have also inhibited the N uptake of ryegrass plants.

These results also suggest that while the ryegrass was able to take up enough N to achieve maximum growth, the low proportion of ryegrass in the sward may have limited the dry matter response to N. McKenzie (1970), O'Connor and Cumberland (1973) and Ball and Field (1982) suggest that for satisfactory N responses, ryegrass dominant pastures must be selected. The pastures were not ryegrass dominant and contained a substantial amount of annual grass (22-28%), clover (6-10%), and dead material (26-31%). If ryegrass had been the major component of the sward in this case, then the response to N fertiliser would be expected to be higher.

4.4.2.3 Annual grass

The response of annual grass production to the treatments varied between blocks 1 & 2 and blocks 3 & 4. The increased production from annual grass in high fertility plots in blocks 3 & 4 (1350 c.f. 937 kg DM ha^{-1}, $P = 0.031$) was not evident in blocks 1 & 2 ($P = 0.940$), possibly due to the water stress that occurred in some of the plots. Annual grass, which comprised 22% of dry matter in low N plots and 28% of dry matter in high N plots also increased production with additional N, viz, 2.83 kg DM ha^{-1} kg N^{-1}. The N content of the annual grass herbage was 4.16% in plots not receiving N fertiliser and increased to 4.48% in plots that did receive N fertiliser. The ability of the annual grass to convert the additional N to dry matter would suggest that the threshold N concentration for maximum growth of annual grass may be higher than that for ryegrass, and that N was limiting production of annual grass in the low N plots.

The relatively high annual grass component of the sward was able to take up additional N and convert this into increased dry matter production. The feed value of the annual grass at this time was very good (4.16-4.48% N). However, during late spring / summer, there is very little vegetative growth, making it a weed in high producing pastures.

4.4.3 Soil acidity

The lack of a pH decline in plots receiving N fertiliser (Table 4.2) was unexpected, as N fertilisers have been shown to reduce soil pH. Although the initial hydrolysis of urea makes the soil alkaline, micro-organisms in the soil convert N in the ammonium (NH_4^+) form to NO_3^- by the process of nitrification, at the same time releasing H^+ ions, lowering the soil pH (McLaren and Cameron, 1996). To neutralise this acidity, Pringle, Edmeades, Shannon and Mansell (1985) suggest that intensive dairy pastures require applications of approximately 2 t lime ha^{-1} every five years. No lime has been applied to the N plots since all plots received a 1 t ha^{-1} basal application at sowing in 1997 (3.2.1.1) although this may still be having a residual effect.

The lack of change in soil pH may be partially attributable to the small subplot size. Additional N in the herbage from N fertiliser would usually be returned to the pasture. However, the herbage from N fertilised plots was a small component of the animals diet, and was very unlikely to be returned to the small experimental subplots. If the plots were larger (say 0.04 ha) animals could be confined to the plots and the effect of animal excreta on soil pH could be assessed.

4.5 Conclusions

- Despite increasing foliar N content of both ryegrass (3.98 c.f. 3.70%) and annual grass (4.48 c.f. 4.16%) the autumn application of N to Caucasian and white clover pastures at high and low soil fertility only increased dry matter production by 3.5-3.9 kg DM ha^{-1} kg N^{-1}.

- In the blocks not affected by uneven watering, Caucasian clover pastures had a total clover production that was up to five times greater than that from white clover at four autumn harvests.

- Soil fertility, in particular pH has not been affected by the application of 420 kg N ha^{-1} over a 12-month period.

- Pasture composition was not affected by the application of 120 kg ha^{-1} N in autumn 2001, nor by the residual effect of 300 kg N ha^{-1} over the previous 12 months.

- Due to the layout of the trial and grazing management, larger, separately grazed plots are required to detect differences in pasture production and composition and soil pH changes between N treatments.

5 Caucasian clover seedling transplantation into two dairy pastures

5.1 Introduction

Maw (2000) suggested that the potentially taller growth habit and larger leaves of Caucasian clover will allow it to be more competitive than white clover against ryegrass stimulated by nitrogen (N) fertiliser. He followed by stating that this could indirectly lead to a greater total yield of clover, as a reduction in ryegrass in Caucasian clover pastures may ultimately allow for greater establishment of white clover from hard seed in the soil.

Caucasian clover size and cover was assessed in autumn 2001, three years after the transplantation of seedlings into two dairy pastures in autumn 1998. The effect of additional N fertiliser, applied in autumn 2001, was also assessed.

5.2 Materials and methods

5.2.1 Site

The experimental areas were situated in paddocks 25 and 35 of the old Lincoln University dairy farm. Paddock 25 was a three year old ryegrass / white clover permanent pasture sown in February 1998 and has received approximately 150 kg N ha^{-1} yr^{-1} since establishment. Paddock 35, an old (20 + years) ryegrass / white clover permanent pasture has not received N fertiliser since 1994 (A.C.W. Whatman *pers. comm.*). Both paddocks have received approximately 50-60 kg P ha^{-1} yr^{-1}. In 1997 soil tests in paddock 35 (pH, 6.7; Olsen P, 42; S, 14; K, 5) indicated a high pH, relatively high P and S, and moderate to low K. There was no specific data for paddock 25 although it was expected to be similar to the rest of the farm when tested in 1999 (pH, 5.9; Olsen P, 41; S, 13; K, 6) with a lower pH than paddock 35. No subsequent soil tests have been carried out.

5.2.2 Experimental

On 23rd January 1998, in the north west corner of paddock 35, 83, 14-month-old Caucasian clover seedlings were transplanted at approximately one metre intervals along a 89.5 m transect line, with a three metre buffer zone from the fence at each end. Each seedling plug was transplanted with the foliage removed and watered with approximately 500 ml of water. Similarly, on 9th February 1998 in the north west corner of paddock 25, 93, 14-month-old Caucasian clover seedlings were transplanted at approximately one metre intervals along a 99 m transect line. On 14 March 2001 in paddock 25 surviving plants were paired with similar sized plants in a similar environment on the same transect line and 100 kg N ha^{-1} (as urea, mixed with 1000 ml water) was applied to one plant in each of eight pairs (+ N). The other plant in each pair also received 1000 mL water (- N). Similarly on 21 March 2001 in paddock 35, surviving plants were paired with similar sized plants in a similar environment on the same transect line and 100 kg N ha^{-1} (as urea, mixed with 1000 ml water) was applied to one plant in each of six pairs. The other plant in each pair also received 1000 mL water.

5.2.3 Climate

The climate experienced in the area was typical of the Canterbury plains with warm dry summers and cool winters. Mean data from Broadfields Meteorological Station (43°38'S, 11 m.a.s.l.) from 1998 until the time of sampling indicated that on average, there was 83 mm less rainfall, temperatures that were 0.5 °C higher, there was and 33 mm less evapotranspiration than the 40 year mean for the duration of the experiment (Table 5.1). However, in the six-month period immediately post-transplanting, there was 159 mm less rainfall, temperatures were 1.6 °C above average and there was 68 mm more evapotranspiration than the long-term mean. Both paddocks are irrigated on a 17-day round (approximate).

Table 5.1 Climate data for January 1998 to August 2001 and 40 year means (40YM) from Broadfields Meteorological Station, Lincoln, Canterbury.

	Mean daily air temperature (°C)					Rainfall (mm)					Evapotranspiration (mm)				
Month	1998	1999	2000	2001	40YM	1998	1999	2000	2001	40YM	1998	1999	2000	2001	40YM
Jan	17.9	17.6	15.2	14.9	16.6	17	36	85	55	50	168	131	121	143	153
Feb	19.6	17.3	16.4	**17.3**	16.4	14	38	20	**10**	51	143	133	113	**118**	118
Mar	16.8	16.9	14.4	**15.3**	14.8	31	56	52	**4**	59	122	107	96	**109**	97
Apr	12.9	12.3	12.4	**12.8**	12.0	11	36	51	**5**	52	73	60	56	**77**	62
May	10.4	11.0	9.9	**9.5**	9.0	54	24	72	**41**	50	41	56	42	**37**	44
Jun	6.9	6.9	8.3	**7.0**	6.3	40	69	41	**37**	63	28	29	0	**39**	33
Jul	8.0	6.4	8.0	4.7	6.0	49	135	11	64	74	37	28	32	39	37
Aug	6.4	7.2	7.4	8.1	7.2	46	58	99	36	68	45	44	48	51	51
Sep	9.7	9.2	10.2	10.0	9.2	19	27	149	15	40	85	74	27	76	69
Oct	12.0	12.6	12.0	12.2	11.4	57	51	79	63	55	109	97	107	90	105
Nov	12.1	13.1	10.8	*	13.1	20	61	83	*	56	116	101	116	*	143
Dec	15.5	13.8	16.9	*	15.2	24	35	41	*	61	149	134	173	*	143
Total						382	626	783	330	680	1115	993	931	779	1053

* Not yet available

Nb. Bolded data are for autumn 2001 experimental period.

5.2.4 Measurements

Plant survival and spread of individual plants was recorded on 14 (paddock 25) and 21 March (paddock 35). Visual estimates of cover using a 0.1 m^2 quadrat and further measurements of plant spread were taken on 14 April and 7 May for paddock 35 (21 and 23 days after grazing, respectively). Similarly, in paddock 25 on 6 April and 12 May, visual estimates of cover and further measurements of plant spread were taken (17 and 13 days since last grazing, respectively). In both paddocks, pasture mass was similar (2000-2100 kg DM ha^{-1}) at each observation, and was grazed soon after. Ryegrass, brome (*Bromus spp.*), tall fescue (*Schedonorus phoenix.* syn. *Festuca arundinacea*), Caucasian clover, white clover, dicotyledon weeds (predominantly dock and Californian thistle (*Cirsium arvense*)), dead material and bare ground components were recorded. At the last measurement in each paddock, the pasture composition was also visually assessed at a representative 0.1 m^2 site one metre to the side of the Caucasian clover plants to assess the effect of the transplantation on pasture composition.

5.2.5 Analysis

As there was no replication of transect lines within each paddock, averages and ranges of the data for each observation variate only are reported. Analysis of variance and alternative statistical tests were considered to be inappropriate (J.R. Sedcole *pers. comm.*).

5.3 Results

5.3.1 Survival

In paddock 35, 22 out of 83 plants (27%) had survived from transplanting in January 1998 until autumn 2001. In paddock 25, 32 of the 93 plants (34%) had survived three years in a dairy pasture from transplanting in February 1998.

5.3.2 Spread

5.3.2.1 Paddock 25

Of the plants that had survived in paddock 25, on average they had spread 40 mm yr^{-1} to have a mean plant diameter (MPD) of 120 mm in mid March 2001. The addition of N in autumn 2001 had little effect on the size of Caucasian clover plants in paddock 25 on 6 April (Table 5.2). The Caucasian clover plants with additional N had a MPD of 99 mm while the plants without additional N had a MPD of 116 mm. The difference between N treatments was again very minimal when measured again on 12 May (101 and 108 mm MPD for + N and – N plants respectively).

5.3.2.2 Paddock 35

The surviving plants in paddock 35 had spread an average of 63 mm yr^{-1} to have a MPD of 190 mm in late March 2001. In contrast to paddock 25, the addition of N had a marked effect on Caucasian clover plant size (Table 5.2). Plants receiving N had a MPD of 155 mm when measured on 14 April, compared to 198 mm for the plants without N. When measured again on 7 May, the difference was even greater (145 c.f. 228 mm MPD for + N and – N plants respectively).

5.3.3 Pasture composition

5.3.3.1 Paddock 25

Of the total ground cover, there was a high ryegrass content in paddock 25 at both samplings (67-78%) (Table 5.2). Caucasian and white clovers made up the bulk of the remaining pasture (3-10 and 7-19% respectively). There was a small amount of brome present (0-1%), and bare

Table 5.2 Mean plant diameter (MPD, mm) of individual Caucasian clover plants (mm) and percentage visual cover of pasture components in 0.1 m^2 quadrats (+ / - additional nitrogen (N) fertiliser) and in an adjacent area (Adj) in paddock 25 (3 yr pasture, 150 kg N ha^{-1} yr^{-1}) on 6 April and 12 May and paddock 35 (old pasture, no N fertiliser) on 14 April and 7 May 2001.

Treatment	MPD	Ryegrass	Brome	Tall fescue	Caucasian clover	White clover	Bare ground	Dead	Dicotyledon weed	Californian thistle
				Paddock 25						
				06/04/2001						
-N	116 (20-380)	67 (22-99)	0	0	10 (0-60)	19 (0-70)	1 (0-5)	1 (0-5)	1 (0-5)	1 (0-10)
+N	99 (10-300)	77 (40-91)	1 (0-10)	0	8 (0-20)	7 (0-19)	3 (0-40)	1 (0-5)	3 (0-10)	1 (0-5)
				12/05/2001						
-N	108 (10-380)	69 (30-94)	1 (0-10)	0	5 (0-25)	18 (0-60)	3 (0-5)	2 (0-10)	1 (0-10)	0
+N	101 (10-380)	72 (45-90)	0	0	3 (1-15)	16 (3-40)	3 (0-20)	3 (0-10)	2 (0-5)	0
Adj	N / A*	78 (50-99)	0	0	N / A*	15 (0-35)	2 (0-15)	2 (0-8)	2 (0-10)	0
				Paddock 35						
				14/04/2001						
-N	198 (25-530)	39 (15-55)	5 (0-10)	10 (0-30)	20 (5-40)	20 (0-50)	1 (0-5)	1 (0-5)	5 (0-10)	0
+N	155 (30-400)	38 (5-60)	2 (0-10)	14 (0-80)	17 (5-60)	22 (0-45)	1 (0-5)	0	5 (0-10)	0
				07/05/2001						
-N	228 (20-600)	26 (5-55)	7 (0-20)	8 (0-25)	8 (1-25)	39 (2-70)	1 (0-3)	6 (0-15)	6 (0-15)	0
+N	145 (10-360)	40 (20-70)	6 (0-15)	5 (0-17)	6 (1-12)	30 (8-57)	5 (0-20)	3 (0-10)	5 (0-10)	0
Adj	N / A*	37 (10-75)	9 (0-40)	5 (0-20)	N / A*	31 (0-60)	5 (0-30)	8 (0-15)	5 (0-15)	0

* Not applicable

ground, dicotyledon weeds, dead material Californian thistle made up the remainder of the pasture cover (1-3% each).

There was little difference in Caucasian clover cover between N treatments at either the first (10% - N and 8% + N) or second (5% - N and 3% + N) observations. However, white clover cover was markedly reduced at the first observation in plots receiving additional N (7 c.f. 19%), but not at the second observation (16 c.f. 18%). The reduction in white clover cover in plots with additional N at the first observation was matched by a corresponding increase in ryegrass cover (77 c.f. 67%).

When compared to an adjacent area in a similar environment, where Caucasian clover had been transplanted (regardless of N treatment) there was a greater total clover cover (average 21 c.f. 15%) and lower ryegrass cover (average 71 c.f. 78%) at the final observation. There was a similar amount of ground covered by unwanted material (e.g. bare ground, dead, dicotyledon weeds and Californian thistle) at both sites (6-7%).

5.3.3.2 Paddock 35

Of the total cover in paddock 35, there was less ryegrass (average 36%), more total clover (average 41%) and more ground covered by unwanted material (e.g. bare ground, dead, dicotyledon weeds and Californian thistle, average 10%) than found in paddock 25. There was also more variety in grass species with both brome (average 5%) and tall fescue (9%) present at the two autumn observations (Table 5.2). Although there was less Caucasian clover at the second observation (average 7%) compared to the first observation (average 19%), there was more white clover at the second than first observation (35 c.f. 21%). There was also slightly less tall fescue at the second observation (7 c.f. 12%) and more brome (7 c.f. 4%) and unwanted material (13 c.f. 7%).

There was little difference between N treatments in ryegrass, white or Caucasian clover percentage cover at the first observation. However, at the second observation, plots that received N had more ryegrass cover (40 c.f. 26%) and less total clover cover (36 c.f. 47%) caused mainly by a reduction in white clover cover (30 c.f. 39%).

At the second harvest there was a greater clover cover in the areas where Caucasian clover had been transplanted (average 42 c.f. 31%) when compared to an adjacent area with a similar environment. There was slightly more brome (9 c.f. 7%) and unwanted material (18 c.f. 13%) at the adjacent site.

5.4 Discussion

The results show that Caucasian clover was able to survive, persist and spread in a dairy pasture, even in a paddock that had received relatively high rates of N. The climatic conditions immediately following transplantation were not ideal for plant establishment (low rainfall, high temperatures and high evapotranspiration, Table 5.1), and it is likely that most plants died in the first two months after transplantation as no follow up watering was done. Also, cows may have pulled plants up in the first grazing after transplantation. Despite this, around 30% of the plants were able to persist for at least three years.

Unfortunately, as the transect lines were not replicated within each paddock, statistical analysis could not be performed to detect significant differences between treatments or adjacent areas where Caucasian clover was not transplanted. However, the results support the findings of Watson *et al.,* (1996b) who found that after optimum establishment conditions, Caucasian clover in a pasture was able to survive and produce more than white clover based dairy pastures in the Bay of Plenty (11.8 c.f. 10.9 t DM ha^{-1}, $P < 0.01$).

At the first observation the plants in paddock 25 had a MPD 69 mm smaller than plants in paddock 35 (Table 5.2). At the second observation they were 82 mm smaller. This could be due to the high rates of N fertiliser used in paddock 25, which may have made the ryegrass more competitive against the transplanted clovers. Another reason for the difference in size could be the older, more diverse pasture in paddock 35 was not as an aggressive competitor as the newly established ryegrass in paddock 25. Another indication of the lack of ryegrass competition in the older pasture was the larger amount of dicotyledon weeds in paddock 35 (5.5%) compared to paddock 25 (1.5%).

Caucasian clover plants that had N applied to them had a MPD smaller that plants without N at both observation times in both paddocks. Similarly, although not as dramatic, in areas where additional N had been applied, there was a lower percentage cover of Caucasian clover compared to areas without N. White clover cover was also reduced with the application of N (the first observation in paddock 35). With this exception, the drop in clover cover and decrease in Caucasian clover MPD was matched with an increase in ryegrass cover. The additional N provided by the urea will increase the competitiveness of ryegrass (particularly for light, but also water and nutrients) which is more efficient at taking up fertiliser N from the soil than legumes (Murphy and Ball, 1985), therefore reducing the clover content in the sward (Ball and Field, 1982; O'Connor, 1982; Harris and Clark, 1996; Harris *et al.,* 1996).

When compared to an adjacent area at the second sampling date in both paddocks, there was a higher total clover cover at the places where Caucasian clover had been transplanted. This result was in agreement with other workers who have shown Caucasian clover pastures have a higher legume content than white clover pastures (e.g. Moss *et al.,* 1996; Watson *et al.*, 1996b; Watson *et al.*, 1998; Black and Lucas, 2000; Black *et al.,* 2000).

The decline in the percentage cover of Caucasian clover at the second sampling compared to the first in both paddocks was probably a reflection of the higher base temperature for leaf development of Caucasian clover compared to white clover (Black, 1998). A lower base temperature for leaf development would mean that thermal time required for a phyllochron (time in °Cd for each successive leaf to appear) would take longer to accumulate for Caucasian clover compared to white clover, and so fewer leaves would be produced in the same chronological time. Therefore, cover percentage for Caucasian clover cover would not be expected to be as high as for white clover.

5.5 Conclusions

- Around 30% of individual Caucasian clover plants transplanted into dairy pastures in the summer of 1998 had survived until autumn 2001.

- This small scale, unreplicated, short-term study was inadequate to show significant differences between treatments. However,

    - The transplantation of Caucasian clover seedlings increased total clover cover (as assessed visually) compared to an adjacent 0.1 m^2 site.

    - Under a dairy system without N fertiliser, Caucasian clover plants had a MPD of 213 mm, and it appeared that when 100 kg N ha^{-1} was applied, this decreased to 150 mm.

    - Under a dairy system with annual N inputs of approximately 150 kg N ha^{-1} yr^{-1} Caucasian clover plants had a MPD of 112 mm. When an additional 100 kg N ha^{-1} was applied, MPD decreased to 100 mm.

6 General Discussion

6.1 Four years of autumn liveweight gain of lambs at high stocking rates grazing Caucasian or white clover based pastures at high and low soil fertility

6.1.1 Liveweight gain

In general, the liveweight gains (LWG) of 55-129 g hd^{-1} d^{-1} (Table 3.5 and Table 6.1) at high stocking rates (35-48 lambs ha^{-1}) in the grazing experiment were less than those generally attained on commercial properties, where the average from weaning to slaughter is between 100-150 g hd^{-1} d^{-1} (Brown, 1990; Kerr, 2000). The LWG on the grazing experiment were only about half of the 168 and 214 g hd^{-1} d^{-1} found by McLean, Thomson, Iversen, Jagusch and Lawson, (1962) and McLean, Thomson, Jagusch and Lawson, (1965) with weaned Corriedale or Romney at 19-24 lambs ha^{-1} grazing pure clover in autumn. However, the resulte from the grazing experiment are similar to the 114-127 g hd^{-1} d^{-1} found with similar lambs at19-24 lambs ha^{-1} grazing pure ryegrass in autumn (McLean *et al.*, 1962; McLean *et al.*, 1965).

The LWG in this experiment was also comparable to recent work on irrigated pasture at the Winchmore Research Station in Mid Canterbury (Moss *et al.*, 2000). Mixed sex, post-weaning lamb LWG for three February / March periods while grazing high quality pastures (46% grass, 10% clover, 14% chicory and 16% dead material) averaged 131 g hd^{-1} d^{-1}. This was similar to other work completed at Lincoln and Winchmore (Westwood and Norriss, 1999). The autumn LWG of Coopworth ewe lambs in their study on endophyte infection in ryegrass were 75 g hd^{-1} d^{-1} in year one (4% clover) and 95 g hd^{-1} d^{-1} in year two (15% clover). Although the ryegrass used in the current study was Grasslands Ruanui zero endophyte ryegrass, lamb production may have been compromised by the invasion of annual grass. Hyslop *et al.* (2000) also measured slow LWG of Coopworth ewe lambs at Lincoln and Poukawa with overall autumn LWG averaging 76 g hd^{-1} d^{-1} when grazing tall fescue and high and low endophyte ryegrass based pastures of varying white clover contents.

6.1.2 Autumn pastures

Autumn pastures have been shown to promote lower lamb LWG than spring pastures (McLean *et al.*, 1962). This could be due to a number of issues including, their nutritive value (pasture composition, crude protein and metabolisable energy content and digestibility), differing response of grasses and clovers to decreasing day-length and temperature, ryegrass endophyte status, facial eczema spore counts and plant nitrate status.

Depending on season and management, autumn pastures can contain a large amount of dead material accumulated over the summer / early autumn period and, along with ryegrass seed-head from reproductive development, can reduce the feeding value of such pastures (R.J. Lucas, *pers. comm.*). As pasture mass increases from low to very high values during a regrowth period, nutritive value declines with advancing plant maturity. The effect was seen as decreases in digestibility and protein content (Nicol and Barry, 1980). However, in general at the grazing experiment, *in vitro* organic matter digestibility for both clover and ryegrass leaf has been similar to or higher than spring pastures (A. D. Black, unpublished data). A similar trend was evident for clover crude protein. But autumn ryegrass crude protein content has generally been greater than in spring and summer.

Caucasian clover and white clover have been shown to have different responses to declining autumn temperatures and day-length. As Caucasian clover has a longer phyllochron and a higher base temperature (below which no development occurs) than white clover (Caucasian clover 279 °Cd, and 4.2 °C, white clover 173 °Cd and 3.1 °C), there was likely to be a faster decline in the Caucasian rather than white clover content of pastures. In the grazing experiment, the decline in clover content was followed by a subsequent increase in the annual grass content of pastures (Table 4.4 and Table 4.6, A.D. Black *pers. comm.*).

The ryegrass used in this experiment was zero endophyte so most animal disorders induced by autumn pastures were avoided. In pastures where high endophyte ryegrass is sown to reduce the damaging effects of Argentine stem weevil (Easton, 1999), moderate to severe ryegrass staggers caused by Lolitrem B may develop in summer and autumn reducing LWG (Fletcher, Sutherland and Fletcher, 1999). Also, particularly in the North Island, outbreaks of facial eczema may be a problem from February to April coinciding with a flush of pasture growth and warm rains (Close, 1990). A strong photosensitivity reaction occurs in severely affected animals with associated liver damage (Familton, 1990). The cause is a myotoxin produced by the spores of the fungus *Pithomyces chartarum* (syn. *Sporidesmium chartarum*). This fungus is a saprophyte and grows only on dead litter at the base of the pasture. Conditions most favourable to the development of the fungus are periods of at least three days of overcast weather, with showers totalling 10 mm or more of rain, air temperatures continuously above 16 °C, and relative humidities above 80%.

Another potential animal health problem of autumn pastures is the flush of N mineralisation that often occurs after prolonged dry periods (Kemp *et al.*, 1999). This can cause high plant nitrate levels, which can be toxic to stock (Familton, 1990).

6.1.3 Comparison with previous autumns

6.1.3.1 Liveweight gain

Although average pasture allowance and intakes in autumn 2001were similar to those measured in autumn 2000, LWG was less in 2001 (80-109 g hd^{-1} d^{-1}) than in 2000 (119-129 g hd^{-1} d^{-1}, Table 6.1), However, the average 2001 LWG were higher than the corresponding gains in autumn 1998 and 1999, despite lower pasture allowances in 2001. These differences must, however, be taken in context as they were only for short periods (52-111 days). Analysis of full year LWG would give a better indication of year-to-year variation.

6.1.3.2 Grazing days

The total number of grazing days in 2001 were less than the corresponding number in 1999 and 2000 and slightly more than in 1998. However, when expressed as the number of grazing days divided by the length of the experiment (in days) they were similar to those measured in 1998 (6.22 grazing days $farmlet^{-1}$ day^{-1}), 1999 (5.90 grazing days $farmlet^{-1}$ day^{-1}) and 2001 (6.13 grazing days $farmlet^{-1}$ day^{-1}). In 2000, the high pre-grazing and lower post-grazing pasture mass allowed a higher stocking rate (46 in 2000 c.f. average of 38 lambs ha^{-1} in 1998, 1999 and 2001) and a greater number of grazing days $farmlet^{-1}$ day^{-1} (7.28) than the other years.

Table 6.1 Mean pre- and post-grazing pasture mass (kg DM ha^{-1}), pre-grazing clover content (%), stocking rate (lambs ha^{-1}), allowance (kg DM hd^{-1} d^{-1}), apparent intake (kg DM hd^{-1} d^{-1}), total grazing days $farmlet^{-1}$ and liveweight gain (LWG) $hectare^{-1}$ day^{-1} and $head^{-1}$ day^{-1} from Caucasian and white clover pastures at high and low soil fertility during autumn 1998 (5 March to 4 May, Black, 1998), 1999 (5 February to 10 June, Amyes, 1999), 2000 (11 February to 23 May, Maw, 2000) and 2001 (12 February to 1 May). Nb. LWG not measured from 11 April to 1 May 2001, grazing days for the full 78 day 2001 period in brackets.

Treatment	Pre-grazing mass	Post-grazing mass	Pre-grazing clover content	Stocking rate	Allowance	Apparent intake	Total grazing days	LWG (kg ha^{-1} d^{-1})	LWG (g hd^{-1} d^{-1})
				1998 (52 days)					
White clover	**2040**	1170	**36.6**	**35**	2.5	0.97	**291**	2.1	60
Caucasian clover	**2360**	1200	**21.8**	**39**	2.4	0.87	**355**	2.6	60
P	***0.005***	*0.221*	***0.020***	***0.015***	*0.718*	*0.187*	***0.014***	*0.252*	*0.938*
Low-fertility	2140	1200	27.7	39	**2.3**	0.92	**328**	2.2	55
High-fertility	2260	1170	30.7	38	**2.6**	0.92	**318**	2.5	66
P	*0.131*	*0.221*	*0.432*	*0.516*	***0.037***	*0.983*	***0.014***	*0.344*	*0.220*
s.e.m.	*110*	*28*	*2.3*	*1.1*	*0.04*	*0.04*	*8.8*	*0.23*	*5.0*
				1999 (111 days)					
White clover	2390	1350	**8.9**	37	**2.6**	1.0	659	3.1	83
Caucasian clover	2310	1300	**13.2**	37	**2.5**	0.99	651	3.1	85
P	*0.185*	*0.424*	***0.004***	*0.439*	***0.035***	*0.689*	*0.445*	*0.724*	*0.568*
Low-fertility	2310	1320	11.0	37	2.5	0.98	648	3.0	81
High-fertility	2380	1330	11.1	37	2.6	1.0	661	3.2	87
P	*0.250*	*0.802*	*0.801*	*0.235*	*0.092*	*0.510*	*0.254*	*0.091*	*0.191*
s.e.m.	*34*	*39*	*0.39*	*0.36*	*0.03*	*0.03*	*6.7*	*0.08*	*2.6*
				2000 (86 days)					
White clover	2520	1240	**10.4**	45	2.0	0.98	622	**5.1**	**112**
Caucasian clover	2600	1210	**17.8**	46	2.1	1.1	630	**5.9**	**129**
P	*0.155*	*0.411*	***0.027***	*0.328*	*0.638*	*0.055*	*0.333*	***0.005***	***0.002***
Low-fertility	**2420**	1220	14.6	**43**	2.1	**0.98**	**587**	**5.1**	120
High-fertility	**2700**	1230	13.7	**48**	2.0	**1.1**	**665**	**5.8**	120
P	***0.004***	*0.812*	*0.638*	***0.001***	*0.638*	***0.048***	***0.001***	***0.008***	*0.786*
s.e.m.	*25*	*27*	*1.3*	*0.33*	*0.03*	*0.02*	*4.5*	*0.08*	*1.2*
				2001 (58 days)					
White clover	**2330**	1270	**10.1**	38	**2.1**	**0.96**	349 (474)	3.1	80
Caucasian clover	**2490**	1300	**20.5**	39	**2.2**	**1.1**	357 (481)	4.3	109
P	***0.016***	*0.207*	***0.006***	*0.391*	***0.014***	***0.021***	*0.391 (0.347)*	*0.365*	*0.373*
Low-fertility	**2350**	1260	15.3	38	2.2	1.0	342 **(466)**	3.6	95
High-fertility	**2470**	1310	15.3	40	2.1	1.0	364 **(490)**	3.8	94
P	***0.035***	*0.083*	*0.975*	*0.058*	*0.422*	*0.835*	*0.058* ***(0.034)***	*0.871*	*0.955*
s.e.m.	*23*	*14*	*1.04*	*0.57*	*0.013*	*0.016*	*5.1 (4.6)*	*0.79*	*20*

6.1.3.3 Clover content

The greater clover content in Caucasian clover pastures in 2001 follows the trend over the previous three autumns where Caucasian clover pastures have had more clover (except autumn 1998) and supported lamb LWG $head^{-1}$ similar to, or greater than white clover pastures. Similarly, in previous autumns, higher clover contents and greater pre-grazing pasture mass have allowed Caucasian clover pastures to support higher rates of LWG $hectare^{-1}$ day^{-1} than white clover pastures. Results from years two and three after sowing from the grazing experiment were reported by Black *et al.* (2000).

6.1.3.4 Fertility

The similar LWG ha^{-1} on high compared to low fertility pastures in autumn 2001 was in contrast to the trend over the previous three autumns where high fertility pastures had clover contents and supported lamb LWG $head^{-1}$ similar to low fertility pastures, but with a greater LWG ha^{-1}. However, high fertility farmlets supported a greater number of grazing days compared to low fertility farmlets in autumn 2001, similar to year three of the grazing experiment (September 1999 to May 2000). In autumn 2000, high fertility plots also supported a higher stocking rate than low fertility plots (48 c.f. 43 lambs ha^{-1}, $P = 0.001$). This effect was also evident in 2001 (40 c.f. 38 lambs ha^{-1}, $P = 0.058$).

Low fertility plots have not received maintenance fertiliser since the experimental site was established in December 1996, and as a result soil tests have shown lower P and S fertility when compared with high fertility plots (Table 3.1). Differences in test values reflect the year-to-year variation of soil test results. In general, as a result of 1 t ha^{-1} superphosphate at establishment and annual maintenance applications of 250 kg ha^{-1}, high fertility plots have had Olsen P and sulphate sulphur test values about twice that of low fertility plots. In low fertility plots, Olsen P averaged 11 for the past four years. Cornforth (1998) recommends that for a medium phosphate retention gley soil, an Olsen P below 11 is an indication of inadequate fertiliser use, and fertiliser is required to increase the nutrient status of the soil, as phosphate availability will be limiting pasture production.

The pasture production as measured from the caged areas (Black *et al.*, 2000) have shown high fertility plots to have greater annual pasture yields than low fertility plots, especially in years three and four after sowing. This has been evident every autumn as the pre-grazing pasture mass for high fertility pastures has been greater than that for low fertility pastures (although only significant in 2000 and 2001). However, the similar lamb LWG head^{-1} on high and low fertility plots found in each autumn since establishment would suggest that the differences in pasture production from the two levels of soil fertility was not large enough to have a measurable effect on animal productivity. No differences in clover content between fertility treatments have been demonstrated.

6.2 The place and value of Caucasian clover as an alternative to white clover in temperate lowland pastures

6.2.1 Clover content

The low white clover content of lowland pastures (Moss, 1987; Ettema and Ledgard, 1992) may be increased with the use of Caucasian clover. This has been shown in several lowland environments and production systems (Moss *et al.*, 1996; Watson *et al.*, 1996b; Watson *et al.*, 1997; Watson *et al.*, 1998; Black and Lucas, 2000; Black *et al.*, 2000). These studies have shown the potential of Caucasian clover to reach the 20-45% clover content required for a sustainable and productive pasture (Thomas, 1992) as well as increasing total dry matter production (Widdup *et al.*, 2001).

It was interesting to note that, in both the caged areas (Table 3.4) and the nitrogen (N) experiment (Table 4.4 and Table 4.6), Caucasian clover pastures contained as much white clover, if not more, than white clover pastures. Black *et al.* (2000) also reported that, in the third year of the grazing experiment, 39% of the total clover in Caucasian clover treatments was volunteer white clover. Also, in dryland Caucasian clover plots, white clover also made up 20% of the total clover content in spring and autumn and 10% in summer (Black and Lucas, 2000). White clover is likely to be present in most commercial pastures due to the widespread presence of hard seed in the soil and the apparent decline in competitiveness of ryegrass when sown with Caucasian clover (Black *et al.*, 2000). This complementarily of Caucasian and white clovers is in contrast to that suggested by Elliot *et al.* (1998). From laboratory evidence they promoted the possibility of poor sociability between the two clovers because of rhizobial incompatibility.

6.2.2 Dairy pastures

Even though N responses of Caucasian clover pastures were low (3.5-7.9 kg DM ha^{-1} kg N^{-1}), they were not different from those of white clover in the present 2001 study nor in autumn / spring 2000 (Maw, 2000). These short-term experiments indicate that Caucasian clover pastures may be able to sustain production similar to white clover pastures, while maintaining a greater clover content. However, to maintain a high clover content, as with N application to white clover pastures (Harris and Clark, 1996), it is critical to utilise all of the additional feed produced to minimise the shading of Caucasian clover.

If Caucasian clover can establish and persist in dairy pastures as shown in the present study, by Watson *et al.* (1997) and on a commercial dairy farm in North Otago (R.G.M. Hurst *pers. comm.*), the need for N fertiliser in dairy pastures may be decreased. Widdup *et al.* (2001) were able to show that although the N concentration in the clover herbage (4.6% N) and the proportion of clover N derived from N_2 fixation (50-60%) were similar for Caucasian and white clover. However, the amount of N_2 fixed ha^{-1} was directly related to the amount of clover dry matter produced by each species. In the second year of the Widdup *et al.* (2001) study Caucasian clover produced four times as much clover dry matter as white clover (5400 c.f. 1450 kg DM ha^{-1}) and a similar proportion of N_2 was fixed in the herbage (136 c.f. 36 kg N ha^{-1}). Decreased use of N fertiliser would both reduce costs and environmental concerns over nitrate leaching into waterways due to increasing N returns from urine (Monaghan, Paton, Smith and Binet, 2000; Roach, Stevens, Clark and Nicholas, 2000).

Clark and Harris (1996) used a model (UDDER) to find the break-even pasture yield for a given gross margin ha^{-1} at different clover contents on a dairy farm. The assumptions made were: \$600 t^{-1} urea, \$3.40 kg MS^{-1}, a variable N fertiliser response starting at 14 kg DM ha^{-1} kg N^{-1} for 100 kg N ha^{-1} yr^{-1} and decreasing to 8 kg DM ha^{-1} kg N^{-1} at 400 kg N ha^{-1} yr^{-1}, clover content assumed to be 20% at 0 kg N ha^{-1} yr^{-1} with a linear decline to 0% at 400 kg N ha^{-1} yr^{-1}, a 3.25% increase in intake with each 10% increase in clover content and a 0.5% increase in diet digestibility with each 10% increase in clover content. A yield of 16.2 t DM ha^{-1} at 20% white clover was assumed and given a relative yield of 1.0 (Figure 6.1).

Using these assumptions, the UDDER model showed that to produce an equivalent gross margin, a pasture containing 50% clover needed to reach a relative yield of 0.9 (14.2 t DM ha^{-}

$^{-1}$), and a 75% clover pasture a relative yield of 0.8 (13.0 t DM ha^{-1}). Their model showed that total pasture production decreased with increasing clover content, improved pasture quality meant milksolids production was not reduced to the same extent. Conversely, where N fertiliser decreased clover content to 10%, relative pasture yield must increase to 1.15 (18.4 t DM ha^{-1}) to give the equivalent gross margin. Clark and Harris (1996) found that a critical factor in achieving equivalent gross margins at higher clover contents was a decreased stocking rate. For example, at 20% clover, a stocking rate of 3.7 cows ha^{-1} gave 1295 kg MS ha^{-1}, while at 50% clover, a stocking rate of 2.9 cows ha^{-1} gave 1213 kg MS ha^{-1}. The lower costs associated with the lower stocking rate compensated for the slight decrease in milksolids production.

Although the price of urea and the milksolids payout have changed in recent years probably changing the gross margins, the should provide a valuable diagnostic tool for analysing the relative merits of fertiliser N and clover N_2 fixation for use with forages with a superior clover content.

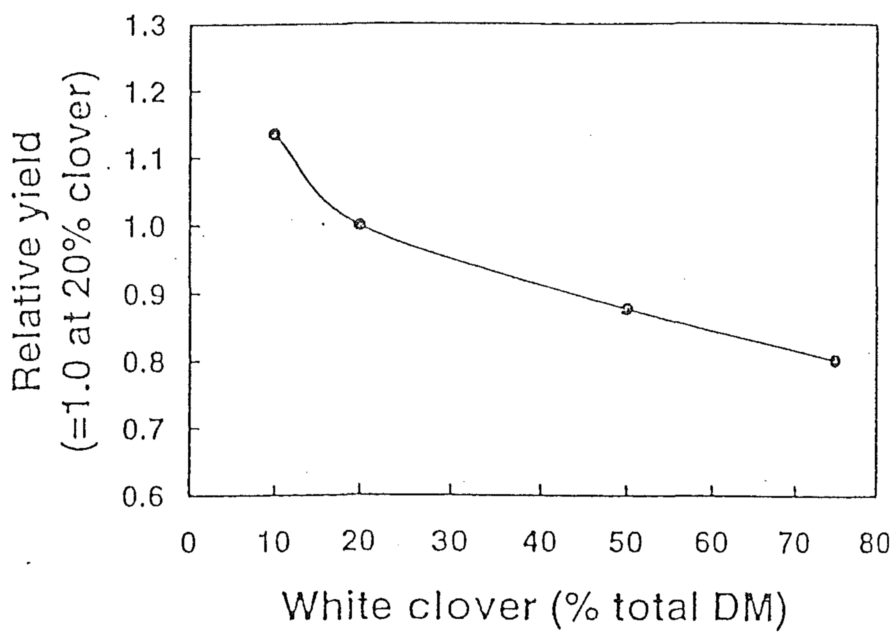

Figure 6.1 UDDER model predictions of the relative pasture yield required to give equal gross margin ha^{-1} at different clover contents for a given set of assumptions.

(From Clark and Harris, 1996)

In year three of the grazing experiment, Caucasian clover pastures also produced 15.7 t DM ha^{-1}, 1.5 t DM ha^{-1} more than white clover (14.2 t DM ha^{-1}, Widdup *et al.*, 2001). So the benefits of Caucasian clover pastures are two fold, it can increase both total legume content and dry matter production.

6.2.3 Further work

6.2.3.1 Establishment

Now that initial rhizobia problems have been solved (Pryor *et al.*, 1998), the establishment of Caucasian clover has been adequate when sown alone (Watson *et al.*, 1996b; Black *et al.*, 2000). Caucasian clover will contribute significantly to production within six months, especially if seeding rates are sufficient to establish plant populations above 200 m^{-2} (about 9 kg ha^{-1} pelleted seed, R.J. Lucas, *pers. comm.*). If seeding rates are lower Caucasian clover will take longer to contribute to production as it spreads through rhizomes and secondary crowns.

Ryegrass can be direct drilled at a later date and, due to the large amounts of hard seed in the soil, volunteer white clover is also likely to establish. However, when sown in mixtures with ryegrass and white clover, Caucasian clover establishment is poor (Hurst *et al.*, 2000). Further work is needed to determine the effects of white clover on Caucasian clover in the establishment period using thermal time to quantify developmental stages. In the same or in a similar experiment, the competition between Caucasian clover and slow establishing species such as timothy cocksfoot or tall fescue, compared to ryegrass, over a range of seeding rates, when sown in mixtures, also needs to be quantified.

6.2.3.2 Suitability for dairy farms

A long-term, large-scale trial is also needed to assess the suitability of Caucasian clover for dairy pastures and further demonstrate its virtues to farmers, the seed industry and the scientific community. Dairy farmers may be unwilling to include Caucasian clover in their pastures due to the period required for adequate establishment when sown alone. However, so long as timothy is sown with Caucasian clover initially, there would only be one grazing lost during the establishment period plus one further grazing lost if ryegrass is over drilled at year two or three when timothy populations may decline (R.J. Lucas, *pers. comm.*). When sown alone with ryegrass over drilled in the autumn, depending on the assumptions made, Caucasian clover was calculated to recover net establishment costs by the fourth year in a Bay of Plenty pasture (Taylor and Watson, 1998). The new Lincoln University dairy farm would be ideal to study the competitive ability, persistence, productivity and profitability of Caucasian clover under dairy farm management (particularly high residual pasture mass) and N inputs.

6.2.3.3 Persistence

Caucasian clover has shown persistence in high country environments for almost 30 years (R.J. Lucas, *pers. comm.*) and, although much work has been done on the initial establishment phase, the persistence of Caucasian clover in lowland environments is yet to be proven. Lowland environments encourage a greater number of biotic stressors due to their increased growth and development in warmer temperatures. The impact on the persistence of Caucasian clover in such environments is largely unknown. In a Bay of Plenty dairy pasture and at the grazing experiment at Lincoln University, Caucasian clover was affected by grass grub either to the same extent or less than white clover (Watson *et al.*, 1996a, 1996b; Amyes, 1999). However, Caucasian clover based pastures were still able to produce more total dry matter with a higher legume content than white clover based pastures (Watson *et al.*, 1996b; Black *et al.*, 2000). The continuation of the Lincoln University grazing experiment for at least another five years to year ten is essential to assess the persistency of Caucasian clover in a lowland environment. Differences in clover content in high and low soil fertility plots may become apparent during the extended period of the experiment.

6.2.4 Conclusions

- Dry matter production and legume content of irrigated Caucasian clover pastures for three years, after an initial establishment year, was superior to that of white clover pastures in a lowland environment.

- More work is needed under dairy farm management to quantify the effects of N fertiliser on Caucasian clover production and its persistence compared to white clover in permanent pastures in lowland environments.

- Autumn and spring dry matter responses to N fertiliser are similar for Caucasian and white clovers, indicating that, along with its increased competitive ability against ryegrass, Caucasian clover is a suitable legume species for permanent pastures on dairy farms. However, more work is required on Caucasian clover pastures over four years old.

Acknowledgements

I would like to thank the following:

My supervisor, Dick Lucas, for his continued guidance and inspiration throughout the year and for the generous use of his HB pencil to decorate my pages

My other proof readers, Janette Busch, Andrew Greer Alistair Black and Blair Cotching for their stirling work.

Alistair Black, for assistance with analysis of the grazing trial data and continued discussion.

Dexcel, the Syd Bodmin Trust, WestpacTrust and the New Zealand Institute of Agricultural Science for financial support during my final year at Lincoln University.

Peter Jones, for ensuring that equipment was always available when it was required (and that it was returned).

The staff and students at the Field service Centre for making my final year an enjoyable and rewarding experience.

Jo, Pies and the Ginger Ninjas for support and light relief at the end of each day.

And finally, my parents, for without whom, none of this would have been possible.

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