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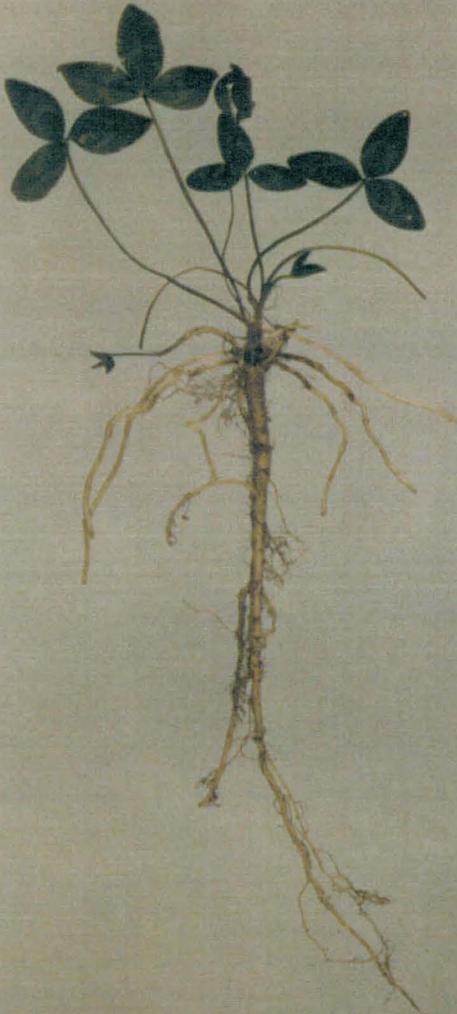
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**CAUCASIAN CLOVER ESTABLISHMENT IN THE HIGH COUNTRY
AND GRAZING RESPONSES IN RYEGRASS/WHITE CLOVER
LOWLAND PASTURE**

**A thesis
submitted in partial fulfilment of the
requirements for the Degree
of
Master of Agricultural Science
at
Lincoln University
New Zealand**

**By
Allister J.E. Moorhead**

**Lincoln University
1997**



Monaro Caucasian clover.



Tahora white clover.



JCDww

16 May 1997

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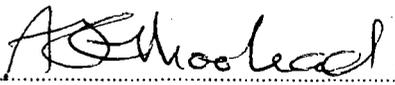
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Lincoln University, New Zealand.

**CAUCASIAN CLOVER ESTABLISHMENT IN THE HIGH COUNTRY
AND GRAZING RESPONSES IN RYEGRASS/WHITE CLOVER
LOWLAND PASTURE**

Allister J.E. Moorhead

ABSTRACT

A trial to measure the effects of establishment techniques and fertiliser application on seedling establishment and early root and rhizome development of Caucasian clover (*Trifolium ambiguum*) was sown in early October 1992, on a low-fertility, depleted, short tussock grassland site at Mesopotamia Station, South Canterbury. Three sowing techniques, broadcasting, sod seeding and strip seeding, each with two rates of fertiliser, 150 or 300 kg/ha molybdc sulphur superphosphate (8% P, 20% S), were used. By mid December, 48% and 38% establishment had occurred in the strip and sod seeding treatments respectively, but only 10% in the broadcast.

Strip seeding resulted in the earliest taproot and rhizome development of Caucasian clover and the greatest lateral spread of rhizomes. However, all plants strip and sod seeding developed rhizomes after nine months. Plants established by broadcasting were small with few rhizomes in the first season. The higher fertiliser rate improved establishment and growth, particularly in the strip seeding treatment. Strip seeded Caucasian clover established as rapidly as white clover and plants were similar in size after five months. However, Caucasian clover had a larger under ground mass which could lead to greater persistence.

A grazing trial was established to observe how two cultivars of Caucasian clover and two seed lines of zig zag clover responded to four diverse grazing treatments. The experiment was located at Lincoln University, latitude 43° 39S and longitude 172° 28E on a medium- to free-draining soil of medium fertility with an annual rainfall of 651mm. In March 1989 a seed production experiment was established and consisted of Caucasian clover cultivars Alpine and Monaro and zig zag clover seed lines Porters Pass and Kentucky. In spring of 1992 high endophyte ryegrass was direct drilled into this experiment. The first grazing to establish mainplot treatments occurred in early October 1993. The experiment design was a randomised block design with two replicates of four treatments. The treatments included two grazing frequencies; rotational grazing and set stocking; and two grazing intensities; hard and lax. Point analysis was used to measure the botanical composition of the pastures.

Only the hexaploid Monaro Caucasian clover was agronomically suitable as a companion for high endophyte ryegrass and white clover under the range of grazing managements. The zig zag clovers showed a classic hay type species inability to persist and contribute to dry matter production under grazing. The diploid Alpine Caucasian clover persisted undergrazing but had a low cover percentage. Monaro Caucasian clover had a mean seasonal cover of between 14% and 21% in the grazing treatments, contributing more to pasture cover in the rotationally grazed treatments. White clover, in contrast was more suited to the set stock hard grazed treatment and to a lesser extent the set stock lax grazed treatment.

Keywords:

Broadcast, Caucasian clover, establishment, grazing frequency, grazing intensity, fertiliser, high country, ryegrass, sod seeding, strip seeding, taproot, *Trifolium ambiguum*, *Trifolium medium*, rhizome, white clover, zig zag clover.

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CHAPTER ONE

INTRODUCTION

There are few pasture legume species in New Zealand as promising as *Trifolium ambiguum* which has great potential as a pastoral legume in the New Zealand's hill and high country because of its outstanding persistence. This rhizomatous perennial species is commonly called Caucasian clover in New Zealand and Australia and goes by the name of Kura clover in America.

Caucasian clover is found in different forms throughout the Crimea, Caucasian Russia, eastern Turkey and northern Iran. Within these areas it has adapted to a wide ecological range including mountain slopes, river banks, forest margins and clearings, valleys and screes, and drier grassy steppes (Bryant, 1974; Khoroshailov and Fedorenko, 1973). Both Bryant, (1974) and Khoroshailov and Fedorenko, (1973) described Caucasian clover in its natural environment as an important pasture component, with early season production, a good response to moisture, cold and drought tolerance, persistence under heavy seasonal grazing and the ability to withstand trampling by cattle. Caucasian clover has also been found growing on acidic (Bryant, 1974), limestone and salty soils (Khoroshailov and Fedorenko, 1973).

Caucasian clover is one of the few *Trifolium* spp. that has a natural ploidy series ($x=8$) with diploid ($2x=16$), tetraploid ($4x=32$) and hexaploid ($6x=48$) being found (Hely, 1957; Kannenberg and Elliott, 1962), the fact that Caucasian clover is still basically an unbred/unselected species, means that there is considerable genetic variation between genotypes within cultivars. This means there is considerable potential within this species to select for superior agronomic characteristics which will be able to overcome some of the current problems associated with slow establishment and low seed production.

Caucasian clover was introduced into New Zealand in the 1960's, where early work by A.H. Nordmeyer was directed at mountain revegetation and erosion repair work (Scott *pers comm*). The emphasis changed with the work that was started in the mid 1970's and its suitability as a pasture species began to be investigated but lack of seed and slow establishment (Lucas *et al.* 1980 and Scott 1985) prevented its wide spread use. The work started on Caucasian clover in the 1980's focussed on its potential as a pasture species particularly in low input systems in the high country (Daly and Mason 1987; Allan and Keoghan 1994).

In its original habitat Caucasian clover evolved under uncontrolled grazing in montane pastures. Outside its natural area of distribution Caucasian clover has mainly been used in limited quantities. In New Zealand, Caucasian clover has the potential to be used from rangeland pastures to low altitude dryland pastures and irrigated dairy pastures.

The status of Caucasian clover in New Zealand has recently moved from one of being available in experimental quantities only to that of being commercially available in limited amounts. The commercial market for New Zealand selected Caucasian clover may ultimately also meet overseas market demand.

The main constraints that have limited the use of Caucasian clover to experimental projects, have been poor establishment (Lucas *et al.* 1980), and inadequate seed production (Hampton *et al.* 1990). These constraints have also contributed to a lack of precise knowledge regarding nitrogen fixation over a range of environments, grazing management and compatibility with commonly used perennial grass species. There also is no knowledge on the phosphate requirement for establishment and maintenance of permanent stands of Caucasian clover.

This study, consisting of two separate experiments, aims to provide information that will contribute to the production of a Caucasian clover management package. The first experiment was an establishment study in a montane environment, comparing three methods of establishment with two rates of fertiliser. The results presented in chapter 3 are from the first year during the establishment phase which is generally recognised as a critical period in

the establishment of a Caucasian clover stand. The second experiment, described in chapter 4, was a grazing management study on a lowland site comparing Caucasian clover with white clover in a high endophyte ryegrass pasture grazed by sheep at two different grazing frequencies and two grazing intensities. Results are presented for the growing period between spring and autumn from the five year old stand of Caucasian clover that had been direct drilled with high endophyte hybrid ryegrass in the previous spring.

The specific aims were to:

- 1a. Measure the effect of three sowing techniques and two rates of fertiliser application on Monaro Caucasian clover seedling establishment on a low fertility, summer moist, high country site.
- 1b. Measure the effect of these treatments on early root and rhizome development of Monaro Caucasian clover seedlings.
- 2a. Measure how Caucasian clover responds to a range of grazing managements in a high endophyte ryegrass pasture.
- 2b. Measure the ability of Caucasian clover and white clover to be miss-managed in high endophyte ryegrass pastures.

CHAPTER TWO

LITERATURE REVIEW

2.1 CAUCASIAN CLOVER: A RHIZOMATOUS PASTURE LEGUME

This review will aim to cover the general botany, establishment, persistence and agronomic characteristics of Caucasian clover. However it will not attempt to cover the topic of seed production. This topic has recently been the subject of a Masters in Agricultural Science Degree carried out at Lincoln University by Jiwan Gurung (1991). Seed production is still one of the main limitations in the commercialisation of the species (Hampton *et al*, 1990) along with the with slow establishment and the relatively uncompetitive nature of the seedling in mixtures and in stressed situations.

2.2 GENERAL BOTANY

2.2.1 Distribution and adaptation

In its natural habitat Caucasian clover (*Trifolium ambiguum* Bieb.) is found over a wide range of environments in the Caucasus mountain region of southern USSR, (steppes, foothill and mountain areas). Within these environments Caucasian clover has been found on limestone and salty soils, along roadsides, along banks of rivers and streams, in river valleys, in meadows that are periodically flooded, on steep slopes of grassy terraces and in mountain meadows (Khoroshailov and Fedorenko, 1973).

Caucasian clover is found in its natural habitat in patches from 1 to 10 m² and is often associated with other legumes and mixed grasses in sunny sites (Khoroshailov and Fedorenko, 1973). Khoroshailov and Fedorenko, (1973) also observed Caucasian clover growing in heavily grazed pastures around sheep yards, suggesting it can persist under intensive constant grazing with high fertility conditions often favouring turf type grasses.

Caucasian clover seedlots have been introduced and distributed in the United States since 1911 (Hollowell, 1955 cited by Townsend, 1970). Caucasian clover was first introduced into Australia in 1931 by CSIRO and tested in Canberra (Bryant, 1974), but it was not introduced into New Zealand until the 1960's (Scott *pers comm.*). Hill *et al.* (1996b) using climatic information and information on persistence of Caucasian clover in a number of sites in Australia, defined potential adaptation zones for Caucasian clover in Australia, which included the Northern Tablelands of New South Wales and lowland pastoral areas of Tasmania where white clover is not persistent, Hill *et al.* (1996a) also suggest the South Island of New Zealand as a potential area of adaptation.

Caucasian clover is responsive to water and can cope with being temporarily inundated but it does not grow on permanently wet soils (Khoroshailov and Fedorenko, 1973). Yates (1993), discovered that it would not persist on heavy black soils in Tasmania which lie wet over winter. Caucasian clover is well suited to persist through cold winters and dry summers (Dear and Zorin, 1985). At a site in the Tasmania at an elevation of 1030 m, with a annual rainfall of nearly 900 mm and with varying degrees of summer drought and frequent snowfalls in winter, Caucasian clover was still present in 1992 after 21 years. From 1981 to 1992 the sward had between 46% and 80% Caucasian clover content. It was found to be completely dormant over winter, surviving both snow cover and freezing of the surface soil at this site (Yates, 1993). This Tasmanian experiment include examples of all three ploidy levels and contained the cultivars Alpine, Forest, Summit, Treeline and Monaro.

On the Tara Hills High Country research station in the South Island of New Zealand's McKenzie Country (elevation 520 m and mean annual rainfall 532 mm), Monaro Caucasian clover proved to be the best adapted of the 21 legume species (73 accessions). Monaro Caucasian clover had a rank score of 2nd for plant survival, second equal for spring vigour, fifth equal for drought tolerance, fourth equal for autumn vigour and third equal for frost tolerance. Under grazing, Caucasian clover is the most promising legume in terms of persistence and spread under both late spring/summer rotational grazing and continuous stocking (Woodman *et al.*, 1992).

2.2.2 Taxonomy

Zohary (1984), has produced the most recent taxonomic classification of *Trifolium ambiguum* which is as follows;

- Family - Fabaceae
- Sub Family - Fabioideae
- Genus - Trifolium
- Section - Lotoidea
- Sub section - Platystylium
- Species - ambiguum

Caucasian clover is taxonomically related to *Trifolium hybridum* (Alsike clover), *Trifolium repens* (White clover), and *Trifolium montanum* (Gillett, 1985; Bryant, 1974).

2.2.3 Ploidy

Caucasian clover is a species with very pronounced intraspecific variation (Townsend, 1970). This is partly due to it being a cross pollinated species that has only undergone domestic selection in the last twenty five years (first cultivar registered in 1970).

Karpechenko (1925) originally determined the chromosome number of Caucasian clover to be $2n=16$, while Keim (1953) reported a somatic number of 48. This variation in somatic number was clarified by Hely (1957) who described a ploidy series consisting of diploid ($2n=16$), tetraploid ($2n=32$), and a hexaploids ($2n=48$). Kannenberg and Elliott (1962) also identified the natural polyploidy of Caucasian clover and described the relationships between the ploidy levels and some morphological and physiological characteristics which are discussed in the following sections.

2.2.4 Growth habit

In general Caucasian clover is a pasture-type with growing points below ground rather than a hay-type species which tend to have growing points above ground (Townsend, 1970), however Kannenberg and Elliott (1962), found large variation within a collection from the same ploidy group with plants ranging from prostrate to erect.

Townsend, (1970) found that height and vigour of Caucasian clover were highly correlated. Hexaploid Caucasian clover has the greatest vigour although some diploids were nearly as

vigorous (Townsend, 1970; Kannenberg and Elliott, 1962). Oram (1990) described the growth habit of the hexaploids as more erect, generally bigger overall, with more robust plants than the diploids, which are generally compact, hemispherical when ungrazed and of medium height (approx. 200 mm). The tetraploid is generally open, asymmetric and tall (approx. 400 mm) (Oram, 1990).

2.2.5 Leaf size

Diploid and tetraploid Caucasian clovers have similar leaf sizes while hexaploids have substantially larger leaves. The three diploid cultivars Summit, Alpine and Forest have average leaf areas of 395, 436 and 467 mm² respectively. The tetraploid Treeline has an average leaf area of 448 mm² and the hexaploids Prairie and Monaro have average leaf areas of 609 and 644 mm² respectively (Dear and Zorin, 1985).

2.2.6 Leaf markings

Leaf markings vary between and within ploidy levels. Of the three diploid cultivars 85% of Summit's leaves have a pale green inverted V while remaining leaves are plain dark green, Forest has unmarked leaves while 65% of Alpine leaves have distinct pale green crescent with the remainder unmarked. Treeline leaves are mostly unmarked, dark leaves with 18% having a pale green, usually faint, inverted V marking. All Prairie plants are clearly marked with a distinct U, and all Monaro plants have a pale green V shaped leaf mark (Oram, 1990).

2.2.7 Seed size

Diploids have the smallest seed size ranging for the three diploid cultivars from 680 000 - 882 000 seeds kg⁻¹, the tetraploid cultivar seed size is intermediate with approximately 616 000 seeds kg⁻¹ and the two hexaploids range between 420 000 and 475 000 seeds kg⁻¹ (Oram, 1990). In contrast white clover (*Trifolium repens*) has 1764 000 seeds kg⁻¹ while red clover (*Trifolium pratense*) has 610 000 seed kg⁻¹ (Rincker and Rampton, 1985).

2.2.8 Selection and breeding

The amount of genetic variation in Caucasian clover between and within ploidy groups as described above (Sections 2.1.3 - 2.1.6) indicates a species with considerable potential for improvement through selection and breeding.

Seven cultivars have been developed in the last 18 years, 6 from Australia and one from the United States although others from the United States are under development. In New Zealand the breeding of Caucasian clover will be further encouraged with the release of a New Zealand bred commercially available hexaploid cultivar Endura.

2.2.9 Cultivars

There has never been enough seed available from any cultivar for it to be made commercially available. Experimental quantities of the seed have been widely used through the New Zealand hill and high country with many of the stands being established in the early 1970's. Since the first cultivar was registered in 1970 there has been a steady improvement in the general characteristics of more recent cultivars.

* cv. Summit is a diploid ($2x=16$), registered 1970 (Australian). It has poor agronomic potential but has good potential as a soil conservation plant for areas above the tree line (Barnard, 1972; Oram, 1990).

* cv. Treeline is a tetraploid ($4x=32$), registered 1970 (Australian). It was selected for revegetation work above the tree line in the Snowy Mountain Ranges (1830m) of New South Wales. It requires a higher plain of nutrition and less severe winter than Summit, and in these conditions it is substantially more productive than Summit (Barnard, 1972; Oram, 1990).

* cv. Prairie is a hexaploid ($6x=48$), registered 1977 (Australian). It has larger, generally more robust plants, with 1 and 2 year old plants differing from previous cultivars in that they are vigorously productive and compact to moderately spreading. It is used for

revegetation at moderate elevations (800-1600m), and could be considered a valuable pasture component for high country (Anon. 1977a; Oram, 1990).

* cv. Forest is a diploid ($2x=16$), registered 1977 (Australian). It is strongly rhizomatous and widely spreading, Forest is an effective pioneer in revegetation work (Barnard, 1972; Anon. 1977b; Oram, 1990).

* cv. Alpine is a diploid ($2x=16$), registered 1983 (Australian). Alpine was developed from Summit and two other high elevation forms. Alpine's advantage over Summit and Forest is its greater vigour and productivity combined with equal persistence. It produces more daughter plants than Summit and Forest. It is designed to replace Summit and is slightly superior to Forest in high alpine pastures with elevation between 950-1300m (Oram, 1990).

* cv. Monaro is a hexaploid ($6x=48$), registered 1983 (Australian). Monaro is more vigorous and productive than any other registered Caucasian clover cultivar. Compared with Prairie, it produces more daughter plants, spreads further, has a greater proportion of plants flowering and is more persistent. Monaro seems to be most suitable for locations receiving some summer rainfall and/or where white clover persistence is poor due to periodic summer drought and pests and diseases (Oram, 1990).

* cv. Rhizo is a hexaploid ($6x=48$), registered 1988 (USA, Oregon). Rhizo has vigorous rhizomatous growth, persistence and disease and insect resistance. It appears to have potential as a pasture legume, but seed production ranges from only 112 to 224 kg ha⁻¹. Rhizo is very winter dormant (Henry & Taylor, 1989)

* cv. Endura is a hexaploid ($6x=48$) selection from Monaro, that was registered in USA and Australia in 1995 and New Zealand in 1996. It was selected for greater seed production than Monaro. Endura is the first commercially available cultivar selected and bred in New Zealand.

2.3 ESTABLISHMENT CHARACTERISTICS

2.3.1 Seed germination

Caucasian clover is grouped with white clover, red clover and strawberry clover (*Trifolium fragiferum* L.), all of which have a minimum temperature for germination of between 4 and 6 °C (Hill and Luck, 1991), Caucasian clover germination is markedly reduced at temperatures higher than 23 °C (Bryant, 1974). Awan *et al.*, (1993) observed that environmental conditions affected seedling germination. Seedling number (plants m⁻²) 75 days after sowing were 30, 10, 56 and 28 plants m⁻² for cool-dry (sown mid June, soil temperatures at 10 cm of 8.5 °C), cool-wet (sown late June, soil temperature 8.5 °C), warm-dry (late March soil temperature 11.9 °C) and warm-wet (early April soil temperature 11.9 °C) soil conditions respectively.

Caucasian clover has a high proportion of hard seed which, on scarification, increase 5 germination from 10% to 79% (Gurung, 1991). Awan *et al.*, (1993) showed that poor results from oversowing resulted from the loss of plants or potential plants, during both germination and establishment phases. The greatest loss of plants was from the non-appearance of seedlings which amounted to approximately 80% of the sown seed. Variation in emergence between Caucasian clover cultivars has been observed with Gurung (1991) showing that after four weeks Monaro (52%) had higher emergence than Alpine (37%) after an autumn sowing.

Chapman *et al.*, (1989) described Caucasian clover establishment as slow because of low seedling vigour and the partitioning of dry matter to the roots. However the seedling vigour and germination characteristics of Caucasian clover from oversowing on four sites ranging in altitude from 600 m to 1100 m was very similar to white clover when improved inoculation techniques were used (Lowther and Patrick, 1992).

2.3.2 Seedling Development

Although there are reports of poor seedling establishment from seed sowing and transplanting (Lucas *et al.*, 1980; Scott, 1985; Awan *et al.*, 1993). Hill and Luck, (1991) and Lowther and Patrick, (1992) found that the growth and early seedling development of Caucasian clover is unlikely to be a problem for its wider use in pastures when inoculated with the correct strains of *Rhizobium* bacteria.

Hill and Luck (1991) detected very little difference in dry matter production in both the top and root, during seedling growth in Monaro Caucasian clover and Haifa white clover, suggesting that the ability to compete in mixed sowings, at least in the early stages, would be equal between the two species. However Gurung, (1991) observed that root extension in Caucasian clover seedlings was greater than petiole extension. This early root development in Caucasian clover has also been reported by Taylor and Meche, (1982). They showed that root length increased three fold between week two (46 mm) and three (61 mm) with root length being 278 mm at 12 weeks in glasshouse conditions.

Root:Shoot ratios indicate little if any difference in the partitioning of dry matter above or below ground between Monaro Caucasian clover and Haifa white clover as young seedlings (Hill and Luck, 1991). Caucasian clover seedlings in a glasshouse did not reach a root to shoot ratio of 1 until 10 weeks of age (Taylor and Meche, 1982). This would indicate that partitioning to the root was not an immediate priority at the seedling stage of establishment. However by 17 months Caucasian clover had a root to shoot ratio of 2.36 and 3.36 for cv. Summit and a hexaploid ecotype respectively. These ratios were some 16 times greater than white clover which averaged a ratio of 0.17 (Spencer *et al.*, 1975). Spencer and Hely, (1982) showed root production by Caucasian clover was up to three times that of white clover in the first year after planting, and that the greater development occurred at each of the 0-5, 5-10 and 10-15 cm depths in the soil.

2.3.3 Establishment techniques

Traditionally experiments using Caucasian clover have been sown by broadcasting or oversowing in the high country (Lucas *et al.* 1980; Daly and Mason 1987; Awan *et al.*, 1993), or transplanted as seedlings (Chapman *et al.* 1989; Allan and Keoghan, 1994), while other experiments have been established by drill in pasture mixtures containing up to 23 species (Scott and Covacevich 1987; Scott and Maunsell, 1986). In these experiments Caucasian clover did not contribute to production in the first 1-4 years of these experiments. This slow or poor establishment was seen as a major limiting factor in the future use of Caucasian clover. However once established Caucasian clover will survive as a young plant, persisting and spreading over time via an extensive rhizome system (Allan and Keoghan, 1994).

Scott and Mason (1992), investigated the use of rhizome fragments to establish Caucasian clover. This was carried out in the expectation that the use of the persistence and the spreading ability of Caucasian clover could be limited by seed supply. The rhizomes were separated into small (0-50 mm), medium (50-100 mm) and large (100-150 mm) fragments. Percentage survival was lowest for the small rhizomes (69%) while the medium and large rhizomes were higher at 88%. The dominating effect on survival and subsequent spread was fertiliser, with no fertiliser having the lowest establishment (39%) while 50 and 200 kg ha⁻¹ of sulphur superphosphate treatments gave survival rates of 98% and 100% respectively.

Direct drills such as the prototype strip seeder described by Horrell *et al.*, (1991) have shown their potential to establish alternative legumes successfully. Lowther *et al.* (1991) and Woodman (1993) both found that the strip seeder established larger numbers of well nodulated plants of Birdsfoot trefoil (*Lotus corniculatus*) and Lucerne (*Medicago sativa*) in semi-arid montane short tussock grasslands than the conventional triple disc. This technique for establishing Caucasian clover has only recently been used in a number of sites (Moorhead *et al.* 1994 Appendix 1).

2.3.4 Nodulation

Parker and Allen (1952) suggested that Caucasian clover nodulates reluctantly and does not benefit from association with rhizobia. However, with the appropriate strain of *Rhizobium*, Caucasian clover nodulates profusely and fixes large amounts of nitrogen (Burton, 1985). This phenomenon was better clarified by Hely (1957), Hely (1962) and Evans and Jones, (1966) who provided evidence that Caucasian clover responded to an effective strain of *Rhizobium*, and that ploidy level had an effect on inoculation, with the diploid race of Caucasian clover responding a lot later than the tetraploid and hexaploid races.

Hely, (1957) obtained isolates of *Rhizobium trifolii* from Caucasian clover in Australia and New Zealand. These isolates failed to nodulate the majority of the test tube grown Caucasian clovers. However Hely, (1962) observed that some initially resistant plants became infected at a latter stage in development. Hely, (1962) demonstrating that late-nodulating habit was generally correlated with an inability to fix nitrogen symbiotically. Among late-nodulating plants there is evidence of nitrogen fixation, but no effect levels of symbiosis. Hely and Zorin, (1975) discovered that Caucasian clover was resistant to strains of rhizobia from ecotypes which developed at different elevations in the same country and gave best responses to specific *Rhizobium* strains. Caucasian clover is resistant to rhizobia from other *Trifolium* spp., however it does form small ineffective nodules with white clover rhizobia (Patrick and Lowther 1995). Townsend, (1970) found that the general vigour of the plant is not always indicative of its nodulation status. Even though nodulation was sparse on some of the more vigorous plants the nodules were reddish brown in colour and considered effective.

In a glasshouse experiment, Taylor and Meche (1982) showed that Caucasian clover nodulation did not begin until the third week, nodule size remained constant until week 10, and nodule number showed no great increase until week 12. One of the main reasons given for poor nodulation from broadcasting is that the seed and inoculum are very susceptible to desiccation when on the surface of the soil; Lowther and Patrick (1992) suggested trampling by stock to improve seed:soil contact to improve establishment .

On 1-2 year old Caucasian clover (Moorhead personal observation) and four year old plants (Dear and Zorin, 1985), most nodules were concentrated around the crown of the parent plant on fine lateral roots. Nodules were also found on the roots derived from rhizomes at some distance from the crown and on the roots of daughter plants in the four year old plants by Dear and Zorin, (1985).

For successful nodulation Lowther and Patrick,(1992) inoculated seed with peat based inoculants at a high rate of 30 g peat per kg seed and pelleted using 40% gum arabic as the adhesive and microfine lime as a coating material. The strains of rhizobia used were ICMP 4073b for Monaro and 4074b for Treeline Caucasian clovers respectively.

Lowther and Patrick, (1992) found seedling nodulation was low in Treeline Caucasian clover at four sites, and that different strains of rhizobia are required for tetraploid (eg Treeline) and hexaploid (eg Monaro) cultivars. They also stated that further selection of rhizobia for nodulation ability under oversowing conditions is necessary to improve establishment of Treeline Caucasian clover.

Using a peat-based inoculant in a gum arabic-lime pellet Patrick and Lowther (1995) found that over nine tussock grassland sites the percentage of effectively nodulated seedlings established from broadcasting increased from a mean of 5% for the lowest inoculation rate to 66% at the highest rate while the commercially recommended rate provided 40% effectively nodulated seedlings after four months. The lowest rate provided 200 rhizobia per seed one day after inoculation while the highest provided 260 000 rhizobia. However four days after inoculation these numbers had dropped to 100 rhizobia and 42 700 rhizobia per seed for the lowest and highest inoculation rates respectively. These results indicate that the number of rhizobia required to maximise nodulation is higher than that obtained by inoculation at the recommended rate (Patrick and Lowther 1995).

Bergersen *et al.*, (1963) found that Caucasian clover nodules over-wintered, and that survival of the vascular system of the nodules appeared to enable tissue capable of nitrogen fixation to be formed at least two weeks before any new roots are developed in the spring, which could be infected and produce new nodules.

Part of the future of nodulation in Caucasian clover is the possible use of genetic engineering. An example of genetic manipulation is given by Townsend (1985) who suggested that the genetic messengers in Caucasian clover responsible for resistance to nodulation by most strains of *Rhizobium trifolii* could be beneficial in attaining nodulation by a compatible highly efficient strain of *Rhizobia*.

2.4 PERSISTENCE

One of the best characteristics of Caucasian clover is its ability to persist under a wide range of conditions and stresses. This quality makes it a highly desirable species for the more sustainable, low input agricultural systems being advocated for the future.

2.4.1 Climatic extremes

Damage by frost, cool temperatures, and excessive heat can be avoided by plants that occupy sheltered positions and by subterranean plant parts ('t Mannelje *et al.*, 1980). This is evident in the root and rhizome development of Caucasian clover which is native to the Caucasus mountains and is also adapted to the Snowy Mountains in Australia (Bryant, 1974). Khorohailov and Fedorenko (1973) described it as an alpine or mountain plant which grows rapidly in spring, is hardy under drought conditions and is winter dormant. Drought resistance and cold resistance have been widely reported (Bryant, (1974), Spencer *et al.*, (1975), Lucas *et al.*, (1980), Speer and Allinson, (1985), Daly and Mason (1987), Chapman, *et al.*, (1989), Woodman, *et al.*, (1992), Hill *et al.*, (1996a), Hill, *et al.*, (1996b), Virgona and Dear, (1996)).

However in a pot trial four month old Caucasian clover cv. Treeline plants were found to be the most frost sensitive of 13 *Trifolium* species tested. Caradus (1994) found that Caucasian clover had the lowest frost tolerance, the temperature causing death of 50% of leaves of -4.8°C compared to -8°C for white clover and -11°C for *Trifolium hybridum*. Caucasian clover was also found to have the lowest regrowth yields after one month, however this was attributed to Caucasian clover having small plant size and low vigour (Caradus, 1994).

This study on the frost tolerance of different legume species is particularly biased against Caucasian clover as it was done within the first six months of establishment, when Caucasian clover is not particularly vegetative relative to other pastoral legume species, and is building up a large underground biomass (Section 2.2). Once established with a high proportion of its dry matter below ground in storage organs, Caucasian clover rapidly recovers from any frost damage experienced in early autumn (personal observation).

Dear and Zorin (1985), described Caucasian clover as a drought resistant, summer growing legume which can tolerate low winter temperatures and heavy frosts and recovers quickly after droughts without having to re-establish from seed. However it is most suited to environments which receive a good summer rainfall. This is demonstrated by its persistence in the trial reported by Lucas *et al.*, (1980) in a South Island high country environment with cold winters and periodically dry summers, but receiving a relatively evenly spread 1000 mm annual rainfall. Caucasian clover has persisted since 1975 at this site and is still a high proportion of the original plots (personal observation). This is a similar observation to that made by Yates (1993) from plots in the high country of Tasmania, Australia.

2.4.2 Grazing

Very limited work has been reported on the effects of grazing management on the persistence of Caucasian clover prior to the late 1980's. However Caucasian clover was described by Khoroshailov and Fedorenko, (1973) as an important fodder and pasture in its natural environment, with it persisting even in over grazed pastures near sheep yards. Many older trials such as those reported by Lucas *et al.*, (1980) and Yates (1993) have been subject to uncontrolled grazing since the finish of the experimental work yet these trial plots still have high levels of Caucasian clover.

A grazing trial on oversown tussock country at Tara Hills Research Station reported by Allan *et al.* (1992) is the only long term information available on persistence of Caucasian clover under different grazing management's. The trial compared three stocking rates, low or traditional (2), medium (3) and high (4 SU ha⁻¹ yr⁻¹), with three management practices at each rate; continuous, alternating grazing, and rotational grazing, with treatment areas divided into one, two and six paddocks respectively. In 1984, 28 legumes were transplanted

into the grazing trial. Caucasian clover was by far the most persistent legume under all grazing rates and management's after five years, with 60%, 77% and 53% survival for the low, medium and high stocking rates respectively. Sheaffer *et al.*, (1992) showed that Caucasian clover persisted under grazing better than birdsfoot trefoil. Persistence was also demonstrated under cutting schedules where Caucasian clover had an estimated ground cover after four years of 95, 95 and 91 % respectively for 2 cut, 3 cut, and 4 cutting schedules per growing season, while in a mixture with birdsfoot trefoil there was 95, 93 and 89 % ground cover respectively which was predominantly Caucasian clover (Sheaffer *et al.*, 1991).

The excellent persistence of Caucasian clover under grazing can be attributed to the substantial underground biomass Caucasian clover builds up in the first few years after establishment (Daly & Mason, 1987; Chapman, *et al.*, 1989) and its ability to spread via rhizomes which protect the growing points from grazing (Dear and Zorin, 1985; Chapman, *et al.*, 1989; Allan & Keoghan, 1994).

2.4.3 Insect tolerance

Caucasian clover has been described as tolerant of grass grub (*Costelytra zealandica*), (Lucas *et al.*, 1980; Daly & Mason, 1987). Grass grub is the major root feeding pest on pasture legumes in New Zealand and is responsible in many cases for reduced persistence of legumes such as white clover in pastures. Grass grub growth rates when fed on Caucasian clover are no different than for white clover (Dymock *et al.*, 1989). This would indicate that it was not resistant but tolerant and that any tolerance Caucasian clovers has to grass grub attack was due to the sheer mass of its root and rhizome system (personal observation). Like most tolerant plants it is still susceptible to grass grub attack as a seedling.

In greenhouse and growth chamber environments it was found that root-lesion nematode *Pratylenchus penetrans* was common on many forage species, however the most suitable hosts included Caucasian clover, alsike clover and white clover (Thies *et al.*, 1995).

2.4.4 Disease resistance

Caucasian clover is generally resistant to mechanical inoculation of peanut stunt virus (PSV) (Anderson *et al.*, 1991), clover yellow vein virus (CYVV) and alfalfa mosaic virus (AMV) (Pederson and McLaughlin, 1989). Resistance to bean yellow mosaic virus (BYMV), red clover vein mosaic virus (RCVMV) and white clover mosaic virus (WCMV) have also been reported (Alconero *et al.*, 1986; Barnett and Gibson 1975).

Cases of susceptibility to CYVV, WCMV, clover yellow mosaic virus (CYMV), and RCVMV have been reported (Pederson and McLaughlin, 1989; Alconero *et al.*, 1986; Barnett and Gibson 1975). In all cases the majority of the plants were resistant to these viruses. However Wijkstra and Guy (1996) found stunted plants of Caucasian clover cv. Endura were infected with alfalfa mosaic virus and that the resistance of Caucasian clover to a number of viruses should be re-examined.

2.5 AGRONOMIC CHARACTERISTICS

2.5.1 Nitrogen fixation.

A study in Tasmania estimated that Caucasian clover was fixing up to 233 kg N ha⁻¹ yr⁻¹ compared with white clovers which fixed only 138 kg N ha⁻¹ yr⁻¹ at the same site. The majority of the nitrogen fixation was found to occur during the periods of active growth between October and January (193 kg ha⁻¹). Factors such as low soil moisture in late summer and autumn and low temperatures (<5°C) over winter months severely limited growth and nitrogen fixation (Lane, 1985). The difference in nitrogen fixation and accumulation in the soil between Caucasian clover and white clover was also seen in plots established in 1976 at Round Plain, New South Wales (Dear and Zorin 1985), where after 17 years total soil nitrogen was 1.752 µg /g on plots where white clover had originally been established, and 2.260 µg /g where Monaro was growing (Hill *et al.* 1996a).

The presence of nitrogen fixation was also shown at a highland site (1150 m) in New South Wales, Australia where under Caucasian clover plots there was a substantial increase in the available nitrogen and total nitrogen levels in the soil compared with plots containing no legume (Dear 1987). The change in total soil N in the top 10 cm indicated that the net

increase in soil N averaged 60-70 kg N ha⁻¹ yr⁻¹. This increase suggests a very effective and long lived symbiosis especially when the short growing season of the environment is considered.

2.5.2 Phosphate

Spencer *et al.*, (1980) suggested that Caucasian clover in those characteristics concerned with phosphorus (P) up-take and utilisation, can only at best be considered marginally superior to white clover, however this observation was made only during the seedling stages of these plants. Caucasian clover is slower to establish than white clover, which gives the impression that it has a lower P requirement (Davis, 1991). However when given similar maximum yields white clover and Caucasian clover have similar P requirements (Davis, 1991). Caucasian clover production increases in response to applied P, and hexaploid Caucasian clover is more responsive to P than diploid or tetraploid forms (Spencer and Hely, 1982). However the higher the chromosome number in Caucasian clover the lower the P concentration in the foliage (Spencer *et al.*, 1980). This may be an indication of greater phosphate efficiency of hexaploid Caucasian clovers over the lower ploidy levels.

Spencer and Hely, (1982) found that mixing fertiliser through the surface 10 cm, was beneficial for hexaploid Caucasian clover root development but they also found that mixing fertiliser was only a slightly more effective than surface application for shoot production in the early years.

2.5.3 Nutrient storage

At Mount John Station, Lake Tekapo, Caucasian clover in a complex mixed sward increased in importance at higher fertility levels (Scott and Covacevich, 1987). However in a lot of cases Caucasian clover is being placed in low fertility sites, where there are limited inputs of fertiliser over time in these conditions nutrient storage is very important for persistence. Caucasian clover is well documented for developing a large root and rhizome masses over time, 12,600 kg ha⁻¹ in a five year old stand (Stewart & Daly, 1980), 17,510 and 5,510 kg ha⁻¹ for 12 and 8 year old stands respectively (Daly & Mason, 1987) and 20,228 kg ha⁻¹ in a 13 year old stand which had 800 kg ha⁻¹ of P at establishment (Strachan *et al.* 1994).

Strachan *et al.* (1994) attributed the persistence and dominance of Caucasian clover over time to this large network of rhizomes and taproots. Nutrient storage in the underground biomass and possible re-translocation of mobile nutrients into the underground biomass pool over the winter may be reasons for continued persistence and good growth of Caucasian clover in older stands. From the trial described by Davies (1991), Strachan *et al.* (1994) found that total nutrient pools in coarse roots and rhizomes and fine roots were 729, 65, 266, 47 and 311 kg ha⁻¹ for N, P, K, Mg and Ca respectively. These values were approximately five time higher than those of early summer herbage.

2.5.4 Soils and pH

Persistence at low pH is one of the characteristics of most registered Caucasian clover cultivars (Oram, 1990), an example of which is where close to 100% survival of Caucasian clover plants were found in the Monaro area of New South Wales, 17 years after establishment, with a soil pH ranging from 4.1 and 4.8 (Hill, *et al.* 1996a).

In pot trials above ground yield of Caucasian clover was low at a pHs of 4.65 and 4.8 with the yield increasing three fold with liming (pH 5.0 and 5.5), (Barnard and Fölscher, 1988). Barnard and Fölscher, (1988) showed a large difference between legume species in their ability to grow in unlimed conditions. Caucasian clover and lucerne were the poorest, whereas birdsfoot trefoil, white clover and especially *Lotus pedunculatus* were the best. These results are from short term pot trials that report above ground herbage only. There was no assessment of under ground development of Caucasian clover in these acid soils. Pots also limit rooting depth of plants which may influence results.

Aluminium (Al) toxicity adversely affected Caucasian clover growth (Davis 1981).

Caucasian clover plants grown in a pot trial, with soil pH <5.4 with high soluble Al resulted in herbage aluminium concentrations of 596, 413, and 478 ppm for Summit, Treeline and Prairie respectively. In contrast lotus and lupins had herbage Al concentrations of 169 and 175 ppm respectively indicating a higher tolerance t of Al toxicity. The high leaf concentrations of Al may be a mechanisms by which Caucasian clover can persist in acidic

conditions. That is the translocating of Al away from the roots which are damaged and restricted by high concentrations of Al and into the foliage.

2.5.5 Rhizome and daughter plant development

Caucasian clover is slow to establish above ground biomass but shows good persistence and spread with daughter plants establishing from rhizomes up to 30 cm from parent plants within three years (Chapman *et al.*, 1989) and after nine years having a maximum spread of 138 cm (Allan and Keoghan, 1994). Chapman *et al.*, (1989) described how a high proportion of early growth in Caucasian clover is concentrated in the development of a network of rhizomes. Taylor and Meche, (1982) found under ideal conditions in a glasshouse, occasional rhizomes were present by the tenth week but vigorous rhizome formation had not commenced by week 12, in contrast however rhizome spread of Caucasian clover established in a complex mixed sward was slow and was not increasing the content of Caucasian clover within the sward until years four and five (Scott and Covacevich 1987).

Dear and Zorin (1985) found that of the cultivars and seed lines tested the two most vigorous lines, Monaro and Alpine formed dense interlocking swards of daughter plants by the end of four years. Monaro was found to have a maximum rhizome length of 46.7 cm and produced 74 daughter plants per parent plant, while Alpine had a maximum rhizome length of 38.3 cm and 53 daughter plants per parent plant. Rhizome length was found to be positively correlated with the number of daughter plants produced and not influenced by ploidy (Dear and Zorin 1985). Allan and Keoghan (1994) found after nine years under nine grazing treatments, that the average spread of Monaro Caucasian clover was 56 cm.

The root and rhizome yield in 0.5 m² of a five year old Caucasian clover, cv. Treeline sample was equivalent to 12 600 kg ha⁻¹, (Stewart and Daly, 1980). Total under ground biomass at hill country and high country sites respectively were 17,510 and 5,510 kg ha⁻¹ for 12 and 8 year old Prairie plots, the rhizome components at each of these sites were 12,100 and 4,930 kg ha⁻¹ (Stewart and Daly, 1980).

With the low seed producing potential of earlier Caucasian clover cultivars and management practices and reports of slow establishment Scott and Mason (1992) investigated the vegetative propagation of Caucasian clover into *Hieracium* infested fescue tussock on the Mt John Station, Lake Tekapo. The percentage survival increased with increased rhizome fragment size, and the addition of fertiliser gave a large increase in survival from 31 % survival for no fertiliser to 98 and 100 % with the addition of 50 and 200 kg fertiliser ha⁻¹, and the fertiliser also added subsequent growth. Scott and Mason (1992), noted that shoots on the expanding edge of nine year old Caucasian clover plants tended to be chlorotic suggesting that the rhizome and the shoots were growing out faster than the associated rhizobia nodulation, however after four years Dear and Zorin (1985) reported nodules on the roots of daughter plants away from the parent plant.

2.5.6 Herbage production

Dear and Zorin (1985), described Caucasian clover as having the potential to be highly productive when conditions are favourable or relatively unproductive, but persistent, under harsh conditions. However Scott and Maunsell (1986) described it as being unproductive after four years in irrigated pastures in the Mckenzie basin. Planted on three sites in the Mackenzie country cv. Treeline and cv. Prairie Caucasian clover were slow to establish and showed low to moderate productivity by the fifth year, the hexaploid Prairie was the most productive (Scott, 1985).

At the elevation of 1150m available herbage averaged 2278, 2127, 1696 and 2482 kg DM⁻¹ ha⁻¹ for the cultivars Forest, Alpine, Treeline and Monaro respectively, from a three month growth period, while the plots of native grasses without a legume present produced 399 kg DM⁻¹ ha⁻¹ (Dear, 1987). On a fertile lowland soil, a moderately fertile hill country soil, and a low fertility high country soil Caucasian clover's annual dry matter production was 12 t ha⁻¹ (cv. Treeline), 8.5 t ha⁻¹ (cv. Prairie) and 2.5 t ha⁻¹ (cv. Prairie) (Daly & Mason 1987).

Daly & Mason (1987) found that in Caucasian clover the root/rhizome to shoot ratio increased from 1.04 on a fertile lowland soil to 2.73 on a low fertility high country as soil and climate conditions become more severe. Taylor and Meche, (1982) showed that the root:shoot ratios, in Caucasian clover growing under ideal conditions in a glasshouse,

remained constant at 0.4 to 0.6 during the first 8 weeks post emergence and increased to 1.2 by week 12, these results however may have been influenced by the restriction of the tap root when grown in pots. Spencer *et al.*, (1975) reported that the root:shoot ratio after 17 months from seeding to range from 2.4 to 3.1, 16 times greater than white clover. Hill & Hoveland (1993) found that after five months in a pot trial the root:shoot ratio in Caucasian clover (0.78) was significantly higher than in ladino white clover (0.42) over all treatments imposed.

Over years 5-12 of a 12 year old trial in the Tasmanian high country the average herbage production of Alpine (552), Forest (577), Summit (551), Treeline (517), Monaro (559) and Prairie (579) was 556 g m⁻² with 57% clover compared with white clover which averaged 479 g m⁻² and 33% clover (Yates, 1993).

2.5.7 Seasonal herbage production

At 1150m in New South Wales Caucasian clover ceased growth in winter. New growth occurred around mid-September with peak herbage production in late November. Growth ceased during dry conditions, with autumn growth depending on the frequency of rainfalls. Growth continued until the first frosts, but regrowth occurred with mild conditions after early frosts (Dear and Zorin 1985).

2.5.8 Production in mixtures

There is very little information on Caucasian clover in mixtures with both grass and other legumes. Evans and Jones, (1966) found that grass plants growing alongside effectively nodulated Caucasian clover gave significantly higher yields than those grown with ineffectively nodulated plants. The benefits of using Caucasian clover in mixtures in relation to nitrogen production have also been reported by Lane (1985) and Dear (1987).

Persistence and forage production of Caucasian clover in a mixture with birdsfoot trefoil following three years of grazing with high herbage allowance was superior to that of birdsfoot trefoil (Sheaffer *et al.*, 1992).

Over three years, on a moderately deep yellow-grey earth soil with border dyke irrigation in the Mackenzie country, Caucasian clover in a grass mixture for hay production did not contribute to the swards yield. Red clover was the highest producing legume in the initial years, while Lucerne (*Medicago sativa*) was the highest producing legume in later years (Scott and Maunsell, 1986). Caucasian clover sown in a general mixture of twenty three species or cultivars using the NZAEI rotary hoe drill was the sixth most successful of the sown legumes after four years and increased in importance at the higher fertiliser level, however rhizomatous spread was slow (Scott & Covacevich, 1987).

Hill and Hoveland (1993) found that in a pot study carried out over five months from establishment, involving different defoliation regimes and moisture stress levels, there was potential for severe competition during establishment of a tall fescue/Caucasian clover mixture. It was suggested that where a perennial grass is well adapted, and does not decline in persistence with time, a lower seeding rate for the grass may be needed to make 'biological space' for Caucasian clover.

A trial was sown in December 1993, at the AgResearch Winchmore Research Station. One of the main aims of the trial was to test the compatibility of dryland grasses with Caucasian clover under typical ryegrass-white clover pasture management practices. Caucasian clover was direct drilled with individual grasses perennial ryegrass (high endophyte) (*Lolium perenne*), 'Grasslands Wana' cocksfoot, (*Dactylis glomerata*), 'Grasslands Maru' phalaris (*Phalaris aquatica*), 'Grasslands Gala' grazing brome, (*Bromus stamineus*) 'Grasslands Roa' tall fescue (*Festuca arundinacea*) and a mixture of phalaris, grazing brome and tall fescue. The treatments were rotationally grazed through the year. Initial establishment of white clover was excellent with good establishment of Caucasian clover in all grass plots except Gala grazing brome. The Gala grazing brome established very vigorously and made it difficult to judge the establishment of Caucasian clover although it does look as if it may be slower away than white clover and the Caucasian clover in the other grass plots (personal observation).

2.5.9 Grazing management.

In Minnesota, USA Caucasian clover yields were similar over three cutting treatments 7.4, 9.2 and 9.2 kg ha⁻¹ for the 2-cut, 3-cut and 4-cuts per season respectively and 60% that of lucerne for the first two years. After three years Caucasian clover was one of the highest yielding legumes, with a similar yield to lucerne (Sheaffer and Marten, 1991). Caucasian clover had a percentage ground cover after three years of 95, 95 and 91 for 2-cut, 3-cut and 4-cut schedule respectively. This compared with lucerne and Cicer milkvetch with 53, 54 and 38% and 53, 75 and 48% respectively (Sheaffer and Marten, 1991).

Stewart and Daly, (1980) described the optimal management of Caucasian clover to be a long rotation (2 months) combined with heavy grazing or cutting (1 cm). Under these conditions a five year old pure stand of Treeline Caucasian clover produced 13 250 kg ha⁻¹ yr⁻¹ when irrigated and 12 100 kg ha⁻¹ yr⁻¹ under dryland conditions. Under glasshouse conditions with a range of cutting heights and regrowth periods six month old Caucasian clover plants cut to 25 mm had the highest accumulated yield and 100 mm cuts had the lowest, the highest accumulated yield occurred at a harvest frequency of 30 days for the 25 mm cut and the lowest at 60 days (Taylor and Meche, 1982).

A grazing trial on oversown tussock country at Tara Hills Research Station, started in 1978 and is still continuing, has highlighted short-comings of clovers traditionally used for rangeland improvement Allan *et al.*, (1992). Plant survival and spread of Caucasian clover was found to be excellent. Under three grazing management's, "Lax" (Low stocking rate (2 SU ha⁻¹)/alternating grazing), "Optimal" (medium stocking rate (3 SU ha⁻¹ / alternating grazing) and "Extreme" (4 SU ha⁻¹/continuous stocking), Caucasian clover plant survival after five years was 67.5, 80 and 53 % respectively compared with the next best 'Huia' white clover with 54, 42.5 and 3% for the lax, optimal and extreme grazing treatments respectively. Allan and Keoghan (1994) found that both spread and vigour (0-5 scale) increased with stocking rate. Nine years after transplanting, Caucasian clover had a spread (and vigour) of 42 (3.0), 59 (3.1) and 66 cm (4.0) for the low, medium and high stocking rates. The grazing treatments of continuous, alternating and rotational grazing developed plants with a spread (and vigour) of 56 (3.5), 47 (3.0) and 65 cm (3.6). These

results suggest that Caucasian clover is tolerant of most grazing managements, however it spreads and possesses the greatest vigour under rotational grazing at a high stocking rate.

2.5.10 Nutritional value

Both Currier, (1979) and Oram, (1990) observed that Caucasian clover has no oestrogen activity. However Caucasian clover does not contain tannins (Currier, 1979) and therefore may cause bloat (Sheaffer, *et al.* 1992).

Allinson *et al.* (1985) indicated that Caucasian clover had a high nutritive value, and was similar in its nutritional characteristics to that of Ladino clover. Sheaffer and Marten, (1991) observed that forage crude protein (CP) and *in vitro* digestible dry matter (IVDDM) concentrations increase with cutting frequency by 360% for CP and IVDDM for a two cut schedule and by 330% for a four cut schedule. Caucasian clover has a greater IVDDM than lucerne, alsike clover, red clover, crownvetch, cicer milkvetch and birdsfoot trefoil, and was among the legumes with the greatest CP concentrations in all cutting schedules (Sheaffer and Marten, 1991).

Sheaffer *et al.*, (1992) again showed that forage IVDDM and CP concentrations of Caucasian clover were equal to, or greater than birdsfoot trefoil, and that the average forage nutritive value of Caucasian clover is similar to, or greater than, those observed in other experiments with grazed perennial legumes.

Sheaffer *et al.*, (1992) found that at a high herbage allowance Caucasian clover provided lamb gains per hectare and animal days per hectare equal to or greater than birdsfoot trefoil. Caucasian clover provided average daily live weight gains of 190g and 205g for a birdsfoot trefoil - Caucasian clover mixture and a Caucasian clover monoculture respectively. This is in an environment where live weight gains of 150g lamb⁻¹ day⁻¹ are considered good. Sheaffer *et al.*, (1992) observed that a reason for the high quality of Caucasian clover is because it has a very high proportion of leaves in the canopy.

Birdsfoot trefoil (*Lotus corniculatus* L.) in a mixture with Caucasian clover did not reduce the incidence of lamb bloat (6% developed bloat, 2% died) when Caucasian clover comprised more than 20% of the mixture (Sheaffer *et al.*, 1992).

2.6 SUMMARY

Caucasian clover is from the Caucasus mountain region of what use to be Southern USSR, where it is found over a wide range of environments. Caucasian clover is taxonomically related to white clover and is one of the few *Trifolium* species to have a naturally occurring ploidy level, consisting of diploids, tetraploids and hexaploids.

Endura Caucasian clover is the first commercially available cultivar in New Zealand, it was selected out of the hexaploid cultivar Monaro for greater seed production. Monaro has been shown to be the most agronomically suitable for pastoral use as it is highly productive and produces more daughter plants and spreads further than any other Caucasian clover cultivar.

Early establishment characteristic of Caucasian clover are very similar to white clover especially when correct strains of *Rhizobium* bacteria are used. However as the Caucasian clover seedlings develop partitioning is prioritised towards root and rhizome development at the expense of leaf production, after one year Caucasian clover can have up to three times the root dry matter as white clover. This partitioning of dry matter to the root and rhizome system has lead to it becoming known as a slow establishing species and stated as one of the limitations to its future uses.

Caucasian clover has had a history of not contributing to production in its first four years in experiments. These experiments have mostly been established by oversowing and transplanting of seedlings, and new technology such as the prototype strip seeder have only recently been used in establishing alternative legumes.

Caucasian clover requires specific rhizobia for nodulation, each ploidy level requires a specific strain of *Rhizobium* for the strongest establishment and nodulation. With the correct strain of rhizobia Caucasian clover nodulates profusely and fixes large amounts of nitrogen. Both seed and inoculum are very susceptible to desiccation when on the surface of the soil.

Once established Caucasian clover is very persistent it has been described as a drought resistant, spring and summer growing legume which can tolerate low winter temperatures and heavy frosts and recovers quickly from droughts without having to re-establish from seed. Caucasian clover is an important fodder and pasture component in its natural environment where it persists under grazing, in New Zealand Tara Hills Research station have reported it to be the most persistent legume under continuous grazing, alternating grazing and rotational grazing over three stocking rates. It has also shown strong persistence with differing cutting schedules in North America

Caucasian clover has been described as being tolerant to grass grub once established however like most species it is still susceptible to grass grub damage as a seedlings. It has also been shown to be resistant to a number of viruses that commonly affect white clover.

Caucasian clover has been shown to fix more nitrogen than white clover in some environments with recorded amounts ranging between 60 to up 233 kg N ha⁻¹ yr⁻¹ this would appear to be associated with its greater persistence, and that it recovers quickly after drought .

It is considered that in characteristics concerning phosphorus up-take and utilisation Caucasian clover is no different to white clover although due to the differences in partitioning of dry matter Caucasian clover may seem more efficient. It is well documented that there is a large build up of under ground dry matter associated with older stands of Caucasian clover, these have ranged between 5,510 kg ha⁻¹ and 20,228 kg ha⁻¹ . There appears to be large nutrient pools present in the roots and rhizomes of Caucasian clover particularly nitrogen, potassium and calcium with lesser amounts of phosphate and magnesium.

Persistence at low pH is a characteristic of established Caucasian clover plants although herbage yield is greatly increased with liming and pH around 6. Reports on Caucasian clovers responses to pH are limited as to their relevance as they are mostly pot trials that have focused on above ground dry matter over short periods of time such as one year and take no account of the important under ground dry matter build up.

Caucasian clover is slow to develop above ground production but shows an ability to persist and spread with daughter plants establishing from rhizomes over a meter from the parent plant. It has been shown that rhizomes can start developing between 10 and 12 weeks after sowing in a glasshouse.

Caucasian clover is very productive and produces large amounts of dry matter between early spring and mid autumn. Caucasian clover has been shown to out produce white clover in a number of sites around New Zealand and Australia again taking advantage of vegetative persistence to respond quickly after droughts, a characteristic that white clover does not have.

Initially herbage production in mixtures is poor with Caucasian clover very rarely contributing to a pasture mix in year one to four, however over time Caucasian clover content builds up and it becomes a more important component of a mixed pasture.

The optimal grazing management for Caucasian clover has been described as a long rotation of up to two months followed by cutting to 10 mm, however other managements that have produced the high accumulative herbage yields include a 30 day rotation with a 25 mm cutting height. Results of a high country grazing trial suggest that Caucasian clover is tolerant of most grazing managements, however it spreads and possesses the greatest vigour under rotational grazing at a high stocking rate.

Caucasian clover does not contain tannins and therefore may cause bloat. However it has no oestrogen activity and is described as having the same high nutritive value, and similar nutritional characteristics to Ladino white clover.

This review has shown two areas of research that have largely not been researched, that is the effects of different establishment techniques on the establishment and subsequent growth of Caucasian clover and the sociability of Caucasian clover with high endophyte ryegrass and white clover under differing grazing managements in lowland sites in New Zealand.

These are two important areas of knowledge required for any management package to be developed for the commercial use of Caucasian clover in New Zealand. It was the lack of information in these two areas that lead to the laying down of the two trials described in the following two chapters in a effort to provide information that may lead to more focused research in these areas in the future.

CHAPTER THREE

ESTABLISHMENT OF CAUCASIAN CLOVER IN THE HIGH COUNTRY

3.1 INTRODUCTION

Caucasian clover shows great promise as a very persistent, competitive legume for the South Island hill and high country. It is a deep rooted, drought tolerant, spring and summer-growing legume which can tolerate low winter temperatures and heavy frosts, and recovers quickly after drought (Dear & Zorin 1985; Woodman *et al.* 1992). Caucasian clover has an extensive root and rhizome system (Daly & Mason 1987) which acts as an important store for nutrients (Strachan *et al.* 1994). Allan & Keoghan (1994) found that Caucasian clover persisted under a wide range of grazing management systems on a mid altitude, shady, Omarama steppeland yellow-grey earth. This persistence under a range of grazing management systems was attributed to Caucasian clover's rhizomatous habit with growing points below ground level. Persistence through vegetative spread was observed by Dear & Zorin (1985) who found four year old Caucasian clover cv. Monaro produced 74 daughter plants/parent and had rhizomes that reached 500 mm in length.

Reports of slow establishment (Lucas *et al.* 1980; Scott 1985) and the lack of seed supplies have restricted the commercial use of Caucasian clover. This has led to proposals that rhizome fragments could be used as a means of establishment (Scott & Mason 1992). However, in contrast to Lucas *et al.* (1980), Lowther and Patrick (1992) reported seedling establishment of white clover and Caucasian clover can be similar under certain conditions.

The aims of this establishment trial were to measure the effects of three sowing techniques and two rates of fertiliser application on Monaro Caucasian clover seedling establishment and early root and rhizome development on a low fertility, summer moist, high country site.

3.2 MATERIAL AND METHODS

3.2.1 Experimental site and design

The experiment was sited on depleted, unimproved tussock grassland dominated by fescue tussock (*Festuca novae zelandiae* (Hack)CKn.), browntop (*Agrostis capillaris* L.) and mouse-ear hawkweed (*Hieracium pilosella* L.) situated at Mesopotamia Station in the upper Rangitata valley. The soil, a Mesopotamia silt loam, is acid (pH 5.2) and low in phosphorus (Olsen P 6) and sulphur (S 2 ppm). The site is 500 m above sea level facing northwest with a slope of about 5° and has a mean annual rainfall of 940 mm. The site was burnt on 21 August 1992 to remove litter and sown with Caucasian clover (*Trifolium ambiguum* Bieb.) cv Monaro on 1 October 1992 using the Lincoln Ventures/AgResearch experimental plot drill. Rainfall was reasonably evenly distributed during the establishment year with 133 mm of rain in the two months following sowing out of a total for spring of 167 mm (Table 3.1).

Table 3.1 Seasonal rainfall and soil temperatures at Mesopotamia station, Rangitata valley, for the period 1992-1994.

Measurement		----- Seasonal distribution -----				Total rainfall
		Spring	Summer	Autumn	Winter	
Rainfall (mm)	1992/93	167	191	235	406	848
Mean daily temperature (°C) [#]	1992/93	NA	NA	8.0 ^{##}	4.2	
Mean daily temperature (°C) [#]	1993/94	10.0	16.5	11.1	3.7	

Soil temperatures at 10 cm depth

From 16 April to the end of May

NA Not available

Seeds were scarified and commercially prepared as a special batch by inoculating with *Rhizobium* strain CC283B followed by coating with fine lime at a rate of 0.7 lime : 1.0 seed. Although no *Rhizobium* counts were done the inoculant was applied at five times the recommended rate, with the aim that the number of viable *Rhizobium* present on the seed would not be limiting. The inoculated, coated seed was stored at 4°C for one day before sowing.

The trial was a balanced incomplete block design with plots consisting of paired comparisons of all treatments. There were three levels of establishment methods and two levels of fertiliser to give six treatments which when arranged in paired comparisons resulted in 15 paired comparisons (30 plots) per replicate. There were therefore five plots of each treatment in each replicate. The trial was replicated twice with each paired plot 20 m in length (Appendix 2).

Seeding rate was calculated to place 100 viable seeds per metre of row based on 72% laboratory germination after mechanical scarification. Treatments consisted of three methods of establishment: an experimental strip seeding system, direct seeding into the sod or broadcast. The strip seeding system described fully by Horrell *et al.* (1991) used an inclined dished disc to cut and invert a ribbon of turf, placing it adjacent to the drilling strip. Next, a spring tine cultivated the soil and banded the fertiliser at a nominal depth of 50 mm. Finally a seed coulter sowed the seed at a shallow depth (approximately 10 mm) and a press wheel firmed the seed bed. Two rows 150 mm apart were sown in the weed free 200 mm strip of bare soil. The sod seeding system used the widely available Duncan 760 till seeder with a 'Baker' inverted T coulter, where fertiliser is placed with the seed. This treatment was also drilled in two rows 150 mm apart. The broadcast treatment was applied by using the plot drill with seed and fertiliser falling directly from two drill hose (150mm apart) 100 mm above the ground and spreading over a strip approximately 300 mm wide. Subsequent observations showed that seed mainly established in two identifiable rows or narrow bands.

Each of the establishment methods was sown with either 150 or 300 kg/ha of molybdc sulphur super phosphate (8% P, 20% S). These rates of molybdc sulphur super were based

on two rows x 150mm to give a 300 mm wide strip per treatment. Basal boron was also applied to the entire experimental area as a solution of borax (11% B) at 10 kg B/ha.

3.2.2 Trial measurements and data analysis

Early emergence and establishment was measured on 14 December 1992 with plant counts made along two 500 mm lengths of row from each paired treatment in each plot.

On 12 March 1993, one spade spit 200 x 150 mm was dug across each of the paired rows of sod and strip seeding treatments at median sites. Owing to a lack of uniform plant numbers in the broadcast treatment spits were dug to obtain a minimum of 5 plants/treatment. Samples were washed and measurements of nodulation, taproot crown diameter, rhizome number/plant and rhizome length were recorded. Dry weights of shoots (above ground herbage), roots and rhizomes were determined.

At the end of the first growing season on 6 July 1993, one 150 mm wide turf was dug across the paired rows of the sod seed and strip seeding treatments. The turfs were long enough to include all lateral rhizome development. Five plants were randomly selected for measurement from the broadcast treatments as five plants were not normally present in one 150 mm wide turf. Measurements were the same as the first sampling plus additional measurements of secondary rhizome number, length, and dry weight per plant and mean plant width, which was the mean of all the plants in each sample with the plant width measured as the distance between the tips of the two longest rhizomes on each plant.

An adjacent fertiliser trial comparing responses of Monaro Caucasian clover and Grasslands "Tahora" white clover to rates of phosphate and sulphur was also sampled. Both species were established on 1 October 1992 using the strip seeding technique. The treatment sampled for this study had 50 kg/ha of both phosphorus and sulphur applied at sowing time. Three spits were dug from this Caucasian clover and white clover trial on 19 April 1993, and root, rhizome, stolon and leaf material measured.

Genstat statistical package was used to analyse data from the paired plot design (Appendix 2).

3.3 RESULTS

3.3.1 Germination and establishment

The strip seeding system was the most successful method for establishment of Caucasian clover with 48% of seeds sown producing seedlings 74 days after sowing. This was followed by the sod seeding treatment (38%), while broadcasting produced comparatively poor results (9%) (Table 3.2). After six months the number of seedlings per meter row counted were the same as the December sampling. In the July sampling however the number of seedlings per meter row length for the sod seeding and strip seeding treatments were reduced by 19% and 23% respectively. The established plants in sod seeding and strip seeding techniques appeared to be very dense within the rows and the intraspecific competition was probably very intense.

Table 3.2 Effect of establishment technique on number of Caucasian clover plants per metre of row over three sampling dates.

Establishment technique	Seedlings per meter row		
	December 1992	March 1993	July 1993
Broadcasting	9	10	5
Sod seeding	38	37	30
Strip seeding	48	48	37
SED	4.44	0.85	2.42
	p<0.001	p<0.046	p<0.001



Plate 3.1 A range of plants found in a broadcast treatment established with 300 kg/ha of molybdic sulphur super sampled on the 12 March 1993 after a 1 October 1992 sowing.



Plate 3.2 The range of plants found in a broadcast treatment established with 300 kg/ha of molybdic sulphur super sampled on the 6 July 1993 after a 1 October 1992 sowing.



Plate 3.3 The above ground comparison and relative establishment between Caucasian clover established by broadcast with 150 kg/ha of molybdic sulphur super and Caucasian clover established by sod seeding with 300kg/ha of molybdic sulphur super taken on the 12 March 1993 after a 1 October 1992 sowing.



Plate 3.4 The above ground comparison and relative establishment between Caucasian clover established by sod seeding with 150 kg/ha of molybdic sulphur super and Caucasian clover established by strip seeding with 300kg/ha of molybdic sulphur super taken on the 12 March 1993 after a 1 October 1992 sowing.

3.3.2 Root and rhizome development

A characteristic of Caucasian clover is its rapid early root development and by March 1993 some taproots from the strip seeding technique had reached more than 700 mm depth. In contrast the broadcast plants had reached only 200 mm depth. At that time, root dry matter to 150 mm of the strip seeding system was more than double that of plants which were sod seeded, and over four times the weight of broadcast plants (Table 3.3). In the July 1993 winter sampling the relative differences between establishment techniques had reduced, with the strip seeding system only 50% greater than the sod seeded which was in turn only 1.6 times the weight of the broadcast root weight (Table 3.3).

Table 3.3 Effect of establishment technique and fertiliser rate on mean root weight (g/plant) to 15 cm depth, in March and July of 1993.

March 1993 Sampling (5 months and 12 days from sowing)					
Fertiliser	Establishment technique				
(kg/ha)	Broadcast	Sod seeding	Strip seeding	Mean	SED
150	0.14	0.28	0.53	0.32	0.055
300	0.16	0.38	0.86	0.46	(p<0.05)
Mean	0.15	0.33	0.69	Interaction	
SED	0.067 (p<0.001)			0.095	N.S.
July 1993 Sampling (9 months and 6 days from sowing)					
Fertiliser	Establishment technique				
(kg/ha)	Broadcast	Sod seeding	Strip seeding	Mean	SED
150	0.45*	0.66	0.77	0.63	0.082
300	0.32*	0.54	1.02	0.63	N.S.
Mean	0.38	0.60	0.90	Interaction	
SED	0.101 (p<0.001)			0.143	N.S.

* These were healthy survivors

There was no effect of fertiliser rate in the July 1993 sampling however in the four months between the March 1993 and the July 1993 samplings the mean root weight for the broadcast, sod seeding and strip seeding techniques established at the 150 kg/ha fertiliser rate increased in weight by 214%, 136% and 45% respectively while those established with the 300 kg/ha rate of fertiliser increased by 103%, 42% and 19% respectively (Table 3.3).

Plate 3.5 shows the increased above ground production from the 300 kg/ha fertiliser treatment compared to the 150 kg/ha fertiliser treatment. This increase in above ground leaf production is directly related to the higher root dry matter seen in the strip seeded treatment established with 300 kg/ha of fertiliser from Table 3.3.



Plate 3.5 The above ground comparison between Caucasian clover established by strip seeding with 150 kg/ha of molybdenic sulphur super (left) and Caucasian clover established by strip seeding with 300kg/ha of molybdenic sulphur super (right) taken on the 12 March 1993 after a 1 October 1992 sowing.

Establishment technique had a significant ($p < 0.001$) effect on taproot diameter, with the plants from the strip seeding technique having 31% greater taproot diameter than the sod seeding technique and 96% greater than the broadcasting technique (Table 3.4).

By July both the strip seeding and the sod seeding techniques increased in diameter at the same rate with the strip seeding technique still being 30% greater than the sod seeding technique. The strip seeding technique however was only 43% greater in the July sampling to the broadcast technique (Table 3.4). Fertiliser rate had no effect on taproot diameter in either the March 1993 and July 1993 sampling.

Table 3.4 The effect of establishment technique and fertiliser rate on mean taproot diameter (mm) per plant from sampling in March 1993 and July 1993.

March 1993 Sampling (6 months from sowing)						
Fertiliser	Establishment technique					
(kg/ha)	Broadcast	Sod seeding	Strip seeding	Mean	SED	
150	2.4	3.4	4.3	3.4	0.20	
300	2.3	3.8	5.1	3.7	N.S.	
Mean	2.4	3.6	4.7	Interaction		
SED	0.24 ($p < 0.001$)		0.34		N.S.	
July 1993 Sampling (10 months from sowing)						
Fertiliser	Establishment technique					
(kg/ha)	Broadcast	Sod seeding	Strip seeding	Mean	SED	
150	4.0	4.0	5.5	4.5	0.37	
300	3.5	4.2	5.2	4.3	N.S.	
Mean	3.7	4.1	5.3	Interaction		
SED	0.303 ($p < 0.001$)		0.53		N.S.	

By March 1993, rhizome development was evident on many plants of the sod seeded and strip seeded treatments although rhizome length and percentage of plants with rhizomes were greater with strip seeded (Table 3.5). By July 1993 all plants in these two treatments had developed rhizomes. Few plants from the broadcast treatment exhibited rhizomes either in March (Table 3.5) or in July. The rhizomes produced by the strip seeding system in March were 5 and 10 times the length of those in the sod seed and broadcast treatment respectively. Even at this early sampling, some rhizomes were 150 mm long in the strip seeded treatments.

The root+rhizome:shoot ratio in the March 1993 was highest in the strip seeding technique at 3.36 which was 7% greater than the plants in the sod seeding technique and 35% greater than the broadcasting technique. Although the effect of establishment technique was significant ($p < 0.001$), fertiliser rate had no effect on root/rhizome to shoot ratio (Table 3.5).

In March 1993 Caucasian clover had produced 10.7 g/DM/m row of top growth using the strip seeding system and 3.7 g/DM/m row for the sod seed technique.

Table 3.5 Effect of establishment technique on percentage plants with rhizomes, average rhizome length (mm), shoot weight (g/meter row) and root+rhizome:shoot ratios, in March 1993.

	----- Establishment technique -----			SED
	Broadcast	Sod seeding	Strip seeding	
Plants with rhizomes (%)	1	43	75	6.50 ($p < 0.001$)
Average rhizome length (mm)	2	4	21	2.26 ($p < 0.001$)
Shoot weight (g/meter row)	2.2	3.7	10.7	1.07 ($p < 0.001$)
Root+rhizome:shoot ratio	2.49	3.15	3.36	0.21 ($p < 0.001$)

There was continued primary rhizome development, in the autumn, between the March 1993 sampling and the July 1993 sampling. By July 1993 some plants in the strip and sod seeding systems had developed secondary branch rhizomes (Table 3.6). Individual rhizomes from both the strip and sod seeding systems were up to 300mm in length, while the widest individual plant spreads were 485 and 405 mm respectively (Table 3.6).

Table 3.6 Effect of establishment technique on the average primary and secondary rhizome length and maximum plant width in July 1993.

	----- Establishment technique -----			
	Broadcast	Sod seeding	Strip seeding	SED
Mean Primary rhizome length (mm) of all plants with rhizomes	8	30	78	5.5 (p<0.001)
Mean Secondary rhizome length (mm) of all secondary rhizomes counted	0	5	32	6.5 (p<0.05)*
Maximum plant spread (mm) [#] of the best plants from each treatment	35	405	485	NA

Plants measured from tip to tip of the two longest rhizomes.

* Statistics are for sod and strip seeding treatments only

Plate 3.6 shows the extensive rhizome development found on plants in the strip seeded establishment technique which included secondary rhizome development (Table 3.6). This compares to the less extensive rhizome development in the sod seeding treatment and absence of secondary rhizomes found on the broadcast plants even though they appeared to be well established •

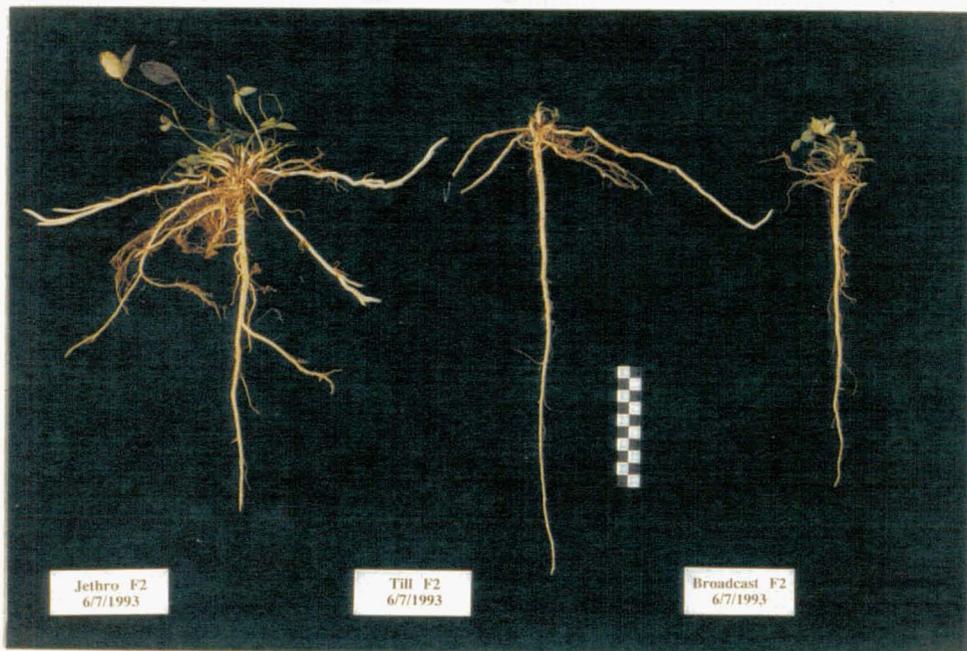


Plate 3.6 Comparison between rhizome development from well established plants in the strip seeded, sod seeded and broadcast treatments respectively, all established with 300 kg/ha of fertiliser and sampled on the 6th of July 1993.

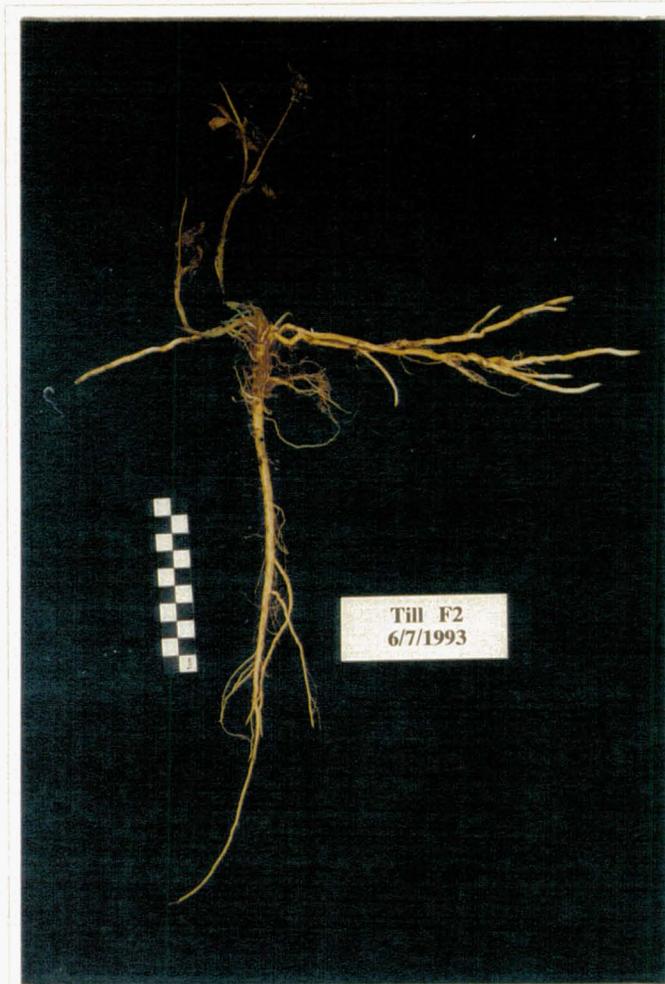


Plate 3.7 Secondary rhizome development on a plant sampled on the 6th of July 1993.

Mean plant width was affected by establishment technique ($p < 0.001$), with plants from the strip seeding technique being 3.2 times wider than plants from the sod seeding technique, and 37 times wider than plants from the broadcasting technique (Table 3.7).

Sampling done in mid spring of 1993, revealed further rhizome growth and development indicating that rhizome extension was not confined to autumn (Moorhead *unpublished*).

Table 3.7 Mean plant width (mm) per plant in July.

Fertiliser (kg/ha)	Establishment technique			Mean	SED
	Broadcast	Sod seeding	Strip seeding		
150	3.5	45.2	154.1	69.0	13.61
300	5.5	54.8	183.3	81.2	N.S.
Mean	4.5	52.1	168.7	Interaction	
SED	16.67 ($p < 0.001$)			23.58	N.S.

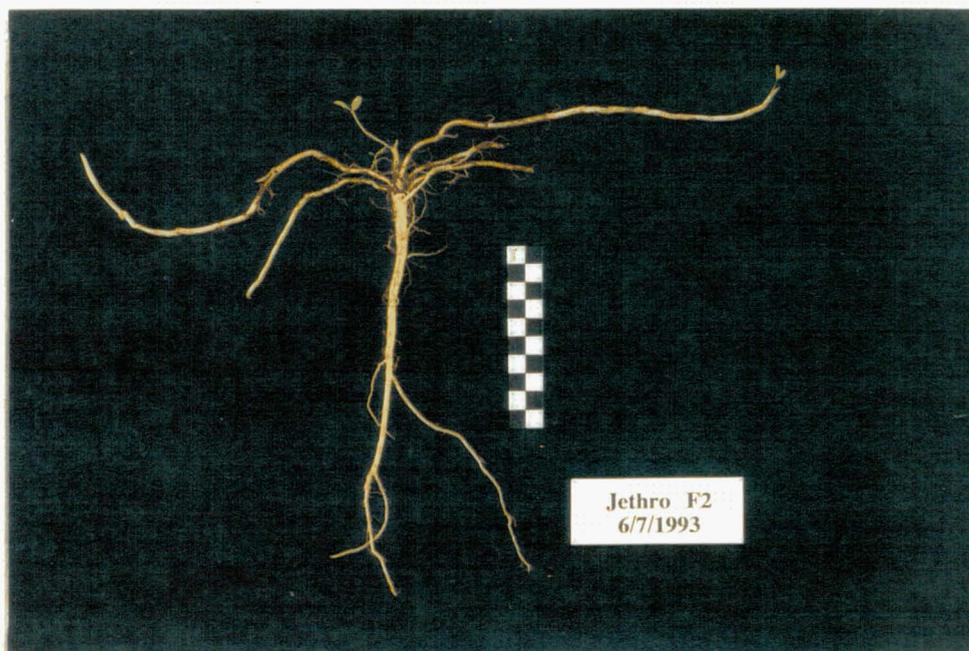


Plate 3.8 Shows an example of a plant with extensive rhizome spread, there is also a developing daughter plant on the longest rhizome on the right.

Aerial stems are defined as stems coming from the crown of the taproot that have grown vertical compared with those that have grown horizontal and underground to become rhizomes. There was a trend for the broadcast treatment to have a higher number of aerial stems than the strip seeding and sod seeding systems (Table 3.8).

Table 3.8 Mean number of aerial stems per plant in July 1993.

Fertiliser (kg/ha)	Establishment technique			Mean	SED
	Broadcast	Sod seeding	Strip seeding		
150	3.1	1.5	1.5	2.0	0.49
300	2.6	2.0	2.3	2.3	N.S.
Mean	2.9	1.7	1.9	Interaction	
SED	0.60 N.S.			0.80	N.S.

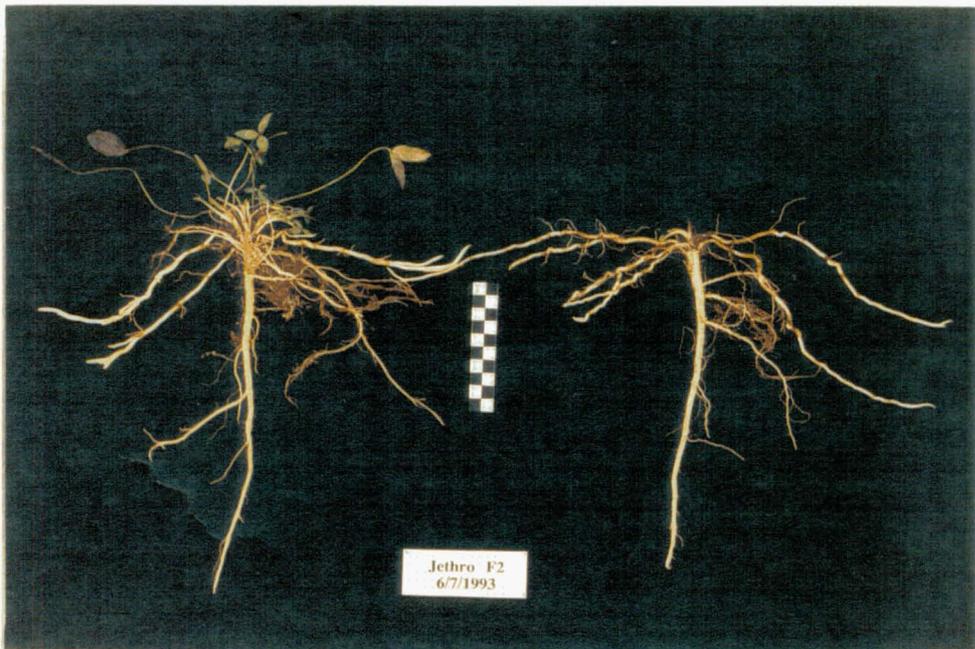


Plate 3.9 Two plants from the same sample and establishment treatment, the plant on the left has many aerial stems while the plant on the right has only one.

3.3.3 Comparison with white clover

Measurements of Caucasian clover and white clover plants drilled with the strip seeder in the adjacent fertiliser experiment showed large differences in their morphology. Individual six month old white clover plants had a higher total leaf DM to Caucasian clover plants; but white clover plants had only half the root DM while its stolons were over five times the weight of Caucasian clover rhizomes (Table 3.9). Caucasian clover had longer tap roots >150 mm compared with 97 mm for white clover. Leaf DM yield was 9.45 g/m row vs 9.54 g/m row for white clover and Caucasian clover respectively (Table 3.9).

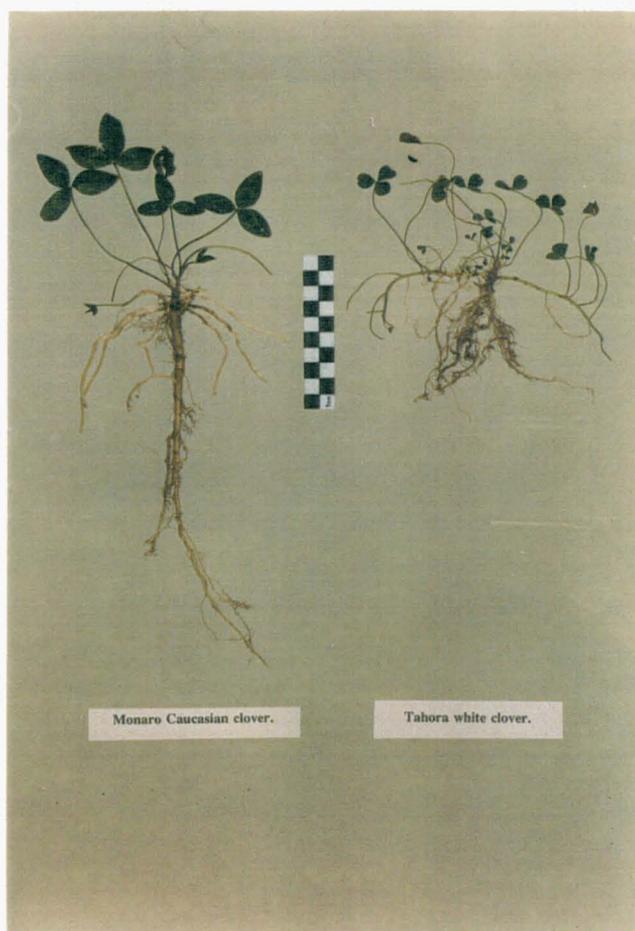


Plate 3.10 Comparison between a Caucasian clover plant left and a white clover right sampled on the 19 April 1993. Both clovers sown on the 1 October 1992, using the same strip seeding technique and 50 kg/ha P and 50 kg/ha S fertiliser rates.

Table 3.9 Comparison of white and Caucasian clover plants on 19 April 1993.

Species	Average plant number /m row	Individual plant DM (g/plant)			Tap root length (mm)	Tap root diameter (mm)	Stolon or rhizome per plant		Leaf number per plant
		Leaf	Root	Stolon or rhizome			Number	Mean Length (mm)	
White	27	0.35	0.31	0.69	97	3.4	6	83	26
Caucasian	53	0.18	0.66	0.13	>150	4.5	3	41	5

3.4 DISCUSSION

3.4.1 Germination and establishment

The success of strip seeding was due to a combination of effects including the physical removal of competing resident vegetation, cultivation to form a narrow seed bed, and placement of fertiliser in a band below the seed. A different micro-climate was also formed by the removal of a ribbon of turf creating a 200 mm deep depression 200 mm across, which would have led to reduced wind run, and higher humidity. All these features would have combined to enhance germination, nodulation and establishment of the seedlings and subsequent growth of roots and rhizomes (Tables 3.2, 3.3, 3.4, 3.5). Similar results with the strip seeder have been achieved with other legume species by Lowther *et al.* (1991) and Woodman (1993).

The sod seed technique was also satisfactory, indicating the importance of seed being placed in the ground close to fertiliser for nodulation, establishment and subsequent growth in this environment. However in drier environments the close proximity of fertiliser may be detrimental (Woodman, *pers.comm.*) and competition from resident vegetation may be more severe.

The poorer establishment from broadcasting can be attributed to a combination of factors but one adverse influence may have been the substantial ground cover of 30% *Hieracium pilosella* leaves which may have resulted in seed landing on the prostrate rosettes rather than bare ground. In addition, both germinating seed and *Rhizobium* are very susceptible to desiccation when on the surface of the soil; this drying effect would have been further aided by lack of litter cover due to burning before sowing. About 80% of the plants from the turfs dug in the broadcast plot in the March 1993 sampling were small and yellow (Plate 3.1). Some of these less vigorous plants were unnodulated while others had small pale nodules which could have been the result of ineffective and/or late nodulation by Caucasian clover rhizobia. Alternatively small white nodules could be the result of nodulation by resident white clover rhizobia which may form ineffective nodules on Caucasian clover (Patrick *et al.* 1993; Ronson *pers.comm.*). It is probable that the most recent recommendation for very heavy inoculation (Patrick *et al.* 1994) would have given better nodulation in the broadcast

situation. However the excellent nodulation of direct drilled plants indicated that there were adequate numbers of rhizobia specific to Caucasian clover present for seed which is placed in soil rather than broadcast on the surface.

The seeding rate used in the experiment was very high, 100 viable seeds sown per meter row length sown by a drill using coulters spaced 150 mm apart would mean that this seeding rate was the equivalent to a 14 kg/ha sowing rate. This depended on there being 6.67 coulters per meter, and 475 000 seeds per kg of the hexaploid Caucasian clover 'Monaro' (Oram, 1990). At this seeding rate and drill spacing, placing 660 seeds per m² the sod seeding and strip seeding techniques would have had a plant population in the July 1993 sampling of 200 and 247 plants per m². The July 1993 sampling showed that some of the best plants had already spread between 405 mm and 485 mm for the sod seeding and strip seeding techniques respectively. Taking into account the potential spreading ability of Caucasian clover the rows could be spaced 500 mm apart using a sowing rate of 2 kg/ha. This would place 50 viable seed per meter row length to give 100 viable seed per m². This would provide enough plants to be productive as well as reduce intraspecific competition within rows which may have benefits such as increasing the number of plants established and increasing the subsequent vegetative spread of these plants. The potential to spread justifies a low seeding rate on areas with low soil density such as high country terraces, where rhizomes appear to spread rapidly. A higher sowing rate would be recommended for broadcasting particularly out of an aeroplane and would depend on soil type, fertility and site conditions such as the amount of plant material on the site and the rainfall in the establishment season.

3.4.2 Root development

The root growth responses in March 1993 (Table 3.4) were presumably due to the same combination of factors which enhanced germination and establishment mentioned earlier; the poorer growth of roots from sod seeding was assumed to be due to competition (Hill & Hoveland 1993) from browntop and *Hieracium*, particularly for nutrients such as phosphate (Jackman & Mouat 1972; Svavarsdóttir *pers. comm.*) while the strip system created a competition free environment for the first months of establishment.

The effect of establishment technique was still vary apparent in the July 1993 sampling compared to the March 1993, but there was no clear effect of the two fertiliser rates in the July sampling (Table 3.3). The rate of increase in root weight per plant was highest in the broadcast treatments with a 60% increase between March and July, while the sod seeding treatment increased by 46% in this period. The strip seeding which has had the heaviest roots per plant at both samplings had the smallest increase with only 23% between March 1993 and July 1993. These responses may indicate that the plants from the strip seeding treatments reached a root dry matter freshold earlier and that carbohydrate partitioning had changed from root development to rhizome development and further increases in root dry matter occur at a lower rate. The sod seeding established plants had not even reached the mean root weights in July 1993 that the strip seeded established plants had reached in the March 1993 sampling, so these plants were still in what could be called a root production or "collection phase" and had a higher rate of increase between March 1993 and July 1993. This same pattern can be seen in the broadcast established plants but at a even earlier stage. The mean root weights of the broadcast established plants were only slightly heavier in the July 1993 sampling than the sod seeded established plants had in the March 1993 sampling. Due to broadcast plants slow initial establishment, they were still at a stage in development where they were increasing at a greater rate than even the sod seeded plants between the March 1993 and July 1993. There was hardly any rhizome development in this broadcast treatment at the July sampling.

It would appear that after an undefined root weight is reached any further increase is made at a much slower rate. This would be possibly due to a change in carbohydrate sink priorities, with more resources being redirected into rhizome extension and vegetative growth.

The mean taproot diameter per plant also exhibited a similar characteristic to that of the root weight. The strip seeded plants again had the largest taproot diameters on both sample dates, and also the lowest rate of increase (11%) in root diameter between the March 1993 and July 1993 sampling. The sod seeded plants also had a low rate of increase (12 %) while the broadcast plants had increased in taproot diameter by 34% between March 1993 and July 1993. This however may be an inflated figure when the plant density and the rate of

plant population decline between the March 1993 and July 1993 (Table 3.2) is taken into account. It is presumed that only the largest broadcast plants survived to the July 1993 sampling. This would be most noticeable in the broadcast treatments as only the more noticeable or larger plants were seen and dug up in the July 1993 sampling.

3.4.3 Rhizome development

The reasons for the excellent rhizome development under the strip seeding system can be attributed to the plants establishing in a 200 mm wide cultivated seedbed free from strong *Hieracium* and browntop root competition, although there was strong intraspecific competition within the rows. The sod seeded plants were subject to both inter and intraspecific competition as individual plants not only received substantial pressure from other Caucasian clover plants along the coulter line, but any sideways growth resulted in strong competition from resident vegetation which formed a very dense root mat.

In the strip seeded established plants mean rhizome length increased between the March 1993 and July 1993 sampling. This can be attributed to the strong early taproot build up that was observed in the March 1993 sampling and would also further indicate that the plants established by this technique had undergone a change in carbohydrate partitioning priorities, with emphasis moving from root development to that of rhizome extension. The advanced stage of these strip seeded plants was further demonstrated by the presence of secondary rhizomes in July (Table 3.6) which had a mean rhizome length greater than that found in the primary rhizomes measured in the sod seeded plants from the same July 1993 sampling. Rhizome development of the sod seeded plants increased between the March 1993 and July 1993 sampling by 87%, however mean primary rhizome length was still only 38% of the rhizome length of the strip seeded established plants (Table 3.6). Rhizome development was hardly present in the broadcast established plants in the July 1993 sampling. This is a strong indicator of a possible "critical" level of root dry matter that maybe needed before carbohydrate partitioning priorities change from root development to rhizome development. It should be noted that the broadcast established plants sampled in July 1993 had 45% less root drymatter than the strip seeded established plants from the March 1993 sampling.

Mean plant width (Table 3.7) followed the same pattern as the mean rhizome length, with the mean plant width of strip seeded established plants being 3.2 times that of the sod seeded established plants and 37 times that of the broadcast established plants. The widest spread was much greater with individual plants having plant widths of 485 and 405 for the strip seeding and sod seeding established plants respectively. Taking into account the spread of a few individual plants established in each square meter there can be a lot of reliance put on clonal spread of Caucasian clover especially when it is well established by techniques such as the strip seeding technique. This means that sowing rates can be lowered especially where the cost of the seed is very high. The key to deciding sowing rate will be to further define the plant numbers that can be reliably established from a given number of seed over a range of environments.

3.4.4 Aerial stems

Broadcast established plants tended to have more aerial stems than strip seeded or sod seeded established plants (Table 3.8). Factors that could have induced this characteristic include the seed not being sown into the ground or below the level of the surface. The plants that established on the surface of the soil had more competition to penetrate the soil while the crown of the developing taproot will be at the surface, as the new rhizomes develop over time they may tend to grow vertically in the direction of least resistance. In the case of the strip seeded and sod seeded established plants their crowns are below the soil surface because of the sowing techniques, and rhizome development will tend to be more horizontal. This however is complicated by genotype effects, there are populations within the Monaro cultivar that have a propensity to produce aerial stems as opposed to rhizomes. Plants with this characteristic may establish better from broadcasting leading to a higher number of plants with this characteristic in the population sampled.

3.4.5 Root/rhizome to shoot ratio

In contrast to many other clovers, Caucasian clover seedlings allocate a much higher proportion of photosynthates to root and rhizome development than growth of leaves (Spencer *et al* 1975). The root plus rhizome:shoot ratios present in the March sampling (Table 3.4) were very similar to those found by Daly & Mason (1987) of 2.73 in cv Prairie, and by Spencer *et al* (1975) who measured ratios of 2.36 and 3.36 in the diploid cv Summit

and a hexaploid ecotype respectively. These ratios emphasise the characteristic strong by Caucasian clover during establishment into root and subsequently rhizome development (Section 3.3.2).

3.4.6 Comparison of Caucasian clover and white clover.

The main difference between Caucasian clover and white clover is in their dry matter partitioning. Caucasian clover, as discussed in section 3.4.2 and 3.4.5 is dominantly focused on the development of the taproot, while white clover is biased towards stolon and leaf production. In the April 1993 sampling the root+rhizome to shoot ratio was 4.4 for Caucasian clover while the root+stolon to shoot ratio for white clover was 2.7. This ratio was taken from one sampling of leaf drymatter nearing the end of the growing season in this environment and has inflated the root+stolon to shoot ratio of the white clover and to a lesser extent Caucasian clover. The shoot production present at this sampling date did not represent the shoot production achieved by these two clovers in the first autumn after establishment as there was a lot of shoot turn over during the autumn and growth rates were much lower at this site in April.

However the Caucasian clover plants had twice the root dry matter of the white clover plants in this environment (Table 3.9) and is a similar result to Spencer and Hely, (1982) which showed that Caucasian clover produced three times the root dry matter of white clover.

The stolon dry matter in white clover was five times greater than for rhizomes in Caucasian clover after six and a half months. These morphological differences between the two clovers emphasises their contrasting growth strategies. White clover produces stolons sooner than Caucasian clover puts out rhizomes, indicating that white clover is a more aggressive coloniser in its juvenile stages. White clover has relatively short lived roots, presence of dormant buds on stolons, storage of mineral nutrients in stolons to boost next seasons production, flowers early in its life history, has high frequency of flowering and a high proportion of annual carbohydrate production being devoted to seed production and the development of a large dormant seed bank. Caucasian clover in comparison devotes the greatest proportion of carbohydrate produced in its first few seasons to developing a large

root and rhizome mass. These growth characteristics enable Caucasian clover to be a very persistent plant once established. The whole aim of Caucasian clover establishment should be to achieve this as rapidly as possible. This research has shown this can be done by sowing seed that is well inoculated with strip seeding to remove competition and sowing seed below ground, with a high fertiliser rate to get it off to a good start.

3.5 CONCLUSIONS

Results of this research showed the importance of good techniques for rapid establishment of Caucasian clover in moist, low fertility, depleted tussock grassland areas.

The most important conclusions which relate to the South Island montane environments are :-

1. The use of either strip or sod seeding will produce large, rhizomatous, well established plants in the first season after spring sowing.
2. The strip and sod seeding establishment techniques are far superior to broadcasting and will produce a higher proportion of nodulated plants from seed sown.
3. Strip seeding will encourage earlier rhizome development and greater root production resulting in faster vegetative spread but sod seeding (which is the most commonly available technology) is also much superior to broadcasting.
4. By using the strip seeding technique Caucasian clover can be established as quickly and successfully as white clover in this environment.
5. High rates (300 kg/ha) of molybdic sulphur super phosphate placed with or under the seed accelerates plant growth and rhizome development and avoids encouraging resident vegetation such as hieracium and browntop.

CHAPTER FOUR

THE EFFECT OF GRAZING FREQUENCY AND INTENSITY ON RHIZOMATOUS CLOVERS

4.1 INTRODUCTION

The continued persistence of Caucasian clover in several hill and high country experiments of up to 20 years of age (Yates, 1993, Lucas et al. unpublished), has led to this species being considered in areas beyond rangeland. The future of Caucasian clover may be in the more intensive farm types, such as sheep production on the foot hills of Canterbury and dry land plains and dairying on border dyked irrigated farms. In these farming systems Caucasian clover will be competing in pastures with grasses such as ryegrass, cocksfoot, grazing brome and tall fescue, while legumes currently used that will also be competing with and/or complementing Caucasian clover are white, red and sub clovers. In these situations Caucasian clover may be subjected to a wide range of grazing managements many of which will not be conducive to legume persistence. There is no information in New Zealand or overseas on the effects of frequency and intensity of grazing, on the botanical composition of ryegrass white clover pastures containing established rhizomatous clovers.

The aim of this experiment was to observe how two cultivars of Caucasian clover and two seed lines of zig zag clover responded to four diverse grazing treatments.

4.2 MATERIALS AND METHODS

4.2.1 Site Description:

The experiment was located in the south west corner of Block D2 of the Plant Science Department Research Area at Lincoln University, 20 km from Christchurch at latitude 43° 39S and longitude 172° 28E.

The soils are Templeton fine sandy loam of variable depth. The A horizon of fine sandy loam is found to 30cm depth, the B horizon is mostly a loamy sand and sand texture ranging from 30cm to 70cm depth. The 2C horizon starts at 70cm where there is some mottling, gravels are found from 80cm depth. These soils are medium- to free- draining with a moderate water holding capacity. The soil fertility is moderate with soil quick-test analysis of samples taken on the 22 September 1993 showing that phosphorus (P) and magnesium (Mg) levels were satisfactory, while pH, sulphur (S), calcium (Ca), potassium (K) and sodium (Na) levels were low (Table 4.1). No fertiliser was applied to the trial area during the experiment described here.

Table 4.1 Soil pH and nutrient quick-test in rep 1 and 2 of the grazing trial prior to the start of the grazing treatments in October 1993.

Rep	pH	Ca	K	P	Mg	Na	S
1	5.4	5	4	17	16	4	3
2	5.3	6	4	14	17	4	4
Ideal Levels for Pasture Production							
	5.8-6.0	5-10	5-8	20-25	8-10	5-20	10-12

The annual mean rainfall for Lincoln is 651mm. The rainfall distribution for the 1992/93 and 1993/94 seasons shown in Table 4.2. The annual mean total Penman evaporation is 1070mm with 92 dry soil days per year (Table 4.2). The mean temperature in 1992/93 was 10.6 °C while, over the sampling season of 1993/94, it was 11.4 °C. These annual temperatures are similar to the annual mean which is 10.8 °C (Table 3). The mean soil temperature at 10 cm depth shown in Table 4.3 was 9.5 °C and 11.1 °C for the 1992/93 and

1993/94 seasons respectively, the 1992/93 yearly mean soil temperature was much lower than the long term annual mean of 10.7 °C.

Table 4.2 Annual and seasonal rainfall, Penman evaporation and dry soil days for Lincoln in 1992/93 and 1993/94.

Measurements	Year	-----Seasonal distribution-----				Yearly Total	Mean Total
		Winter	Spring	Summer	Autumn		
Rainfall (mm)	1992/93	286	201	188	190	865	651
Penman Evaporation (mm)		130	239	363	180	912	1070
Dry Soils Days		0	0	32	18	50	92
Rainfall (mm)	1993/94	65	195	113	146	519	651
Penman Evaporation (mm)		103	251	375	186	915	1070
Dry Soils Days		0	21	64	27	112	92

Table 4.3 Mean seasonal air temperatures and soil temperatures to 10 cm soil depth at Lincoln for 1992/93 and 1993/94 seasons.

Measurement	Year	-----Seasonal distribution-----				Yearly mean	Annual mean
		Winter	Spring	Summer	Autumn		
Mean Air Temperature (°C)	1992/93	6	10.5	14.8	11.1	10.6	10.8
Mean soil temperature °C (10cm)		2.7	8.7	14.5	9.3	8.8	10.7
Mean Air Temperature (°C)	1993/94	6.8	10.8	16.6	11.5	11.4	10.8
Mean soil temperature °C (10cm)		4.1	11.2	18	11.1	11.1	10.7

4.2.2 Site History

This experiment was established on 22 March 1989 as a rhizomatous clover seed production experiment (Gurung, 1991). It consisted of two cultivars/ seed lines from each of the two species, Caucasian clover cultivars Alpine and Monaro and zig zag clover seed-lines Porters Pass and Kentucky.

Caucasian clover cultivars have been fully described in Chapter 1, the Caucasian clover cv. 'Alpine' is a diploid cultivar registered in 1983 (Oram, 1990). Caucasian clover cv. 'Monaro' is a hexaploid cultivar registered in 1983, and was more vigorous than any other Caucasian clover cultivar registered at that time (Oram, 1990).

Zig zag clover (*T. medium*) is a taprooted, rhizomatous perennial clover with a similar growth habit to Caucasian clover, the main difference however is that the vegetative growing points of zig zag clover are above ground and may be more sensitive to grazing. Zig zag clover is a hay type of clover suited to old permanent hay pasture, while having similar grazing requirements to red clover (*Trifolium pratense*) (Grime et. al. 1990).

Seeds were sown by cone seeder at 1 cm spacing (100 seeds/m row). The initial experimental design was a randomised block design with three replicates. There were three blocks; each block was considered as one replicate which comprised four plots. Each plot was 80 m x 3.75m (including a 0.75 m gap between each plot) in size and consisted of four rows 0.75m apart.

In the spring of 1992 Marsden high endophyte hybrid ryegrass (*Lolium boucheanum* Kunth Syn. *L. hybridum*) was direct drilled parallel to the rows of rhizomatous clovers. Volunteer Huia white clover (*T. repens*) was abundant throughout the site, this being the main reason for the site not being used for seed production experiments. Red clover (*T. pratense*) plants were also common.

The area was laxly rotationally grazed by sheep once the ryegrass was established from the summer of 1992/93 until July/August of 1993. The mainplot fences for this experiment were erected in September 1993 and the first grazings to establish the mainplot treatments occurred in early October 1993.



Plate 4.1 Caucasian clover cultivar Monaro on 7 April 1994, spreading through high endophyte ryegrass.



Plate 4.2 Caucasian clover cultivar Alpine on 7 April 1994.



Plate 4.3 Zig zag clover seed line Kentucky on 7 April 1994.



Plate 4.4 Zig zag clover seed line Porters Pass on 7 April 1994

4.2.3 Experimental design

The experimental design for the grazing treatments was a randomised block design with two replicates, two factors each at two levels to give four treatments. The two grazing frequency levels were, achieved through set stocking and rotationally grazing. The two levels of grazing intensity were hard and lax. The aim was to maintain the hard set stock pasture mass at between 700 and 800 kg/ha and the lax set stocking at around 1800 kg/ha. The pre-grazing herbage masses for the lax rotationally grazed pastures was aimed to be between 3000-3500 kg/ha with post-grazing mass residuals of 1800-2000 kg/ha. The grazing management of the hard rotationally grazed pastures aimed to have pre-grazing herbage masses of 1800-2000 kg/ha and 700-800 kg/ha residuals.

To achieve this experimental design and to have the most suitable gate placement for ease of stock movement, treatments were fenced east to west across the original three reps of the seed production experiment. This created 8 mainplots each 10m x 45m that had 3 subplots of each of the cultivar/seedlines within each mainplot (Plate 4.5, 4.6, Appendix 4). The subplot level was a strip plot design rather than a split plot design because the sub plots were not independently randomised within each main plot.

Analysis of variance was determined using Genstat 5.2 statistical package. The analysis provided tables of means for effects of grazing and species cultivar/seedline treatments and treatment x species interactions. It identified significant results and produced a standard error of the difference for treatment, species and interaction results. The analysis of variance also provided contrasts between species, and between hard versus lax and rotational grazing versus set stocking (Appendix 5).



Plate 4.5 Over-veiw of the experimental design taken on the 21 November 1993 just after the sheep were added to graze the rotationally grazed treatments.



Plate 4.6 The experimental site after the grazing of the rotationally grazed treatments. The sheep grazing set stock treatments can still be seen.

4.2.4 Grazing protocol

Grazing of the rotational grazed treatments occurred approximately every 28 days, and lasted for up to four days. The set stocked treatment employed a grazing timetable of five days on and three days off for the hard set stock and three days on and five days off for the lax set stock. In each rep 3 or 4 sheep would spend five days on the set stock hard treatment and in turn three days on the set stock lax treatment.

4.2.5 Pasture masses and grazing measurements

Pre-grazing measurements consisted of pasture heights using a sward stick, where the reading was taken when 5 leaves touched the perspex plate. Two pre-grazing pasture mass cuts of 0.2 m² were taken from mean pasture height positions per main plot using hand clippers. Two cuts of 0.2 m² and pasture heights were carried out on the residuals of the rotationally grazed plots. Because the set stocked treatments were maintained at a set pasture mass (Plates 4.7,4.8), post grazing cuts were not applicable but current pasture mass was measured when pre-grazing cuts were taken from the rotationally grazed plots.

The pre and post grazing measurements from the rotational grazed treatments provided a measurement of utilisation of pasture on offer for each of rotational graze treatments. The utilisation of pasture on offer was calculated by the following calculation;

$$\text{Postgrazing DM} / \text{Pregrazing DM} \times 100/1 = \% \text{ utilisation.}$$

4.2.6 Botanical composition

Point analysis was used to measure the botanical composition of the pastures to the grazing treatments. A board 80 cm long with 20 nails in it was placed at 90° across each sown row of rhizomatous clovers, along a transect line up the middle of each mainplot. Each nail was viewed from directly above and the pasture component below the nail point was recorded. Point analysis was carried out 14 days after rotational grazing on both of the rotationally grazed treatments. The set stocked treatments were also measured at the same time as the rotationally grazed treatments, with 80 points recorded for each of the four row subplots. This gave a total of 240 points per cultivar/seedline in each mainplot and a total of 960 points in each treatment mainplot.

4.3 Results

4.3.1 Pasture management and sward development

The number of grazing days per plot were similar between reps for each treatment over five grazings (Table 4.4). The set stock lax and rotational graze lax treatments had a similar number of grazing days, while the greater difference between the set stock hard and rotational graze hard grazing treatments was more due to the fact, that the rotational grazed hard treatment was grazed with mobs of 30 to 40 hoggets at a time. When trying to maintain a very low residual on the rotational graze hard treatment it was sometimes necessary to keep the hoggets on the treatment an extra day to achieve the desired post-grazing mass but in fact very little dry matter would be grazed during that time, however this did increase the grazing days substantially.

Table 4.4 Total grazing days for each of the grazing treatments recorded from the start of the grazing treatments on 11 October 1993 to 22 April 1994.

	Grazing days per treatment (11/10/93 - 22/04/94)			
	Set stock hard	Set stock lax	Rotational graze hard	Rotational graze lax
Rep1	478	325	723	377
Rep2	452	330	692	349
Mean	465	327.5	707.5	363

Although there was a similar pattern of utilisation of the pasture in the lax rotationally grazed treatment the actual utilisation varied between replicates. The lowest pasture utilisation occurred in January when the pasture dry matter and the reproductive stem was at a high. The utilisation between replicates in the hard rotational graze treatment was very similar, remaining between 76 and 91% utilisation between November and April.

Table 4.5 Rotational grazing treatments pasture utilisation from 25/11/93 to 7/4/94

Grazing Treatment	Grazing Utilisation (%)									
	25/11/93		22/12/93		20/1/94		23/02/94		07/04/94	
	rep1	rep2	rep1	rep2	rep1	rep2	rep1	rep2	rep1	rep2
Rotational graze hard mean	84	87	84	80	78	78	81	76	91	90
	85.5		82		78		78.5		90.5	
Rotational graze lax mean	49	42	20	48	17	20	30	44	47	33
	45.5		34		18.5		35		40	

The pastures took time to develop into the type of swards that were desired to achieve the aim of testing the clovers under extreme grazing managements. Table 4.6 shows that the pregraze herbage dry matters peaked in late February and April for the rotational graze hard and lax treatments at 1945 and 2088 kg/DM/ha and 3428 and 2948 kg/DM/ha respectively. The highest dry matters for the set stock hard and the set stock lax occurred in January and February at 813 and 745 kg/DM/ha and 1973 and 2080 kg/DM/ha respectively (Table 4.6).

Table 4.6 Pre- and post- grazing dry matter (kg/DM/ha) for each of the grazing treatments from 25/11/93 to 12/4/94.

Timing of pasture cuts	Date of cut	Days between grazing	Pasture dry matters for each grazing treatment			
			Set stock hard	Set stock lax	Rotational graze hard	Rotational graze lax
Pregrazing	25/11/93	(1/10/93) 26	725	1129	1481	2250
Postgrazing	01/12/93		-	-	515	1219
Pregrazing	22/12/93	21	729	1593	1290	2474
Postgrazing	26/12/93		-	-	529	1611
Pregrazing	20/01/94	28	813	1973	1678	2810
Postgrazing	27/01/94		-	-	662	2293
Pregrazing	23/02/94	28	745	2080	1945	3428
Postgrazing	27/02/94		-	-	726	2142
Pregrazing	07/04/94	34	744	1198	2088	2948
Postgrazing	12/04/94		-	-	506	1732
Pregrazing	Means	27	751	1595	1696	2782
Postgrazing	Means		-	-	588	1799

Pre grazing pasture heights in the lax treatments peaked in late December as reproductive elongation was at its highest (Figure 4.3.1), while in the hard grazed treatments all reproductive growth was removed. This meant that the pregrazing pasture height in the hard rotational grazed treatment showed little variation, ranging between 22 cm in November and 17 cm in February. The removal of the reproductive stems in the hard grazed treatments meant that the development of a dead component in those swards was greatly reduced.

Figure 4.3.1 Pasture heights for the set stock treatments and pre and post grazing for the rotational graze treatments.

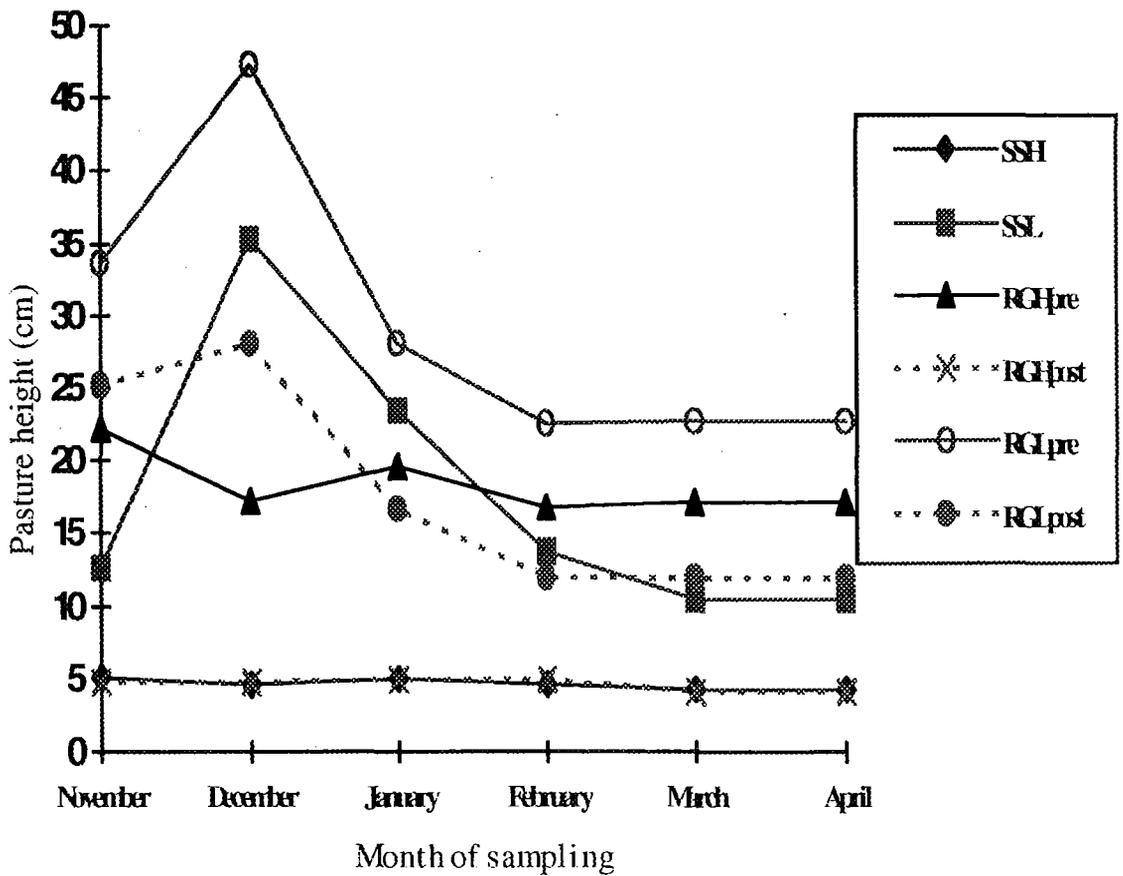




Plate 4.7 Shows the comparison between a lax rotational graze treatment pre-grazing (left) and a hard set stock treatment (right) on 25 November 1993.



Plate 4.8 Shows the comparison between a lax rotational graze treatment post-grazing (left) and a hard set stock treatment (right) on 30 November 1993.



Plate 4.9 Shows the comparison between a lax rotational graze treatment pre-grazing (right) and a hard set stock treatment (left) on 7 April 1994.



Plate 4.10 Shows the comparison between a lax rotational graze treatment post-grazing (left) and a hard set stock treatment (right) on 12 April 1994.



Plate 4.11 Shows the comparison between a hard rotational graze treatment pre-grazing (left) and a lax set stock treatment (right) on 25 November 1993.

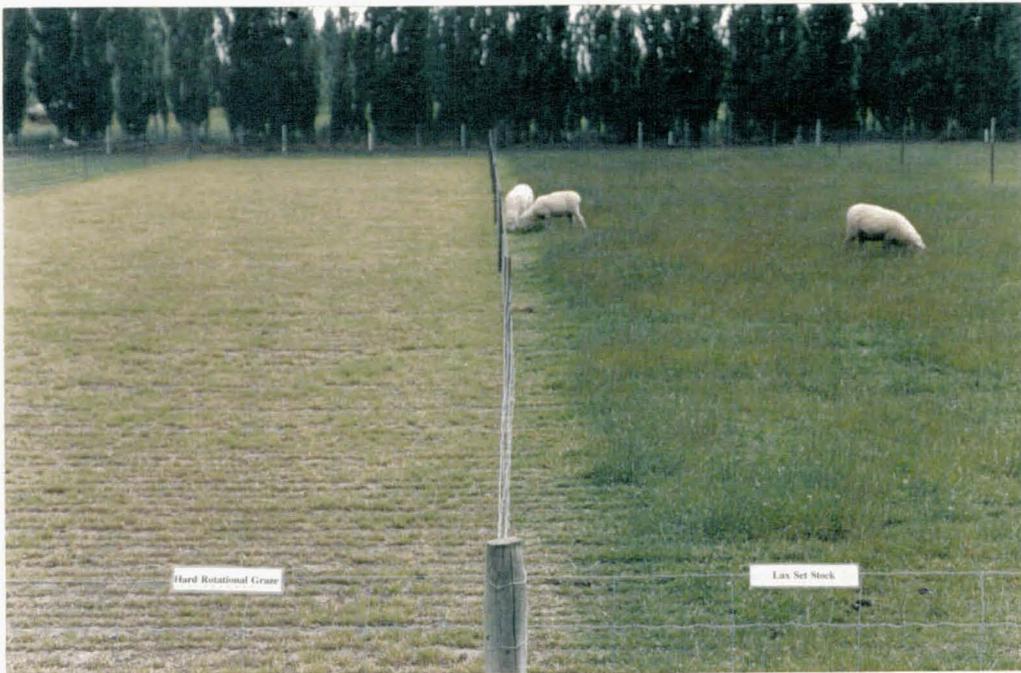


Plate 4.12 Shows the comparison between a hard rotational graze treatment post-grazing (left) and lax set stock treatment (right) on 30 November 1993.

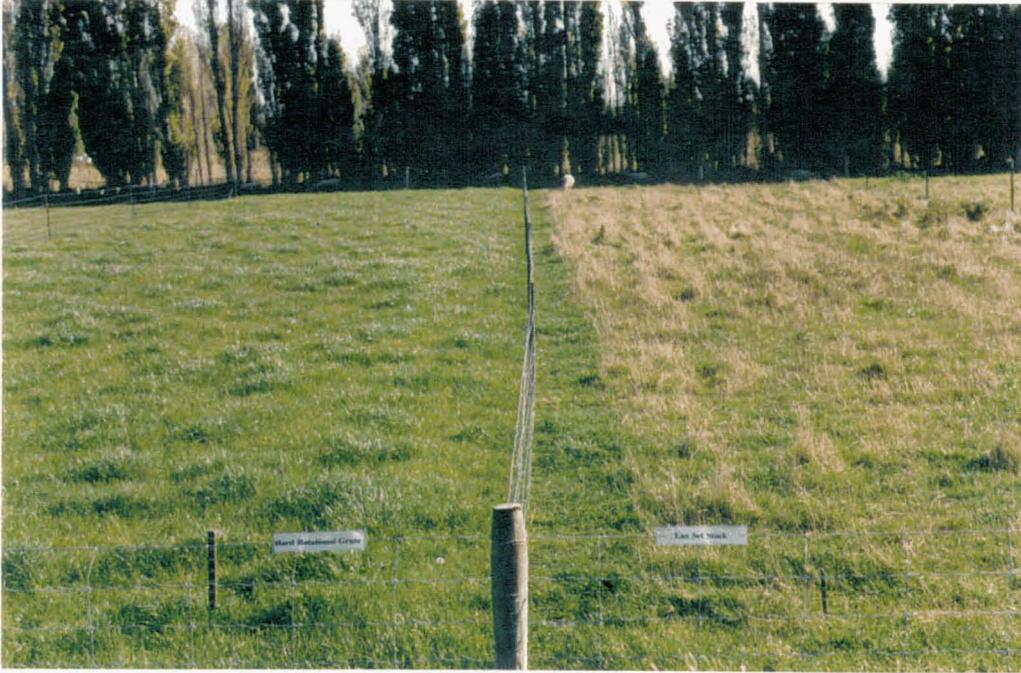


Plate 4.13 Shows the comparison between a hard rotational graze treatment pre-grazing (left) and a lax set stock treatment (right) on 7 April 1994.



Plate 4.14 Shows the comparison between a hard rotational graze treatment post-grazing (left) and a lax set stock treatment (right) on 12 April 1994.

4.3.2 Botanical composition

Grazing treatment had a major effect on the botanical composition of the pasture. There were significant differences in the grass content between the grazing treatments in November, February, March and April 1993/94 (Table 4.7, Appendix 6). Grazing frequency had a significant effect on grass content in February and March while grazing intensity had an significant effect on grass content in November, February and April, however there were no significant interactions. The species of rhizomatous clover also had a significant effect on grass content in December, February, March and April (Table 4.8, Appendix 6). This was mainly attributable to the under ground biomass of Monaro Caucasian clover and the competitive effect this may have on ryegrass.

Table 4.7 The effect of grazing treatments on grass cover (%) across the rhizomatous clover plots and the P values for main effects, contrasts and interactions.

Grazing Treatment	Grass cover (%)					
	November	December	January	February	March	April
SSH	59	59	65	54	56	55
SSL	69	59	76	61	61	68
RGH	66	58	74	65	65	55
RGL	68	69	76	66	65	71
Treatment p values	0.048*	0.188	0.203	0.026	0.030	0.022
significant contrast						
SS vs RG p values	0.091	0.296	0.257	0.012	0.013	0.371
Hard vs Lax	0.034	0.126	0.105	0.047	0.088	0.006
Interaction	0.058	0.165	0.311	0.138	0.092	0.403
SED	2.1	4.0	4.4	2.0	2.8	2.0

* The bolding indicates significance

Table 4.8 The effect of rhizomatous clovers on the grass cover (%) taken across the rhizomatous clover plots and p values for main effects contrasts and interaction.

Rhizomatous clover	grass cover in rhizomatous clover plots (%)					
	November	December	January	February	March	April
Monaro	61	58	69	59	59	58
Alpine	66	60	73	60	60	63
Kentucky	66	64	75	66	65	64
Porters pass	68	63	75	64	64	65
Clover line p values	0.116	0.020	0.880	0.059	0.181	0.046
significant contrasts p values						
Caucasian vs zig zag	0.078	0.006	0.065	0.028	0.043	0.018
SED	2.4	1.4	2.9	2.0	2.4	2.2

There was an interaction between grazing frequency and grazing intensity on the white clover component of the pasture in February, March and April (Table 4.9). There were significant treatment effects in all three of these months with grazing frequency also having a significant effect on white clover content in January as well (Table 4.9). The set stock hard had consistently the highest proportion of white clover present particularly between December and April at between 19 and 25% white clover compared with set stock lax which reduced from 23 and 6% between December and April. The rotational grazed treatments varied very little with both the hard and the lax ranging between 16 and 5% from November to April (Table 4.9, Appendix 8).

Table 4.9 The effect of grazing treatment on the mean cover of white clover (%) taken across all the rhizomatous clover subplots and p values for main effects, contrasts and interactions.

Grazing Treatment	White clover cover (%)					
	November	December	January	February	March	April
SSH	13	21	20	25	23	19
SSL	13	23	15	8	9	6
RGH	9	15	8	11	6	5
RGL	10	16	10	10	6	5
Treatment p values	0.189	0.177	0.079	0.002	0.001	0.012
significant contrasts	p values					
SS vs RG	0.062	0.055	0.028	0.006	0.001	0.011
Hard vs Lax	0.655	0.530	0.449	0.001	0.001	0.021
Interaction	0.525	0.931	0.197	0.002	0.001	0.017
SED	1.6	2.8	2.9	1.1	0.5	2.0

There was a rhizomatous clover line effect on white clover content within the rhizomatous clover plots from December to February (Table 4.10). There was a significant difference between Caucasian clover and zig zag clovers in December. The contrast deviations were significantly different from December to February. The significant deviations indicates that the white clover within one of the Caucasian clover or zig zag clover lines was different from the other within that species. Monaro Caucasian clover had a significantly lower amount of white clover within its plots in December, January and February (Table 4.10, Appendix 8).

Table 4.10 The effect of rhizomatous clovers on the mean white clover cover (%) taken across all the rhizomatous clover subplots plots and p values for main effects, contrasts.

Clover Line	White clover cover (%) in rhizomatous clover subplots.					
	November	December	January	February	March	April
Monaro	8	15	8	9	9	6
Alpine	13	20	15	15	13	10
Kentucky	14	21	14	14	11	10
Porters Pass	11	20	14	15	11	9
Clover line p values	0.056	0.003	0.012	0.035	0.370	0.468
significant contrasts	p values					
Caucasian vs zig zag	0.118	0.007	0.077	0.138	0.804	0.659
Deviations	0.051	0.004	0.009	0.027	0.236	0.330
SED	1.6	1.0	1.6	1.9	2.4	2.0

There was a significant difference between rhizomatous clover lines in all six sampling periods. There was also a significant contrast between Caucasian clover and zig zag clover in six sampling periods, this being due to Monaro Caucasian clover being present at between 3.6 and 2.2 times that of Alpine, Kentucky or Porters Pass clovers (Table 4.11, Appendix7).

Table 4.11 The mean cover (%) of individual cultivars/seedlines of rhizomatous clovers over all mainplots between November and April and p values for main effects, contrasts.

Clover Line	Cover of rhizomatous clovers (%) .					
	November	December	January	February	March	April
Monaro	21	18	18	16	15	11
Alpine	8	8	5	6	5	4
Kentucky	6	5	4	3	1	1
Porters Pass	9	8	5	5	4	3
Clover line p values	0.001	0.001	0.002	0.001	0.001	0.001
significant contrasts	p values					
Caucasian vs zig zag	0.001	0.003	0.004	0.001	0.001	0.001
Deviations	0.001	0.002	0.003	0.061	0.001	0.002
SED	1.3	1.8	1.7	1.2	0.9	0.9

There was an interaction between grazing frequency (SS vs RG) and grazing intensity (Hard vs Lax) on rhizomatous clover content in November (Table 4.12). There were grazing treatment effects in November and March and contrasts between set stocking and rotational grazing in November and March (Table 4.12). There was an interaction between frequency (SS vs RG) of grazing and intensity (Hard vs Lax) of grazing on Monaro Caucasian clover in April. Monaro content was affected by frequency of grazing in November, March, and

April and was affected by intensity of grazing in March and April all cases lead to a higher clover cover in the Monaro plots (Table 4.12, Appendix 7).

Table 4.12 The effect of grazing treatment on mean rhizomatous clover cover (%) and the effect of grazing treatment on Monaro Caucasian clover over the sampling period (November-April) and p values for main effects, contrasts and interaction.

Grazing Treatment	Rhizomatous clover cover (%)					
	November	December	January	February	March	April
SSH	8	8	6	6	5	4
SSL	9	9	6	6	4	4
RGH	14	13	10	10	9	6
RGL	13	10	9	8	6	5
Treatment p values	0.001	0.104	0.304	0.209	0.043	0.117
significant contrasts p values						
SS vs RG	0.001	0.056	0.104	0.098	0.018	0.094
Interaction	0.023	0.085	0.906	0.437	0.294	0.147
SED	0.3	1.4	2.0	1.5	0.9	0.8
	Monaro Caucasian clover cover (%)					
SSH	16	14	15	15	13	13
SSL	16	19	13	13	11	11
RGH	26	21	23	23	21	15
RGL	23	18	20	15	14	9
p values						
Treatment	0.032	0.432	0.337	0.127	0.012	0.015
SS vs RG	0.010	0.347	0.126	0.077	0.008	0.001
Hard vs Lax	0.251	0.972	0.479	0.113	0.013	0.006
Interaction	0.251	0.214	1.000	0.329	0.061	0.024
SED	2.0	3.8	4.8	2.8	1.3	0.9

Table 4.13 shows the effect of grazing treatments on Monaro Caucasian clover and white clover content of the pastures. The white clover data presented is the mean of three plots per treatment (white clover measured within the Alpine, Kentucky, and Porters Pass plots) which in combination with the Monaro Caucasian clover plots went towards the analysis of variance. There was an interaction between grazing frequency (SS vs RG) and grazing intensity (Hard vs Lax) on Monaro Caucasian clover and white clover content in February, March and April (Table 4.13, Appendix 7). There was a difference between Monaro Caucasian clover and white clover in November and December. Both the treatment by species contrast and the frequency by Monaro vs white clover contrasts were highly significant from November to April with Monaro having a higher clover cover than white

clover under rotational grazing. There was also a highly significant interaction by Monaro vs white clover effect in February, March and April.

Table 4.13 The effect of grazing treatment on the comparison between Monaro Caucasian clover cover (%) and white clover cover (%) and p values for main effects, contrasts and interactions between November 1993 and April 1994.

Grazing Treatment	Monaro Caucasian clover vs White clover cover											
	November		December		January		February		March		April	
	Monaro	white clover	Monaro	white clover	Monaro	white clover	Monaro	white clover	Monaro	white clover	Monaro	white clover
SSH	17	14	14	31	16	21	15	27	13	22	13	20
SSL	17	14	19	24	13	16	13	8	11	9	11	6
RGH	27	9	22	17	23	9	22	13	21	8	15	5
RGL	23	12	17	18	20	12	15	12	14	8	8	6
p values												
Frequency	0.646		0.098		0.111		0.010		0.004		0.010	
Intensity	0.904		0.781		0.420		0.001		0.002		0.010	
Interaction	0.719		0.826		0.226		0.001		0.005		0.016	
SED	2.0		2.3		2.9		0.5		0.8		1.41	
Monaro vs w/c	0.001		0.049		0.111		0.405		0.210		0.254	
SED	1.0		1.3		2.1		1.9		2.6		2.3	
Treatment. spp.	0.001		0.042		0.001		0.001		0.001		0.001	
Frequency. Monaro vs w/c	0.001		0.001		0.001		0.001		0.001		0.001	
Interaction. Monaro vs w/c	0.130		0.057		0.139		0.001		0.001		0.001	
SED	2.9		3.5		4.1		3.0		3.5		3.2	

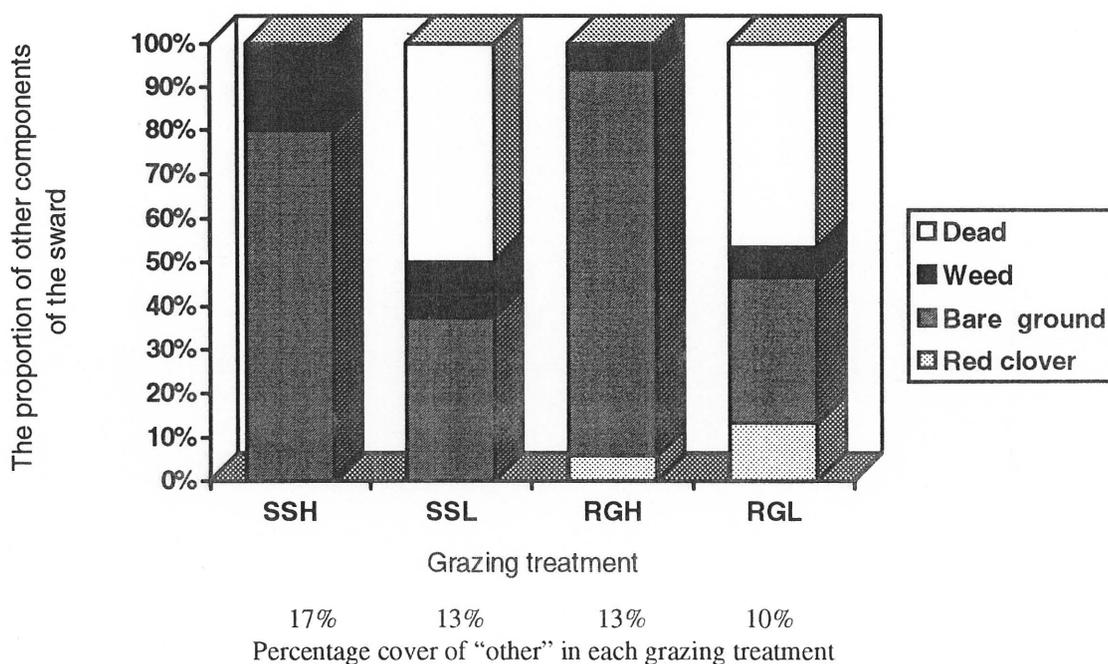
Table 4.14 indicates the mean composition of the pastures created in the four grazing treatments within the Monaro plots and shows the legume content of both Monaro Caucasian clover and white clover over the six sampling periods. The mean legume content of the treatments was very similar across all four grazing treatments with rotational graze hard and rotational graze lax being the highest and lowest with 28% and 22% respectively with set stock hard and set stock lax treatments having a mean legume content of 30% and 25% respectively (Appendix 9 and 10).

Table 4.14 Mean pasture composition of each of the grazing treatments over the six sampling periods between November and April within the Monaro Caucasian clover plots.

Pasture Composition	Grazing Treatment			
	Set Stock Hard	Set Stock Lax	Rotational Grazing Hard	Rotational Grazing Lax
Grass	53%	62%	59%	68%
Monaro	14%	14%	21%	17%
White clover	16%	11%	7%	5%
Other	17%	13%	13%	10%
Mean Legume	30%	25%	28%	22%

The “other” component of the pastures was made up of bare ground, dead material, weed and red clover. Bareground made up over 80% of the “other” component of the pasture in the set stock hard and rotational graze hard but only 38% and 29% in the set stock lax and the rotational graze lax grazed treatments respectively (Figure 4.3.2). In the lax treatments around 50% of the “other” component of the sward was made up of dead material. Weed was highest in the set stock treatments at 20 and 12% for the hard and lax set stock treatments respectively and lowest for the rotational graze hard and rotational graze lax treatments with 6 and 7% respectively. Red clover was only present in the rotational graze hard and rotational graze lax treatments in very low amounts making up 6 and 14% the “other” components respectively.

Figure 4.3.2 The relative cover composition of the “Other” proportion of the sward.



4.4 DISCUSSION

This chapter describes the first year of results from a long term grazing trial. The treatments imposed resulted in rapid changes in sward structure and composition .

4.4.1 Pasture characteristics of grazing treatments

The set stock hard grazing treatment had the lowest proportion of ryegrass. This was most apparent in November, February, March and April. The morphology of the ryegrass under the set stock hard grazing treatment was the most different (Table 4.7). The grazing protocol required the set stock hard treatment to be maintained at as close to 5 cm as possible. This produced densely tillered ryegrass plants that stayed in clear drill rows, maintaining leaf area through having a high tiller density but allowing a lot of space for secondary pasture species such as the clover and flat weeds. The set stock lax treatment was also densely tillered although more bulky than the set stock hard treatment. The rotational graze hard treatment was the easiest to maintain as the growth on offer to the sheep pregrazing was always of a high quality with insignificant amounts of dead material present. Grazing in this treatment was just as severe as the set stock hard treatment, however because the 28 day rotation allowed the pasture to build up to an average 1700-1800 kg/DM/ha the sheep took up to four days to graze the pasture down to 5 cm. The ryegrass in this treatment was very much more upright, with fewer tillers, creating a lot of open space post grazing between drill rows which were clearly visible. The rotational graze lax treatment had a lot of drymatter present pregrazing through the season (Table 4.6) this meant the ryegrass plants present were tall and the ryegrass cover was the highest of the grazing treatments throughout the season.

The ryegrass was at its lowest proportion in the sward in the Monaro Caucasian clover plots through out the season. This was most noticeable in December and April, however as a species Caucasian clover had a lower proportion of grass in its plots in December, February, March and April compared with the zig zag clover (Table 4.8). The underground mass of Monaro Caucasian clover was such that the drill rows of Monaro were visibly raised, this under ground mass looked to have prevented the direct drilled ryegrass establishing in a number of patches in each plot, this would not have been helped by a high grass grub

population present not long after the establishment of the ryegrass. While this is an experiment where Caucasian clover is grown in a lowland medium fertility site with a strongly competitive grass the establishment of both clovers and ryegrass was not done conventionally. The clovers being established in wide rows and the ryegrass being direct drilled into them 2 years latter.

4.4.2 Performance of rhizomatous clovers

Both the zig zag clovers had very poor persistence under all of the grazing treatments including the rotational graze lax treatment which would tend to suit a plant with hay type morphological characteristics (Grime *et.al.* 1990). The diploid Caucasian clover cultivar Alpine appeared to be just as weak in presence as the zig zag clovers from the point analysis results, however it was a lot more persistent under all the grazing treatments. Alpine did have a lot more plants visible than the zig zag clovers, however they were of small diameter and not present in great numbers along the transect lines.

The hexaploid Caucasian clover, Monaro was the most successful rhizomatous clover under grazing in this trial. This is a similar result to that described by Allan and Keoghan (1994) who found Monaro Caucasian clover to be persistent over a range of grazing treatments in low fertility rangeland. This is the first time however the rhizomatous clovers have been tested under a range of grazing managements with a highly competitive high endophyte ryegrass. Table 4.12 showed Monaro Caucasian clover was not only far superior to the other three rhizomatous clovers lines but it was also able to maintain a high clover content across all four grazing treatments in the pasture of 15% or greater in five out of the six months. The lower April sampling would represent Caucasian clovers growth tailing off as temperatures and photoperiod were reducing in mid autumn this is as expected for a winter dormant species such as Caucasian clover.

4.4.3 Pasture composition of white clover

The interaction between grazing intensity (Hard vs Lax) and grazing frequency (SS vs RG) in February, March and April on white clover content in the pasture was the result of the set stock lax white clover content declining to that of the white clover content of rotational grazed pastures of between 11 and 5% while the set stock hard still maintained at a very

high level of white clover at between 25 and 19% (Table 4.9). White clover was lowest in November in the set stock hard after which it stayed between 19 and 25% within the set stock hard treatment. The slow start could be attributed to the time required to adjust to the grazing treatments by possibly increasing stolon density and developing a low small leaved morphology which will sustain leaf area under hard set stocking. In the set stock lax treatment the drop off in white clover content within the treatment coincided with the set stock lax dry matter reaching its highest level of between 1,973 and 2,080 kg/DM/ha in January and February respectively. White clover in both the rotational graze treatments was low, reaching maximum values in both lax and hard treatments in December of 16 and 15% respectively.

There was a depression of white clover in the Monaro Caucasian clover plots compared with the Alpine, Kentuck and Porters Pass plots (Table 4.10). This was starting to be seen in November and was obvious in December, January and February while there were no differences in the white clover cover percentage values in the other three rhizomatous clovers. This lower content of white clover within the Monaro Caucasian clover plots may have been caused by the low persistence of white clover in the two rotational grazed treatments compared with Monaro. Monaro could have had an competitive effect on white clover , although white clover was very competitive with Monaro Caucasian clover in the set stock hard and set stock lax grazing treatments.

Due to the white clover content in the Alpine, Kentucky and Porters Pass plots not being different and the low presence of the rhizomatous clovers within these plots the white clover in these plots was used as white clover plots to analyse the comparison between Monaro Caucasian clover and white clover under the four grazing treatments.

4.4.4 Comparison of white clover and Monaro Caucasian clover

The interaction between grazing frequency and gazing intensity was the result of white clover being more dominant in the set stock hard treatments in February, March and April compared with Monaro Caucasian clover while in the set stock lax and rotational graze hard, Monaro was significantly higher than white clover (Table 4.13). The naturalised white clover present at this site was best suited to set stock hard grazing treatment, and could not

cope with the competition for light and nutrients imposed by the rotational graze lax treatment while the grazing on the rotational graze hard treatment also reduced cover greatly as there was little protection from grazing low into the pasture by the ryegrass pseudostem and stolon removal must have taken place with the hard grazings this treatment received. The set stock lax treatment was the treatment that most closely resembled a possible grazing practice a farmer may employ, under this grazing regime the proportion of white clover and Monaro Caucasian clover present in the pasture was very similar for both species.

When looking at the total botanical composition of these pastures and the total mean legume content throughout the sampling season (Table 4.14) it can be seen that it takes a combination of white clover and Monaro Caucasian clover to provide a legume content close to the 30 %. This is a figure that is desired for a high performing ryegrass clover pasture in terms of both nitrogen fixation and animal performance. The major benefit of having Monaro Caucasian clover within these pastures is that while mismanagement, environmental condition or high grass grub populations make white clover unreliable the Monaro Caucasian clover will be present to take advantage of better growth conditions that may be found during and follow these adversities. This is most clearly seen in Table 4.14 where white clover persistence and production was reduced by the two rotational grazing treatments employed and that Monaro Caucasian clover was able to persist and contribute substantially to the pasture production and maintenance of forage quality in both these treatments.

4.4.5 Experimental limitations

This experiment had several limitations which could not be avoided either through the space available or the time required to carry out the extra measurements needed to provide more in depth information. The main limiting factors in this experiment was the area available to run the trial, as mentioned in the materials and methods. The resultant shape of the plots meant there was a very large perimeter around each treatment, as they were shaped as long thin rectangular mainplots of 50 x 10 m. There was a 1.5 m fence line effect of stock camping, nutrient transfer, over grazing or grazing through the fence and tracking up and down the fence lines which meant that this area was unavailable for measurement, this left

each mainplot with only 66% of the 50 x 10 m main plot area available for measurement. This put limitations on the ability to destructively harvest the rhizomatous clovers especially when the experiment is looking to be run for more than this first year.

Compaction is another variable that would have been desirable to measure as this seemed to be a problem that may have affected the rotational graze hard and possibly the set stock hard grazing treatments. Grazing of large numbers of sheep on the rotational graze hard treatments for three to four days occasionally occurred when the soil was wet. The end result in terms of compaction could have contributed to the poor persistence of white clover, reduced dry matter production of the sward as a whole and prevented the further spread of white clover and therefore increased content of Monaro Caucasian clover within its plots in this grazing treatment.

Nutrient transfer is also a factor that was hard to control within the experiment, fasting of the larger mobs of sheep before grazing the rotational graze hard treatments was not always ideally achieved, while the sheep were given adequate time to clean out before taking them off the treatment while forcing them to graze the rotational graze hard treatment to 5 cm. In contrast the sheep in the rotational graze lax treatment were leaving the treatment full which would have lead to substantial transfer of nutrients off the rotational graze lax treatment area.

Measurement of pasture production using cages within the two set stocked treatments would have been desirable, however in such a small effective area, the cages would caused camping, nutrient transfer and preferential grazing to occur, the effects of which may continue in that site even if the cage were continually moved.

4.5 CONCLUSIONS

After one season of grazing treatments conclusions include:-

1. Of the rhizomatous clovers present only Monaro Caucasian clover was agronomically suitable as a companion for high endophyte ryegrass under a range of grazing managements. While Alpine Caucasian clover persisted over time it did not contribute significant amounts to pastures production. The zig zag clovers Kentucky and Porters Pass showed a classic hay type legumes species inability to persist and contribute to dry matter production under grazing in the presence of strong grass competition and continuous or relatively frequent grazing.
2. Monaro Caucasian clover was present in moderate amounts in all four grazing treatments. In the rotational graze hard treatment where Monaro was most vigorous, below ground growing points would have protected it from over grazing which may have limited white clover in this treatment. Monaro Caucasian clover also persisted and contributed to pasture production in the rotational graze lax treatment where petiole extension enabled it to get leaves into the canopy of the pasture, and large underground reserves which Monaro Caucasian clover has will also have helped it to persist under this grazing treatment. Monaro Caucasian clover also persisted under very strong competition from white clover in the set stock hard grazing treatment.
3. White clover had variable persistence under the more adverse grazing treatments where either competition for light, water and nutrients in the rotational grazing treatments and possible stolon removal from the rotational graze hard treatment meant white clover contributed very little to the pastures created by these treatments. However white clover was very much suited to the open short sward created by the set stock hard treatment and to a lesser extent the set stock lax treatment.

4. To obtain maximum clover content over a range of grazing managements throughout the growing season a combination of white clover and Monaro Caucasian clover provided a pasture with a legume content of nearly 30% in both the set stock hard and the rotational graze hard treatments. This combination of clovers will mean that a high quality component of a pasture is present even if the grazing management is not ideal for maintenance of pasture quality in the face of drought or grass grub which may limit the amount of white clover present in the pasture. The benefits to the pasture through continued nitrogen fixation and to animal production by maintaining the high quality component of the pasture means that maximum profit may be gained from a pasture containing these two legumes over a range of grazing managements throughout the growing season.

CHAPTER FIVE

GENERAL DISCUSSION

The literature review in Chapter Two, showed that a lack of information in at least two major areas was inhibiting the development of a management plan for the use of Caucasian clover over a range of farming systems and environments. Chapters Three and Four described experiments that provided new information on the establishment and grazing management of Caucasian clover, more general aspects of these findings are discussed further in this chapter.

5.1 ESTABLISHMENT TECHNIQUE

Reports of slow establishment have been stated as one of the major limiting factors to the wider use of Caucasian clover in New Zealand (Lucas *et al.* 1980, Scott 1985). Chapter Two indicated that there was little previous work on the effect different forms of establishment, may have on the establishment of Caucasian clover. The experiment reported in chapter three, was established to measure the effects of three establishment techniques and two fertiliser rates on establishment characteristics of Caucasian clover.

The germination and subsequent early development of Caucasian clover seedlings differed greatly between establishment techniques. The strip seeding treatment was the best form of establishment closely followed by the sod seeder, while the broadcast treatment showed comparatively poor results. Fertiliser treatments were important in the first sampling in March where the high fertiliser treatment increased root dry matter particularly in the strip and sod seeding treatments.

Nodulation appeared to have a large influence on the broadcast treatment plant establishment with many seeds germinating but not forming effective nodules (Plate 3.1). The correct inoculation with satisfactory numbers of live effective rhizobia present at germination would have to be questioned in the case of the broadcast treatment. This however would not appear to be the case as the strip and sod sown treatments (Table 3.3) had no yellow or unnodulated plants. The major difference between strip and sod seeding treatments and the broadcast treatments was that seeds were put in immediate contact with the soil in both the strip and sod seeding and protected by means of a microclimate from desiccation. Inoculation of the seed in this trial would therefore seem to be satisfactory for establishing Caucasian clover by sowing into the soil, however the presence of the yellow plants in the broadcast treatment would indicate that plants were being lost from the population due to ineffective nodulation for whatever reason. This would indicate that inoculation and subsequent effective nodulation of plants from broadcasting was still the major issue for this establishment technique.

The strip seed treatment had the highest underground dry matter at the March sampling as well as the earliest rhizome development. The sod seed treatment had less below ground dry matter production than the strip seed treatment, however it did have some rhizome development. The broadcast treatment had the lowest underground dry matter and no rhizome development even by the July sampling.

It would seem that Caucasian clover has a critical level for root dry matter, that the individual plant had to reach before partitioning would change in favour of rhizome development. There also appears to be a limit to which the rhizome mass has to get to before partitioning balances out to include substantial herbage production from daughter plants. Once the plant has stabilised partitioning appears to be split evenly between rhizome expansion and shoot production while root production becomes a much smaller sink than in the younger establishing plant. Nutrient storage in the root and rhizome and possible re-translocation of mobile nutrients into the root/rhizome pool over winter may be reasons for continued persistence and good spring and summer growth of Caucasian clover.

These results show that Caucasian clover can be well established within a year using direct drilling techniques when the resident vegetation is unproductive and fertiliser is placed in close proximity to the seed.

5.2 GRAZING RHIZOMATOUS CLOVERS

There has been no reports on the effects of different grazing treatments on Caucasian clover in swards containing high endophyte ryegrass and white clover. The trial reported in Chapter Four was the first year of a grazing trial that observed how Caucasian clover and zig zag clover responded to four diverse grazing managements. The results provide new information on the composition of ryegrass/white clover/Caucasian clover swards under two grazing frequencies and two grazing intensities. As well as setting the foundation for the continuation of the trial into its second and third years, the first years results provided differences in pasture composition that were measurable and give some indication as to possible future trends.

Zig zag clovers were not well adapted to any of the grazing treatments including the rotational graze lax treatment which was the most likely to encourage a hay type plant like zig zag clover. This may have been due to the competition effect that the ryegrass had on the rotational graze lax treatment or that the spelling period between grazings of between 21 and 34 days was not long enough for zig zag clover. This species was never very strong even at the time of laying down the trial, zig zag clover did not even measure 10% of the sward at the start of the trial and the composition only decreased as the trial progressed.

This very poor contribution and persistence of zig zag clover meant that the trial focused on Caucasian clover particularly Monaro and white clover, with the white clover in the zig zag clover plots being used to compare Caucasian clover to white clover under the four grazing treatments.

Monaro Caucasian clover had a higher clover cover in the rotational graze hard treatment than any of the other grazing treatments. This treatment was regularly grazed down to a low residual over the whole of the growing season, which had an adverse effect on white clover

content possibly due to stolon removal. This grazing treatment however suited Monaro with its daughter plants spreading strongly between the upright, open rows of ryegrass, created by this grazing treatment.

The rotational graze lax grazing treatment was particularly hard on white clover with a continual bulk of ryegrass out competing white clover for light and forcing it out of the sward. The Caucasian clover however maintained its presence within the dense ryegrass sward created by this grazing treatment. This was achieved by a combination of the excellent ability of Caucasian clover to increase petiole length and leaf area under lax grazing and the large amount of under ground reserves Caucasian clover possess^{es} in its root and rhizome system.

White clover was particularly well adapted to the set stock hard grazing treatment with its ability to spread via stolon run and having leaf plasticity to reduce leaf size and maintain leaf area under close grazing. Compared to the hard rotational graze treatment the ryegrass in the set stock hard treatment was much more clumpy and densely tillered this would have provided more protection for the white clover stolons while the continued close grazing prevented Caucasian clover from maintaining leaf area due to it having less points of growth than white clover and therefore prevent it from recharging its underground reserves.

The set stock lax grazing treatment of all the treatments had the most similar amounts of Monaro Caucasian clover and white clover with the mean composition over all the sampling periods being very similar. Of the four treatments used the set stock lax treatment developed a pasture most likely to be seen under normal farming conditions and the combination of both Monaro Caucasian clover and white clover under this management shows that both clovers may have a future together within the same pastures, although the Caucasian clovers establishment may limit this.

5.3 GENERAL CONCLUSION

5.3.1 Establishment

Establishment technique has a large effect on the speed at which Caucasian clover becomes established. Due to the characteristic of directing a high proportion of its dry matter partitioning into its under ground root and rhizome system, Caucasian clover will always be slower than white clover to establish and to produce large amounts of herbage.

To achieve quick establishment and early herbage production in Caucasian clover it is essential to build the under ground dry matter up as fast as possible. This was best achieved by the strip seed technique, which created a worked seed bed, free of competition and the fertiliser placed banded below the seed. The sod seed technique had a stronger establishment than the broadcast technique. This advantage was achieved by the seed being buried in the ground, and the fertiliser being banded in the rows with the seed compared with seed being spread on the surface of the ground with the fertiliser also being randomly spread around the seed and surrounding vegetation.

In conclusion, given that other establishment conditions are similar (eg. competition, moisture) the ability for the Caucasian clover seedlings to obtain as much of the establishment fertiliser as possible, will limit the speed at which the under ground dry matter will build up and hence the subsequent increase in herbage production. The main factors affecting the amount of the establishment fertiliser that the seedling may obtain are the actual amount of fertiliser applied at establishment and the number of other plant species directly competing for that fertiliser.

5.3.2 Grazing management

The hexaploid Caucasian clover cultivar Monaro is the most agronomically suitable rhizomatous clover tested at this lowland site, both the zig zag clovers and the diploid Caucasian clover cultivar Alpine look to be out of their climatic and environmental range at this site and were not coping well with the grazing treatments applied to them.

Once Caucasian clover is well established its taproots are large and the rhizomes are producing daughter plants. Caucasian clover will stand a number of grazing managements that would lead to a reduction of white clover in a pasture. Caucasian clover does however appear to require periods of rotational grazing to allow the taproot crown and daughter plants to build up leaf area and allow some continued carbohydrate build in the root and

5.4 PRACTICAL RECOMMENDATIONS

5.4.1 Establishment

1. For the best establishment of Caucasian clover, seed should be sown into a worked seed bed with fertiliser ideally placed below the seed at a rate of around 300 kg/ha molybdc sulphur super phosphate, a sowing rate of 2 kg/ha will provide enough plants per meter squared for early herbage production.
2. If direct drilling the placing of high rates of fertiliser (eg. 300 kg/ha molybdc sulphur super phosphate) near the seed is very important to encourage fast establishment, a sowing rate of 2 kg/ha will provide enough plants per meter squared for early herbage production.
3. When broadcasting the seed should be inoculated at a high rate with the correct strain of rhizobia, if the seed is left for longer than 6-8 days after inoculation, seed should be re-inoculated prior to sowing. This may be done on farm by purchasing rhizobia from the seed supplier mixing into a slurry and spreading over the seed prior to sowing. Broadcasting will be more successful when the soil temperature is increasing such as in the spring and there is rainfall not long after broadcasting. It would be recommended that a higher seeding rate is used for broadcasting if early herbage production is required from this sowing technique.
4. If sowing in a general pasture instead of as legume by its self, it would be ideal to rig a system for sowing Caucasian clover by its self in every fourth or fifth drill row with the general pasture including white clover sown in the remanding rows. This would reduce competition as well as reducing the amount of seed required per hectare.

5.4.2 Grazing management

These grazing management recommendations are completely dependant on the establishment of Caucasian clover in a mixed pastoral situation and that the plants are at a well established stage with a good tap root and some rhizome development.

1. Caucasian clover can withstand adverse grazing managements as long as it is not a continual yearly practice. Caucasian clover will cope with hard set stocking in early spring over lambing and this should not affect it as long as a rotation is returned to by mid spring when Caucasian clover becomes most productive.
2. Caucasian clover will survive under very lax grazing management and is well suited to a hay cropping system where it will persist in a large standing bulk of grass as long as it is cut or hard grazed once or twice each season.
3. Caucasian clover is suitable for intensive rotationally grazing on a 20 to 30 day rotation and may be grazed on a shorter rotation as long as the rotation is lengthened at some point during the growing season to allow build up of reserves.
4. Caucasian clover may be used in ryegrass/white clover pastures, however the white clover will need to be oversown the following season to allow the Caucasian clover to get adequately established with out being further by the more vigorous white clover as well as the grass.

5.5 LIMITATIONS FOR FUTURE USE OF CAUCASIAN CLOVER

5.5.1 Seed Availability

A serious effort is being made by Wrightsons to grow and commercialise their propriety cultivar Endura. This has the potential to develop the first reliable supply of commercial seed. At present seed yields are so unreliable that retail seed prices are around the \$15 mark and given the very poor wool and beef markets at present this will limit the amount of seed, farmers are willing to use with a lot of sowings being done at very low rates. This in turn will reduce the speed at which the Caucasian clover will contribute to pasture production.

5.5.2 Establishment

At present the establishment of Caucasian clover is very exacting in its requirements and failure to meet these requirements leads to a chance of failure;

1. Caucasian clover is established with more success in the spring and summer when the soil temperatures are increasing rather than the autumn.
2. It is essential that seed is inoculated with high numbers of effective rhizobia and that inoculated seed is stored at cool temperatures and sown within six to ten days of inoculation, sooner if possible.
3. Other vigorous competing legumes such as white clover should be kept to a minimum or not be present.
4. Vigorous competition from grass should be kept to a minimum.

These requirements will limit successful establishment to farmers that pay close attention to detail.

5.5.3 Seasonal Production

The strong bias that Caucasian clover has towards late-spring early summer production combined with winter dormancy will limit Caucasian clover's uses to zones with moist springs and cold winters.

In milder winter zones it is likely to be suppressed by more winter active species such as white clover. However, there may be potential to breed for more winter active forms as this has never been seriously attempted.

5.6 ADVANTAGES OF USING CAUCASIAN CLOVER

Caucasian clover has many desirable characteristics that are not present in the forage legumes used in farming systems at present.

Caucasian clover's strongest agronomic attributes are that it is a high quality forage legume that is very persistent with similar productivity to other perennial clovers. There are growing numbers of reports of Caucasian clover stands particularly in the high country that are over 20 years of age with no signs to suggest that they will not persist for another 20 years (Yates, 1993, Lucas *pers com.*).

Characteristics of Caucasian clover that could provide advantages to the New Zealand farmer include;

1. Persistent under a wide range of grazing managements, providing nitrogen fixation over a sustained period of time.
2. Being resistant to climatic extremes including summer drought and low winter temperatures and heavy frosts.
3. Once established, being tolerant of high numbers of grass grub and other pests such as nematodes.
4. Being able to persist at low fertility levels once established.
5. Being able to spread by rhizomes to colonise adjacent areas from an initial low plant population.

Caucasian clover is highly productive when conditions are favourable, and fixes nitrogen as well if not better than white clover in high country environments (Lane, 1985). Caucasian clover is of a high nutritive value and similar in its nutritional characteristics to Ladino clover (Allinson *et. al.* 1985).

5.7 FUTURE WORK

Areas for potential future studies concerning Caucasian clover arising from this study include;

1. A study of the partitioning of carbohydrates and dry matter in young Caucasian clover plants over the first two years of establishment. The aim would be to identify whether there are critical dry matter levels that the Caucasian clover tap root has to achieve before rhizome development starts and herbage production increases, and the time frame that this may occur in when different rates of fertiliser and competition are used.

This information would help give an accurate estimation of how fast or slowly Caucasian clover could be expected to establish under any given condition. This will help give farmers more accurate information on the establishment of Caucasian clover as a plant.

2. A study in the translocation of nutrients in Caucasian clover between roots and rhizomes. Also to identify the main storage organs in Caucasian clover that are used as a sources of carbohydrate for the recovery of leaf area after grazing, and how different cutting treatments or grazing practices effect root or rhizome dry matter and whether Caucasian clover requires any particular seasonal rest period to recover root and rhizome mass?
3. To further study the *Rhizobium*/Caucasian clover interaction and in co-operation with work being done on *Rhizobium* strain selection and improving inoculation techniques identify and select lines of Caucasian clover that are more susceptible to

early rhizobia invasion and affective nodule formation. It would also be important to identify and select for increased nitrogen fixation, be it through selection within the rhizobia or the Caucasian clover gene pools.

4. The identification and selection of lines of Caucasian clover with high seedling vigour and establishment characteristics, particularly with the aim to create a selection that can be reliably established ~~and can be reliably established~~ from early Autumn sowing. It would also be important to identify whether or not selecting for these characteristics change the plants characteristics ie. reduce rhizome development, reduce root dry matter, reduce persistence?
5. Selection for winter active lines of Caucasian clover and to study the effect that selecting for winter activity would have on other plant characteristics like, establishment, seed production and persistence.
6. Although it bears no direct link to the research in Chapters Three and Four, further studies into seed production will be required to make Caucasian clover a successful commercial species. These studies would revolve around the effects of weed controls, plant spacing, water and fertility requirements required for improved seed production. It would also be interesting to see whether selecting for seed production is related to improved establishment characteristics.

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Effect of sowing method and fertiliser application on establishment and first season growth of Caucasian clover

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Abstract

A trial to measure the effects of establishment techniques and fertiliser application on seedling establishment and early root and rhizome development of Caucasian clover (*Trifolium ambiguum*) was sown in early October 1992, on a low-fertility, depleted short tussock grassland site at Mesopotamia Station, South Canterbury. Three sowing techniques, broadcasting, sod seeding and strip seeding, each with two rates of fertiliser, 150 or 300 kg/ha molybdc sulphur superphosphate, were used. By mid December, 48 and 41% establishment had occurred in the strip and sod seeding respectively, but only 10% in the broadcast. Strip seeding was the most successful technique, resulting in earlier rhizome and tap-root development and wider lateral spread of rhizomes. However, both strip seeding and sod seeding resulted in all plants developing rhizomes 9 months after sowing. Plants from broadcasting were small with few rhizomes in the first season. The higher fertiliser rate improved establishment and growth, particularly in the strip seeding treatment. By using a strip seeding technique Caucasian clover was established as rapidly as white clover and plants were similar in size after 5 months.

Keywords: broadcast seeding, establishment, fertiliser, rhizomes, sod seeding, sowing methods, *Trifolium ambiguum*, *Trifolium repens*, tussock grasslands

Introduction

Caucasian clover shows great promise as a very persistent, competitive legume for the South Island hill and high country. It is a deep-rooted, drought-tolerant, spring- and summer-growing legume which can tolerate low winter temperatures and heavy frosts, and recovers quickly after drought (Dear & Zorin 1985; Woodman *et al.* 1992). Caucasian clover has an extensive root and rhizome system (Daly & Mason 1987) which acts as an important store for nutrients (Strachan *et al.* 1994). Allan & Keoghan (1994) found that Caucasian clover persisted under a wide range of

grazing management systems because the rhizomes and growing points were below ground level. Persistence through vegetative spread was observed by Dear & Zorin (1985) who found 4-year-old Caucasian clover cv. Monaro produced 74 daughter plants/plant and had rhizomes nearly 500 mm in length.

Reports of slow establishment (Lucas *et al.* 1980; Scott 1985) and the lack of seed supplies have restricted the commercial use of Caucasian clover. This has led to proposals that rhizome fragments could be used as a means of establishment (Scott & Mason 1992). However, in contrast to Lucas *et al.* (1980), Lowther & Patrick (1992) reported seedling establishment of white clover and Caucasian clover to be similar.

The aims of this establishment trial were to measure the effects of sowing technique and fertiliser application on Caucasian clover seedling establishment and early root and rhizome development on a low-fertility, summer-moist, high-country site.

Material and methods

Experimental site and design

The experiment was sited on depleted, unimproved tussock grassland dominated by fescue tussock (*Festuca novae zelandiae*), browntop (*Agrostis capillaris*) and *Hieracium pilosella* situated at Mesopotamia Station in the upper Rangitata valley. The soil, a Mesopotamia silt loam, is acid (pH 5.2) and low in phosphorus (Olsen P 6) and sulphur (S 2 ppm). The site is 500 m above sea level and has a mean annual rainfall of 940 mm. The experimental site was burnt to remove litter and sown with Caucasian clover (*Trifolium ambiguum* Bieb.) cv. Monaro on 1 October 1992 using the Lincoln Ventures/AgResearch experimental plot drill. Rainfall was reasonably evenly distributed during the establishment year with 133 mm of rain in the two months following sowing out of a total for spring of 167 mm (Table 1).

Seeds were scarified and commercially prepared as a special batch by inoculating with *Rhizobium* strain CC283B followed by coating with fine lime at a rate of 0.7 lime : 1.0 seed. Although no *Rhizobium* counts were done the inoculant was applied at 5 times the recommended rate, with the aim that the number of viable *Rhizobium* present on the seed would not be limiting. The inoculated, coated seed was stored at

Table 1 Seasonal rainfall and soil temperatures at Mesopotamia station, Rangitata valley, for the period 1992-1994.

Measurement		Seasonal distribution				Total rainfall
		Spring	Summer	Autumn	Winter	
Rainfall (mm)	1992/93	167	191	235	406	848
Mean daily temperature (°C) [#]	1992/93	NA	NA	8.0 ^{##}	4.2	
Mean daily temperature (°C) [#]	1993/94	10.0	16.5	11.1	3.7	

Soil temperatures at 10 cm depth
From 16 April to the end of May
NA Not available

4°C for 1 day before sowing. The trial was a balanced incomplete block design with plots consisting of paired comparisons of all treatments. The trial was replicated twice with each paired plot 20 m in length. Seeding rate was calculated to place 100 viable seeds per metre of row. Treatments consisted of 3 methods of establishment: an experimental strip seeding system, direct seeding into the sod or broadcast. The strip seeding system, described fully by Horrell *et al.* (1991), used an inclined dished disc to cut and invert a ribbon of turf, placing it adjacent to the drilling strip. Next, a spring tine cultivated the soil and banded the fertiliser at a nominal depth of 50 mm. Finally a seed coulter sowed the seed at a shallow depth (approximately 10 mm) and a press wheel firmed the seed bed. Two rows 150 mm apart were sown in the weed free 200 mm strip of bare soil. The sod seeding system used Duncan 760 till seeder with a 'Baker' inverted T coulter form of direct drilling, with fertiliser placed with the seed, and was also drilled in two rows 150 mm apart. The broadcast treatment was sown by the plot drill with seed and fertiliser falling directly from the coulter and spreading over a 200 mm wide strip.

Each of the establishment methods was sown with either 150 or 300 kg/ha of molybdc sulphur super phosphate (8% P, 20% S). Basal boron was also applied as a solution of borax (11% B) at 10 kg B/ha.

Trial measurements and data analysis

Early emergence and establishment was measured on 14 December 1992 with plant counts made along two 500 mm lengths of row from each paired treatment in each plot.

On 12 March 1993, one spade spit 200 x 150 mm was dug across each of the paired rows of sod and strip seeding treatments at median sites. Due to lack of uniform plant numbers in the broadcast treatment spits were dug to obtain a minimum of 5 plants/treatment. Samples were washed and measurements recorded on nodulation, rhizome number/plant and rhizome length. Dry weights of shoots (above-ground herbage), roots and rhizomes were determined.

At the end of the first growing season on 6 July

1993, one 150 mm wide turf was dug across the paired rows of the sod seed and strip seeding treatments. The turfs were long enough to include all lateral rhizome development. Five plants were randomly selected for measurement from the broadcast treatments. Measurements were the same as the first sampling plus additional measurements of secondary rhizome number and length, and dry weight per plant.

An adjacent fertiliser trial comparing responses of Monaro Caucasian clover and Grasslands Tahora white clover to rates of phosphate and sulphur was also sampled. Both species were established on the 1 October 1992 using the strip seeding technique. The treatment sampled for this study had 50 kg/ha of both phosphorus and sulphur applied at sowing time. Three spits were dug from this Caucasian clover and white clover trial on 19 April 1993, and root, rhizome, stolon and leaf material measured.

Genstat statistical package was used to analyse the paired plot design.

Results and discussion

Germination and establishment

The strip seeding system was the most successful method for establishment of Caucasian clover with 48% of seed sown establishing. This was closely followed by the sod seeding treatment (41%), while broadcasting produced comparatively poor results (10%) (Table 2). It is assumed that the success of strip seeding was due to a combination of effects including the physical removal of competing resident vegetation, cultivation to form a seed bed, formation of a microclimate and placement of fertiliser in a band below the seed. These all combined to enhance germination, nodulation and establishment of the seedlings and subsequent growth of roots and rhizomes (Tables 3 and 4). Similar results with the strip seeder have been achieved with other legume species by Lowther *et al.* (1991) and Woodman (1993). The sod seed technique was also satisfactory, indicating the importance of seed being placed in the ground close to fertiliser for establishment and subsequent growth in this

environment. However, in drier environments the close proximity of fertiliser may be detrimental (Woodman pers. comm.). The poorer establishment from broadcasting can be attributed to a combination of factors but the main adverse influence may have been the substantial ground cover of 30-50% *Hieracium pilosella* leaves which would have resulted in a high proportion of seed landing on the prostrate rosettes rather than bare ground. In addition, both germinating seed and *Rhizobium* are very susceptible to desiccation when on the surface of the soil; this drying effect would have been further aided by lack of litter cover due to burning. About 80% of the plants in the broadcast plot were small and yellow at the March sampling. Some were un-nodulated while others had small pale nodules which could be the result of ineffective and/or late nodulation by Caucasian clover rhizobia. Alternatively this could be the result of nodulation by resident white clover rhizobia which may form small ineffective nodules on Caucasian clover (Patrick & Lowther 1993; Ronson pers.comm.). It is possible that the most recent recommendation for inoculation (Patrick & Lowther 1994) would have given better nodulation in the broadcast situation. However, the excellent nodulation of direct-drilled plants indicates that there were adequate numbers of rhizobia specific to Caucasian clover present for seed which is placed in soil rather than broadcast on the surface.

Root and rhizome development

A characteristic of Caucasian clover is its rapid early root development and by March 1993 some tap-roots from the strip seeding technique had reached more than 700 mm depth. In contrast the broadcast plants had reached only 200 mm depth. At that time, root dry matter to 150 mm of the strip seeding system was more than double that of plants which were sod seeded, and almost 6 times the weight of broadcast plants (Table 3). There was an interaction between sowing method and fertiliser, with a larger response to the higher level of fertiliser in the strip seeding treatment. The root growth responses in March 1993 were presumably due to the same combination of factors which enhanced germination and establishment mentioned earlier; the poorer growth of roots from sod seeding was assumed to be due to competition from browntop and *Hieracium*, particularly for nutrients such as phosphate (Jackman & Mouat 1974; Svavarsdóttir pers. comm.).

By March 1993, rhizome development was evident on many plants of the sod seeded and strip seeding treatments although rhizome length and percentage of plants with rhizomes were greater with strip seeding

Table 2 Effect of establishment technique on percentage of Caucasian clover plants per metre of row in December 1992.

Establishment technique		
Broadcast 9	Sod seeding 38	Strip seeding 48
SED 4.44		(p<0.001)

Table 3 Effect of establishment technique on root weight (g/plant) to 15 cm depth, March 1993.

Fertiliser (kg/ha)	Establishment technique			Mean	SED
	Broadcast	Sod seeding	Strip seeding		
150	0.143	0.276	0.528	0.316	0.055 (p<0.05)
300	0.157	0.376	0.857	0.464	
Mean	0.150	0.326	0.693	Interaction	
SED	0.067 (p<0.001)		SED 0.095 (p<0.05)		

(Table 4). By July 1993 all plants in these two treatments had developed rhizomes. Few plants from broadcasting exhibited rhizomes either in March (Table 4) or in July. The rhizomes produced by the strip seeding system in March were 5 and 10 times the length of the sod seed and broadcast treatment respectively. Even at this early sampling, some rhizomes were 150 mm long in the strip seeding treatments. The reasons for this excellent rhizome development under the strip seeding system can be attributed to the plants establishing in a 200 mm wide cultivated seedbed free from strong *Hieracium* and browntop root competition. The sod seeded plants were subject to both inter and intra-specific competition as individual plants not only received substantial pressure from other Caucasian clover plants along the disc line, but any sideways growth resulted in strong competition from resident vegetation which formed a very dense root mat.

Table 4 Effect of establishment technique on percentage plants with rhizomes, average rhizome length, and root/rhizome:shoot ratios, in March 1993.

	Establishment technique			SED
	Broadcast	Sod seeding	Strip seeding	
Plants with rhizomes (%)	1	43	75	6.50 (p<0.001)
Average rhizome length (mm)	2	4	21	2.26 (p<0.001)
Root/rhizome:shoot ratio	2.49	3.15	3.36	0.21 (p<0.001)

There was continued primary rhizome development in the autumn between the March 1993 sampling and the July 1993 sampling. By July 1993 the strip and sod seeded plants had developed secondary branch rhizomes (Table 5). Individual rhizomes from both the strip and sod seeding systems measured up to 300 mm in length, while the maximum plant width was 485 and 405 mm respectively (Table 5).

Table 5 Effect of establishment technique on the average primary and secondary rhizome length and maximum plant width in July 1993.

	----- Establishment technique -----			SED
	Broadcast	Sod seeding	Strip seeding	
Primary rhizome length (mm)	8 [#]	30	78	5.5
Secondary rhizome length (mm)	0	5 [#]	32 [#]	6.5
Maximum plant width (mm) ^{##}	35	405	485	NA

Average of plants with rhizomes and secondary rhizomes.
Plants measured from tip to tip of the two longest rhizomes.

Sampling done in mid spring of 1993 revealed further rhizome growth and development indicating that rhizome extension was not confined to autumn (Moorhead unpublished).

Root plus rhizome to shoot ratio

In contrast to many other clovers Caucasian clover seedlings allocate a much higher proportion of photosynthates into root and rhizome development than growth of leaves (Spencer *et al.* 1975). The root plus rhizome:shoot ratios present in the March sampling (Table 4) were very similar to those found by Daly & Mason (1987) of 2.73 in cv. Prairie, and by Spencer *et al.* (1975) who measured ratios of 2.36 and 3.36 in the diploid cv. Summit and a hexaploid ecotype respectively. These ratios emphasise the characteristic partitioning of nutrient and carbohydrate resources of Caucasian clover during its establishment into its root and rhizome systems. In March 1993 Caucasian clover had produced 10.7 g DM/m row of top growth using

the strip seeding system and 3.7 g DM/m row for the sod seed technique. The herbage production by the strip seeding system (approx. 700 kg DM/ha at the row spacing used) together with the substantial underground biomass suggests that this treatment could have been lightly grazed within six months of establishment (Moorhead unpublished).

Comparison with white clover

Measurements of Caucasian clover and white clover plants drilled with the strip seeder in the adjacent fertiliser experiment showed large differences in their morphology. Individual 6-month-old white clover plants were similar in total leaf DM to Caucasian clover; but white clover plants had only one third the root DM while its stolons were nearly 3 times the weight of Caucasian clover rhizomes (Table 6). Caucasian clover had longer tap-roots >150 mm compared with 92 mm for white clover. Leaf DM yield was 8.4 g/m row length vs 10 g/m row length for white clover and Caucasian clover respectively.

Conclusions

Results showed the importance of good techniques for rapid establishment of Caucasian clover in moist, low fertility, depleted tussock grassland areas.

The most important conclusions are:

1. The use of either strip or sod seeding will produce large, rhizomatous, well established plants in the first season after sowing.
2. The strip and sod seeding establishment techniques are far superior to broadcasting and will produce a higher proportion of nodulated plants from seed sown.
3. Strip seeding will encourage earlier rhizome development and greater root production, causing faster vegetative spread, but sod seeding (which is the most commonly available technology) is also much superior to broadcasting.
4. By using the strip seeding technique Caucasian clover can be established as quickly and successfully as white clover in this environment.
5. High rates (300 kg/ha) of molybdenic sulphur superphosphate placed with or under the seed

Table 6 Comparison of white and Caucasian clover plants on 19 April 1993.

Species	Average plant number /m row	Individual plant DM (g per plant)			Tap root length (mm)	Tap root diameter (mm)	Stolon/rhizome per plant		Leaf number per plant
		Leaf	Root	Stolon/rhizome			Number	Length (mm)	
White	40	0.21	0.26	0.49	92	3.4	5	72	18.3
Caucasian	50	0.20	0.81	0.18	>150	4.8	4	44	5.2

accelerates plant growth and rhizome development in this environment.

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Appendix 2. Mesopotamia Caucasian clover establishment plan.

Mesopotamia - Experiment 1 Method of Establishment
of Caucasian Clover, 1992
Improved Plan, 16 Nov 1993.

Rep 1

W		v	E	
Till F ₂		v	Jethro F ₂	1
Till F ₂	$\frac{F_2}{F_1}$	v	Till F ₁	2
Till F ₂		v	BC F ₂	3
Till F ₁		v	BC F ₁	4
Till F ₁		v	Jethro F ₂	5
BC F ₂		v	Jethro F ₂	6
BC F ₂		v	Till F ₁	7
Till F ₂		v	Jethro F ₁	8
Jethro F ₂	$\frac{F_2}{F_1}$	v	Jethro F ₁	9
BC F ₂	$\frac{F_2}{F_1}$	v	BC F ₁	10
BC F ₁		v	Till F ₂	11
Jethro F ₁		v	BC F ₂	12
Jethro F ₁		v	Till F ₁	13
BC F ₁		v	Jethro F ₂	14
Jethro F ₁		v	BC F ₁	15

Rep 2

Jethro F ₂	$\frac{F_2}{F_1}$	v	Jethro F ₁	17
Till F ₁		v	BC F ₂	16
Abandoned				
BC F ₂		v	Jethro F ₂	18
Till F ₂		v	BC F ₂	19
BC F ₁		v	Till F ₂	20
BC F ₂	$\frac{F_2}{F_1}$	v	BC F ₁	21
Till F ₁	$\frac{F_1}{F_2}$	v	Till F ₂	22
Till F ₁		v	Jethro F ₂	23
BC F ₁		v	Till F ₁	24
Jethro F ₂		v	Till F ₂	25
Jethro F ₁		v	BC F ₂	26
Jethro F ₁		v	BC F ₁	27
Jethro F ₁		v	Till F ₂	28
Jethro F ₁		v	Till F ₁	29
Jethro F ₂		v	BC F ₁	30

BC = Broadcast seed & fertiliser
 Till = Sodseed seed and fertiliser with Baker coultter
 Jethro = Double-disc opener & drill seed and fertiliser in bare soil

F₁ = 150 kg Sulphur super/ha
 F₂ = 300 kg Sulphur super/ha

→N

Sown 1/10/92

Appendix 3 Genstat programme and example of data input used to analysis treatment results.

```

$ set verify=noimage
$ genstat

! Design for Mesopotamia Trial - Caucasian Clover
  J.G.H. White - 10 September 1992
  Exp. 1.
Aim:      To measure establishment, rhizome development & early d.m. yield
          of Caucasian clover.
Treatments: 3 Sowings; Broadcast, Sod seeded, Jethro system,
            2 Fertilizer levels; 150 kg/ha, 300 kg/ha
Design:    Balanced incomplete block. Blocks of size 2. The machinery
          is set up to sow two strips of two rows. As there is not a
          complete set of cultivators, two of the blocks will have to be
          run over twice; once with the cultivators on one side, then
          with them on the other side.

```

This program written 15 Sept.1992

```

units [60]
fact [le=3;la=!T('Broadcast','Sod seeded','Jethro system')] Sowing
fact [le=2;la=!T('150 kg/ha','300 kg/ha')] No_Super
fact [le=15;va=2(1..15)2] blocks
fact [le=2;va=30(1,2)] reps
!The following layout follows the 'Trial Design' of J.G.H.W.'s memo,
!except that 3 plots are added; viz BC F1 x BC F2, Till F1 x Till F2, and
!Jethro F1 x Jethro F2.
!The whole sequence of blocks repeated for the second rep.
read Sowing, No_Super
2 2 3 2 2 2 2 1 2 2 1 2 2 1 1 1 2 1 3 2 1 2 3 2 1 2 2 1
2 2 3 1 3 2 3 1 1 2 1 1 1 1 2 2 3 1 1 2 3 1 2 1 1 1 3 2
2 1 1 2 3 2 3 1 1 2 3 2 2 2 1 2 1 1 2 2 1 2 1 1 2 2 2
1 1 2 1 3 2 2 2 3 1 1 2 3 1 1 1 3 1 2 2 3 1 2 1 3 2 1 1
read Plant_no, UnpodPl_no, StemD, PLWRH, RH_no, TKH, LeafWt, RootWt, RHWt
19 0 0 3.8 5 18 11.5 1 53 4.77 0.01
10 0 0 6.2 9 43 1630 3 83 12.42 1.85
7 0 0 4.4 6 22 105.5 2 12 5.77 0.04
7 0 0 3.9 3 14 34 0.91 3.11 0.02
18 0 0 3.9 7 28 130 1.91 5.9 0.04
14 2 2 2.6 0 0 0 0.83 1.82 0
7 0 0 3.8 2 6 23 0.85 2.29 0.01
8 1 1 2.3 0 0 0 0.27 0.87 0
10 0 0 4.1 3 9 37 1.75 4.41 0.02
14 0 0 5.8 11 57 1549 8.18 14.71 1.2
8 3 3 1.7 0 0 0 0.23 0.48 0
13 0 0 5.9 10 46 928 3.75 11.41 1.2
15 0 0 3.7 2 8 27 0.99 4.88 0.02
8 0 0 3.7 7 25 72.5 0.94 4.55 0.02
4 0 0 3.9 5 13 31.5 1.5 4.8 0.01
10 0 0 4 7 23 153.5 1.46 5.4 0.06
23 0 0 5.5 15 56 1621 4.81 16.46 1.44
9 0 0 4.6 3 11 240 1.58 5.1 0.23
7 3 3 1.8 0 0 0 0.1 0.33 0
20 2 2 2.3 0 0 0 0.46 1.22 0
10 0 1 2.3 0 0 0 0.39 0.9 0
10 0 0 3.6 3 13 50 1.12 4.39 0.02
17 0 0 4.8 10 41 723 2.56 7.72 0.42
15 0 0 3.2 2 5 16 0.65 1.25 0.01
19 0 0 4.7 14 67 1915 4.56 12.52 1.61
11 0 0 4.3 8 29 284 2 7.41 0.19
6 1 1 2.3 0 0 0 0.28 0.76 0
12 0 0 3.4 8 36 323 2.18 5.21 0.12
13 0 0 4 8 27 910.5 2.54 7.9 0.45
6 0 0 2.1 0 0 0 0.22 0.54 0
8 0 0 4.2 7 28 223 1.2 5.16 0.19
8 0 0 2.1 0 0 0 0.59 1.34 0
10 0 0 3.3 6 14 49.5 0.8 3.21 0.04
11 0 0 3.3 5 15 76 0.77 2.62 0.03
8 2 2 2.3 0 0 0 0.32 0.75 0
15 0 0 5.9 11 81 1759 3.87 11.48 1.4
13 0 0 3 4 18 59.5 1.09 2.71 0.02
19 0 0 2.8 0 0 0 1.27 3.45 0
13 0 0 4 2 0 0 0.87 1.31 0
9 0 0 4.2 6 25 190 1.61 5.05 0.07
11 0 0 3.2 4 11 12 1.25 2.59 0.01
10 2 2 1.7 0 0 0 0.15 0.38 0
27 0 0 3.8 9 32 47 2.53 8.25 0.02
10 0 0 4.1 5 20 273 1.26 4.14 0.13
8 0 0 3.1 3 11 15 1.11 2.58 0.01
16 0 1 5.6 8 44 1480 4.62 10.29 1.21
14 1 1 3 0 0 0 0.38 0.95 0
20 0 0 3.6 11 32 89 2.01 5.83 0.02
22 0 0 4 5 17 83 1.55 4 0.21

```

18	0	3.6	5	22	168.5	2.09	4.8	0.06
11	0	4.1	8	21	430	1.52	4.44	0.44
6	0	1.5	0	0	0	0.18	0.32	0
17	0	4.3	9	21	307.5	1.97	5.84	0.17
11	2	2.6	0	0	0	0.48	1.03	0
15	0	3.9	12	47	684.5	2.58	7.84	0.38
11	0	3.5	3	11	75	1.31	3.64	0.03
10	0	3.6	6	26	266	1.11	3.8	0.1
15	0	2.7	1	2	4	0.46	1.91	0.01
14	0	4	12	44	353	2.97	7.91	0.13
11	1	2.5	0	0	0	0.32	1.03	0

```

:
calc [zdz=z] AvRHL = TRHL/RH_no
calc SR = LeafWt/RootWt
calc SRRH = LeafWt/(RootWt+RHwt)
calc RRHS = (RootWt+RHwt)/LeafWt
calc Lfwtpt = LeafWt/plant_no
block reps/blocks
treat Mo_Super*Sowing
!The analysis shows two levels of strata: the first level corresponds to
the between block effect. The total number of d.f.s equal those for the
blocks within reps term. The second stratum corresponds to the units
(within block) effects and is the one to consider.
calc Plant_no = Sqrt(Plant_no)
calc TRHL = Log10(TRHL+1)
for dummy = Plant_no, UnnodPl_no, StemD, PlWRH, RH_no, TRHl, LeafWt, RootWt,
RHwt, AvRHL, SR, SRRH, RRHS, Lfwtpt
  anov [fprob=y;design=zxc123] dummy ;f=fits; r=resids
  !graph [nc=20;nc=60] resids ; fits'
endfor

```

Appendix 4 Trial plan of rhizomatous clover grazing with treatments established in October 1993.

	Rep 1				Rep 2			
	Set stock hard	Rotational graze lax	Set stock lax	Rotational graze hard	Set stock hard	Rotational graze hard	Rotational graze lax	Set stock lax
Alpine								
Monaro								
Kentucky								
Porters Pass								
Monaro								
Porters Pass								
Alpine								
Kentucky								
Porters Pass								
Monaro								
Alpine								
Kentucky								

Key:

- Fence
- Gate



Four rows of each of the rhizomatous clovers



Appendix 5 The Genstat programme for analysing the grazing trials randomised block design with a strip block design at the subplot level.

```

1 set lexp21
2 set covelcity
3 gen
4 fact [le=2; va=48(1,2)] rep
5 fact [le=4; va=12(1,3)] 2] column
6 fact [le=3; va=(1,3)] 3] row
7 fact [le=4; va=3(1,4)] 8] strip
8 fact [le=4; la=1(Monaro,SL,RH,RL); va=12(1,4,2,3,1,4,3,2)] treat
9 fact [le=4; la=1(Monaro,Alpine,Kentucky,Porters,Pass)] spp ; \
10 va=1(3(1,4)8)
11 read apr94wc.prr;2;input
12 read [ch=2] grass, rhz_clo, whi_clo, red_clo, bare_gnd, weed, dead
13 print rep, treat, spp, column,row,strip,grass,
14 matrix [rows=1(2,grazing', 'intensity', 'interaction'); columns=4; values=]
15 -1, -1, 1, 1, \
16 -1, 1, -1, 1] m1
17 matrix [rows=1(1,Monaro vs WC'); columns=4; values=-3,1,1,1] m2
18 block (rep/column)+(row/strip)+rep, column,row
19 treat reg(treat;3;m1)* reg(spp;1;m2)
20 for dummy = grass, rhz_clo, whi_clo, red_clo, bare_gnd, weed, dead ;
21 any. [fprob=y; des=z-zx-z] rhz_clo
22 endfor ;
23 stop

```

Appendix 6 Probabilities for all variates and contrasts for the grass component of the pastures.

Variate	Nov 93	Dec 93	Jan 94	Feb 94	Mar 94	Apr 94
Treatment	p<0.048 *	p<0.188	p<0.203	p<0.026 *	p<0.030 *	p<0.022 *
Frequency	p<0.019	p<0.296	p<0.257	p<0.012 *	p<0.013 *	p<0.371
Intensity	p<0.034 *	p<0.126	p<0.105	p<0.047 *	p<0.088	p<0.006 **
Interaction	p<0.058	p<0.165	p<0.311	p<0.138	p<0.092	p<0.403
Species	p<0.116	p<0.020 *	p<0.88	p<0.059	p<0.181	p<0.046 *
CCvsZZ	p<0.078	p<0.006 **	p<0.065	p<0.028 *	p<0.043 *	p<0.018 *
Deviation	p<0.184	p<0.191	p<0.510	p<0.175	p<0.895	p<0.182
Treatment *	p<0.536	p<0.431	p<0.733	p<0.489	p<0.781	p<0.360
Species						
Frequency	p<0.752	p<0.933	p<0.750	p<0.548	p<0.461	p<0.469
CCvsZZ						
Intensity	p<0.031 *	p<0.615	p<0.084	p<0.139	p<0.290	p<0.030 *
CCvsZZ						
Frequency	p<0.554	p<0.077	p<0.310	p<0.161	p<0.886	p<0.837
Deviation						
Interaction	p<0.838	p<0.900	p<0.720	p<0.923	p<0.483	p<0.638
CCvsZZ						
Intensity	p<0.671	p<0.794	p<0.890	p<0.749	p<0.686	p<0.618
Deviation						
Deviation	p<0.614	p<0.220	p<0.975	p<0.459	p<0.321	p<0.219

Appendix 7 Probabilities for all variates and contrasts for the rhizomatous clover (%) component of the pastures.

Variate	Nov 93	Dec 93	Jan 94	Feb 94	Mar 94	Apr 94
Treatment	p<0.001 **	p<0.104	p<0.304	p<0.209	p<0.043 *	p<0.117
Frequency	p<0.001 **	p<0.056	p<0.104	p<0.098	p<0.018 *	p<0.094
Intensity	p<0.269	p<0.840	p<0.631	p<0.254	p<0.071	p<0.122
Interaction	p<0.023 *	p<0.085	p<0.906	p<0.437	p<0.294	p<0.147
Species	p<0.001 **	p<0.001 **	p<0.002 **	p<0.001 **	p<0.001 **	p<0.001 **
CCvsZZ	p<0.001 **	p<0.003 **	p<0.004 **	p<0.001 **	p<0.001 **	p<0.001 **
Deviation	p<0.001 **	p<0.002 **	p<0.003 **	p<0.061	p<0.001 **	p<0.002 **
Treatment *	p<0.349	p<0.694	p<0.040 *	p<0.002 **	p<0.006 **	p<0.020 *
Species						
Frequency	p<0.673	p<0.902	p<0.048 *	p<0.016 *	p<0.021 *	p<0.187
CCvsZZ						
Intensity	p<0.208	p<0.582	p<0.015	p<0.028 *	p<0.001 **	p<0.006 **
CCvsZZ						
Frequency	p<0.041 *	p<0.455	p<0.026 *	p<0.525	p<0.341	p<0.054
Deviation						
Interaction	p<0.629	p<0.951	p<0.433	p<0.186	p<0.031 *	p<0.087
CCvsZZ						
Intensity	p<0.587	p<0.590	p<0.994	p<0.223	p<0.801	p<0.290
Deviation						
Deviation	p<0.823	p<0.190	p<0.754	p<0.868	p<0.900	p<0.826

Appendix 8 Probabilities for all variates and contrasts for the white clover component of the pastures.

Variate	Nov 93	Dec 93	Jan 94	Feb 94	Mar 94	Apr 94
Treatment	p<0.189	p<0.177	p<0.079	p<0.002 **	p<0.001 **	p<0.012 *
Frequency	p<0.062	p<0.055	p<0.028 *	p<0.006 **	p<0.001 **	p<0.011 *
Intensity	p<0.655	p<0.530	p<0.449	p<0.001 **	p<0.001 **	p<0.021 *
Interaction	p<0.525	p<0.931	p<0.197	p<0.002 **	p<0.001 **	p<0.017 *
Species	p<0.056	p<0.003 **	p<0.012 *	p<0.035 *	p<0.370	p<0.468
CCvsZZ	p<0.118	p<0.007 **	p<0.077	p<0.138	p<0.804	p<0.659
Deviation	p<0.051	p<0.004 **	p<0.009 **	p<0.027 *	p<0.236	p<0.330
Treatment * Species	p<0.744	p<0.356	p<0.955	p<0.086	p<0.168	p<0.165
Frequency CCvsZZ	p<0.218	p<0.142	p<0.762	p<0.199	p<0.072	p<0.309
Intensity CCvsZZ	p<0.337	p<0.375	p<0.762	p<0.509	p<0.740	p<0.642
Frequency Deviation	p<0.534	p<0.559	p<0.969	p<0.404	p<0.540	p<0.808
Interaction CCvsZZ	p<0.731	p<0.686	p<0.218	p<0.626	p<0.699	p<0.207
Intensity Deviation	p<0.960	p<0.510	p<0.576	p<0.112	p<0.194	p<0.481
Deviation	p<0.385	p<0.116	p<0.909	p<0.029 *	p<0.078	p<0.017 *

Appendix 9 Botanical composition and legume content of the mean of each grazing treatment through the 1993/94 sampling periods

Pasture Components	Grazing treatments																							
	November				December				January				February				March				April			
	ssh	ssl	rgh	rgl	ssh	ssl	rgh	rgl	ssh	ssl	rgh	rgl	ssh	ssl	rgh	rgl	ssh	ssl	rgh	rgl	ssh	ssl	rgh	rgl
Grass	47	55	53	54	47	47	46	55	52	61	59	61	43	49	52	53	45	49	52	52	44	54	44	57
Monaro	13	13	21	18	11	15	17	14	12	10	18	16	12	10	18	12	10	9	17	11	10	9	12	7
White clover	10	10	7	8	17	18	12	13	16	12	6	8	20	6	9	8	18	7	5	5	15	5	4	4
Other*	30	22	19	20	15	20	15	18	20	17	17	15	15	35	21	27	27	35	26	32	31	32	40	32
Legume content**	23	23	28	26	28	33	29	27	28	22	24	24	32	16	27	20	28	16	22	16	25	14	16	11

* Other includes in order of contribution, dead material, bare ground, weeds, red clover.

** Legume content only includes Monaro and white clover

Appendix 10 Mean legume content of all treatments through the 1993/94 sampling periods.

Clover	Monthly means					
	November	December	January	February	March	April
Monaro	17	14	14	13	12	9
White clover	10	16	11	12	9	8
Total	27	30	25	25	21	17