A review of legume introduction in tussock grasslands with particular reference to species tolerant of low nutrient inputs

James G. H. White

Professor Emeritus, Department of Plant Science, P O Box 84, Lincoln University, Canterbury.

Abstract

The agronomic limitations of white clover in tussock grasslands are outlined, and efforts to select or breed cultivars of white clover with tolerance of low soil phosphate status are briefly reviewed. The advantages of Maku lotus and Russell lupin as legumes with high phosphate efficiency and acid tolerance are reviewed and their agronomic advantages and limitations are described. It is concluded that Caucasian clover shows most promise as a low-input legume for the tussock grasslands, because of its ability to develop a large rhizome/root system, which allows it to persist and produce for many years under a range of grazing managements and irregular topdressing.

Additional key words: *white clover*, Trifolium repens, *Maku lotus*, Lotus pedunculatus, *Russell lupin*, Lupinus polyphyllus, *Caucasian clover*, Trifolium ambiguum, *low-input legumes, tussock grasslands, high country.*

Introduction

For over 20 years agronomists have been searching for legumes that are able to grow in the low fertility conditions of tussock grasslands with minimal fertiliser inputs, and which survive and spread in these conditions, withstand grazing by sheep and rabbits, and yet produce good quantities of quality herbage and fix nitrogen for associated grasses. It is only now that some progress can be reported. The quest for such plants has been spurred on by lower returns from livestock in the high country, coupled with the withdrawal of Government subsidies for farm development in the early 1980s. Consequently, white clover (*Trifolium repens* L) the standard legume used in improvement, has declined in productivity or even disappeared almost completely from many previously-improved tussock blocks because farmers cannot afford a prime requirement for existing cultivars; the application of fertiliser annually or biennially. High country pastoral systems based on white clover can only be sustained when prices for fine wool and other animal products are high. If new low-input legume-based systems are not developed, the exploitative pastoralism which commenced 140 years ago will continue, resulting in further decline in plant cover and soil fertility in the more fragile parts of the high country.

Successful legumes in this environment need to have most or all of the following attributes:

- high nutrient use efficiency, especially for phosphorus and sulphur.
- ability to compete for nutrients with resident vegetation such as mouse-eared hawkweed or browntop.
- tolerance of acid soils and high soluble aluminium levels.
- good nodulation and symbiotic nitrogen fixation.
- easy and low cost establishment from oversowing or direct drilling.
- ability to survive and spread from initial establishment, e.g., good seed production and dispersal, rhizomatous or stoloniferous growth.
- production of many growing points at or below ground level to allow the species to survive close grazing by sheep.
- tolerance or resistance to grassgrub and other insect pests.
- good quantities of high quality dry matter.
- good commercial seed production potential.

This paper discusses the low-input possibilities of white clover, Maku lotus, (*Lotus pedunculatus* Cav.), Russell lupin (*Lupinus polyphyllus*) and Caucasian clover (*Trifolium ambiguum* M.Bieb), particularly reviewing research by staff and postgraduates of the Plant Science Department at Lincoln University. Other legumes with low-input attributes include zigzag clover (*Trifolium medium* L.), *Lotus corniculatus* L., and the shrubs broom (*Cytisus* spp) and gorse (*Ulex europaeus* L.).

Which Legume?

1. White Clover (*Trifolium repens*)

Much research on the introduction, production and management of white clover in the tussock grasslands of New Zealand has been conducted in the last 40 years (e.g., Ludecke and Molloy, 1966; Keoghan and Allan, 1992), but little progress has been made on its adaptation to low nutrient inputs.

White clover is easily and cheaply established from seed, it responds quickly to fertiliser addition, and has the ability to spread by stolons and by seed dispersal (Patterson, 1993). It fixes large quantities of nitrogen and increases both quantity and quality of dry matter several fold in the first five years from its introduction, both from the clover itself and from associated grasses stimulated by nitrogen transferred from the clover (Kee, 1981). Because of these attributes it is not surprising that scientists should seek ecotypes which are more efficient than our present cultivars in the use of phosphate and other nutrients. Populations of white clover tolerant of low soil phosphate levels were first identified in Welsh hill country (Snaydon and Bradshaw, 1962), and the parents of Grasslands Tahora were obtained from low fertility North Island hill country with this attribute in mind (Williams and Caradus, 1979). Disappointingly, in subsequent testing at Ballantrae, Tahora failed to show any significant advantage over Huia at low phosphate levels (Williams *et al.*, 1982). Caradus has continued to search for ecotypes with tolerance of low-phosphorus soils (Caradus *et al.*, 1991) by screening 119 white clover cultivars and breeding lines from 25 different countries. In addition he has made selections for tolerance to high soil aluminium (Caradus, Mackay and Wewela; 1991, Crush and Caradus, 1992).

This work of Caradus and fellow scientists has not yet resulted in new, low input cultivars for the tussock grasslands. However, it is possible that low fertility tolerant ecotypes already occur as resident clover in the tussock grasslands. Patterson (1993) collected seed from resident white clover growing on soil deficient in P and S on Longslip Station in the Ahuriri valley, North Otago. He compared the growth and root development of this ecotype with Huia in a pot trial (Table 1). The resident clover had many of the characteristics of Tahora (Williams *et al.*, 1982), with more, longer stolons than Huia, smaller leaf size, but higher dry matter production. Patterson (1993) observed that the resident clover had a very extensive fibrous root system, much greater than Huia, an attribute known to occur in white clover populations adapted to low-P soils (Caradus, 1994).

Table 1. Comparison of Huia and resident white clover, Longslip Station, North Otago. (Patterson, 1993)

	Huia	Resident
DW/plant (g)	0.36	0.40
Stolons/plant	2.5	5.6
Longest stolon (cm)	4.4	10.1
Leaflet length (cm)	1.3	1.0

Unfortunately he did not include rates of phosphate in the pot trial. Further research on AgResearch Grasslands breeding material, and on local ecotypes of white clover, may prove fruitful in obtaining low-nutrient input white clovers.

2. Lotus (*Lotus pedunculatus*)

The release of tetraploid Grasslands Maku lotus in 1973 (Armstrong, 1974) sparked a series of experiments in the tussock grasslands comparing this legume with Huia white clover. Early work by Brock (1973) in the Manawatu had already indicated that Maku could be important as a low input legume, when he measured yields of 30% more than white clover from a low P input. These results were confirmed on a moist acid yellow-brown earth (pH 5.25) at Mesopotamia Station, where Maku outyielded Huia by 40% (Lucas *et al.*, 1981), and at a range of moist sites in Otago (Scott and Mills, 1981) where Maku outyielded Huia by 3:1, particularly on soils where the pH ranged from 4.6 - 5.0. Scott and Mills (1981) concluded that Maku lotus was favoured over Huia white clover when the soil pH declined below 5.2, and the superior P efficiency was partly due to its ability to tolerate high levels of exchangeable Al in these acid soils, a factor already observed by Nordmeyer and Davis (1977) and Davis (1981).

Kee (1981) made an intensive study of the Mesopotamia field experiment established by Plant Science staff at Lincoln University (Lucas *et al.*, 1981) in 1975. This trial compared oversown Maku lotus, Huia white clover and Prairie Caucasian clover at four levels of establishment phosphate (10, 25, 50 and 100 kg P/ha) and three levels of maintenance fertiliser (zero control, and 125 kg superphosphate either annually, or biennially). He found that both P and N yields in legume herbage harvested in spring of 1978 and 1979 were significantly higher from lotus than white clover, which in turn was much higher than Caucasian clover (Table 2). This was partly due to higher dry matter yields (Lucas *et al.*, 1981) but also because of higher P and N concentrations in the herbage (Fig. 1).

Kee (1981) found that the P uptake efficiency of lotus measured in terms of kg of P recovered in the herbage per kg of P applied was significantly higher than for white or Caucasian clovers (Table 3). Using ^{32}P labelled phosphate he found that lotus absorbed P from a greater distance laterally in the soil than white clover, while in solution culture lotus roots were significantly more efficient in P uptake, especially from dilute P solutions.

In a grazing trial on an acid (pH 4.8) yellow-brown earth at Waiora hill farm, Invermay, Lowther (1991) found that 3 years after P topdressing ceased, the legume component of a white clover sward declined to 35% of biennially topdressed plots, compared to 66% with Maku

Table 2. Phosphorus and nitrogen yield (kg/ha) in legumes and grass, from spring cuts in 1978 and 1979, Mesopotamia (Kee, 1981)

	Legume		Grass	
	P	N	P	N
Maku lotus	3.74	45.0	2.13	11.2
White clover	2.35	31.8	2.84	15.5
Caucasian clover	1.81	21.7	0.96	4.6
Significance	***	***	***	***
S.E.M.	0.20	2.3	0.18	2.5

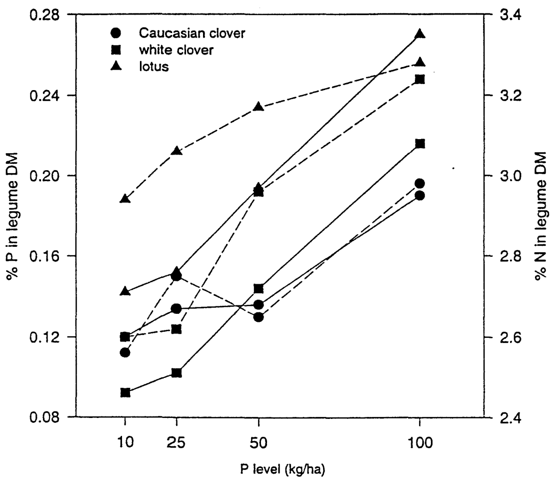

Figure 1. Effects of establishment P on P (——) and N (----) concentrations in legume DM harvested in spring 1977 (Kee, 1981).

Table 3. Efficiency of P recovery as measured by kg P recovered in above ground herbage per kg P applied, Mesopotamia (Mean of 1978 and 1979 spring harvests, Kee, 1981).

	Legume	Grass
Maku lotus	0.119	0.073
White clover	0.078	0.082
Caucasian clover	0.049	0.035
Signif.	***	**
S.E.M.	0.007	0.006

lotus, with little further change in the final 3 years of the trial. Lowther advocated the use of Maku lotus in moist P deficient tussock grassland where P is applied infrequently.

Maku lotus has other valuable attributes besides high P efficiency. It is resistant to grass grub (*Costelytra zealandica)* because of the presence of saponins in its roots (Sutherland, 1976; Lucas *et al.*, 1981) and is nonbloating because of the presence of condensed tannins in the herbage (Ulyatt *et al.*, 1977). In spite of these attributes Maku lotus has not become widely used by run holders. Establishment failure can occur (Patterson, 1993) as it has low seedling vigour and requires specific rhizobia for establishment, while there is little spread by seed dispersal (Wedderburn and Lowther, 1985). Although it can spread laterally by short rhizomes, these only develop satisfactorily from autumn spelling. The weakest feature of this plant is the low number of growing points which are produced, coupled with slow regeneration from grazing (Sheath, 1981). It is consequently intolerant of set stocking which will cause it to quickly disappear. It will only persist under lax or long rotational grazing as used by Lowther (1991), i.e., three grazings annually. In conclusion, because Maku lotus has limited competitive ability, its use should be confined to soils of low P status, and under lax grazing.

3. Russell lupin (*Lupinus polyphyllus*)

The horticultural escape, Russell lupin has attracted the attention of both agronomists and farmers in recent years because of its ability to establish and spread on moist, moderate fertility, unimproved acid sites in the tussock grasslands. The present populations were either garden escapes or were introduced by locals, (e.g., Mrs Connie Scott, Godley Peaks Station) to stabilise Tekapo roadsides or avalanche debris at the Hermitage, Mt. Cook

(Scott, 1993), and have since spread widely along roadsides and in riverbeds.

Research by the Forest Research Institute (Davis, 1981) showed that lupin was capable of growing on acid subsoils (pH 5.0) in the presence of high levels of soluble Al and limited supplies of P, whereas white clover failed to thrive. The lupin seemed to actively exclude Al uptake, accumulating only 175 ppm in the tops, whereas white clover levels reached 569 ppm.

Davis established a field trial on Mt Possession Station in 1979 (pH 5.3, Olsen P 5) comparing Russell lupin with eight other legumes under nine different phosphate levels ranging from nil to 800 kg P/ha (Davis, 1991). The lupin grew well and showed no positive response to phosphate. It fixed nitrogen at all levels of phosphate as evidenced by the growth of browntop *(Agrostis capillaris)* and sweet vernal *(Anthoxanthum odoratum)* along the whole P gradient 13 years later (Svavarsdottir *et al.*, 1994; Svavarsdottir, 1995). White, red (*Trifolium pratense*) and alsike (*T. hybridum*) clovers only thrived at higher P treatments, suggesting that Russell lupin is capable of extracting soil P not available to the clovers. In 1982, Grasslands Division, DSIR established a long-term grazing trial at Mt John, in the Mackenzie country, where Russell lupin was mixed with 22 other species. The lupin quickly became the dominant legume at low P inputs, (Scott and Covacevich, 1987) and has remained dominant, especially under lax grazing. (Scott *et al.*, 1989).

White *et al.* (1996) and Jarvis (unpubl.) have further quantified the fertiliser requirements of Russell lupin in an experiment on an acid yellow-brown earth (pH 5.3) deficient in P (Olsen P 6), and S (2 ppm), established at Mesopotamia Station in 1990. No growth of lupin occurred unless sulphur was supplied. In the first year triple superphosphate was superior to rock phosphate, but by the second year rock phosphate was superior (Fig. 2). In the third and subsequent years responses to either form of P had largely disappeared, suggesting that some mechanism, possibly proteoid root development, had allowed the lupin to extract P from soil receiving no other fertiliser than sulphur. Although proteoid roots have not been reported for Russell lupin, they have been identified for *Lupinus albus* (Gardner and Parbery, 1982) and possible P mobilisation mechanisms described (Gardner *et al.*, 1983).

Overdrilling is a simple way of establishment (Scott and Covacevich, 1987; Scott, 1989; White *et al.*, 1996) where topography permits, but broadcasting is also possible (Scott, 1989). Inoculation of the seed with the specific strain of rhizobia is a wise precaution for sites where lupins have not grown previously. Young seedlings are susceptible to close grazing and stock should be withheld in the first season (Scott, 1989; White, unpubl.).

Lupin seeds readily and spreads several metres following the explosive bursting of seed pods in hot strong north-west wind conditions. This seed germinates readily on the soil surface, often at quite low temperatures (Svavarsdottir, 1995; White *et al.*, 1996), while a proportion remains hard and will germinate in later years.

Lupin does not survive continuous set stocking, although plants can be periodically grazed to ground level, provided they are allowed to recover. Lax grazing at low to moderate stocking rates is probably preferred (Scott and Covacevich, 1987; Scott, 1989). Russell lupin contains an alkaloid which increases in level in summer when flowers and pods are produced, resulting in reduced palatability at podding, thus allowing some seed to mature (Gibbs, 1988). In a comparison of Russell lupin, red clover and alsike under grazing by young Merino wethers over five years, Scott *et al.* (1994) found that while lupin gave the highest amount of feed on offer, it produced the lowest per animal weight gain, only 53% of Pawera red clover, which gave 110 g/day.

Because lupin grows to a metre in height at flowering, it has a pronounced shading effect on prostrate, light-demanding plants. In particular, mouse-eared hawkweed *(Hieracium pilosella)* is significantly

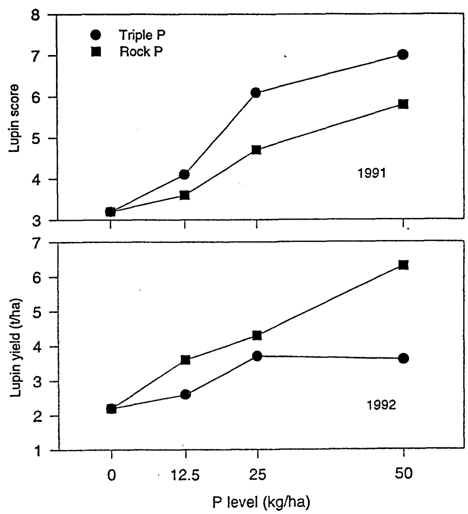

Figure 2. Russell lupin DM production in the first two years in response to form and level of phosphorus (White, Jarvis and Lucas, 1996).

reduced by the low light levels (Svavarsdottir, 1995) while the leaves of surviving plants grow more vertically, seeking light, and are thus able to be grazed by livestock (White, unpublished).

Lupin is known to fix large quantities of nitrogen (Davis, 1991) which becomes available to associated browntop, sweet vernal and cocksfoot (*Dactylis glomerata*) after 1-2 years of growth (Davis, 1991; Svavarsdottir, 1995; White *et al.*, 1996). Because of its tall stature lupin is less likely to be shaded by these associated grasses than prostrate legumes such as white clover.

In conclusion Russell lupin can be used on acid, low phosphate soils, but requires sulphur and needs lax grazing to thrive.

4. Caucasian Clover (*Trifolium ambiguum*)

A native of Caucasian Russia, Turkey and Iran, Caucasian clover was introduced into Australia in 1931 by CSIRO, Canberra (Bryant, 1974). Alan Nordmeyer, of Forest Research Institute obtained several ploidy lines from CSIRO in 1970 and tested them at Rangiora and at various sites in the Craigieburn Ranges. He quickly recognised that this perennial clover had valuable attributes for soil stabilisation and for sustainable grazing systems in the high country. With the release of hexaploid cultivars such as Monaro which were specifically bred for pastoral use (Dear and Zorin, 1985), research in New Zealand has concentrated on Caucasian clover as a grazing plant in recent years.

Bryant (1974), in his review, identified a number of valuable characteristics such as persistence under heavy seasonal grazing, early spring growth, vigorous rhizome development, ability to grow in acid soils, and both cold and drought tolerance. The drought tolerance of Caucasian clover has been confirmed by both Spencer and Hely (1982) and by Woodman *et al.* (1992), and is associated with the development of a strong deep root system. Early field experiments where Caucasian clover was included were established at Mesopotamia in 1975 (Lucas *et al.,* 1981), Mt Possession in 1979 (Davis, 1991; Svavarsdottir *et al.*, 1994), Mt John in 1982 (Scott and Covacevich, 1987) and Tara Hills research station in 1984 (Allan and Keoghan, 1994). At the first three sites Caucasian clover was relatively slow to establish compared to white clover, especially at Mesopotamia where seed was broadcast on the soil surface. Part of the reason was related to slow, ineffective nodulation, a problem earlier identified by Australian workers (Zorin *et al.*, 1976). Recent work (Patrick *et al.*, 1994) has shown that the combination of a high rate of the correct strain of inoculum with gum arabic sticker and lime pelleting will overcome the problem. Using this technique Lowther and Patrick (1992) achieved nodulation and establishment of broadcast Monaro Caucasian clover equal to that of white clover. Where the terrain permits, sod-seeding is a much superior method to broadcasting, particularly where a strip seeder (Horrell *et al.*, 1991) is used. With this technique Moorhead *et al.* (1994) have had outstanding success in a browntop/mouse-eared hawkweed dominant sward at Mesopotamia, obtaining excellent establishment, good nodulation and strong rhizome development within 6 months of sowing. A standard sod seeding treatment was almost as good but broadcast plants were few in number, small and lacking any rhizome development in the first 6 months.

In contrast to Maku lotus and Russell lupin there is little evidence to suggest that Caucasian clover is more efficient than white clover in competing for phosphate or other nutrients. The Mesopotamia experiment (Lucas *et al.*, 1981; Kee, 1981) showed a similar but lower P response curve to white clover, while the total P and N accumulated in above-ground biomass (Table 2) was significantly less. The P efficiency of Caucasian clover was 63 % of white clover and only 41 % of Maku lotus (Table 3). In solution culture Kee (1981) found that Caucasian clover roots were significantly shorter and root diameter larger per unit weight than white clover or Maku lotus, and that efficiency of P uptake and translocation of absorbed P was also inferior. Spencer and Hely (1982) found similar results to Kee (1981) in a five year field trial in the Australian highlands. They found that both Caucasian and white clovers were highly responsive to P fertiliser. The lower responses of Caucasian clover to P in the first two years, also recorded by Kee (1981) and Lucas *et al.* (1981) were attributed to the preferential development of roots rather than shoots.

The findings of Kee (1981) are somewhat misleading as neither Lucas *et al.* (1981) nor Kee (1981) measured root and rhizome biomass in the field. The development of long rhizomes which enables Caucasian clover to spread laterally and produce new aerial shoots at the nodes is an important feature of the plant. The underground biomass of rhizomes and roots increases over time, and mature plants commonly have a rhizome/root:top ratio of 3 or higher (Table 4).

High rates of fertiliser applied at establishment accelerate plant growth and rhizome development (Moorhead *et al.*, 1994; Strachan *et al.*, 1994). In the ungrazed field trial at Mt Possession only 3t/ha of below-ground biomass was measured in plots receiving 50 kg P 13 years previously, but 15t were recorded with 200 kg

Table 4. Root/rhizome: shoot ratio of Caucasian clover.

Location	Ratio	Plant age	Source
Victorian Mts, Aust.	3.13	17 months	Spencer *et al.* (1975)
Victorian Mts, Aust.	5.73	12 months	Spencer and Hely (1982)
Mesopotamia	2.73	9 years	Daly and Mason (1987)
Mesopotamia	3.15 sod-seeded 3.36 strip seeded	6 months	Moorhead *et al.* (1994)
Mt Possession	4.60	13 years	Strachan *et al.* (1994)

of P and over 20t where 800 kg of P was topdressed (Strachan *et al.*, 1994). This is partly the reason why Lucas *et al.* (1981) and Kee (1981) recorded lower top growth from Caucasian clover than from white clover and Maku lotus in the first 4 years; much of the biomass was accumulating underground.

This large underground biomass acts as an important store of nutrients which can be remobilised for growth in the absence of regular topdressing. For example, Strachan *et al.* (1994) measured 58 kg P/ha stored in the best plots at Mt Possession, equivalent to the P contained in 650 kg of superphosphate.

The persistence and often the continued dominance of Caucasian clover in long-term trials is a feature which is only now beginning to emerge (Daly and Mason, 1987; Yates 1993; Allan and Keoghan, 1994; Strachan *et al.*, 1994; Svavarsdottir *et al.,* 1994; Svavarsdottir, 1995; Virgona and Dear, 1995). At Mesopotamia the last maintenance superphosphate was applied in 1981 and white clover declined rapidly in the next three years because of grassgrub attack and competition from browntop, while Maku lotus also declined due to grass competition and the effects of heavy mob stocking. By 1984 Caucasian clover plots yielded almost double those of white clover and Maku lotus, with a legume content of 27 %, twice that of the other two legumes (Daly and Mason, 1987). This advantage has continued to the present (1995) (Lucas, Jarvis and White, unpubl., with Caucasian clover plots containing a high legume content. They are grazed closely under set stocking by deer, while white clover and Maku lotus plots contain largely rank browntop, sweet vernal and dead material untouched by animals.

The main reason for Caucasian clover persistence and dominance without maintenance fertiliser in the long-term experiments at Mesopotamia and Mt Possession is likely to be the ability of the plant to store and reutilise nutrients from its below-ground biomass. There are also indications that Caucasian clover competes strongly with resident grasses, partly because of slower cycling of fixed N compared with white clover and lotus (Lucas *et al.*, 1981; Kee, 1981; Table 2 and Fig. 1), and possibly by competition for moisture by the large underground biomass (Svavarsdottir, 1995). After a period of years without fertiliser, Caucasian clover is capable of responding quickly and strongly to topdressing (Virgona and Dear, 1996) a valuable attribute under low-input systems on high country farms. Caucasian clover is also tolerant of grassgrub attack. Lucas (unpubl.) has observed that the larvae will eat the finer roots but larger taproots and rhizomes will survive.

Because many of its growing points are below ground level, Caucasian clover is very tolerant of continuous grazing and will continue to spread laterally. After 20 years rhizomes have spread up to 2-3m outside the original plots at Mesopotamia (Lucas, Jarvis and White unpubl.) under set stocking by deer, while new plants have spread from seed dispersal at Mt Possession (White, unpubl.). In 1984, Allan and Keoghan (1994) planted a wide range of legumes and grasses into each of 9 different stocking rate/management systems at Tara Hills research station and found that Monaro Caucasian clover was exceptional in its plant survival and spread and was ranked first out of 56 germplasm lines under examination. The Caucasian clover averaged 58 cm spread in 9 years from planting and achieved this under a very wide range of Merino sheep grazing management systems. Lucas *et al.* (1995) found that at Lincoln, Caucasian clover performed much better under rotational grazing than under set stocking, but further large scale grazing experiments are still required to evaluate pasture quality, seasonal production, and annual performance of this unique clover in commonly-used high country management systems.

The major factor which is restricting farm-scale use of Caucasian clover is shortage of seed. Caucasian clover is cross-pollinated, but is attractive to bees. Daly *et al.* (1993) measured up to 400 kg seed/ha from small plots, while establishment techniques for seed production have been evaluated by Steiner and Snelling (1994). The production of seed in Canterbury is affected by competition from white clover (Daly *et al.*, 1993) which occurs as hard seed in most cropping soils. Selection and development of cultivars with potential for high seed yields is being carried out by a local seed company, and once this is completed seed supplies at reasonable prices should become available.

Summary and Conclusions

High country farmers are finding that they can only afford the relatively high-cost system of white clover based pastures on relatively small areas of higher fertility flats, terraces and low hills. If sustainable pastoral systems are to be developed on a wider scale in the high country, then alternative legumes with improved adaptation to soils of lower nutrient status than the current white clover cultivars must be used. This review identifies the most promising legumes for this purpose, and summarises present knowledge of their attributes for pastoral farming.

No nutrient efficient white clovers are yet available, while Maku lotus, although P efficient and Al tolerant, has limited use on farms because of its limited competitive ability and susceptibility to set stocking particularly at moderate to high rates. Russell lupin is P efficient and acid tolerant, and may be more widely used in future under lax grazing systems, but has some limitations in animal performance compared to clovers. Neither Maku lotus nor Russell lupin are yet known to show improved efficiency of sulphur use, which means that levels of S similar to the needs of white clover should be applied to these legumes. The most promising of the four legumes for low-input systems is Caucasian clover because its large rhizome/root system allows it to be persistent under a range of managements. It is able to survive and produce when fertiliser is withheld for several years, but gives a quick response via its underground rhizome system when further fertiliser is applied.

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