Agronomic potential of Russell lupin (*Lupinus polyphyllus* L.) as a legume for high country grazing systems.

Literature Review

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Executive Summary

This review refers to the considerable body of research on perennial lupin (*Lupinus polyphyllus* L.) by Dr David Scott at Mt John, Tekapo, together with the limited number of New Zealand and international publications plus some unpublished results from current contract research by Lincoln University staff and students sponsored by Merino New Zealand.

Perennial lupin is often referred to as Russell lupin but there are other forms growing wild and in cultivation. The plant is a herbaceous perennial that grows up to 1.5 m high; giving it a competitive advantage over shorter associated species in grazed pastures. It dies back to a stout crown each winter and it can spread by prolific reseeding. Its ability to grow in acidic soils (pH < 5.5) with high exchangeable aluminium (soil Al >3 is toxic to clovers and lucerne) and low soil phosphorus (Olsen P < 10) means that perennial lupins are well adapted to soils where conventional pasture legumes will not thrive without large inputs of lime and fertiliser. Perennial lupin has persisted and out-yielded other pasture legumes at several low fertility, high country sites. Most notably at Mt John where lupins supported the greatest number of sheep grazing days. It does not thrive in very low rainfall areas (< 500 mm), and prefers well drained sites in medium and high rainfall zones (>600 mm).

In grazed pastures, the alkaloid content of perennial lupins is sufficient to inhibit rapid herbage intakes by ruminants, and offers resilience against any insect pests. Low grazing preference by sheep of the primary legume in a pasture can be advantageous. Species such as white clover are normally preferentially grazed and rarely exceed 15% of herbage on offer in a mixed sward. In contrast, lupins with a lower grazing preference can persist as a dominant species in pastures for decades. Hence, high protein herbage continues to be produced and high rates of nitrogen cycling can be maintained. Lupin flowers and leaves, which have lower levels of the bitter tasting alkaloids, are preferentially grazed. Mature seed is protected by high alkaloid content and is unlikely to be eaten. No toxic effects of lupin alkaloids on livestock have been identified. It is assumed that stock are protected from excessive consumption by the bitterness of alkaloids. It has been suggested that the selection of lower or nil alkaloid perennial lupin cultivars would be advantageous, but increased grazing preference would be likely to result in reduced persistence.

Lupinosis is a mycotoxicosis caused by the ingestion of toxins produced by the fungus *Phomopsis leptostromiformis* and has not been recorded on sheep grazing perennial lupin in New Zealand. It is a condition that occurs in Australia when sheep graze mature annual lupins and out of season rains encourage fungal growth.

Establishment of perennial lupin pastures can be straight forward but the high price of the relatively large seed may encourage some farmers to adopt a prolonged establishment phase where low rates (2 to 4 kg/ha) of lupin seed are sown and the initial establishment is managed to set seed to ‘thicken up’ the initial lupin population. Rapid establishment of a lupin based pasture will normally require herbicide treatment of resident vegetation and possibly winter greenfeed crop(s) before direct drilling with 8 to 12 kg seed/ha, a desirable companion grass species (e.g. cocksfoot), and one clover (e.g. Caucasian). Preferred time of sowing will vary with environment. Commercial lupin seed should be scarified so that germination is at least 70 %. Ideal sowing depth is between 10 and 20 mm. Lupin seed will germinate and establish from broadcast sowings but success will be strongly influenced by surface conditions such as litter presence and timely rainfall. Seed inoculation with respective rhizobial inoculants is desirable to get rapid nodulation. Maximum nitrogen fixation rates have been estimated at about 200 kg N/ha/year. However, if it is assumed 25 kg N is fixed per ton of lupin dry matter produced, greater amounts of N may be fixed from dense lupin stands under favourable conditions.

While it may seem from the summary above that sufficient is known about perennial lupin as a pasture legume, our knowledge is wanting in several important areas. These relate to environmental as well as production unknowns. For instance:

- Research is required to determine nitrogen relationships; a vital question here relates to the behaviour of lupin N fixation in the presence of high levels of available soil N. Does it cease N fixation and use the easily available soil N or does it continue to fix N in the presence of high nitrate levels? This has implications in relation to N leaching and species succession.
- Grazing experiments are required to compare animal performance from lupin based pastures with standard conventional mixtures and lucerne; a component of that would include measurement of species performance under the lupin canopy.
- Detailed study of lupin growth and development would provide a rationale for any specific seasonal grazing management requirements; this would include assessment of the need for autumn spelling to build root reserves for spring regrowth plus responses to grazing intensity and apical dominance.
- When/if cultivars with varying alkaloid contents are developed, grazing studies will be required before they are released commercially.
- There is a lot of qualitative data surrounding lupin response to fertilizer but no systematic studies have been conducted to define these by soil type or environment.

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1 Introduction

High country rangeland and developed pastures in the South Island of New Zealand cover approximately 3.4 million hectares (Scott *et al.*, 1995). In this area the growth and persistence of conventional forage legumes such as white clover (*Trifolium repens* L.) and lucerne (*Medicago sativa* L.) are often limited by soil and climatic conditions (Scott *et al.*, 1995). Therefore, finding alternative forage legumes that are suited to dry and/or infertile soils, to initiate nitrogen cycling in hill country pastures is a priority for research.

A wide ranging review of forage species suitability in the New Zealand high country was given in Scott *et al.* (1995). This review defined species suitability in terms of four environmental gradients: temperature in terms of latitude, altitude, aspect and slope; soil moisture in terms of rainfall, drainage, soil depth, and irrigation; soil fertility – either natural or applied; and the interaction of grazing and treading (= grazing management) with the growing points of species. Within those gradients, each forage species had a niche where it could be considered as the most appropriate and productive species to grow. That review suggested that *L. polyphyllus* was the most suitable legume species for loose textured soils, under low rates of sulphur fortified superphosphate (Scott, 1989a), in the moderate to high rainfall areas, or seepage and streamside areas of dry zones. It saw *L. polyphyllus* as either a general purpose over-sowing species, or more latterly as a 'special purpose' pasture.

The validation and demonstration of the use of environmental gradients to determine species suitability within those gradients has been the basis of the three decade study at Mt John (Lake Tekapo) and other experimental sites. However, a wider range of sites and more accurate quantification of results is required to confirm the environmental gradients and plant responses.

This review discusses the agronomic potential of *L. polyphyllus* as a forage legume for high country pastures in the South Island of New Zealand.

2 *Lupinus* species within New Zealand

There are currently three perennial *Lupinus* species in NZ; ***L. polyphyllus, L. arboreus, L. perennis.***

These three perennial lupins are native to western North America. *L. polyphyllus* was introduced to eastern Europe in the late 1700's/early 1800's and is apparently now relatively wide spread. We do not know of its relative abundance there as a horticulture, adventive or animal fodder species. It was one of the species used in Germany for the development of plant tissue culture methods (Wink, 1987).

> ***L. polyphyllus***: The older straggly blue-flowered form of the horticultural 'Russell lupin' has probably been in NZ for some time. Some stands pre-date the multi-coloured form. The multi-coloured form is a hybrid selected by George Russell in the UK. *Lupinus polyphyllus* forms the majority of its parental genetic material with small contributions from *L. arboreus* and *L. nootkatnensis* (Gladstones, 1970). It was introduced into NZ as a garden horticultural species. In the high country Merino context there have been garden escapes and deliberate spreading on roadsides and other areas by at least 'seven lupin ladies and three gents' (Scott, 2012b). From 1950 – 1970 it was investigated and used for soil conservation purposes (Nordmeyer and Davis, 1977).

It was the success of *L. polyphyllus* on the bare well-drained roadsides; wet areas; acidic, low P, high Al soils, eroding subalpine soils, and ungrazed areas, but general absence from adjacent grazed land, which indicated its possibilities as a sown forage species.

> ***L. arboreus*** (yellow tree lupin): This is wide spread on lower altitude riverbeds and coastal sand dunes. It is generally regarded as weed in being un-acceptable to stock, or changing the nature of braided river floodplains, but has been recognised for its soil improving ability in relation to coastal sand forestry plantations.
>
> ***L. perennis***: This has currently been introduced as a forage species for seed production and re-export, and has not been evaluated within NZ as a forage species. The difference between *L. polyphyllus* and *L. perennis* seems to be small.

There are two annual species of *Lupinus* which are/have been used for forage species in NZ – *L. angustifolius* (blue lupin) (as bitter and white flowered sweet forms), and *L. luteus* (yellow lupin) (Claridge and Hadfield, 1972). Blue lupin reached its peak as lamb fattening feed (best grazed just before coming into flower) in the 1940's and 1950's (McPherson, 1940; Greenall, 1956), but was mostly subsequently replaced with increased use of lucerne.

3 *Lupinus polyphyllus* L.

Lupinus polyphyllus is a herbaceous perennial (Plate 3.1), which dies back to a stout crown each winter. A mature plant with reproductive stems can grow to a height of 1.5 m. Stems usually remain inconspicuous during its vegetative growth period. Leaves arise from the crown with 15 – 40 cm petioles. Each leaf contains 9 – 16 pointed palmate leaves of 5 – 15 cm long. The plant produces woolly seed pods, 2.5 to 5.0 cm long, containing about 9 seeds. Seeds are brown to black in colour with a glossy sheen (Horn and Hill, 1982; Horn *et al.*, 1987).

Lupinus polyphyllus could potentially replace clovers at hill country sites where marginal soils cannot be economically corrected for traditional perennial pasture species (e.g. lucerne) (Scott and Covacevich, 1987; Scott, 1989a; Wangdi *et al.*, 1990). Several reports suggest it produces more biomass than clovers on soils lacking in phosphorous (Davis, 1981b), and has greater tolerance of acidity and exchangeable aluminium, than most other legumes (Nordmeyer and Davis, 1977; Davis, 1981a; Scott, 1989b; Scott *et al.*, 1995; White, 1995).

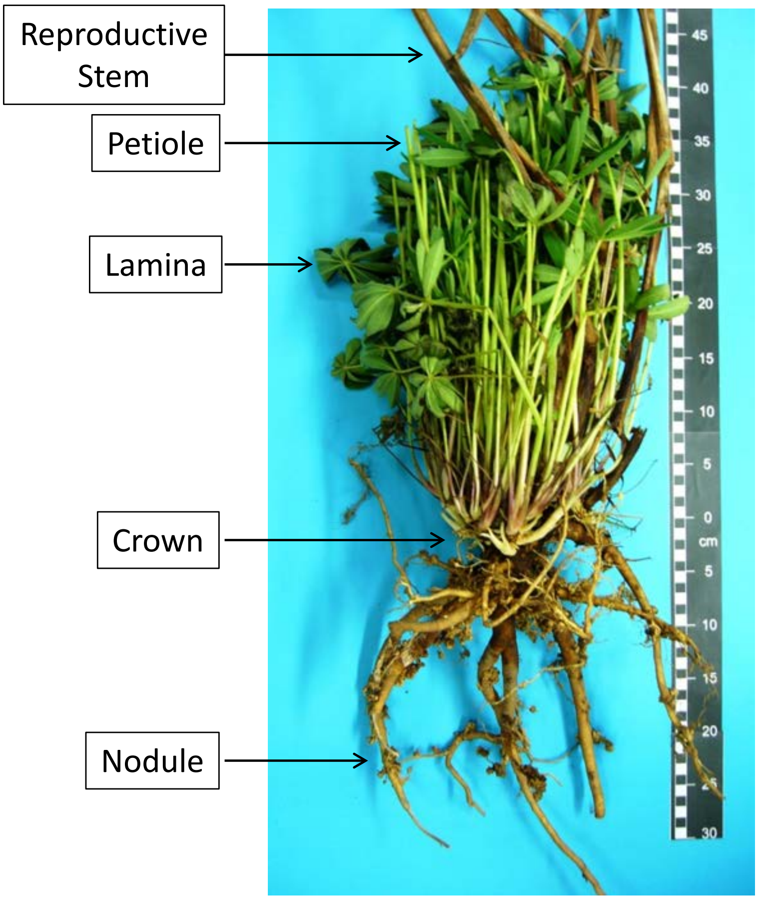

Plate 3.1 Whole *L. polyphyllus* plant taken from an 8 year old lupin stand at Sawdon Station, Tekapo (21 May 2012).

4 ‘Graze/fert’ and ‘PxS’ trials at Mt John – Tekapo

The first large scale demonstration of the potential role of *L. polyphyllus* in New Zealand was sown in 1982. The experiment aimed to demonstrate the influence of the four environmental gradients, on *L. polyphyllus* and several other species. Several other experiments were subsequently established during the development of this large high country trial area at Mt John, Lake Tekapo (43°58’45.72°S, 170°27’23.29°E and 780 m above sea level) to include alternative grazing treatments (Scott, 1994, 2008; Scott, 2012a).

The site has a mean rainfall ~ 600 mm, and is on rolling moraines with Pukaki/Tekapo high country soils. The depleted fescue tussock (*Festuca novae-zelandiae*) grassland was dominated by hawkweed

(*Hieracium pilosella*) (Scott, 1999). Soil quick-test values from 0 – 5 cm were pH = 5.2, exchangeable Al = 2.8, CEC = 6.6, P retention = 28, Olsen P = 40 (drift regime), and sulphate S = 5. Over the course of the 25 year study, no further soil test values were provided. A mixture of 25 different legumes, grasses and herbs was sown across all treatments using a rotary hoe drill in both experiments. Treatments were subsequently fenced so that grazing treatments could be initiated.

1. The 58 treatments of the 'Graze / fert' trial were combinations of 5 fertiliser levels (nil, 50, 100, 250, or 500 kg/ha/yr superphosphate with irrigation at the 500 kg/ha/yr rate), 2 stocking methods (sustained grazing (S), or short-term mob stocking (M)); and 3 grazing pressures at each fertility level, 2 (lax): 3 (= best guess): 4 (hard), and 2 spatial reps.

2. The treatments of the 'P x S' trial were 31 combinations of P and/or S rates of 0, 5, 10, 20, 50 and 100 kg elemental S/ha/yr (0-1000 kg/ha superphosphate) on the same multi-species sowings. In both trials the fertiliser treatments were maintained for the first 20 years. No fertiliser has been applied since 2002.

Over time the species responded to the range of fertiliser and grazing treatment combinations, and persisted or were suppressed in the different contexts.

Of the 25 sown species in the 'Graze/Fert' experiment, the most common in subsequent years were lupin (*L. polyphyllus*), hawkweed, alsike clover (*Trifolium hybridum*), Caucasian clover (*Trifolium ambiguum*), white clover, red clover (*Trifolium pratense*), chewings fescue (*Festuca rubra* ssp. *rubra commutate*), cocksfoot (*Dactylis glomerata*), fescue tussock, tall oat grass (*Arrhenatherum elatius*), and sweet vernal (*Anthoxanthum odoratum*) - depending on the particular combination of treatments (Table 4.1).

Plots were visually scored for relative abundance of each species in late spring in all years, following a common regrowth period over winter.

Initially, species had a rapid response to the differing fertiliser levels used, and slower changes subsequently mainly relating to the legume to grass transition as soil N built up (Table 4.1). This is shown in summary for the most dominant species in the 'Graze/fert' trial in successive periods and in more detail in referenced papers (Scott and Covacevich, 1987; Scott, 2001, 2008).

The main features were; *Hieracium* remaining dominant in the absence of fertiliser; the initial success of alsike clover; the dominance and persistence of lupin in the lower fertiliser treatments; the transition to cocksfoot dominance for a period in the second decade at higher fertiliser levels following a legume phase; the slow vegetative spread of Caucasian clover to become the dominant species of the moderate and high fertiliser treatments in the second decade and later; the increase of tall oat grass in the moderate fertiliser treatments; and chewing fescue and Kentucky bluegrass as small base grass species across a wide fertiliser range. The grazing management effects on species dominance, was small relative to that of fertiliser rates.

Table 4.1 **Change in species dominance over six periods in 25 years related to fertiliser levels (superphosphate in kg/ha/yr: 1 = nil, 2 = 50, 3 = 100, 4 = 250, and 5 = 500 + irrigation) and grazing management (H = high stocking rate, M = moderate, L = low, and s = set stocking and m = mob stocking). A =alsike clover, C = chewings fescue, D = cocksfoot, H = *Hieracium*, K = Caucasian clover, L = lupin, O = tall oat grass, W = white clover, and Z = fescue tussock (Scott, 2008).**

Grazing	Year 2 - 4					Year 5 - 8					Year 9 - 12					Year 13 - 16					Year 17 - 20					Year 21 - 24				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Hs	L	A	A	L	A	H	A	A	H	W	H	L	K	K	C	H	K	K	K	C	H	K	K	K	C	H	K	K	K	C
Hm	L	L	L	L	W	L	L	L	L	D	H	L	L	L	K	L	K	K	L	K	L	K	K	K	K	L	K	K	K	K
Ms	L	L	A	L	A	H	L	L	A	W	H	L	L	K	C	H	L	L	K	C	H	L	L	K	C	H	L	L	K	C
Mm	L	L	L	L	A	H	L	L	L	D	H	L	L	L	D	H	L	L	L	C	H	K	K	K	K	H	O	O	K	C
Ls	L	L	L	L	A	H	L	L	L	D	H	L	L	L	C	H	L	L	L	C	Z	K	K	K	K	Z	O	O	K	C
Lm	L	L	A	L	A	H	L	L	L	L	H	L	L	L	L	Z	L	L	L	C	Z	O	O	O	K	Z	O	O	O	C

In particular, lupin became dominant, and remained dominant at the lower fertiliser levels, but not without fertiliser. In that sense the 50 kg/ha/yr S fortified superphosphate was the most relevant treatment for discussing the potential role of lupin. There was no discernible effect of grazing intensity on lupin in the 'Graze/fert' trial during the first decade but it decreased subsequently under the moderate, and more particularly the high stocking rate treatments.

In the 'P x S' trial lupin was initially moderately abundant across all S and P fertiliser combinations but subsequently increased in the high (elemental) S combinations. Similarly, White *et al.* (1995) found that *L. polyphyllus* would persist under low phosphorus conditions provided sulphur was not deficient. Extended use of sulphatic fertiliser may have acidified soil over time and increased exchangeable aluminium levels, thus reducing the ability of other species to persist. However, this effect was not quantified.

5 Agronomy

5.1 Establishment

5.1.1 Pre-Sowing Herbage Treatment

Resident species are often well adapted to the environment which they are growing in, and are competitive for resources such as moisture, nutrients and light. Practices used to reduce the negative impact of resident species on establishing seedlings are partial or full cultivation, herbicide use, burning and hard grazing.

In the lowland Lincoln environment, Wangdi *et al.* (1990) found that emergence (seedling with two fully extended cotyledons) of *L. polyphyllus* was not influenced by prior burning or spraying (contact herbicide). However, establishment (plant population 6 weeks after sowing) was highest in plots sprayed with paraquat herbicide (rate = not defined) (Table 5.1). Reduced regrowth of resident competition in burnt and sprayed plots meant seedlings had an improved chance of successful establishment. Dry weight of individual plants was 50, 600 and 320 mg/plant for control, sprayed and burnt treatments, respectively. Smaller seedlings will be less competitive in adverse conditions, and have a lower chance of survival.

Table 5.1 Effect of pre-emergence herbicide treatment, before seed sowing on the success and dryweight of *L. polyphyllus* at 45 days after sowing. Plots were sown using an Ojyord cone seeder, and results represent the mean of four sowing depths (0, 1, 2 and 3 cm) (Wangdi *et al.*, 1990).

Herbage treatment	Establishment (%)	DM production (mg/plant)
Control	26	50
Sprayed	37	600
Burnt	34	320
SE	**4.3**	**32**

5.1.2 Scarification

L. polyphyllus is very hard seeded. Scarification is a process which softens/damages the seed coat to allow water permeability. This can be important for legumes that have a high proportion of hard seed (Kimura and Islam, 2012). Whilst hard seed can be a useful trait for legume species (protection against 'false breaks' and/or drought avoidance), there is often a need to reduce the content of hard seed within commercial seed lots to improve seed germination and uniformity when establishing new pastures (Kimura and Islam, 2012).

Raza *et al.* (1999) investigated the effect of scarification on the emergence of *L. polyphyllus* seeds (Figure 5.1). Acid scarification was carried out by soaking seeds in a 70% H_2SO_4 (sulphuric acid) solution for five minutes, followed by fresh water wash and drying.

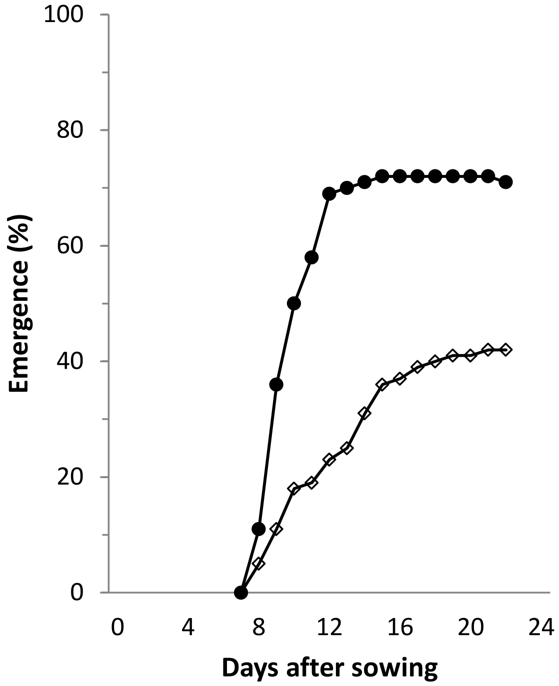

Figure 5.1 Effect of five minute 70% sulphuric acid scarification (●) on seedling emergence in a field planting on 9 May 1995 at Geneva, New York. (◊ = control) (adapted from Raza *et al.*, 1999).

By soaking seeds in sulphuric acid prior to sowing in the field, emergence of *L. polyphyllus* was improved from 40% to 71% (Figure 5.1).

Results from Tesfaye (1989) suggest that soaking *L. polyphyllus* seed in H_2SO_4 (two volumes of acid to one volume of seed) for between 30 and 120 minutes would improve germination rate (Figure 5.2). Seeds soaked in acid for 30 and 45 minutes gave the highest cumulative germination of 80%, which was double that of the control. After 180 minutes in H_2SO_4, cumulative germination was 8% lower than the control, probably as a result of acid damage to embryonic tissue in seeds with a thin testa. Seed should be thoroughly washed (15 minutes under running water) following acid soaking (Tesfaye, 1989) to prevent embryonic damage. It should be noted that different seedlines may have different hardseededness. Therefore time in acid should be conservative initially.

Wangdi *et al*. (1990) also found that mechanical scarification (seed rubbed between sandpaper) gave a field emergence of 80%, which was greater than control and acid scarified seeds (50 and 75%, respectively). Mechanical scarification offers a practical and viable method of scarification for paddock sowings. A wide range of mechanical scarification methods can be used. However, the most applicable ‘on farm’ technique is probably the use of a cement mixer with 10 kg of coarse sand for 5 – 10 minutes. Seed purchased from reputable merchants should ideally have a high germination (> 90%), as they have appropriate machinery for the scarification of seed prior to sale.

Seed age was not indicated in the studies of Wangdi *et al*. (1990) or Raza *et al*. (1999), which limits data interpretation around the emergence and germination of control seeds. Hardseededness may be reduced as lupin seed ages, thus increasing emergence %. Storage conditions will influence rate of seed aging and possibly germination. On farm, seed should be stored in a cool dry environment. In general, the life of seed is doubled for every 1% reduction in moisture content and every 5 °C decline in temperature. It should be noted, that refrigerators and meat coolers are unsuitable for seed storage because of their high humidity (> 70% RH). This implies particularly to coated seed.

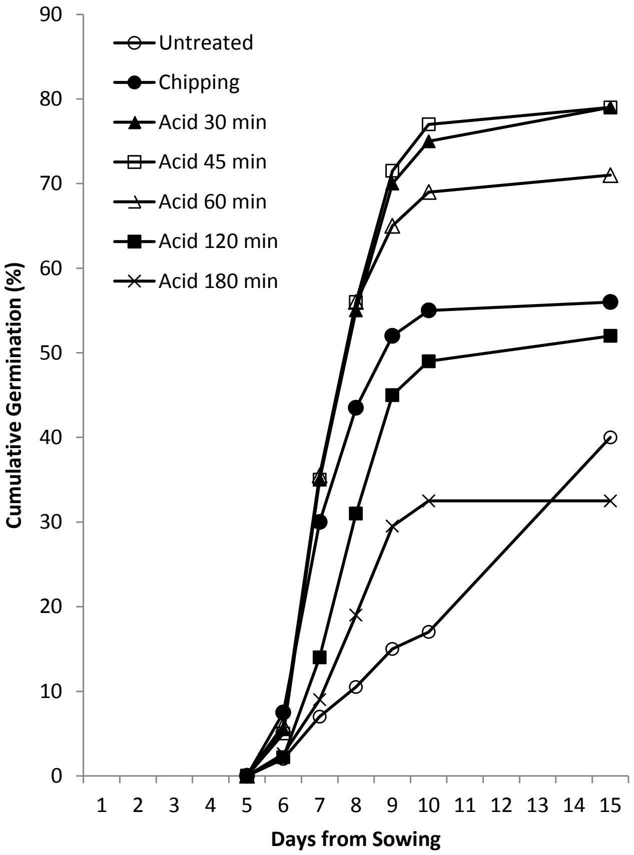

Figure 5.2: Effect of scarification method on normal seedling emergence of *L. polyphyllus* sown at 1 cm in un-sterilised sand at 20 °C (Tesfaye, 1989).

5.1.3 Germination: - temperature response

Germination temperatures in the range of 10 to 25 °C had differing effects on the speed and final emergence of *L. polyphyllus* seed (Figure 5.3). Final seedling emergence remained similar across temperatures of 10, 15 and 20 °C, with seedlings requiring 120 °Cd to reach 75% emergence. However, an incubation temperature of 25 °C gave a final emergence of 64% which was considerably lower than 91% at 20 °C. Lag period was strongly affected by temperature (Figure 5.3 and Table 5.2). At a temperature of 10 °C, seedlings took 8.1 days to emerge, which was nearly 4 times that of 25 °C (2.2 days). Differences in emergence were seen between incubation temperatures of 15 °C and 10 °C. However, these were small and probably insignificant. This study showed that *L. polyphyllus* was sensitive to germination temperatures ≥ 25 °C and that acceptable seedling emergence will occur between temperatures of 10 to 20 °C (Tesfaye, 1989).

Further quantification is required for *L. polyphyllus* at low (3, 6, 8 °C, etc.) germination temperatures in relation to mid/late autumn sowings and natural shedding of seed in autumn from ripe pods in high country field situations. The base temperature for germination needs to be defined but appears to be about 1 °C.

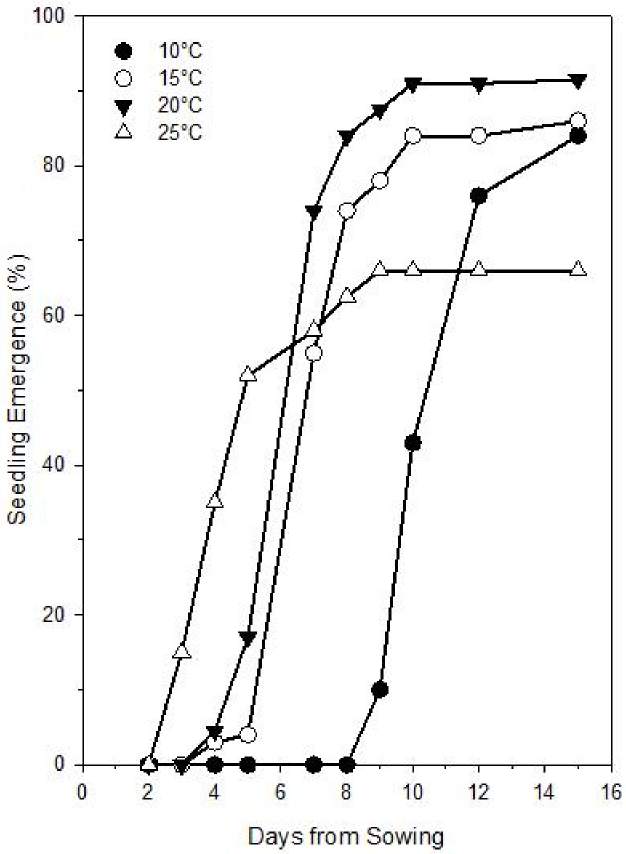

Figure 5.3 The effect of temperature on emergence of *L. polyphyllus* seed in sand (Tesfaye, 1989).

Table 5.2 The effect of temperature on days to onset of emergence, days to 50% emergence, and the emergence rate of *L. polyphyllus* (adapted from Tesfaye, 1989).

Temperature (°C)	Days to onset of emergence	Days to 50% emergence	Thermal time @ 50% emergence (°Cd)
10	8.1	10.4	105
15	3.5	6.8	102
20	3.1	6.2	120
25	2.2	5.4	125

5.1.4 Inoculation

Seed inoculation with N-fixing micro-organisms is recommended. The strain available is that for annual lupins (NZP2141) and there are no reports of host specific strains for *L. polyphyllus*. However, plants grown from uninoculated seeds do tend to nodulate eventually, though there has been no evaluation of their effectiveness/efficiency (Scott, 1989b) .

There is also the option of seed coating with elemental S and relatively insoluble P fertiliser (Scott and Archie, 1978).

5.1.5 Sowing Date

The dilemma in sowing time is between temperature and moisture for germination, the general slow growth of the seedling, and approaching summer dry conditions. *Lupinus polyphyllus* seedlings seem to have reasonable frost tolerance and growth at low temperatures (Scott, 2012b). Scott (2012b) recommended that *L. polyphyllus* be sown in autumn. This recommendation is based on the moisture and freeze/thaw cycles of winter breaking the hard seed coat, and allowing seeds to germinate as soon as conditions improve. This is an acceptable method when unscarified seed is being used and relates to what happens in nature. Autumn sowing in the high country is acceptable for fast establishing grass species (e.g. perennial ryegrass), greenfeed cereals, and some annual clovers if moisture is available in late January/February.

Perennial lupin appears to have a relatively long quiescent period after the large cotyledons emerge and before leaf growth starts, and seedlings can be caught by approaching summer dry conditions at that stage (Scott, 2012b). However, this requires quantification. Moot *et al.* (2000) suggested that spring sowings would offer more security for the successful establishment of temperate perennial species with slow seedling growth. In low rainfall areas a winter fallow is recommended.

5.1.6 Sowing Rate

The suggested seeding rate for *L. polyphyllus* given in Scott *et al.* (1995) is 2-5 kg/ha (7 – 17 seeds/m^2). Many of the successful stands at Mt John were established at 2 kg/ha using a rotary hoe drill. Sowing rates of 2 - 5 kg/ha are acceptable when plants are spelled during their first season, and allowed to reseed; allowing the second generation of seedlings to establish. However, rapid establishment and achieving early productivity is required for high input farming. Recent experiments by Lincoln University plant scientists at Glenmore Station, Tekapo, suggest that sowing rates of 8 – 12 kg seed/ha (27 – 40 seeds/m^2, based on an average thousand seed weight of 30 g), will provide rapid ground cover and an adequate number of established plants.

5.1.7 Sowing Method

Existing lupin stands have been established by surface broadcast seeding, partial cultivation and broadcast seeding, and drilling using various drill types – some giving partial cultivation. Many of the existing ‘natural’ stands, and the thickening of sown stands represents ‘broadcast’ seeding.

As indicated in other sections the preference would be for any method that reduces competition between species in the establishment year. The suppression of vigorous rhizomatous grasses (e.g. *Poa pratensis*, browntop (*Agrostis capillaris*) and twitch (*Elymus repens*)) with herbicides is important on fertile/moist sites.

Sowing depth can have a profound effect on the successful establishment of plants. Whilst it is desirable to sow seeds at a depth where moisture will not limit their growth, seeds sown too deeply are likely to exhaust their food reserve before the cotyledons can reach the soil surface and begin photosynthesis. Under glasshouse (Tesfaye, 1989) and field (Wangdi *et al.*, 1990) conditions, seedling emergence of *L. polyphyllus* was highest when sown at a depth of 1 - 2 cm (Figure 5.4 and Table 5.4). Emergence of broadcast seed was lower than seed sown at 2 cm (Figure 5.4) (32% vs. 57%), and field establishment declined to 25 and 40%, respectively (Table 5.4).

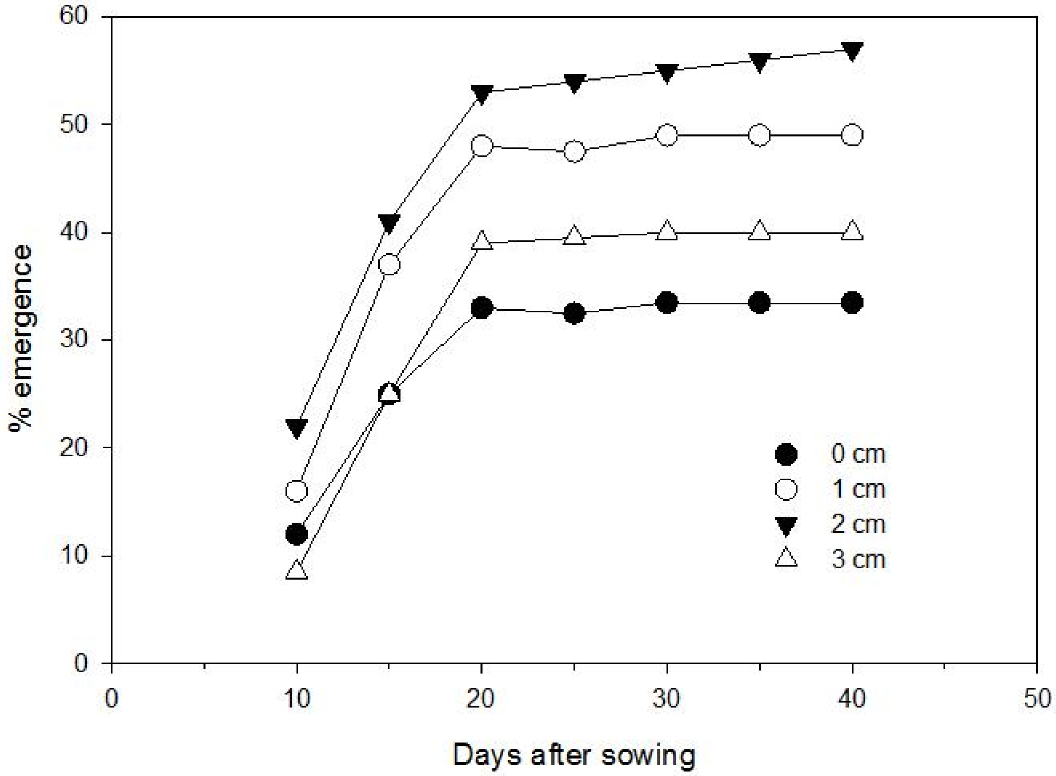

Figure 5.4 The effect of depth of sowing on field emergence (%) of *L. polyphyllus* seedlings (adapted from Wangdi *et al.*, 1990).

Seed sown at 0, 3, 4 and 5 cm failed to reach 50% emergence; after 57 days under glasshouse conditions (temperature not stated) (Table 5.4). Onset of emergence was highest in seed sown at 0 and 1 cm (6.8 and 6.1 days, respectively), whilst root and shoot dry weight were lowest for broadcast seedlings. The inability of broadcast seeds to reach 50% emergence under glasshouse conditions (not limited by water), suggests that only modest establishment can be expected from oversowing, particularly under field conditions, where seedlings are much more likely to suffer from desiccation.

As a generality Hampton *et al.* (2000) stated that about 5 – 20% of seed broadcast, onto cultivated land, produces an established plant, and that surface moisture has a considerable impact on seedling establishment. Establishment values of ~1% would be more realistic on un-cultivated rangelands (Scott, 2012b). Wangdi *et al.* (1990) achieved moderate establishment success from oversowing (Table 5.1). However, sowing depths of 10 and 20 mm gave the highest level of establishment at 35% and 40%, respectively. Plant weight was not significantly affected by sowing depth 45 days after sowing. Results from Table 5.1 suggest that *L. polyphyllus* is tolerant of sowing depth variation.

Table 5.3: Effect of sowing depth on the success and dryweight of *L. polyphyllus* at 45 days after sowing (Wangdi *et al.*, 1990).

Sowing depth (cm)		Establishment (%)	DM production (mg/plant)
0		25	330
1		35	350
2		40	300
3		29	310
	SE	**5.0**	**37**

Oversowing is a useful technique on unploughable land, and represents a relatively cheap method of establishment; providing seed price is not prohibitive. Improved development of roots and shoots at sowing depths of 1 - 2 cm will improve seedling survival, and plant population. Under field conditions at Lincoln, Wangdi *et al.* (1990) found that sowing depths up to 30 mm had minimal effect on seedling weight (Table 5.3).

Table 5.4 Effect of sowing depth on emergence, shoot DM, root DM and root to shoot ratio of *L. polyphyllus* 57 days after sowing. Adapted from Tesfaye (1989).

Sowing Depth (cm)	Days to onset of emergence	Days to 50% emergence[a]	Shoot DM (mg/plant^{-1})	Root DM (mg/plant^{-1})	Root to shoot ratio
0	6.8	-	46.7	17.8	0.38
1	6.1	10.3	57.8	33.3	0.56
2	10.1	20	55.6	28.9	0.51
3	12.5	-	46.7	20.0	0.42
4	25.1	-	NA	NA	NA
5	27.5	-	NA	NA	NA
Significance	NA	NA	***	***	***
LSD (0.05)	NA	NA	4.96	7.36	0.07

[a] - Final emergence percentages were less than 50%. NA = not significant, * = p≤0.05, ** = p≤0.01, and *** = p≤0.001

5.2 Fertiliser requirements

In the high country context the main fertiliser requirements are likely to be as superphosphate (N-P-K-S = 0-9-0-12) and/or elemental sulphur, and in the respective rates and proportions of S and P across the rainfall moisture gradient (Scott *et al.*, 1995). These range from S deficiency and possible sufficient P in the lowest rainfall areas, to a rapidly increasing P deficiency and slower increasing S deficiency as rainfall increases (though the latter S deficiency adequately covered by the S content of superphosphate). There is also the generality that fertiliser requirements are more critical to coarse rooted legumes than strongly competitive fine rooted grasses. Almost all comparative trials show *L. polyphyllus* as one of the most responsive legume species at lower fertiliser rates but this tends to plateau at higher fertility.

The 'Graze/fert' and 'P x S' trial at Mt John showed *L. polyphyllus* responding to both S and P fertiliser rates with the response being greater to S than P on that site where P levels were naturally high (Olsen P; 40) (Table 4.1). The fertiliser levels for initial establishment ~ 50 kg/ha S fortified superphosphate. The fertiliser efficiency study indicated that the longer term maintenance fertiliser rate was in the region of 50 kg elemental S/yr (or 250 kg/ha/5 years) (Scott, 2000a, 2008).

Fertiliser requirements and superphosphate results are more generally discussed in terms of P response. But the S requirements and responses are equally or more important in many low rainfall situations.

At Mesopotamia Station, in Canterbury, White *et al.* (1995) found that lupin growth was very poor, at a 700 mm rainfall low fertility site (Olsen P - 6, SO_4 – 2, pH - 5.3) in the absence of applied S (Figure 5.5). Lupins showed little or no response to increasing rates of applied P, as either triple superphosphate (0-21-0-1) or rock phosphate (0-14-0-0), under nil S treatments. However, lupins showed a strong response to P in the presence of S (40 kg/ha elemental S applied at sowing in September 1990 and a further 20 kg/ha applied in October 1991); particularly those receiving soluble triple superphosphate. In the same experiment, Jarvis *et al.* (1997) highlighted the importance of post-establishment S application (Figure 5.6). Lupin showed an eight fold increase in biomass production (0.5 vs. 4.1 t DM/ha) with a 60 kg/ha topdressing of S, 45 months after sowing, in plots that received 25 kg P/ha at sowing. Furthermore, lupins with zero P at establishment, gave a three-fold increase with S at establishment and after 45 months.

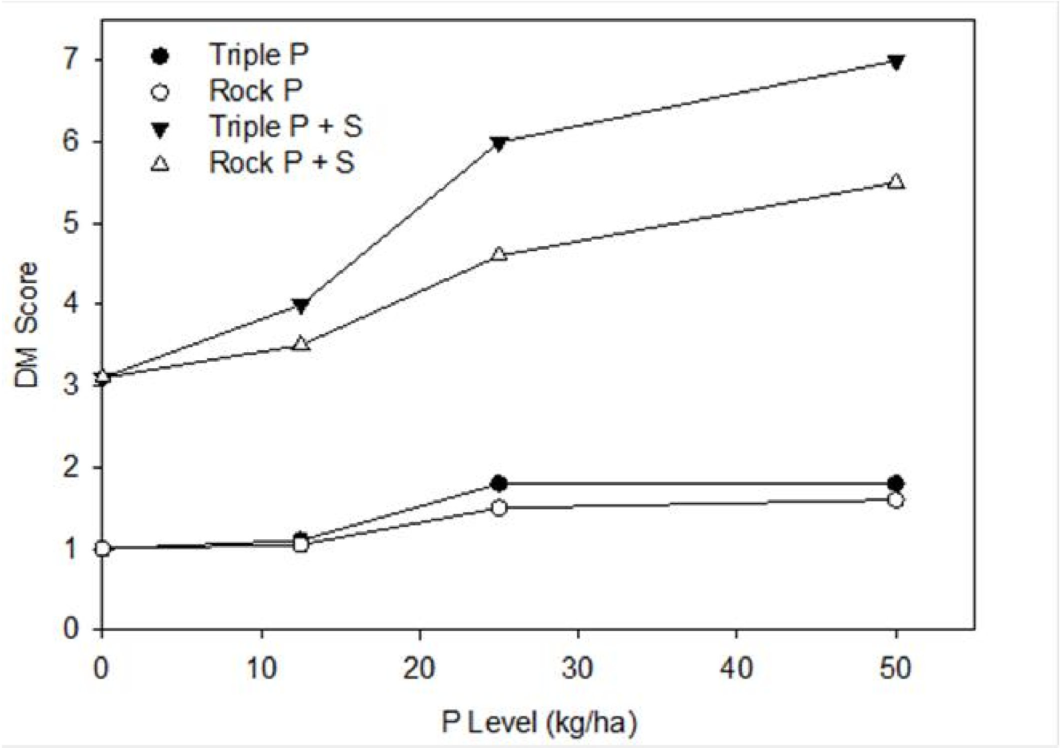

Figure 5.5: **Effect of rates of phosphorus (0, 12.5, 25, and 50 kg P/ha) and sulphur (0 and 40 kg S/ha) on the visual dry matter (DM) score of Russell lupin (*L. polyphyllus*) in December of the second growing season at Mesopotamia Station, South Canterbury (White *et al.*, 1995). Plots were visually scored on a scale of 1 -10.**

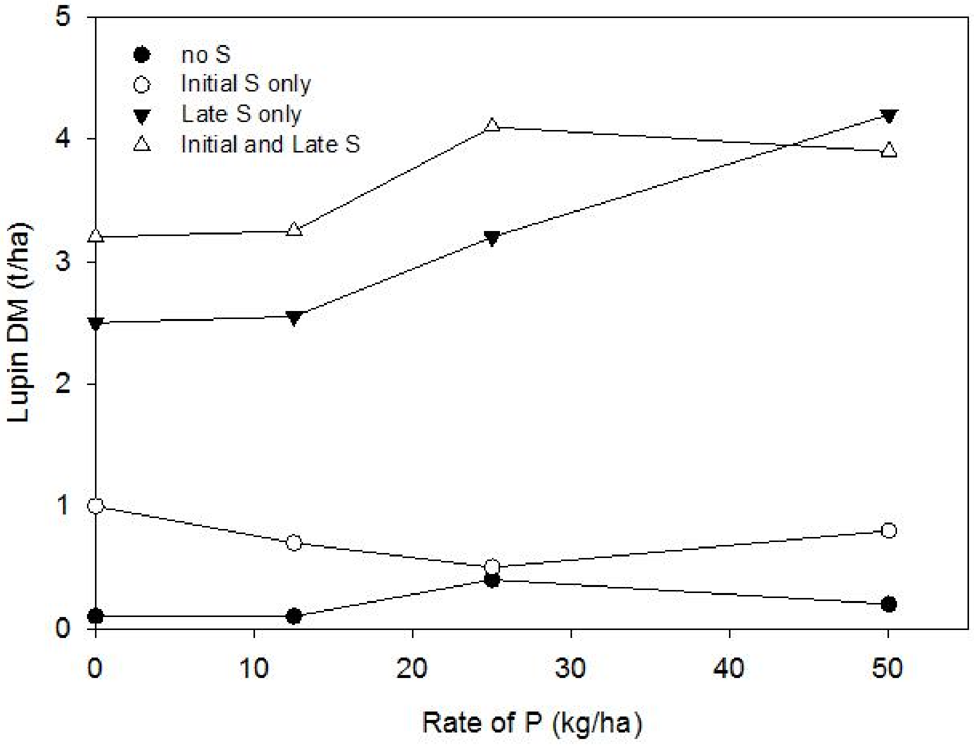

Figure 5.6: Effect of P rate (0, 12.5, 25, and 50 kg P/ha) and applications of elemental S (0, early S (40 kg/ha at sowing in September 1990 and 20 kg/ha in October 1991), late S only (50 kg/ha in May 1994), and a combination of early and late S, on the yield (kg DM/ha) of Russell lupin at Mesopotamia Station, South Canterbury (Jarvis *et al.*, 1997).

5.3 Yield, Yield Components and Quality

Pasture yields are a function of the environment rather than the species per se, with yields being dependent on the moisture, temperature and soil fertility of the particular site and management conditions. In the low to moderate fertiliser range (0 – 100 kg superphosphate/yr) of the Mt John trials in which *L. polyphyllus* was dominant or abundant, these were in the range of 5-7 t DM/ha/yr (Scott, 2000b).

Kitessa (1992) studied the yield and quality of *L. polyphyllus* and its potential for sheep grazing. Plots were sown in December 1987, and individual plants were cut, dried and weighed every 3 weeks from 5 October 1989 to 18 January 1990 (Figure 5.7). The plants reached maximum biomass yield (g DM/plant) at the dry pod stage (160 g DM/plant). However, 75% of this had been produced by the full bloom stage on 16 November. The largest yield increase was during October when plant size increased from 42 to 100 g DM/plant. The second largest increase was from 28 December to 18 January when plant weight increased from 120 to 160 g DM/plant. The onset of flowering and development of stem material gave this yield increase (Figure 5.8).

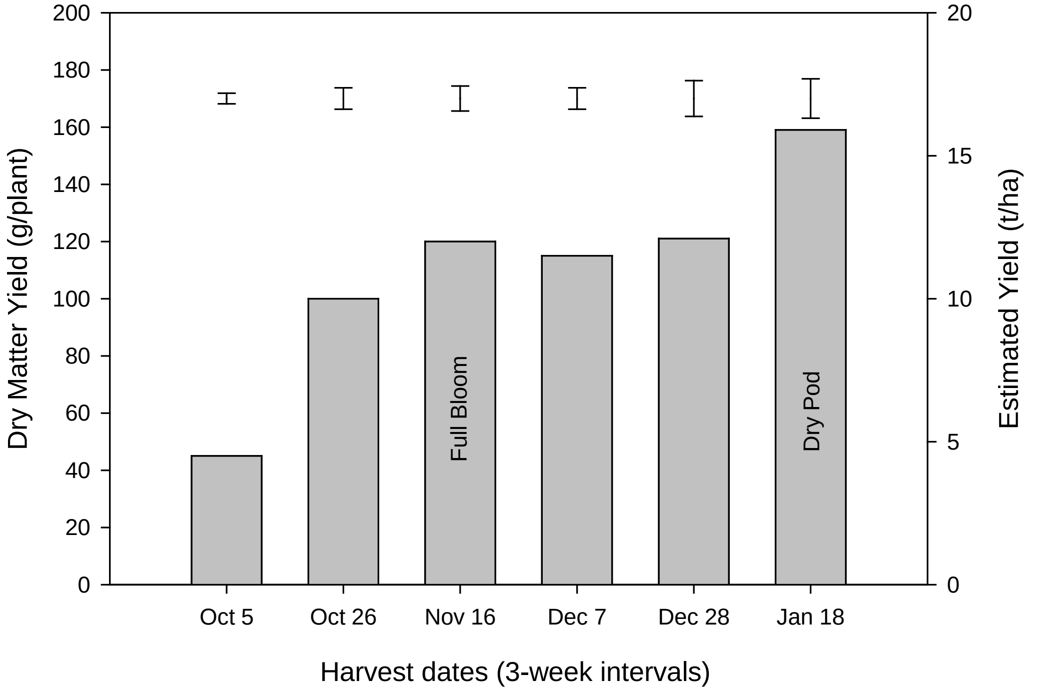

Figure 5.7 Dry matter yield of individual *L. polyphyllus* plants at different growth stages. Estimated yield based on plant population of 10 plants/m^2 (Kitessa, 1992).

Dead material represented 38% of total DM on 18 January 1990, suggesting that DM, which accumulated between full bloom and dry pod, had a low grazing preference (Figure 5.8). Proportions of leaf and petiole in the total DM decreased in a linear trend as plants moved from a vegetative to reproductive state.

Leaves and flowers retained their quality (MJ ME/kg DM) throughout all harvest periods, whereas the ME of stem and petiole reduced from 13.2 to 3.8 and 10.1 to 5.8 MJ ME/kg DM, respectively (Table 5.5). Scott (1989b) stated that reduced acceptability of lupins over the summer was probably due to high levels of alkaloid in the leaves but provided no results to support this claim. Rather than high levels of alkaloid, it is probable that the substantial increase of stem and dead material over summer had a negative impact on grazing preference. However, under more frequent or intensive grazing, fresh regrowth may be able to maintain feeding value.

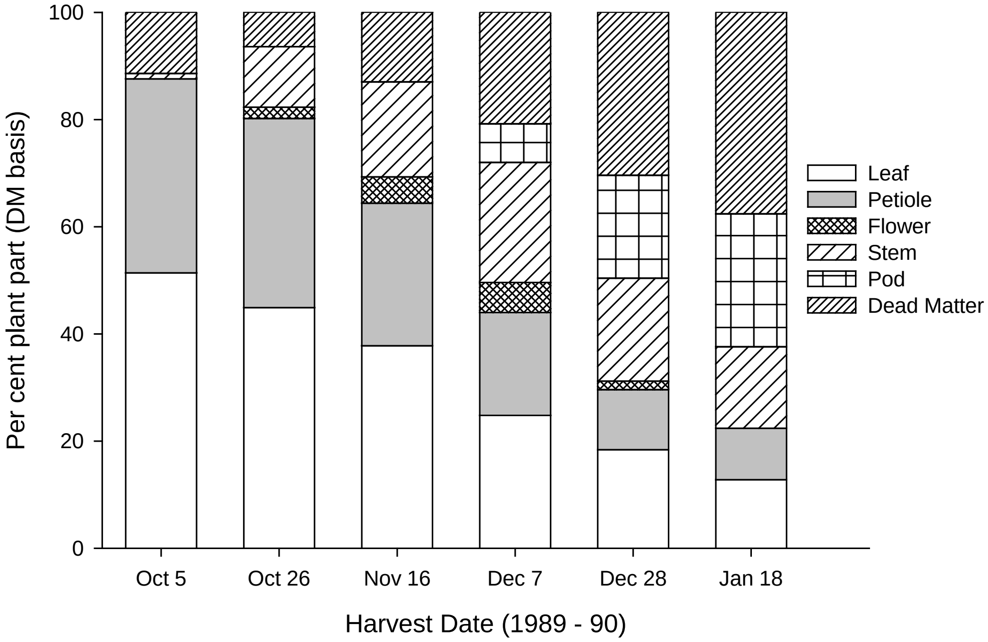

Figure 5.8 **The distribution of plant parts in the total dry matter yield per plant of *L. polyphyllus* at 3 week intervals from 5 October 1989 to 18 January 1990 (Kitessa, 1992).**

Plate 5.1 ***Lupinus polyphyllus* plant following grazing at Sawdon Station, Tekapo on 29 April 2012.**

Table 5.5 Within-harvest comparison of the mean metabolisable energy (MJ ME/kg DM) of different plant parts of *L. polyphyllus* at various growth stages from 5 October 1989 to 18 January 1990 (adapted from Kitessa, 1992).

	Plant Part							
Harvest Date	Stem	Petiole	Leaf	Flower	Pod	Dead matter	[1] L.S.D.	[2] CV
Oct-05	13.2	10.1	12.2	-	-	2.6	0.05	0.04
Oct-26	11.5	9.1	12.8	11.4	-	4.2	0.07	0.05
Nov-16	7.1	7.1	12.4	12.2	-	7.5	0.04	0.11
Dec-07	5.0	6.9	12.5	12.2	11.8	5.2	0.07	0.05
Dec-28	4.4	6.9	12.6	11.9	8.1	4.0	0.06	0.05
Jan-18	3.8	5.8	12.2	-	6.5	4.5	0.17	0.15

[1] L.S.D. = Least significant difference at $P<0.05$. [2] CV = Coefficient of variation (%).

Kitessa (1992) indicated that leaf material remained the most acceptable of all yield components regardless of growth stage (Table 5.5). When sheep were introduced to lupin plots on 27 November, animals removed 99% of leaf material within 4 days (Figure 5.9). Recent field observations indicate that flowers are the most preferred component of lupin yield, followed by leaves (Plate 5.1). All other components (petiole, stem, and dead matter) were not heavily grazed until the majority of leaf material had been removed. Table 5.5 also indicates that sheep performance will decline once flowers, leaves and immature green pod have been removed.

Plate 5.2 ***Lupinus polyphyllus* at full-bloom/green pod growth stage. Understory species: yarrow (*Achillea millefolium* L.), white clover and Italian ryegrass (*Lolium multiflorum* L.) at Sawdon Station, Tekapo (23 March 2012).**

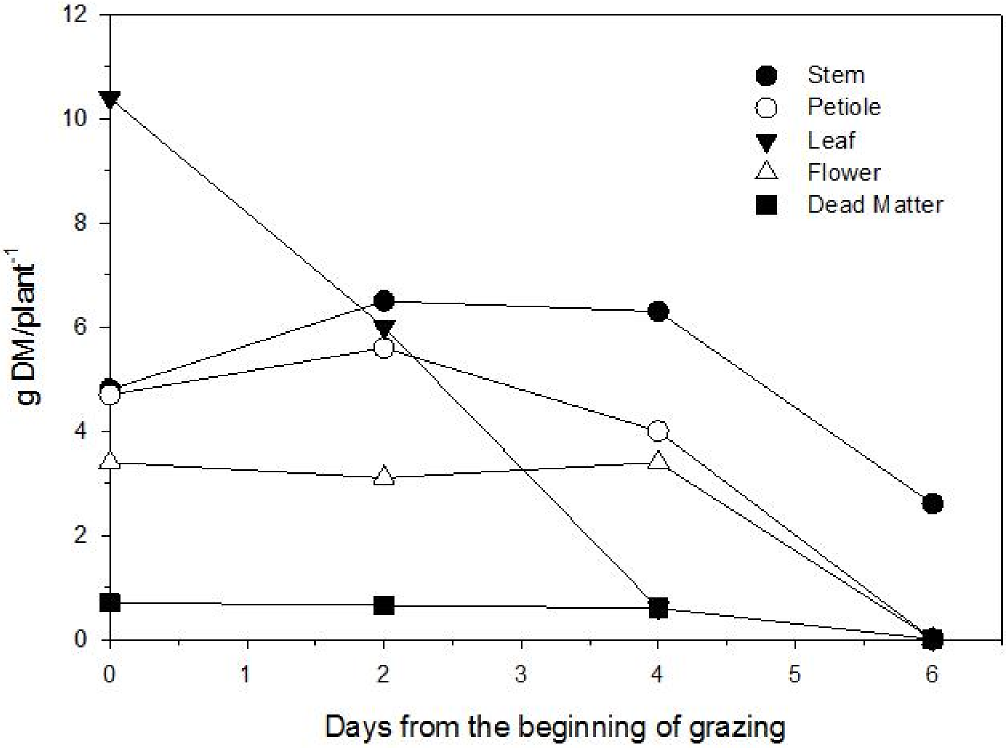

Figure 5.9: The pattern of disappearance of individual yield components over successive days of grazing from 27 November 1990 to 3 December 1990 (Adapted from Kitessa, 1992).

When Kitessa's sheep grazed lupin at full bloom, residual herbage was 270 kg DM/ha, which was considerably lower than the 960 and 1920 kg DM/ha left after the green and dry pod grazings, respectively (Table 5.6). Increasing proportions of stem, pod and dead matter decreased whole-plant quality; which reduced grazing preference.

Full bloom harvestable regrowth yield after grazing in late November was 4872 kg DM/ha, which was three times greater than the regrowth of plants grazed at the dry pod stage (1597 kg DM/ha). Vegetative regrowth was limited after dry pod grazing in late summer, with plants having little time to recover before autumn grazing.

Grazing at the full bloom stage provided a balance between herbage quality and quantity, and added flexibility in autumn. Lupin regrowth in autumn could also be used as feed for flushing ewes (Kitessa, 1992).

Table 5.6: Effect of timing of spring/summer grazing on autumn regrowth of *L. polyphyllus* (Kitessa, 1992).

	Autumn regrowth yield	
Growth stage at spring/summer grazing	Residual (kg/ha)	Regrowth (kg/ha)
Full Bloom (27/11/90)	270	6690
Green Pod (17/12/90)	960	2818
Dry Pod (21/01/91)	1920	362

5.4 Nitrogen Fixation

Like other legumes, lupins have the ability to fix atmospheric N into their own tissues (Gladstones, 1970; Epstein, 1972; Gross, 1986; Kitessa, 1992; Wills *et al.*, 2003). This relies on the successful establishment of a relationship between the plant and N-fixing bacteria. Lupins are nodulated by root nodule bacteria of the 'slow growing group' (Gladstones, 1970). Bacteria of this group appear to be more tolerant of low soil pH and are more capable of surviving in soils of low fertility (Norris, 1956).

Plots dominant in *L. polyphyllus,* at the Mt John trial site, indicated N fixation was 150 – 223 kg N/ha/yr (Scott, 2000c).

5.5 Adaptations to Grow Under Sub Optimal Soil Conditions

The ability of lupins to tolerate soil acidity and associated high levels of soluble aluminium (Al) (Davis, 1981b; Scott and Covacevich, 1987; Scott, 1989b; Scott *et al.*, 1995) makes it a noteworthy plant in areas where only low fertiliser inputs are used.

The main features of lupins, with respect to productivity under adverse soil conditions, are listed below.

a) Lupins are tolerant of low soil P levels, and are capable of utilising soil P which is unavailable to most other plants (Davis, 1981b; Borie, 1990). Borie (1990) listed four probable root adaptations of lupins growing on P-deficient soils: (i) root excretion of acid substances, (ii) deep roots and other geometry of rootlets, (iii) exudation of root phosphatases, and (iv) formation of mycorrhizal associations. However, the review of Lambers *et al.* (2013) acknowledged the ability of lupins to mobilise unavailable P, but found no explanation for the ability of *L. polyphyllus.*
b) Borie (1990) speculated that lupins may have the potential to mobilise unavailable P in excess of their own requirement. This may increase P availability to companion species and further increase the productivity of low input pastures.
c) Their large root system improves soil structure and aids erosion control on loose-textured soils by increasing the soil organic matter content, which forms and stabilises aggregates (Rowland *et al.*, 1986), and encourages N cycling (Scott *et al.*, 1995).

5.6 Drought Tolerance

Lupinus polyphyllus is not suitable for areas with less than 500 mm/year rainfall. They prefer to grow on loose textured soils in areas with moisture seepage or moderate to high levels of rainfall (> 500 mm/year) (Scott, 1989b; Scott *et al.*, 1995). However, information regarding the depth of root penetration is limited, and further work on drought tolerance is required. It is likely to be influenced by a number of factors (e.g. grazing management, soil type, climate, etc.)

5.7 Seed Production

The main issues in seed production are the explosive shattering of pod, its strong temperature dependence, the differing maturing time of pods within the spike, and between plants.

Seeds are ready for harvesting in late December and January. Maximum seed yields are achieved about 3 weeks after the first 1% of pods turn brown. Crops should be cut when about a quarter of the pods are brown and left to dry in the windrow for only 2-4 days with any turning done in the early morning dew. The process is very temperature dependent with temperatures >25 °C causing pod shattering.

The alternative is direct heading of maturing seeding stands which may be simpler though only achieving about a third of the potential yield.

Hand harvesting measurements indicate potential of 2 t seed/ha, or 1 t/ha in a 10 day period. Mechanical harvesting achieves at least 0.5 t/ha. The thousand seed weight is 25 - 30 g.

Hand harvesting is possible, but tedious. It is done by plucking the whole spike when more than a quarter has brown pods. These are partially dried to even up pod maturity inside or shade, followed by exposure to sun to allow self-shattering or threshing.

For indirect within-farm spreading of *L. polyphyllus* there may be the possibility of immediate spreading of cut or silorated (*sic*) material from a seeding stand to new areas, or the delay in making of hay or silage so as it contains seed for later feeding out to new areas.

In stock grazing it is probable the seed would survive through the digestive tract, but there is no impression that this has been a significant factor in its spread.

5.8 Pests and Diseases

Lupinus polyphyllus has no known insect pests in NZ.

Anthracnose and canker are low frequency diseases that can cause brown to pink lesions in late summer on stems and pods. It was first seen in the Craigeburns several decades ago, has become more prevalent in the wetter low country, and over the last two decades has been moving up Burkes Pass into the Mackenzie Basin. It occasionally results in the death of older plants. However, the related tree lupin suffered from severe fungal disease approximately 10 years ago, and its abundance in the Rakaia River bed was considerably reduced.

6 Phenology

6.1 Flowering and apical dominance

The flowering of *L. polyphyllus* is indeterminate and not considered influenced by day length or vernalisation but this has not been quantified. It will try to flower under any conditions good for growth. Generally this in November and December, but can occur in any season.

Lupinus polyphyllus is strongly apical dominant with plant response determined by the stem growing point. Continued vegetative growth or repeat flowering is strongly dependent on the absence of any previous flowering stem – even if partly dead. Therefore, it is desirable to continue grazing until the stem is eaten (or mower topping) to encourage further vegetative growth, and a possible second flowering. However, forcing high priority stock to graze low-quality material will have adverse effects on animal performance. Therefore, mechanical topping to remove apical dominance may be a useful alternative.

6.2 Growing points

The growing points of *L. polyphyllus* are somewhat above ground, so grazing should preferably be down to, but not below, 2 - 4 cm (Scott, 2012b).

Lax grazing of *L. polyphyllus* is preferred, and lupins can be periodically grazed to ground level if given sufficient regrowth time to recover (Scott, 1989b). In this instance, lax grazing refers to the residual herbage left following grazing. It is likely that animal performance would be strongly sacrificed if consistent residuals of 2 – 4 cm were sought. Therefore, damage to the growing point is unlikely in the majority of grazing systems.

Stand density can be manipulated by implementing varying degrees of grazing intensity at different growth stages. Under lower stocking rates in late spring/early summer stock tend to select other species. By contrast, Scott (1989b) suggested heavy stocking in spring and autumn/winter would reduce dense stands but data has not been presented to confirm this.

7 Legume/grass transition

One of the limiting factors in high country farming is winter-feed and the desirability of winter tolerant grasses in the pastures with either maintenance of herbage feed quality, or some continued growth.

It is a general phenomenon of grassland development for fine rooted grass species to replace coarse rooted legumes as the later build up soil N levels. The time scale of the transition is dependent on the legume rate of N fixation, and probably the continued proportion of legume, and rate of N fixation in the resulting grass/legume pasture.

In the experiment of Scott (2012a) an eight species mixture was sown into two seedbeds of differing development. Undeveloped tussock was direct drilled, or land that had been through five years of clover; ± prior herbicide; spring versus autumn drilling; conventional disc drill compared with new partial cultivation drill; and use of nil or 150 kg N/ha in first two years; and superphosphate at three rates (50 or 150 kg/ha/yr or 150 kg/ha every 3rd year).

The nutrient balances on the Mt John trials indicated that the nitrogen fixation rates were proportional to the fertiliser rates rather than the legume species per se. Also, at the low fertiliser rates, pastures were still lupin dominant for over two decades (Table 7.1). Thus, for initial lupin based pasture the natural transition may be delayed for many years. On previously undeveloped land it is somewhat uncertain whether these companion species can be introduced as part of the easier original sowing or at a later separate introduction stage. The dilemma is illustrated in Table 7.1.

Table 7.1: Percentage composition of species in three periods following over-drilling in prior developed block (left) compared with previously undeveloped block (right). The average within-year standard error for group proportions was 1.02% (Scott, 2012a).

	Developed			Undeveloped		
Period (yrs)	2 - 6	7 - 12	13 - 18	2 - 6	7 - 12	13 - 18
Clovers	12.1	4.3	1.3	37.6	7.9	0.7
Lupin	0.6	1.2	11.2	14.4	28	41.2
Cocksfoot	7.1	4.4	0.7	4.4	5.8	1.1
Tall oat	6.5	11.4	10.8	0.5	5.5	9.1
Small grass	20	27.3	26.6	6.9	18.1	18.1
Tussock	15.2	24.8	25.2	8.4	21.5	19.2
Hieracium	6.3	10.6	17.6	22.8	9	8.6

7.1 Stand duration

L. polyphyllus is a long lived perennial and once established can persist for many decades both by persistence of original plants and recruitment from self-seeding. However, grazing management, fertiliser applications, extreme weather events and possible disease outbreaks are possible influences on lupin population fluctuations.

7.2 Companion species

Any companion species should have similar environmental requirements to lupin. Currently the best estimate for the taller grasses, in order of priority, is either cocksfoot, tall oat grass, or smooth brome, with chewing fescue as a smaller understory species (Scott, 2012b). Other species which may have a place are Caucasian clover, red clover (*Trifolium pratense* L.), and plantain (*Plantago major* L.). It should be noted that annual clovers were not included in the original mixes used at Mt John and may also have a role.

8 Decomposition

Lupinus polyphyllus had the highest leaf litter decomposition rate with decreasing calcium content (Scott, 2000b). Its shoot material decayed at the greatest rate compared with other sown species. However, its nodules have a slower decay rate relative to other pasture legumes (Wardle, 1985). The biomass and carbon components of the low fertiliser, *L. polyphyllus* dominated treatment in the 15th year for shoot, litter, and soil fractions down to 40 cm are given in (Scott, 2000c). That treatment had the highest litter fraction.

9 Conserved feed

Lupin as a crop for hay or silage has not been seriously investigated in NZ. This needs to be considered both for conservation feed per se and the management of lupin as a grazing forage.

It has a high early summer yield and hollow stem and would be favourable for rapid drying in the higher rainfall areas of the high country. A few trial observations suggest it is easy mown or silorated (*sic*) but that the cut material is relatively fragile when dry.

Early summer is also the peak production period for other higher preference forage species and lupin tends to be by-passed. This leads to greater frequency of flowering stems and stalks whose existence, as the previous section on apical dominance suggests, limits continued green leaf production. This is evident on the side of the road in the MacKenzie District where the resident road side population is mown each summer after flowering and regrows vegetatively.

A suggested option is to take a hay or silage crop in late November/early December at full bloom, followed by summer regrowth for autumn/early winter grazing, with conserved feed for later winter use.

10 Alkaloids

At the start of the 20th century, much of the alkaloid content was removed from annual lupins, and modern hybrids often contain low amounts of alkaloids (Gladstones, 1970). However, low levels of alkaloid are still present and they serve an important purpose. Michael Wink completed extensive research on lupin alkaloids throughout the 1980's, and the following information is predominantly from his work.

Lupins contain alkaloids that belong to the quinolizidine group (Wink, 1983; Wink and Witte, 1984; Wink, 1987). Their chemical structure (see Wink 1987) is responsible for the bitterness associated with such compounds (von Baer and Feldheim, 1982). Quinolizidine alkaloids (QA) are synthesized in the chloroplasts (Wink *et al.*, 1982) and are derived from lysine and its decarboxylation product, cadaverine (Wink, 1987). The alkaloids are produced in the leaves and are translocated throughout the plant via the phloem (Wink *et al.*, 1982). In mature plants, the QA tend to accumulate in the seeds, pods, stems and roots (Gladstones, 1970; Wink and Hartmann, 1981; Williams and Harrison, 1983; Wink, 1987). Williams and Harrison (1983) found that 80 – 95% of total plant alkaloid was present in the seed upon full ripening.

Williams and Harrison (1983) found a close correlation between dry weight and alkaloid content. Due to this, they suggested that alkaloids are an end product of synthesis, rather than an active reactant of metabolism. In contrast, Wink and Witte (1984) suggested that alkaloids are not in fact a 'waste product' but are an important compound for the biological fitness of such a plant, and they are an important component of the plant's defence system.

The level of QA in leaves, and other lupin structures, show a strong diurnal relationship, with high values during the day (high light intensity) and low values at night (low light intensity) (Wink and Hartmann, 1982; Wink and Witte, 1984). As QA's are derived from the amino acid lysine, Wink (1987) suggested that the breakdown products of such compounds will release nitrogen, which can then be reused in the metabolism of a plant.

The use of alkaloids as a defence mechanism and resultant plant survival; is certainly a plausible explanation for their presence. As a result of their presence, grazing ruminants might experience bitterness whereas insects are repelled by bitterness of alkaloids, even when present at low levels. Animals are protected to the extent that the bitterness of alkaloids, either in seeds or green tops, would normally prevent excessive consumption (Gladstones, 1970).

Gibbs (1988) determined the alkaloid levels in the same eighteen lines of *L. polyphyllus* investigated by Tesfaye (1989) and Scott and Tesfaye (2000). She found the average content was 2.4% - though in spring one line had 1.5% and another 3.1%. Those were composite samples from many plants indicating possibilities of lower levels for individual plants. That contrasted with levels of 5.2-7.9% in *L. arboreus*.

11 Grazing

11.1 Stock adaptation

It is known in general agriculture that animals and their ruminant micro-organisms need time for adaptation to a new feed type. The present *L. polyphyllus* is not highly acceptable to stock because of its bitterness from its alkaloid content. It has a high novelty to stock when at low densities. But they have to initially be forced to feed when it is at high plant densities by fencing and mob stocking – though they seem to become adapted to it. There is a need for further investigation into grazing preference at different seasons, ages of herbage, soil fertility and abundance of associated species in lupin pastures.

11.2 Stock performance

At Tekapo, Scott *et al.* (1994) showed Merino wethers set-stocked on perennial *L. polyphyllus* from November to March had a mean live-weight gain of 58 g/head/day compared with 110 g/head/day and 77 g/head/day for red and alsike clovers, respectively.

At Lincoln University, Kitessa (1992) conducted a grazing trial and speculated that *L. polyphyllus* should be grazed before the green pod and dry pod stages, but no animal performance results were reported.

There is need for further investigation of animal live-weight gain on *L. polyphyllus*. Several of the present investigations on the grazing capacity of different high country pasture mixtures come from David Scott's Mt John trial site. There, the main performance parameter has been sheep grazing days achieved to reach a common pasture residual level. That may contain a partial fallacy if lower acceptability leads to a greater time needed to graze and hence apparent greater grazing capacity.

The fertiliser efficiency study of the 'P x S' trial at Mt John had indicated that pasture species distribution was related to P fertiliser levels, but sheep grazing days were mainly dependent on elemental S fertiliser levels. The greatest benefit for increase in carrying capacity for dollars spent was for ~ 53 kg elemental S/yr (or 250/ 5 year) – directly in the realm where lupin dominated (Scott, 2000a, 2008).The correlation with S fertiliser is partly understandable with S being a component of wool proteins (~3%).

11.3 Animal Health

The main issue for animal health is probably the alkaloid bitterness possibly limiting feed intake (Section 10).

L. polyphyllus stands, in NZ, in different situations, have been exposed to stock grazing for many decades. There seems to have been no experience of any other particular stock health problems.

With alkaloids sheep are observed to eat green seed pods with seed, but with the shattering of pods and highest alkaloid content in dry seed the intake of mature seeds seem unlikely.

Lupinosis is a mycotoxicosis caused by the ingestion of toxins produced by the fungus *Phomopsis leptostromiformis* (van Warmelo *et al.*, 1970; Edgar *et al.*, 1986), which commonly colonises dead lupin tissue (Gardiner and Petterson, 1972). The disease poses a considerably greater problem to the use of lupins for stock feeding than alkaloids, particularly in Australia where out-of-season rains can result in serious outbreaks (Gladstones, 1970; Kitessa, 1992). However, this information is mostly based on annual lupin and outbreaks are not known to occur in *L. polyphyllus.*

12 Species evaluation

Within pastoral research there is a constant search for new species or more productive forms by breeding within existing species. This has been particularly true for the NZ tussock grassland. Scott *et al.* (2004) have estimated that since the 1930's, 30-50 different accessions per year have been planted and evaluated. These have principally been plant accessions from breeding programs for other regions of NZ. However, it has also included a large component of introduction and evaluation of possible pasture species from matching environments in other parts of the world.

With the recognition of *L. polyphyllus* as a potential herbage species in the 1980's it was included as one of the reference control species along with white, red, alsike and Caucasian clovers; lucerne; and the two *Lotus* species. In general, over all trials, it exceeded those species and other introduced accessions.

13 Plant selection and breeding

All of the larger scale *L. polyphyllus* fertiliser and grazing trials in New Zealand have used unselected seed collected from the road-side or other locations of the spreading adventive horticultural material.

However, there has been some plant breeding at different sites around the world and the start of the selection and breeding of material within NZ.

Probably the most intensive selection for different types of *L. polyphyllus* has been by Kurlovich *et al.* (2008) in Finland. Over four decades "of self-pollination", numerous presumed recessive mutants have been isolated and fixed. Among these are: reduced alkaloid content; large seed; non-shattering pods; water-permeable seed coat; annuals as well as perennials; alternative flower colours; and alternative seed colours.". In particular the low alkaloids forms are consistent with a single recessive gene.

The available NZ and overseas material has already gone through several breeding cycles within NZ (Scott and Tesfaye, 2000). In the 1970's there was screening of accessions for soil conservation purposes by the Plant Materials Centre of MOW. The first selection cycle of 18 accessions from a pasture perspective was at Lincoln (Gibbs, 1988; Tesfaye, 1989). The second three-year selection cycle was of 39 accessions at Mt John. The third three-year cycle was also at Mt John of seed from the 96 elite plants of the second cycle plus 15 further accessions. Elite plants were selected on the basis of growth, persistence and some indication of sheep acceptability. Thirty one elite plants were selected and seed from each plant saved and lodged in the Margot Forde Germplasm Centre.

To date none of these selections has been multiplied up for larger scale plot evaluation.

In the light of Kurlovich's information, David Scott has started searching those NZ selected breeding lines for possible low alkaloid forms. The time scale of the search with the retention of other desirable species features will be a matter of several years.

14 Conservation issues

Conservationists regard *L. polyphyllus* as an undesirable exotic, invasive species with a number of projects to remove it from specific areas. The general public and tourists have mixed views on it, with both strong positive and negative views.

The Department of Conservation is asked to comment on any proposals for pasture development on lease-hold crown land, so there is likely to be some resistance to its wider use. Accordingly it is suggested that it would be preferable that initial expansion of its use be in controlled paddock situations rather than general over-sowing.

15 Conclusions

1. Three decades of trials show that *L. polyphyllus* is a viable pasture option for a particular set of environmental and soil conditions for a sector of Merino grazing lands.
2. These are for the loose textured soils, under low rates of S fortified superphosphate levels, of the moderate to high rainfall areas, or seepage areas in dry zones.
3. Autumn regrowth is determined by time of grazing or harvesting removal of flowering stems in the previous summer.
4. Application of herbicide (prior to sowing), heavy grazing, and/or residue burning will significantly improve the establishment of *L. polyphyllus*.
5. Seed scarification significantly decreases hardseededness, which results in improved germination and emergence.
6. Optimum establishment will be achieved at a sowing depth of 10 - 20 mm.
7. Up to 75% of total spring/summer yield is produced when plants have reached full-bloom.
8. *Lupinus polyphyllus* should be grazed prior to or at the full-bloom growth stage to ensure feed quality and acceptability is at its highest.
9. Inoculation is preferred but not essential.
10. Alkaloids provide an effective deterrent against insect pests and varmint herbivores.

16 Future Research

1. Evaluation of lupin hay and silage.
2. Liveweight gain data exists only from farmer trials, and has not been accurately quantified. Performance of grazing animals requires further investigation under controlled experimental conditions.
3. Kitessa (1992) estimated DM yield based on plant population and DM weight of individual plants. Lupin plants can vary in size considerably within a single sward, which could affect the accuracy of this technique. Also, the technique did not measure the contribution of companion species to total yield. An accurate and effective method of determining botanical composition and DM yield needs to be devised to improve future measurements.
4. Select low alkaloid forms of locally adapted material.
5. Is there a rumen adaption period for the present higher alkaloid *L. polyphyllus* forms?
6. The sowing rate of *L. polyphyllus* requires investigation, as there is currently no published information. The large size and high price of perennial lupin seed means sowing rate becomes an economically important aspect.
7. Timing, rate and number of pre-sowing herbicide treatments relative to resident vegetation, vigour and species. This is important for hill country situations where new pastures are often direct drilled or oversown.
8. Further analysis of herbage quality, and how it relates to growth stage, is required. Modern equipment (NIRS) requires calibration for lupin tissue samples to be accurately analysed.
9. Nitrogen fixation of *L. polyphyllus* needs to be quantified; using the 15N natural abundance technique.
10. The effect of sowing date on plant establishment and subsequent growth after initial grazing is required.

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