

Dryland legumes: perspectives and problems

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Abstract

The different perspectives or concepts involved in developing legumes for dryland pastoral systems is commented on in relation to: N-fixation versus animal feed; root nodule bacteria requirements; large introduced legume flora compared with indigenous; species niche in relation to environmental gradients of moisture, temperature, fertility, and grazing; species adaptation along the decreasing fertility gradient from fine-root nutrient scavenging grasses, N-fixers, mycorrhiza, and proteoid roots; interaction of N-fixation with soil organic matter; establishment; determinants of pastures legume composition; and the possible role of allelopathy.

Key words: dryland, environmental gradients, legumes, N-fixation, pasture composition

Introduction

The topic of legumes for dryland systems is discussed in relation to the dryland areas of eastern districts of both North Island and South Island, including dry hill country and inland basins.

Legume application in pastoral systems has two contrasting and occasionally conflicting aspects. The first is related to soil fertility because legumes are the main source of N-fixation, while the other relates to their role as the supplier of high quality animal feed. In New Zealand, much past emphasis has been on the N-fixation of legumes. In the wider context, as general soil fertility conditions increase, along with the use of artificial N fertiliser and irrigation, the trend has been towards greater emphasis on the feed quality of legumes. However, in dryland developed areas and in marginal developable areas, the emphasis remains on the N-fixation aspects.

In terms of N-fixation, the legume host is only a half of a symbiotic partnership. The other crucial partner is the root nodule bacteria. This relationship is generally very species specific so correct partners must be present for an effective N-fixation system. This is important since all of the major legumes in New Zealand agriculture systems have been introduced. Resident populations of appropriate root

nodule bacteria that allow pasture renewal with bare seed are probably sufficient for the common legumes in areas with a reasonable history of pasture development. Where new legume species are used, or legume species introduced to new areas, it is essential to ensure simultaneous introduction of appropriate root nodule bacteria.

Assuming appropriate inoculation technology has been applied, this paper will consider a range of other concepts and topics, some speculative, that may give a different perspective to the general issue of finding effective legumes for dryland systems.

N fixation

The legume/root nodule bacteria N-fixation system is generally the main justification for legume inclusion in agricultural systems. In this there is a general basic difference between herbaceous and woody legume species. Woody legume species (and non-legume N-fixing woody species), have a relatively low potential maximum N-fixation rate of up to ca. 50 kg N ha⁻¹ yr⁻¹ (O'Connor 1969). By contrast New Zealand studies in the 1950s indicated that herbaceous legumes have higher potential N-fixation rates with some producing up to 600–800 kg N ha⁻¹ yr⁻¹ under best conditions in low organic matter soils.

However, pasture N-fixation rates were reappraised in a national series of trials in the 1970s, in response to an apparent reduced fixation rates compared with earlier measurements (Hoglund *et al.* 1979). One of the conclusions of that review was that the reduction in fixation rates was related to the general increase in pasture soil organic matter. As organic matter increased with pasture development in the moister regions, N-fixation rates dropped to ca. 100–200 kg N ha⁻¹ yr⁻¹ as legumes used N released by the mineralisation cycle.

Hoglund & Brock (1978) suggested a generalisation that N-fixation was proportional to legume growth independent of species. Thus, a search for the most suitable N-fixing species for a dryland system would be for the legume that grows best in such an environment. This is not supported by a trial of a

multi-species legume/grass seeding mixture sown across a range of fertility levels and judged by the speed of legume to grass transition (Scott 2001). The transition was determined more by S and P fertiliser levels than by the cumulative growth of the legume components. There is also a possible confounding factor in that high tannin species have slower mineralisation rates (Lowther pers. comm.).

It should not be assumed that because a legume is present in a pasture, it fixes nitrogen. Besides the requirement for a compatible root nodule bacteria

symbiont, the N fixation process requires high energy, and legumes like other species, preferentially use available soil nitrogen as soil organic matter and mineralisation increase.

Similarly, there is probably a need to reevaluate the role of legumes in N fixation in dryland cropping and horticultural systems as soil organic matter and application of N fertiliser increases. The beneficial role of legumes in such systems is so ingrained in our thinking from old literature that we probably do not reconsider it under changing conditions.

Table 1 Legume species related to New Zealand dryland agriculture. A number of species could be relevant in more than one category, but have been limited to their most important category. # = as part of evaluation trials only.

<p>Main stream legumes in pastoral agriculture</p> <p><i>Lotus pedunculatus</i> (lotus) <i>Medicago sativa</i> (lucerne) <i>Trifolium hybridum</i> (alsike clover) <i>Trifolium pratense</i> (red clover) <i>Trifolium repens</i> (white clover) <i>Trifolium subterraneum</i> (subterranean clover)#</p>	<p>Minor legumes</p> <p><i>Chamaecytisus palmensis</i> (tagasaste) <i>Coronilla varia</i> (crown vetch) <i>Hedysarum coronarium</i> (sulla) <i>Lathyrus odoratus</i> (sweet pea) <i>Lotus corniculatus</i> (birdsfoot trefoil) <i>Lupinus polyphyllus</i> (Russell lupin) <i>Ornithopus sativus</i> (serradella) <i>Trifolium ambiguum</i> (Caucasian clover) <i>Trifolium dubium</i> (suckling clover) <i>Trifolium fragiferum</i> (strawberry clover) <i>Trifolium medium</i> (zigzag clover)</p>
<p>Main stream legumes in cropping or horticulture</p> <p><i>Lupinus angustifolius</i> (blue lupin) <i>Phaseolus coccineus</i> (scarlet runner) <i>Pisum sativum</i> (garden pea) <i>Vicia faba</i> (broad bean)</p>	<p>Native species</p> <p><i>Canavalia</i> (1) <i>Carmichaelia</i> (24) <i>Clianthus</i> (2) <i>Edwardsia</i> (5) <i>Montigena</i> (1) <i>Sophora</i> (5)</p>
<p>Naturalised herbaceous species</p> <p><i>Dipogon lignosus</i> (mile-a-minute) <i>Galega officinalis</i> (goats rue) <i>Lathyrus grandiflorus</i> (large-flower everlasting peas) <i>Lathyrus latifolius</i> (everlasting pea) <i>Lathyrus nissolia</i> (grass vetchling) <i>Lathyrus pratensis</i> (meadow pea) <i>Lathyrus sylvestris</i> (narrow-leaved everlasting pea) <i>Lathyrus tingitanus</i> (Tangier pea) <i>Lotus angustissimus</i> (slender birdsfoot trefoil) <i>Lotus suaveolens</i> (hairy birdsfoot trefoil) <i>Medicago arabica</i> (spotted bur medick) <i>Medicago glomerata</i> <i>Medicago lupulina</i> (black medick) <i>Medicago minima</i> (woolly bur medick) <i>Medicago nigra</i> (bur medick) <i>Mellilotus indicus</i> (king island melilot) <i>Ornithopus perpusillus</i> (wild serradella) <i>Ornithopus pinnatus</i> (yellow serradella) <i>Parochetus communis</i> (shamrock pea) <i>Phaseolus lunatus</i> (sieva pea) <i>Trifolium angustifolium</i> (narrow-leaved clover) <i>Trifolium arvense</i> (haresfoot trefoil) <i>Trifolium aureum</i> (yellow clover)</p>	<p>Weeds</p> <p><i>Cytisus scoparius</i> (broom) <i>Lupinus arboreus</i> (tree lupin) <i>Ulex europaeus</i> (gorse)</p> <p>Naturalised woody species</p> <p><i>Calicotome spinosa</i> <i>Crotalaria agatiflora</i> <i>Cytisus multiflorus</i> <i>Goodia lotifolia</i> <i>Kennedia rubicunda</i> <i>Laburnum anagyroides</i> <i>Ononis campestris</i> <i>Oxylobium lanceolatum</i> <i>Psoralea pinnata</i> <i>Pultenaea daphnoides</i> <i>Scorpiurus muricatus</i></p>

Trifolium campestre (hop trefoil)
Trifolium cernuum (drooping-flowered clover)
Trifolium glomeratum (clustered clover)
Trifolium hirtum (rose clover)
Trifolium incarnatum (crimson clover)
Trifolium micranthum (lesser suckling clover)
Trifolium ochroleucon (sulphur clover)
Trifolium ornithopooides (trigonal)
Trifolium resupinatum (reversed clover)
Trifolium retusum
Trifolium scabrum (rough clover)
Trifolium tomentosum (woolly clover)
Vicia cracca (tufted vetch)
Vicia disperma (small french tare)
Vicia hirsute (hairy vetch)
Vicia lathyroides (spring vetch)
Vicia lutea (yellow vetch)
Vicia tetrasperma (smooth tare)

Indicative potential in trials

#*Astragalus* spp
 #*Dorycnium pentaphyllum*
 #*Dorycnium hirsutum*
Erythrina Xsykesi (coral tree)
Lotus tenuis
Lupinus luteus (yellow lupin)
Medicago arborea (tree medick)
Melilotus alba (sweet clover)
Melilotus officinalis (yellow sweet clover)
Robinia pseudacacia (false acacia)
 # *Trifolium balansae*
 # *T. canescens*
T. striatum (striated clover)
T. suffocatum (suffocated clover)
 # *T. tumens*
 # *T. trichocephalum*
Vicia sativa (vetch)
Vicia villosa (fodder vetch)

Spartium junceum
Teline monspessulana
Teline stenopetala
Ulex minor
Wisteria sinensis

Non-indicative in pastoral trials

#*Cologania ovalfolia*
 #*Medicago falcata*
M. media
M. rigidula
 #*Onobrychis* spp
 #*Trifolium alexandrinum*
 #*T. alpestre*
 #*T. caucasicum*
 #*T. decorum*
 #*T. montanum*
 #*T. michelianum*
 #*T. quartianum*
 #*T. pannonicum*
 #*T. parryi*
 #*T. rueppellium*
 #*T. semipilosum*
 #*T. steadneri*
 #*T. thalii*
 #*T. versiculosum*
Vicia spp

A large number of legume species already exist in New Zealand, and most were introduced. This group of closely related species, formally known as Leguminosae, is treated as one family (Fabaceae) with three subfamilies (Caesalpinioideae, Fabioideae and Mimosoideae) in current taxonomy (Webb *et al.* 1988).

Table 1 lists most of the legume species known to be in, or to have been trialled, in New Zealand. Those in the 'mainstream' categories are in extensive use, have large volumes moving in the seed trade, and commonly involve large breeding efforts and are represented by several cultivars.

Those listed in the 'minor legume' category are species already available in the seed trade, but which either have a well established but small role in general agriculture (e.g. blue lupin as a green manure crop in horticulture, or a winter/spring green-feed crop in moderate fertility drylands), or are new species that research has shown to have good potential, but are still in the process of establishing their position or niche in general agriculture (e.g. perennial or Russell lupin). Caucasian clover listed in this category may be regarded by many as already having made the transition to 'mainstream'.

The 'naturalised' category illustrates the high number of introduced legume species that are already present in New Zealand and successfully maintaining small populations (Webb *et al.* 1988).

The combination of superphosphate with legumes has been the keystone to New Zealand's agricultural pastoral systems. Consequently, there has been extensive past and continuing evaluation of legume introductions to ascertain their potential. Table 1 attempts to categorise those that exhibited sufficient

desirable characteristics to warrant further evaluation for pastoral use versus those that did not. These two categories should be treated with caution, as most species have not been evaluated in a full range of environments. Two species in an earlier category illustrate this. *Lotus pedunculatus* and Caucasian clover were both species in which much of the evaluation was done in one type of environment (high altitude revegetation). Subsequent experience is suggesting that these species have a major role in completely different environments. The chief limitation to the further evaluation of promising accessions has generally been insufficient seed supply for larger scale trials.

‘Woody weeds’ are the category of introduced legumes that have been too successful in growth but undesirable in pastoral systems. This group should probably include many of the low palatable and toxic woody species included in the ‘naturalised woody’ category.

The New Zealand native flora consists mainly of perennial slow growing evergreens with very few annuals or deciduous species. Speculation is required on the relative paucity of the native herbaceous legume flora relative to the apparent success of the introduced legume flora. For native legumes there are about 37 shrubby species and only 1 herbaceous species. All seem to have low N-fixation rates in accordance with their woody nature, and none feature in non-rangeland agricultural systems. I speculate that the reason is because in a global sense, N-fixation systems are dependent on a precursor of adequate P regimes - something that has been inadequate in a long evolutionary history of generally low P status in mature New Zealand soils. In addition introduced legumes were better pre-adapted to take advantage of the changed circumstances of superphosphate fertiliser application, including the non-fertilised sites of higher P status through erosion, or through the change in herbivore type from birds to ruminants.

Environmental gradients and species niche

In seeking to categorize the role of the different introduced legumes and grasses, initially in the Mackenzie Country, I came to consider the high country, New Zealand, and the world in terms of pasture production and species suitability along four environmental gradients (Scott *et al.* 1995). The first is moisture as related to rainfall, drainage, etc., and

the associated variability in drought conditions as rainfall decreases. The second was temperature. Others refer to latitude, altitude, aspect and slope, which as such cannot affect production or legume suitability directly and are in reality surrogates for inverse gradients of temperature. Moisture and temperature are generally fixed for a site and only occasionally amenable to alteration through management.

The two environmental factors amenable to management in agricultural systems are those of soil fertility and the interaction of grazing or disturbance on plant growing points. The soil fertility gradient relates to the natural erosion, soil forming and soil aging processes, principally related to soil P, S and N levels, and to the shorter time scale affects of addition of fertiliser, like superphosphate.

In combination these four gradients determine the main variation in pasture production with indication of a logarithmic increase associated with increasing moisture and temperature, a 4-5 fold increase in productivity when moving from low to high fertility status through P and S fertiliser, and for dryland regions a 2-3 fold increase from irrigation water per se, and a 2-3 fold probable increase through use of N fertiliser rather than legume.

The first derived concept is that potential pasture production is determined primarily by environment, not species per se, and is unique for each particular combination of environmental conditions. Plant species exploit the environment, so there will also be a strong tendency for selection among the available species, from whatever source, to form vegetations or pasture combinations that approach that potential production.

The second derived concept is that of species niche. Pasture legume species have the same general response to the four environmental factors, but differ in detail. Each species has a particular adaptation niche in which it is best suited, or better suited than any other contending species, and become the species which allows release of the full potential of a site for the particular combination of environmental conditions. In the present context, the desire is to identify the legume species whose best niche is the moisture and temperature regime of a particular dryland site and the particular fertility, defoliation and treading management that will be applied.

An initial assessment of the key niches for a few of

the main legume species is reproduced in Figure 1 (and given for other species in Scott *et al.* (1995)), with the emphasis on those on the dry end of the moisture gradient where there is a clear separation of species. Separation along the temperature cum altitude gradient is not so well assessed. This is probably because trials are mostly in the lowlands and have not been assessed from that perspective. In lowland environments management factors of fertility and grazing management have probably had a greater influence. The best example is subterranean clover, which clearly has a temperature/altitudinal limitation in New Zealand.

There is also a clear difference in legume suitability according to soil fertility level. Most of New Zealand's pasture production land was previously forest at the higher end of the moisture gradient, with corresponding emphasis on species suited to those conditions. There has also been an almost automatic emphasis on high fertility species for the same environments, because without higher stocking supported by higher fertilities there is a tendency for shrub or tree reinvasion. In contrast, present dryland pastures have usually developed from previous shrublands or tussock grasslands, so there is the potential option for effective pastoral agriculture to be applied over a greater range of soil fertility conditions.

Lucerne is the best example of a legume suited to high-fertility dry sites, however Figure 1 suggests there is a suite of legume species that are suited to

moderate fertility conditions.

The gradient concept gives a different interpretation of a number of legume species present in low fertility pastures. Some are even regarded as weeds, e.g. suckling clover or haresfoot clover. An alternative interpretation is that these species are those best suited to the specific conditions and able to release the full production potential of a site under the particular conditions of soil fertility, and thus should not be scorned.

The very precise nature of the adaptation of each species to particular environmental conditions should never be underestimated. It has been demonstrated in the very rapid selection between resident and sown species from a multispecies seeding mixture when different fertility and management conditions were subsequently applied (Scott 2001). In that sense, the mere occurrence of a species becomes a very useful bio-indicator, if we can interpret what it indicates about the environment. What is the range of minor adventive legume species present in our drylands indicating about the environments? The converse is that if we consider undesirable, or we wish to increase them, then it is the environment that has to be changed, unless a more adapted and desirable species is found.

The adaptation niche is considered to be highly characteristic of each species. Where cultivars exist within species, these are likely to represent small shifts or satellites around the central species positions,

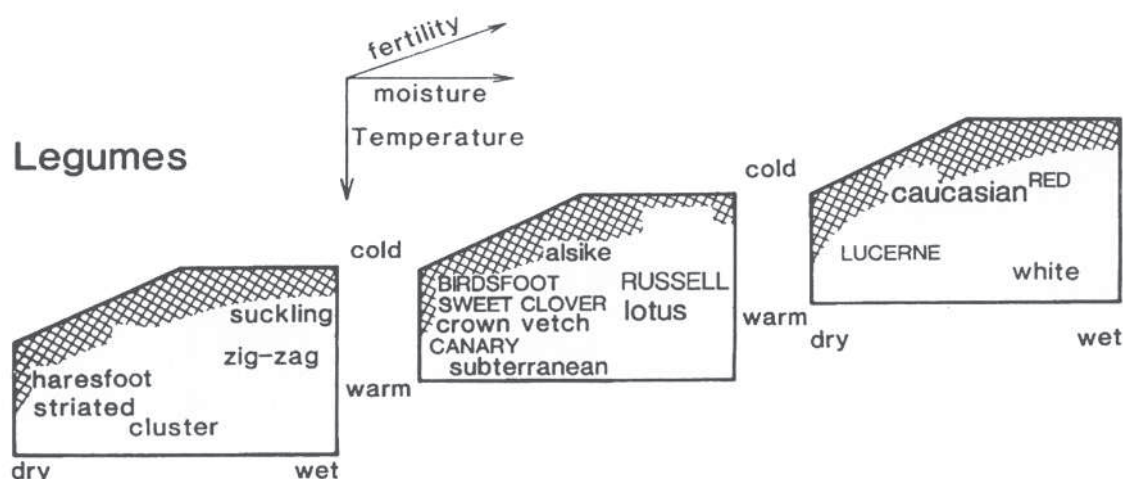


Figure 1 Role or niche of some common New Zealand legume species in relation to environmental gradients of moisture, temperature, soil fertility, and grazing management (species more suited to lax grazing in capital letters). From Scott *et al.* 1995.

rather than significant movement into the domain of another species. Thus, in the search for appropriate dryland legumes, the initial objective should be correct selection at the species level, before effort is made on finer discrimination by breeding cultivars.

As is often the case there is a rider in this selection of species for the low or moderate fertility conditions. While there are already a range of legumes present, the pasture and animal production can only remain at the lower general levels associated with those fertilities.

The gradient concept suggests an alternative selection strategy. The usual approach is to start with a potential species and then adjust the environment and management systems until its performance is adequate and the management system practical. The alternative is to set up a management system of interest, e.g. late autumn legume finishing feed, perhaps allowing some use of nitrogen fertiliser, and then to simultaneously evaluate a range of legume species in those conditions to determine which is best.

A factor not adequately incorporated in the gradient concept is the treatment of time. This is particularly important for legumes that feature prominently in the initial stages of pasture development, and are often regarded as the driver of that development. However, in the gradient concept, the change in fertility (generally S and P fertiliser) would be viewed as the main driver, and the legume species as the conduit for the release of that increased production.

Fertility gradients - fertilisers

N-fixation is dependent on P, and the Australasian pasture economies have principally relied on cheap oceanic phosphate deposits, their manufacture into superphosphate, and application in combination with introduced legumes. For P, the research work and developed concepts have been on: the low P status of mature New Zealand soils; the establishment of our mindset of the importance of P in the few decades following the North Island bush burns; and the increased P deficiency and consequent fertiliser requirements as rainfall and leaching increase. There has been considerable work on the soil dynamics and interaction of P from weathering sequences, clays types, P retention, available P forms, and associated Al levels. The general relationships between climate,

soil weathering, and consequent fertiliser requirements have been given by Sinclair & McIntosh (1983).

However, superphosphate contains more S than P, and for dryland systems, S is equally or more important. Sulphur is known to be increasingly deficient and hence fertilisation amendment is increasingly required for general pasture production as rainfall decreases. As a consequence of the early work of Ludecke (1965), various grades of elemental S-augmented superphosphate have been developed in New Zealand. Sulphur is of known importance for particular species, to root nodule bacteria, and mycorrhizal relationships. It may be more important for sheep production than for pasture production, and it may be a more cost-effective on-ground fertiliser for general application or through seed-coating. It is likely S will increasingly feature in our understanding and management of dryland systems as our knowledge of its interactions increase (e.g. Boswell & Friesen 1993; Boswell & Gregg 1998).

The role of liming in legume establishment and maintenance probably requires reappraisal. The general benefit to legumes and pastures is conceded, but lime application, at the rates used, combined with transport and spreading costs, may not be a cheap fertiliser. Soil acidification is associated with high N-fixation rates. The older literature, mostly European, on liming fertilisation needs cautious reinterpretation. The principal lime response was reported to be an increased legume establishment through raised soil pH levels (e.g. Cornforth & Sinclair 1984). More recent studies have indicated that the raised soil pH is only necessary for the initial bacteria/root inoculation stage and that thereafter the duo can function in a wide range in soil pH levels. Thus, the lime coating generally associated with root nodule bacteria seed coating may more efficiently and precisely satisfy that requirement than the need for general lime fertilisation. An additional source is superphosphate, which contains more Ca than S or P.

The micronutrient molybdenum is required for N fixation and is applied in high rainfall where excess leaching occurs. It is not generally deficient or needed for dryland soils, although commonly used as insurance. The evidence on whether molybdenum requirements can be supplied through seed coating is ambiguous (Lowther 1987 cf. Scott & Archie 1978).

Boron is known to be important and often deficient in soil for legume growth and seed production. It is known to be relevant in establishment of conifers in marginal environments. Further investigation is warranted on its possible role in legume establishment in dryland environments.

Any use of N fertiliser to aid legume establishment is a fine balancing act at low application rates (e.g. Pollock 1989). Legumes preferentially use available soil N rather than establish their root nodule bacteria N-fixation system. Although there may be an apparent beneficial response of legume establishment to N fertiliser in the first year, the legumes often fail in subsequent years because of the non-establishment of their root nodule bacteria system, with a more dramatic collapse the more marginal the environment. This limitation does not apply if the legumes are grown only for their feed quality attribute.

Fertility gradients - species adaptation

An alternative view of fertility gradients is in the general way that species have evolved to adapt to them. The potential for high plant growth under high soil fertility conditions means that the interaction between species is mainly in competition for light and nutrients, and in which finerooted grasses win over coarse-rooted legumes, if they are not overtopped by taller growing shrubs and trees. It is the intermediate position that we aspire to in pasture development.

At earlier successional stages, at lower N fertility conditions but still adequate P levels, then the more coarse-rooted legumes, with their own N source in the form of a root nodule bacteria relationship, have a competitive advantage. The role of legumes in this successional stage is present in pasture development and many overseas natural successional stages. However, in New Zealand's native situations this role appears to have been filled by non-legume N-fixing species (*Discaria*, *Coriaria*).

At still lower soil fertility where P becomes more limiting, some species that may be coarse-rooted increase their effective scavenging area through mycorrhiza associations, and have a competitive advantage. Most species in lower fertility environments are mycorrhizal, and unlike root nodule bacteria, the fungi concerned can have a wide host range (Crush 1976). Although mycorrhizal relationships can be beneficial at low soil fertilities, they can be neutral or even pathogenic at higher soil

fertilities.

Another group of species that function at very low soil fertility conditions is the 'proteoid' root type. These exude citric acid from their roots into the soil environment to help release nutrients from primary minerals in the soil. Although this adaptation is mainly characteristic of the Proteaceae, it has also been reported for a few *Lupinus* spp. (Gardner *et al.* 1983). It has been suggested, but not verified, that this is one of the explanations for the success of *L. polyphyllus* in parts of New Zealand. There is also the possible effect of acid production in the free-living phase of the rhizobia life cycles (O'Connor 1969).

Legume establishment

Seed is the easiest method of introducing a new species into a pastoral system. In subsequent use the preference is for plants not to flower or seed, remain vegetative, spread vegetatively or have other characteristics giving them long term perenniality. From an evolutionary or seed merchant perspective these are conflicting requirements. This is particularly so for dryland species, where several of the more promising species are high polyploids, long term perennials, with underground rhizomes, but consequential low seed production (e.g. *Trifolium medium*, *T. ambiguum*).

For dryland systems, further consideration needs to be given to the development of technologies for establishment of vegetative materials of desirable legume species. Such methods are regarded as conventional for forestry, shrubs, horticulture, or earthworm transfer. We have demonstrated that replanted rhizome sections of a few centimetres of Caucasian clover, zigzag clover and crown vetch can spread to two metres in 10 years (Scott & Mason 1992). The field spiking method used for vegetative establishment of bermuda grass pastures in the eastern USA probably warrants evaluation.

Annuals

The role of annual legumes in New Zealand dryland pastoral systems remains debatable. The technology has been best developed for subterranean clover, and it is unclear whether its wider use is limited by a reluctance to accept the more strict management systems that annuals require, including possible resting to allow annual reseeding, or the temperature limitation that subterranean clover has in the New

Zealand environment.

There are many annual legumes in the adventive flora and from plant introduction programs, and several are widespread, e.g. haresfoot clover in dry environments and suckling clover in the moister environments. Most are of small stature, generally associated with lower fertility conditions and the lower productivity associated with those conditions, and tend to fluctuate widely in prominence with climate variation between years. Although they do respond to fertiliser, there is minimum information on their N-fixation role and how they might be incorporated into some general pasture development strategy at probably low or moderate fertiliser regimes.

Pasture composition

A further perspective on dryland legumes comes from consideration of vegetation composition as reflected by the proportion of legume in a pasture, the legume to grass transition with development, the swing between legume and grass dominance within a season, and the place of weeds or minor species within a pasture. The implication is that there are features and processes acting at larger vegetation, time or space scales that are more than the combined physiological characteristics of component species.

Vegetation composition literature indicates there is a strong tendency for a relatively fixed relationship between the relative abundance of different species (Preston 1948; Scott 1993). This is usually expressed as a linear relationship between the logarithm of the relative abundance of a species and its rank order from most to least important species. This relationship may be approximated by several functions like a geometric series, or truncated log-normal. For example in a geometric series if the most abundant species was 80% of the pasture, the 2nd species will be $0.2 \times 80 = 16\%$, the 3rd $0.2 \times 16 = 3.2\%$, etc. The average for grasslands is for the first species to be ca. 68%.

Initial pasture composition may be determined by the relative seeding rates of sown species and their physiological characteristics. However, following this an 'ecological requirement' may force pastures to adjust proportions with respect to the log/linear relationship, and of a 'need' for some volunteer species to complete the lower abundance ranks. 'Volunteer' or 'weeds' in low proportions may be a requirement.

Conceivably, alteration of site, time, climate or management results in a change to the rank order of species suitability. Thereafter, there is a rapid readjustment of species proportions to that compatible with their new rank order. A minor shift in the physiological suitability of a grass versus legumes could result in a major shift between an 80% legumes:16% grass pasture to an 80% grass:16% legume pasture. The unsatisfactory aspect of the log/linear abundance/rank concept is that there is no good explanation of why it occurs. However, the tendency of a log/linear relationship has been sufficiently demonstrated in a wide range of vegetation and other data that we should accept it, along with the $3/2$ thinning law, as among a few ecological laws.

Allelopathy

It is a common experience in pasture development, especially in more marginal environments, that legumes are seldom as good or spectacular again in subsequent sowings as they were in their initial sowing. This may be because the first legume phase may have raised soil N status to a level so that other species were more competitive, or that residual diseases build up in the first phase. A third possibility is that the legume has altered the soil in some other manner. Plants or decaying plant material release chemical, notably phenols, at rates similar or higher rate than we associated with the like of N-fixation and alter the soil environment either positively or negatively for other species (Siqueira *et al.* 1991).

The presence of such allelopathic substances was one of the explanations given for the problems in oversowing 'danthonia' country, and the need to apply herbicide several weeks prior to attempting sowing to allow materials to dissipate (Beggs 1964; Parle 1964). It was also investigated in the Mackenzie to try and explain the short-term nature of some legumes like alsike clover and the lack of associated grass establishment (Scott 1975; Macfarlane 1980). There was a strong influence of applied white clover shoot material on establishment of subsequently sown species, and it was ameliorated by use of phenol absorbents. The effect is greater the more marginal the environment. This chemical interaction between species is a relatively unexplored field in legume and pasture establishment. It is unclear why there are not other reports on the adverse allelopathic aspects of white clover.

Allelopathy is one explanation of why it is better to have a fallow or alternative pasture phase between successive lucerne crops. However, lucerne in marginal environments also exhibits another phenomenon for which there is no adequate explanation. Lucerne crops may fail in the first year or so, but any remaining plants get better and better over time scales of years or decades rather than weeks or months. Seed taken from such plants and resown suggests the effect is not genetic.

Stock acceptability

Legumes as a group contain many novel chemical constituents that affect their suitability as feed for domestic stock. These can range from poisons, to low-palatability (e.g. broom), to seasonal variation in acceptability (e.g. alsike clover), to hormonal effect on animals (e.g. red clover—regarded as either good or bad depending on whether the emphasis is on the estrogenic or growth promoter aspects). These chemical constituents may be seen as evolutionary adaptations to herbivory protection or stress tolerance. However, the impression from some agricultural legumes is that such feed deterrents may be more prevalent in early season growth and decrease or reverse with age. This would seem to be the reverse expectation if the features were stress adaptations e.g. some summer or frost curing for ready acceptance of alsike clover; lower early season acceptance of tagasaste but active stem debarking in the autumn, and the active stock excavation of Caucasian clover rhizomes and lupin crowns in late autumn.

Discussion

The main concerns with dryland legumes for pasture development will continue to be their methods of establishment along with their associated root nodule bacteria, feeding value, and management for continued persistence. The present paper adds some other perspectives on those features. The first is to consider the environment and species as a continuum of gradients, with any consideration of drylands having to simultaneously include aspects of species adaptation to temperature, fertility and the interaction of plant growing points with the defoliation regime required or imposed by management.

The second is that while there is already a wide range of legumes present, considered, or will be further introduced, that history and general systems considerations would predict that only a very few will ever be in widespread use. Whether they are

among those already in use is the point of debate. They probably are.

Changes to legume success are likely to be subtle adaptations around the two factors over which we can exert some control—soil fertility and grazing management, and the time scale over which adaptation or sustainability is considered. Soil fertility and grazing will continue to be a compromise between what is needed or affordable and what is required to maintain the species. This will require further consideration of the general fertility/productivity relationship, the corresponding relevance of the different microbiological relationships, possible allelopathic-like interactions, and the general systems considerations of legume pasture composition. With the wide seasonality and yearly variation of legumes in dryland environments, particularly of annuals, there may be a need to take a long term perspective on sustainability issues in dryland legumes, considering decades rather than years for their occasional pulse of N input, and possibly discounting their regular annual feed production considerations.

REFERENCES

- Beggs, J.P. 1964. Growth inhibitor in soils. *New Zealand Journal of Agriculture* 10: 529–535.
- Boswell, C.C.; Friesen, D. K. 1993. Elemental sulfur fertilizers and their use on crops and pastures. *Fertilizer Research* 35: 127–14.
- Boswell, C.C.; Gregg, P.E.H. 1998. Sulfur fertiliser in grazed management systems. pp. 95–135 *In*: Sulfur in the environment. Ed. Maynard, D.G., Marcel Dekker, New York.
- Cornforth, I.S.; Sinclair, A.G. 1984. Fertiliser and lime recommendations for pasture and crops in New Zealand. Wellington, Ministry of Agriculture & Fisheries. 66 pp.
- Crush, J.R. 1976. Endomycorrhizas and legume growth in some soils of the Mackenzie Basin, Canterbury, New Zealand. *New Zealand Journal of Agricultural Research* 19: 473–476.
- Gardner, W.K.; Barber, D.A.; Parbery, D.G. 1983. The acquisition of phosphorus by *Lupinus albus* L. III. The probable mechanism by which phosphorus movement in the soil/root interface is enhanced. *Plant and Soil* 70: 107–124.
- Hoglund, J.H.; Brock, J.L. 1978. Regulation of nitrogen fixation in a grazed pasture. *New Zealand Journal of Agricultural Research* 21: 73–82.
- Hoglund, J.H.; Crush, J.R.; Brock, J.L.; Ball, R.; Carran, R.A. 1979. Nitrogen fixation in pastures. 12. General discussion. *New Zealand Journal of*

- Experimental Agriculture* 7: 45–51.
- Lowther, W.L. 1987. Application of molybdenum to inoculated, lime coated white clover seed. *New Zealand Journal of Experimental Agriculture* 15: 271–275.
- Ludecke, T.E. 1965. Further aspects of sulphur nutrition of legumes. *Proceedings of the New Zealand Grassland Association* 27: 129–138.
- Macfarlane, M.J. 1980. Allelopathic effects of white clover (*Trifolium repens* L.) on pasture species in high country environments. M. Agr. Sc. thesis, Lincoln College, University of Canterbury., Lincoln, New Zealand. 144 pp.
- O'Connor, K.F. 1969. Studies of lime and phosphate relations of rhizobia–legume systems. *Soil News* 5: 154–167.
- Parle, J.N. 1964. Some aspects of the nodulation problem occurring in the Wither Hills. *Proceedings of the New Zealand Grassland Association* 26: 123–126.
- Pollock, K.M. 1989. Grass establishment and performance on a high country soil fertilised with nitrogen. *New Zealand Journal of Agricultural Research* 32: 7–15.
- Preston, F.W. 1948. The commonness and rarity of species. *Ecology* 29: 321–326.
- Scott, D. 1975. Allelopathic interactions of resident tussock grassland species on germination of oversown seed. *New Zealand Journal of Experimental Agriculture* 3: 135–141.
- Scott, D. 1993. Constancy in pasture composition? *In: Proceedings of XVII International Grassland Congress* 1604–1606.
- Scott, D. 2001. Sustainability of New Zealand high-country pastures under contrasting development inputs 7. Environmental gradients, plant species selection, and diversity. *New Zealand Journal of Agricultural Research* 44: 59–90.
- Scott, D.; Archie, W.J. 1978. Sulphur, phosphate and molybdenum coating of legume seed. *New Zealand Journal of Agricultural Research* 21: 643–649.
- Scott, D.; Mason, C.R. 1992. Potential for high country pasture improvement from planting of rhizome fragments of spreading legumes. *Proceedings of the New Zealand Grassland Association* 54: 127–129.
- Scott, D.; Maunsell, L.A.; Keogh, J.M.; Allan, B.E.; Lowther, W.L.; Cosssens, G.G. 1995. A guide to pastures and pasture species for the New Zealand high country. Palmerston North, New Zealand Grassland Association. 41pp.
- Sinclair, A.G.; McIntosh P.D. 1983. Soils and fertiliser for pasture production in the South Island hill and high country. pp. 27–34 *In: Proceedings of the 1983 Hill and High Country Seminar*. Centre for Resource Management, Lincoln.
- Siqueira, J.O.; Nair, M.G.; Hammerschmidt, R.; Safir, G.R. 1991. Significance of phenolic compounds in plant-soil-microbial systems. *Critical Reviews in Plant Science* 10: 63–121.
- Webb, C.J.; Sykes, W.R.; Garnock-Jones, P.J. 1988. Flora of New Zealand Vol. IV. Naturalised Pteridophytes, Gymnosperms, Dicotyledons. Christchurch, DSIR Botany Division. 1365 pp.