Management and nitrogen fertiliser options for increased pasture productivity in dryland hill systems

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Abstract
Legume productivity in dryland pastures is often less than 10% of the total annual growth and dominated by annual species. White clover content of these pastures is often less than 5% because the period of potentially most active growth coincides with that of low soil moisture levels. Therefore variations in summer rainfall have a dominant effect on the white clover content of the pasture in the following spring. Predictive relationships for white clover content are presented.

Attempts to introduce alternative legumes into dryland hill pastures have generally been unsuccessful because of the harsh climate during late spring–summer and competition from resident species. It is unlikely that further research will change this situation.

This paper compares improved legume productivity from dryland pastures with the use of N fertiliser as options to increase winter and spring pasture growth for increased economic gain. To optimise productivity and summer persistence of resident legumes, grazing management, especially in spring, must aim to avoid accumulation of surplus grass that will shade associated legumes.

During winter and early spring, when soil moisture is adequate, pasture growth in dryland hill pastures is limited by inadequate soil nitrogen (N), due to low legume content and N fixation, even where soil phosphorus (P) is at moderate to high levels. Consequently, pasture responds well to applied N fertiliser. At Waipawa in Hawke's Bay, the magnitude of response to N fertiliser was inversely related to the legume content of the pasture and so was greatest (e.g. up to 47 kg DM/kg N) on steep north aspects with little clover, and much less (8-17 kg DM/kg N) on easy slopes. In winter, N fertiliser offers reliable and significant increases in pasture growth. To optimise economic returns from the additional pasture dry matter, winter stocking rates could be increased. However, a simulation study showed that the maximum economic benefit would be obtained by maintaining ewe numbers and increasing fecundity to produce more lambs.

Key words: hill country, legumes, nitrogen fertiliser, pastoral dryland

Introduction
New Zealand pastoral dryland is characterised by regularly low summer-autumn rainfall such that soil moisture levels fall below those needed for active pasture growth, and commonly to those defined as drought conditions. Summer-dry soil conditions may occur on both flats and slopes in low rainfall regions, and on north facing hill slopes in more moderate rainfall zones. Consequently, many hill farms contain some land units with pastures that are annually subject to drought, or near drought conditions. The main features of such pastures are low annual dry matter production (i.e. 5-10 t DM/ha/yr; McIntosh & Sinclair 1983; Vartha & Hoglund 1983; Gillingham *et al.* 1998), and especially low legume content. (e.g. from 2 to 5% white clover contribution; Barker & Dymock 1993; Orr & Wedderburn 1996). In areas of regular summer rainfall, white clover content of pastures remains relatively stable and high from year to year. In regions with consistently low summer soil moisture levels, white clover will not persist and annuals that are able to flower and set seed before the onset of drought predominate (Sheath & MacFarlane 1990).

In more variable climates, the white clover content of the pasture in spring is largely determined by the rainfall over the previous summer (O'Connor *et al.* 1968; Hutchinson *et al.* 1995). Rainfall and pasture legume measurements at the Waipawa research area in Hawke's Bay over a 7-year period from 1995-2002 have been used to further examine this relationship. Results showed that the best predictor of a likely change in white clover content of spring pasture was the difference in total rainfall between the previous two summers (December to February). The white clover means were derived from 40 pasture measurement sites on easy slopes of both north and south aspects described by Gillingham *et al.* (1998). Rainfall differences between successive summers ranged from 105 to 376 mm. Figure 1 shows the relationship for both high ($R^2 = 0.84$) and low ($R^2 = 0.85$) Olsen soil phosphorus (P) test levels. The difference in slope of the two relationships reflects the greater white clover content in the high P compared with the low P pastures at any one time. Results show that if there was a drought in the summer (e.g. January) of year 1 and high summer rainfall in year 2, then there will be very little clover in the pasture in the subsequent spring (e.g. September) of year 1, but a large increase in white clover content in the spring of year 2. However, if there was again similarly high rainfall in the summer of year 3, then the further increase in clover in the spring of year 3 would not be as great. In this second situation, the difference between successive summer rainfalls was not great, so the effect in further increasing the white clover content was also not great. The same relationship applies in going from a wet summer to a dry one the next year. At Waipawa it is obvious that when the white clover content of spring pasture increased, the annual legume content also increased (results not shown) and vice versa. Interestingly, the relationship between summer rainfall change and annual legume change was not as strong as with white clover, and not modified by soil P status. This indicated that annual clovers were better able to accommodate variation in rainfall from year to year.

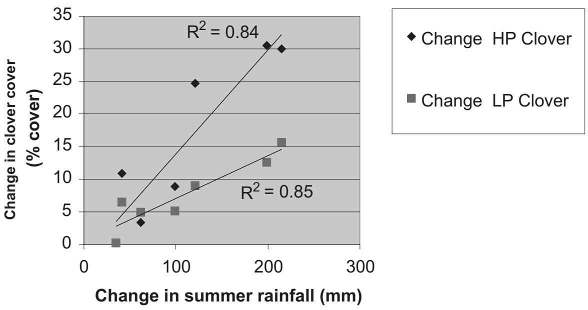

Figure 1 Relationship between change in rainfall (mm) over any two successive summers (December to February) and the subsequent change in white clover cover (% frequency) on easy slopes in the following spring for each of high (Olsen P =28) and low (Olsen P =9) soil P levels.

The main conclusion from this analysis was that the manager can only expect to take a subordinate role to climate in influencing the legume content of dryland hill pastures, although as shown in this study, the effects can be accentuated by conditions that enhance clover growth, such as improved soil P levels. What else can be done? This paper considers the options for improving the productivity of dryland hill pastures by either encouraging improved legume productivity, or using N fertiliser.

Management Options

There are a number of management inputs that can potentially affect legume persistence and productivity, and in turn seasonal and annual pasture productivity. These include the introduction of improved pasture species, optimised grazing management and improved soil fertility. These aspects have had sufficient research to now draw some conclusions.

Improved legume species or ecotypes

For many dryland pastures that experience regular drought, resident legumes are dominated by annual species such as *Trifolium arvense, T. dubium, T. glomeratum and T. subterraneum***.** A more detailed evaluation of their roles is covered in associated papers at this Symposium.

Where drought is irregular and/or easy contoured land classes form a mosaic within steeper topography, white clover populations pulse with summer rainfall as previously described. However, many attempts to introduce new white clover cultivars into dryland pastures containing a background of resident ecotypes have failed to increase the long-term content of white clover. The resident ecotypes simply dominate the re-established pastures (Wedderburn *et al*. 1996). Unless there are major changes to soil conditions and/or grazing management within mixed livestock systems, there is little likelihood of pasture renewal leading to increases in legume content in summer dry hill country, over and above that achieved by resident legumes. It is time to recognise that further pursuit of this goal, at least with conventional technology and costs, is likely to be similarly unsuccessful.

Optimised grazing management

An alternative to the introduction of new legumes is the management of pastures to optimise legume production and the associated level of N fixation. Grazing management is a key part of this approach for hill pastures.

In dryland environments, an essential task is to maximise pasture productivity and quality during the period of reliable soil moisture, which is generally from autumn to mid-spring. This involves a mix of maximising pasture utilisation and conditioning pastures to carry vegetative growth through to the dry period (Sheath & Boom 1985). This means control of spring pasture is crucial, especially in the South Island where it represents a high proportion of total annual growth. In mid-late spring, legumes are particularly susceptible to management practices that allow grass to accumulate. Shading of white clover stolons, and their removal by subsequent hard grazing, will retard legume persistence and production (Sheath & Boom 1985). Sub-clover is similarly affected (Sheath & MacFarlane 1990). Spring grazing management that holds pasture cover between 1 200-1 800 kg DM/ha from November to January will optimise legume persistence and productivity (Sheath & Boom 1985).

Meaningful summer rainfall that promotes pasture growth is a bonus. However if growth is not under control by late summer, it will restrict both legume and grass recovery when reliable rainfall resumes in autumn. Sufficient subdivision to enable grazing control in priority areas of the farm is usually a first requirement.

Improved soil fertility

A basic principle of New Zealand farming is that P fertiliser needs to be applied to most soils to allow clovers to grow and to fix atmospheric N. This applies well in most locations. In regions with reliable summer rainfall, legumes consistently support high producing pastures. However, in dryland regions, sulphur (S) may be more important than P in limiting pasture production (Sinclair *et al*. 1985). Therefore, S-fortified fertilisers are used with only low to moderate rates of fertiliser P. Similarly, in many of the more moderate rainfall locations (1 000 mm + /year), where parts of farms are dry due to steepness and/or aspect, pastures on these sites respond to only low rates of P. This occurs because they basically lack the required moisture levels for significant pasture growth and associated legume content (Gillingham *et al.* 1998). Table 1 presents results from Whatawhata (Gillingham *et al.*1990) and Waipawa (Gillingham *et al.* 1998) fertiliser trials that show the increase in annual pasture growth from easy and steep slopes with increase in soil P test. The pasture dry matter production levels and responses (kg DM/ha) to the same P fertiliser inputs on steep slopes are typically about half of that from easy slopes, even in higher rainfall regions such as the Waikato. In these trials the pasture responses on steep slopes to increasing soil P levels were not significant. Such areas will not respond to further increased applications of P fertiliser, and in many cases are already at excess soil P levels (i.e. greater than 12-15 Olsen P test units). Continued sulphur application is generally required because it

Table 1 Average annual pasture production (kg DM/ha) on easy and steep slopes at increasing Olsen soil P tests for contrasting locations.

Whatawhata* (1985–88)	Soil P test = 8	Soil P test = 11	Soil P test = 30	SED***
Easy (10–20°)	12 000	13 000	14 750	4.3
Steep (30–40°)	8 150	7 500	8 500	365

Waipawa** (1995–2002)	Soil P test = 9	Soil P test = 15	Soil P test = 28	SED
Easy (15–25°)	3 700	4 300	4 900	2.5
Steep (25°+)	2 000	2 200	2 700	478

* = Average from 0–30 and 30–70 mm soil depths

** = 0–75 mm soil depth

*** = Standard error of the difference

is subject to loss through the soil, even where there is low effective rainfall (McIntosh & Sinclair 1983).

The Role of Nitrogen Fertiliser

Pasture responses to nitrogen fertiliser

During the seasons of adequate soil moisture, and despite moderate to high soil P levels, dryland pasture growth is often limited by inadequate levels of soil N (Peri *et al.* 2002). This typically occurs in pastures where there is low legume content and associated low N fixation (Grant & Brock 1974). Such pastures should respond strongly to N fertiliser application during the winter–spring period.

A large-scale trial at the Waipawa research area examined the relative importance of P and N fertilisers on summer dry hill pastures (Gillingham *et al.* 1998). This work has been further extended in a series of on-farm trials in the east coast of both North and South Islands to evaluate pasture responses under a wider range of climatic conditions (Gillingham, unpublished reports).

From these trials, some clear conclusions can be drawn. Nitrogen fertiliser applied in early-mid winter at 30 kg/ha resulted in significant pasture responses in winter, carrying through to early summer. The response was about twice as high on north as on south aspects (Table 2), and very high on the steep north aspect slopes, which have near zero clover. High responses to N fertiliser were also measured on moist hill country by Ball *et al.* (1976) and Lambert & Clark (1986).

Table 2 Average annual pasture responses (kg DM/kg N applied) from urea fertiliser at 30kg N/ha on contrasting topographic land units from 1995-2000 at Waipawa.

	Easy	Steep
North aspect	17	47
South aspect	8	23
Statistical significances		
N fertiliser	*	
Slope	***	
Aspect	***	

* = P< 0.05; *** = P< 0.001.

The lower total response on easy slopes and south aspects is because such pastures, with naturally better clover content, suffer some shading of legumes in late spring-summer as a result of the increased grass growth, especially if grazing pressure is low. This depresses total growth during this period. The effect is accentuated where the application of P fertiliser has previously encouraged increased clover growth. Subsequent application of N fertiliser to such sites increases grass growth and the associated shading of clovers. On steep north aspect slopes this does not occur, or occurs to a much lesser extent.

The timing of the response was related to the soil temperature when active pasture growth commences. Therefore, on south aspects at Waipawa the pasture response to N applied in winter did not occur until August/September but was not diminished because of this delay. Similarly, the regional trials showed that N responses in the South Island did not occur until October/November.

The basic message from these trials was that the pattern and extent of pasture response to N fertiliser was strongly related to soil temperature and inversely related to the pasture clover content, regardless of whether on north or south aspects, or on easy or steep slopes.

Stock policies and management systems

Of the management options discussed above, the use of N fertiliser for additional pasture growth appears to offer the most immediate benefit to sheep and beef production systems in dry regions. N fertiliser will give reliable increases in pasture production, but there are some side effects to be aware of.

The pasture production response may occur in mid winter on north aspects in the North Island, or in late spring in the South Island. This will enable more ewes to be carried through winter on North Island farms, but may aggravate pasture surpluses in late spring - early summer further south.

If N fertiliser is applied to areas with reasonable clover content to provide extra pasture growth in early spring, the potential effects of grass shading on legume growth will cause some reduced pasture growth in late spring-early summer. Such effects must be traded off against the advantages of having extra pasture growth in early spring and how effectively it is used at that time. The areas receiving N fertiliser can be rotated to minimise any long term, detrimental effects on pasture composition.

The Waipawa results were obtained from grazed pastures. An optimum response can be expected from vegetative swards with little bare ground. However, where pastures are either heavily grazed, and opened up before N fertiliser application, or where rank pasture has not been controlled by late autumn, then the pasture response to applied N fertiliser will be lower.

Table 3 Economic net margin ($/ha) and associated relativity (%) for contrasting farmlets at Waipawa from 2000 to 2003.

	Moderate P	Mod P+N	High P	High P+N
2000-2001	446	490	465	502
2001-2002	395	465	488	535
2002-2003	255	284	228	269
Average	365	413	394	435
Relative %	100	113	108	119

What can N fertiliser offer in economic returns? Results from the four farmlets in the Waipawa trial offer some guide. Self-contained farmlets (12 ha) were structured on easy-steep slopes that comprised a balance of both north and south facing slopes. Ewe numbers were allocated in relation to anticipated winter pasture responses. Pastures in all farmlets were grazed to a common level that varied with season (i.e. 1 000-1 300 kg green DM/ha), and aimed to achieve a high level of pasture utilisation. Two farmlets had a moderate soil P level (Olsen P = 15), and N fertiliser was applied to steep slopes in one farmlet only at 50kg N/ha. The soil P level in the other two farmlets was at a high level (Olsen P = 28) and again, N fertiliser was applied to steep slopes in one farmlet only. Animal production and associated economic analysis results are available for the 2000-2003 years (Table 3). The application of N fertiliser at both moderate and high soil P levels increased the economic net margin by at least 10%. The high P farmlet required a large initial capital input of P fertiliser (100 kg P/ha) to establish the higher soil P levels and the charge on this extra capital expenditure depressed the net margin compared with that of the moderate P farmlet.

These results from Waipawa are for a specific, steep hill country situation and it can be expected that the economic benefits of applying N fertiliser will vary with the farming system used. To explore the economic effects of different systems, computer-based simulations were run using Stockpol (Marshall *et al*. 1991). The base-farm scenario, structured on the Hawke's Bay-Wairarapa summer dry model as described in the MAF Sheep & Beef Monitoring Report (2002), ran a mix of sheep and cattle (60:30 su ratio), with the cattle a mix of breeding cows and finishing bulls. The three scenarios that were compared with this base system all received 30 kgN/ha across the whole farm in mid-June. The pasture response levels used were assumed to be 22 kg DM/kg N for steep land (20% of the farm) and 12 kg DM/kg N for easy land (80% of the farm). The three comparative scenarios were:

- Base farm plus N - no stock policy change, with gains reflected in lamb live weights only.
- More ewes plus N - an increase in wintered ewe numbers, with earlier and lighter store lamb sales.
- More lambs plus N - an increase in ewe fecundity with increased lambing % and lighter lambs.

To avoid stock class - product value interactions, cattle policies and performances were held constant for all 4 scenarios, i.e., only the sheep system was altered and allowed to respond. The results are presented in Table 4.

Animal production in each of the simulated scenarios was raised (e.g. stocking rate, lambing percent), until it was impracticable to continue. In each case the main constraint was a shortage of summer-autumn feed in year 1. Seeking benefits from N fertiliser

Table 4 Stocking rate, lamb production and economic benefits from simulation of N fertiliser application to contrasting dryland farming systems.

	Stocking Rate (su/ha)	Lamb live weight (kg/ha)	Gross Margin ($/ha)
Base farm N- N	9.6	139	557
A. Same stock +N	9.6	142	555
B. More ewes +N	10.9	142	581
C. More lambs + N	9.6	207	642

through simply increasing ewe and lamb liveweight (i.e. 'Same stock +N' scenario) did not improve gross margins. In the 'More ewes +N' scenario, stocking rate was increased by 13% and this led to a gain of $26/ha. The greatest economic benefits of N fertiliser occurred when lambing percentage was increased from 120% (base) to 165% ('More lambs +N'). In this system, increased winter-spring pasture production was most successfully converted to economic gain, through the sale of more lambs prior to summer drought. These cases illustrate the need to carefully redesign the farm system if the full benefits of changed inputs are to be realised.

However, not all trials have shown such positive results. At Whatawhata the application of 30 kg N/ha produced only 7-9 kg DM/kg N applied, and was not modified by introduced or resident pasture species. (Sheath *et al.*1991). Sheath *et al.* (1991) concluded that the use of N fertiliser in this context was not profitable. However, this was mainly because the earlier lambing system evaluated in conjunction with N fertiliser application, also resulted in lower lamb numbers, compared with the traditional system. This result directly offset the pasture production advantages from using N.

In contrast, a trial at Lincoln (Hoglund & Pennell 1989) measured significantly heavier ewe weights at lambing and subsequent higher lamb birth weights and total production from applying 50 kg N/ha in autumn. The advantage may have been largely associated with faster pasture recovery after drought by the N treated pastures. In this way, N fertiliser is a management tool that offers significant potential benefits. In support of this it was noted at Waipawa that the pasture response to N in winter was in fact greater after a drought, maybe because of the near zero legume content, than in other years with more normal rainfall. The pattern of responses from autumn applied N fertiliser can be variable (O'Connor 1982), but where the initial pasture response is slow, especially due to low soil temperatures, the residual response can be significant.

Conclusions

- Despite considerable research and farmer experience, the success rate from sowing improved legumes into dryland pastures has been low.
- The variability in legume content of the pasture is dominated by the pattern of summer rainfall.
- Perhaps the most that should be expected is to optimise legume production and persistence by maintaining management control in winter and spring, when moisture levels are reliably adequate for growth.
- Nitrogen fertiliser offers reliable and economically beneficial increases in winter and spring pasture production. The optimisation of returns may require modification of existing management systems. Simulation analysis will assist in defining the best option.

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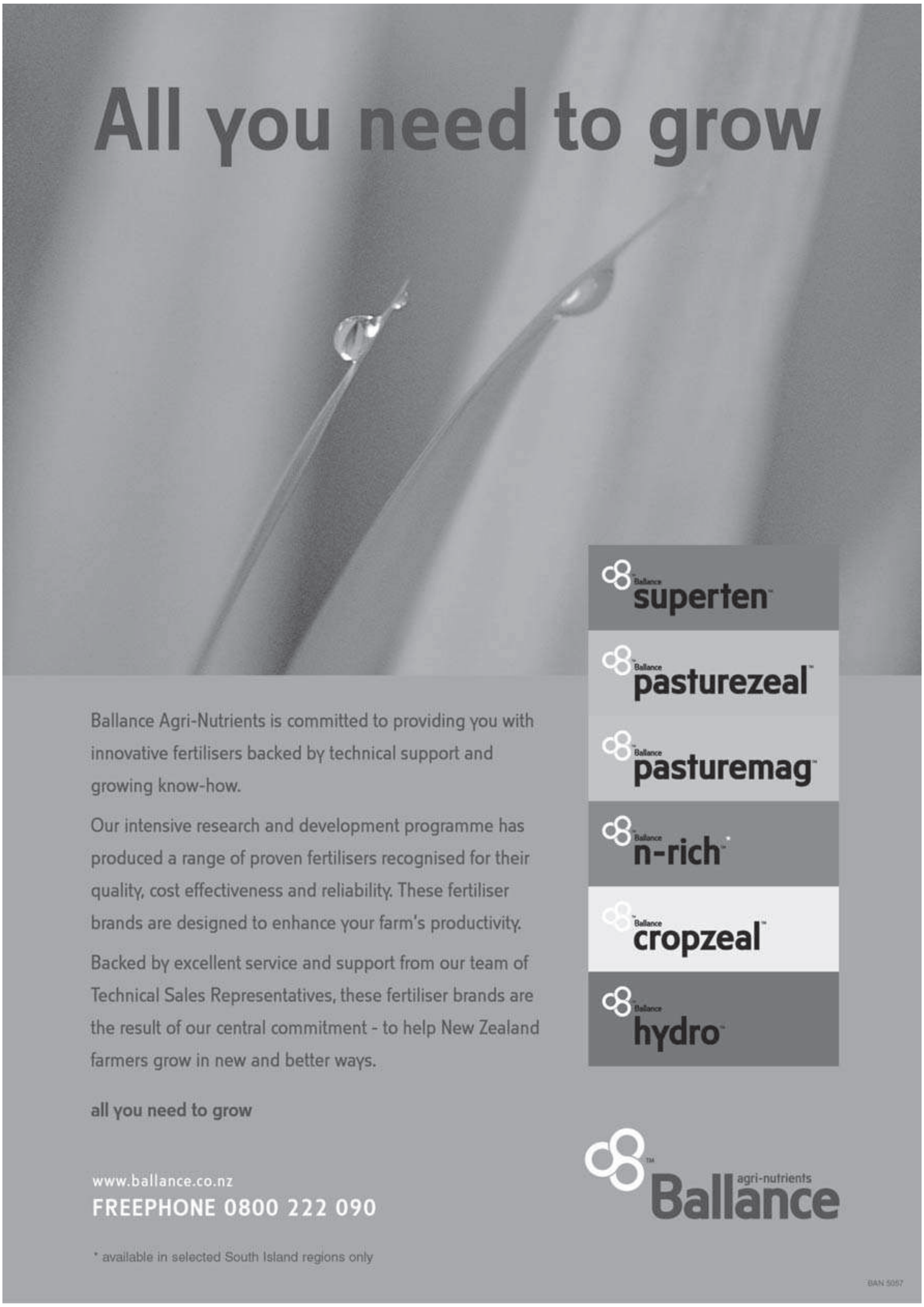
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