

Redefining the production potential of hill pastures using fertiliser nitrogen

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Abstract

Farmer perceptions of the productive potential of land influence their attitudes to productivity improvement. Pasture production information has generally been gathered within management systems that were considered feasible at the time. A sheep grazing trial was run over 2 years in southern Hawke's Bay hill country in which a Fertiliser treatment involving a very high rate of nitrogen (N) fertiliser (400 kg N/ha annually as 8 split dressings of 50 kg N/ha) was applied to blocks with historically low, medium or high fertility. Additional fertiliser P and S was also applied as part of the Fertiliser treatment, however the responses were judged to have been mainly due to the N fertiliser. Annual pasture production increased from an average 9.2 t DM/ha in Control areas to 17.1 t DM/ha in Fertiliser treatment areas. Similar responses of 18 to 22 kg DM/kg N fertiliser occurred across the 3 fertility blocks. Average annual pasture production for the historically high fertility-Fertiliser treatment combination was 19.4 t DM/ha, higher than on most dairy farms. Pasture content of high-fertility-responsive grasses such as ryegrass increased, at the expense of low-fertility-tolerant grasses such as browntop, legumes such as white clover, and herbaceous weeds. Nitrate leaching measurements suggested annual losses were increased by 25 kg N/ha or 6% of the N applied. Given present-day cost structures and returns, these results suggest use of higher rates of N fertiliser than is current practice is an economic option for hill farmers. However long-term sustainability of systems receiving such high dressings of fertiliser N requires further investigation before such an approach should be adopted as part of commercial practice.

Keywords: botanical composition, hill country, New Zealand, nitrate leaching, nitrogen fertiliser, pasture production potential

Introduction

Farmers have aimed to increase productivity from New Zealand hill country since it was cleared of forest and pastures were established about 100 years ago. Achievement of this aim has been aided by improvements in understanding of the function and responsiveness of the components of the farm system

(e.g. pasture responses to phosphatic fertiliser), by technological developments (e.g. electric fencing), by external influences (e.g. economic policy), and by farmer perceptions of the productive potential of the resources being utilised (e.g. livestock performance or pasture production potential). For example, improvements in sheep genetics, feeding practices and health programmes have made twinning of hill country ewes accepted commercial practice, whereas 20 years ago many farmers regarded a healthy single lamb as being acceptable. Perceptions of pasture production potential can similarly influence expectations.

Sources that influence farmer perceptions of pasture production potential include research results and industry experience. Research data include measurements of pasture production e.g. cutting trial data for sites throughout New Zealand (e.g. Radcliffe 1974), grazing trial results (e.g. Suckling 1975; Lambert *et al.* 1983) or estimates based on stocking rate assessments, such as in the land use capability bulletins published by the Ministry of Works & Development (e.g. Noble 1985). This information gives false impressions of production potential because measurements/estimates were generally obtained under conditions that were considered "feasible" at the time the data were collected e.g. N inputs were predominantly from symbiotic N fixation by legumes fed with P and S fertilisers, and moisture supply was directly from rainfall only. In our experience soil moisture and plant-available mineral nitrogen (Lambert *et al.* 1982) are manageable factors that limit hill pasture production, however, information on production levels when these limitations are alleviated is scarce.

In 1996 a high fertiliser application treatment was superimposed on a long-term grazing trial in southern Hawke's Bay hill country investigating pasture and animal responses to fertiliser regimes. Responses to this treatment give an indication of the production potential of hill pastures under very high rates of fertiliser N application and results are presented here.

Experimental

Site

The trial was conducted from June 1996 to May 1998

at the AgResearch Ballantrae hill country research station near Woodville in southern Hawke's Bay. The experimental area is at 250-350 m altitude, and average annual rainfall is about 1200 mm. Soils are Yellow-brown Earths and related stepland soils formed from tertiary sediments and sedimentary drift material, now classified as Brown soils (Hewitt 1998).

Trial paddocks

Twelve paddocks, 0.55-1.13 ha in area and having an average slope of 21° (range 13-26°) were selected within the trial area described by Lambert *et al.* (1996). Four of the paddocks were within a block ("Low") that had received 125 kg/ha superphosphate annually during 1974-80 and had not been fertilised subsequently. Another four were in a block ("Med") that had received 125 kg/ha superphosphate annually since 1974; and four paddocks were in a block ("High") that received an average 625 kg/ha annually during 1975-79 then 375 kg/ha superphosphate annually subsequently. All 3 fertility blocks had been set-stocked since 1975 with sheep to achieve similar grazing pressures i.e. paddocks were stocked at a rate proportional to annual pasture production. In 1996 average soil Olsen P status was 6, 8 and 23 µg/ml soil for Low, Med and High fertility blocks respectively.

Treatments

The historical fertiliser regimes for each of the "fertility blocks" (i.e. 0, 125 and 375 kg/ha superphosphate annually in spring, for Low, Med and High fertility blocks respectively) were continued. Two paddocks within each fertility block represented a "Control" treatment, and the other two received a "Fertiliser treatment" comprising additional annual inputs of 70 kg P, 50 kg S and 400 kg N/ha. Replicate pairs of Control and Fertiliser treatment paddocks were matched for slope and aspect as closely as possible. The P and S were applied by hand at the start (in June) of each of the 2 measurement years, as a single dressing of triple superphosphate plus maxi-sulphur superphosphate. The N fertiliser was applied by hand as urea in 8 dressings throughout each year at the rate of 50 kg N/ha, and at a frequency related to the historical seasonal pasture production pattern. Nominal N application dates were 1 June, 24 August, 16 October, 17 November, 12 December, 5 January, 1 February and 14 March for 1996-97 and 1997-98.

Grazing regime

The paddocks continued to be set-stocked with breeding ewes at a rate proportional to pasture

production. Numbers were adjusted when pasture covers and/or ewe liveweights deviated markedly from normal seasonal expectations.

Measurements

Pasture production was measured using a trim-spell-harvest technique and grazing exclusion cages (Lambert *et al.* 1983), with 14 harvests being made during the two-year period. Individual harvest data were used to calculate seasonal pasture production, based on 4 three-month seasons per year; winter being June – August. Botanical composition was estimated by hand-dissection, drying and weighing sub-samples of herbage harvested from the exclusion cages. Results were combined to give four species categories: high-fertility responsive grasses (e.g. *Lolium perenne*, *Holcus lanatus*, *Dactylis glomerata*, *Poa trivialis*); low-fertility-tolerant grasses (e.g. *Agrostis capillaris*, *Anthoxanthum odoratum*, *Cynosurus crotatus*, *Festuca rubra*); legumes (e.g. *Trifolium repens*, *T. pratense*, *Lotus pedunculatus*, *T. dubium*); and weeds (e.g. *Hypochaeris radicata*, *Leontodon taraxacoides*, *Plantago lanceolata*). Three cages were used in each paddock, located on micro-sites with slopes approximating each paddock's average slope.

Data analysis

Seasonal and annual pasture production and seasonal botanical composition data were analysed using Genstat, as a split-plot design to test the effect of treatment, year and treatment x year. Effects involving season were tested using repeated measures ANOVAs. The effect of fertility block was not tested as these blocks were not replicated.

Results

The Fertiliser treatment markedly increased seasonal and annual pasture production (Table 1). Averaged across the 3 fertility blocks and 2 years, pasture production increased from an average 9.2 t DM/ha in the Control paddocks to an average 17.1 t DM/ha in the Fertiliser treatment paddocks. Season affected ($P=0.005$) the level of response, and there was a tendency for the greatest responses to occur in summer and spring. The size of the seasonal and annual pasture production responses was similar across the fertility blocks (Table 2), the average annual production response ranging from 7.3 to 8.9 t DM/ha. N response efficiency (average annual pasture production response calculated as a function of annual fertiliser N application rate) was similar across fertility blocks and ranged from 18.2 to 22.3 kg DM/kg N applied (Table 2).

Table 1 Pasture production (kg DM/ha) averaged across the fertility blocks, for the Control and Fertiliser treatments, the size of the differences between the treatments (kg DM/ha) and the statistical significance of those differences.

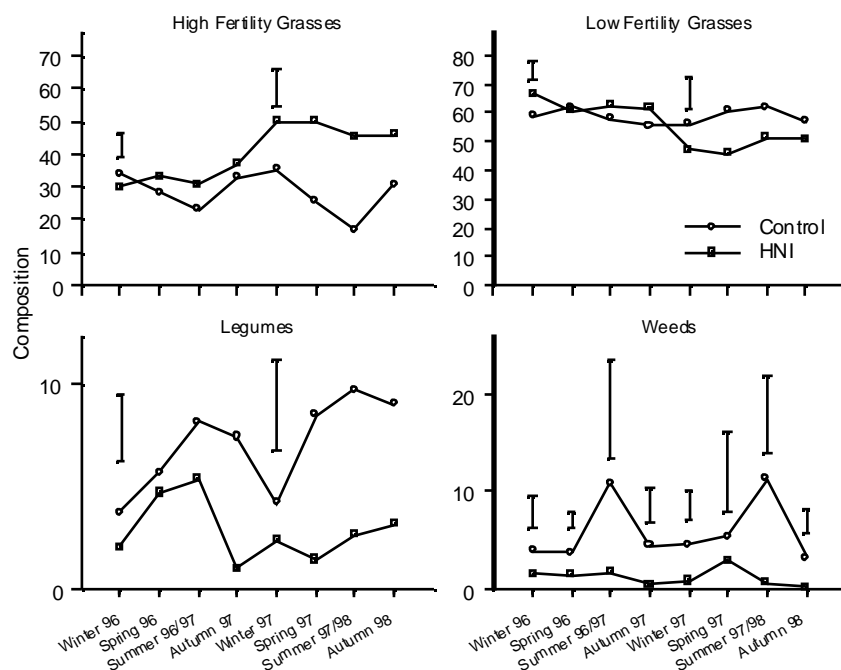
	Year 1					Year 2				
	Win	Spr	Sum	Aut	Ann	Win	Spr	Sum	Aut	Ann
Control	1059	2826	3071	2439	9394	916	2768	3543	1865	9092
Fertiliser	1860	5254	5899	4512	17525	1927	5249	6960	2574	16710
Difference	802	2428	2828	2073	8131	1011	2482	3416	709	7618
Significance	**	***	***	***	***	***	**	**	*	***

Win = winter, Spr = spring, Sum = summer, Aut = autumn, Ann = annual total.
 * P<0.05, ** P<0.01, *** P<0.001.

Table 2 Average seasonal and annual pasture production (kg DM/ha) for Control and Fertiliser treatments within each of three fertility blocks (Low, Med, High), pasture production differences between treatments, and annual N response efficiencies (kg DM/kg N applied).

		Winter	Spring	Summer	Autumn	Annual
Low	Control	669	1984	2296	1684	6633
	Fertiliser	1394	4823	6094	3231	15542
	Difference	725	2838	3798	1547	8909
	N response efficiency					22.3
Med	Control	1020	2764	2974	2208	8966
	Fertiliser	1835	5002	6063	3485	16385
	Difference	815	2238	3089	1277	7419
	N response efficiency					18.5
High	Control	1273	3642	4651	2563	12129
	Fertiliser	2452	5930	7131	3912	19425
	Difference	1179	2288	2480	1349	7296
	N response efficiency					18.2

Figure 1 Average seasonal contribution (%) of high-fertility-responsive grasses, low-fertility-tolerant grasses, legumes and weeds to pasture production in Control and Fertiliser (Fert) treatments over the 2 years of the trial. Bars represent annual LSD (5%) values apart from those for weeds which are presented for individual seasons.



The Fertiliser treatment did not significantly increase the high-fertility-responsive grass percentage in the first year ($P=0.325$), but did ($P=0.005$) in year 2 (Figure 1), i.e. there was a treatment x year interaction ($P=0.007$). There was also a significant ($P=0.048$) treatment x year interaction for low-fertility-tolerant grass percentage, because there was little effect ($P=0.149$) in the first year, but a strong trend ($P=0.071$) towards a decline in content in Fertiliser treatment pastures in year 2. There was also a tendency ($P=0.067$) for the Fertiliser treatment to depress legume content in year 1, and this effect was statistically significant ($P=0.026$) in year 2. On average, weed percentage was decreased by the Fertiliser treatment ($P=0.028$), however this effect depended on season (treatment x season interaction $P=0.015$). The depression in weed percentage was much greater ($P=0.026$) in summer than in the other seasons (Figure 1).

Discussion

The effect of the Fertiliser treatment on pasture production was immediate (the size of the response in the first winter and spring was similar to that in the second year) and large. There was an average 85% increase in annual pasture production. The annual production level achieved on the historical "High" fertility block (19.4 t DM/ha) was higher than that achieved on most high producing dairy farms (de Klein *et al.* 2000).

The response in annual pasture production was similar across fertility blocks (7.4 to 8.9 t DM/ha). This similarity, coupled with the probability that P and S were not major limitations to plant growth on the High fertility block because of years of above maintenance P and S application, suggests the response on all fertility blocks was primarily driven by enhanced supply of plant available N rather than by the additional annual dressings of P and S. This is supported by Ball *et al.* (1982) who concluded after reviewing available evidence that "even when little additional P fertiliser was applied the N response was essentially independent of additional fertiliser P". This was because grasses had a much lower P requirement than clovers. This suggests that where N inputs to pastoral systems are to be dominantly from fertiliser rather than symbiotically fixed N, markedly lower inputs of P and S will be required, which saving can be offset against the cost of the fertiliser N.

If the response is solely attributed to the N component of the fertiliser, then the N response efficiencies of 18 to 22 are very high given the large annual N input. While N response efficiencies in hill pastures of the order of 20 kg DM/kg N applied have

been recorded for lower rates of N application, particularly when measured in grazing rather than mowing trials where clippings are removed and potential for fertiliser N to be recycled is reduced (e.g. Ball *et al.* 1982), decreasing marginal returns should mean response efficiencies would be much less than 20 at an annual application rate of 400 kg N/ha. The recycling of N that occurs in grazed hill pastures means that responses to fertiliser N application can occur over several seasons following application (Lambert & Clark 1986). Long-term response efficiencies to N application have almost certainly been under-estimated where trials are run under mowing rather than grazing regimes, and where measurements are discontinued before the response has fully expressed itself.

One of the potential environmental impacts of increased use of fertiliser N is greater leaching of nitrate from the soil profile. We measured nitrate leaching as part of the overall study and although the data are not reported here, preliminary results (MG Lambert *et al.* unpublished data) suggest that annual nitrate loss from the Control paddocks was about 6 kg N/ha and from the Fertiliser treatment paddocks 31 kg N/ha i.e. an increased nitrate loss of 25 kg N/ha, or 6% of the fertiliser N applied. This leaching loss is a little less than that of an average dairy farm using 50 kg N/ha and producing 13.0 t DM/ha annually (36 kg N/ha), but much less than a dairy farm using 200 kg N/ha and producing 18.5 kg DM/ha for which annual losses are about 77 kg N/ha (de Klein *et al.* 2000). This comparison is confounded because leaching losses from cattle exceed those from sheep (Williams & Haynes 1994); however the comparison still suggests that hill systems may be less leaky than systems on easier topography, at least in the short term. The NZ Fertiliser Manufacturers' Research Association Code of Practice for Fertiliser Use (www.fertresearch.org.nz) suggests that annual applications of more than 200 kg N/ha may lead to unacceptably high levels of nitrate leaching. However the Code acknowledges that higher rates may be possible without adverse effects where there are mitigating factors, such as with soils of higher C:N ratio, as is the case with hill soils.

The general effect of the Fertiliser treatment relative to the Control in terms of botanical composition was for an increased high-fertility-responsive grass percentage, at the expense of low-fertility-tolerant grasses, legumes and weeds. Most of these changes would be regarded as positive by farmers, with the exception of the decline in legume content. However, one of the major reasons for use of legumes in pastures is their symbiotic N-fixing ability, and the importance

of this is much less where high rates of N fertilisation are the ongoing practice. The Fertiliser treatment effect on pasture botanical composition was greater in year 2 than in year 1. This slow rate of change, coupled with the relatively small magnitude of the changes in response to a dramatic change in supply of N (the most limiting plant nutrient), suggests that the botanical composition of such pastures is well-buffered and that increases in high-fertility responsive grasses might be expected to continue over a number of years.

Estimates of potential stock carrying capacity were made more than 20 years ago using advice from local consultants during development of the New Zealand Land Use Capability Classification. That work estimated "potential carrying capacity" for land similar to that of the trial area, at 19 SU (stock units)/ha as compared to that being achieved by "top farmers" at that time of 16 SU/ha (Noble 1985). Assuming an annual intake of 595 kg DM/SU (Coop 1965) and an 80% utilisation of pasture production, that 19 SU/ha potential carrying capacity would be associated with a pasture production potential of about 14.1 t DM/ha. Using the same assumptions, the potential carrying capacity for the "High" fertility-Fertiliser treatment paddocks in the current trial would be 26 SU/ha.

This trial was run to stretch the boundaries of current practice, and to assess some of the production and environmental consequences. The production consequences were dramatic and our limited data suggest the environmental consequences were not overly severe in terms of nitrate leaching. Simple economic analysis shows that with the high N response efficiencies measured the extra feed grown by N fertilisation was at very low marginal cost (about 7 c/kg DM). However, cost-benefit analysis should take into account fixed as well as variable costs. Such large increases in pasture DM production mean the fixed costs associated with owning or leasing land would be much lower per unit DM produced, and provided this DM was efficiently utilised the cost-benefit outcome would be very favourable indeed.

It is our view that potential exists for greatly increasing hill country production levels using fertiliser N. However we caution that potential on- and off-site impacts, including effects on nitrate and greenhouse gas emissions, soil and pasture condition and nutrient cycling require further study in order to establish whether such high N application rates would affect long-term sustainability. Also, a large proportion of the extra pasture grown occurred in spring and summer when feed supply is commonly not limiting on summer-moist hill country farms and where mechanical harvesting of surpluses is difficult,

so new farming systems would need to be devised to profitably utilise that extra feed.

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