The relative strengths of phosphate fertiliser application and white clover cultivar introduction for hill pasture improvement

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Abstract
Combinations of four phosphorus (P) fertiliser rates (0, 8.5, 22.5 or 26.5 kg/ha/year of citrate-soluble P) and three pasture types with different white clover germplasm, 'resident' cv. Huia and cv. Tahora were compared in self-contained, replicated farmlets grazed by sheep over 4 years. Fertiliser increased white clover herbage accumulation (HA) 3- to 4-fold compared with the control treatment, and increased total sward HA by 50%. Introduction of Tahora white clover significantly increased white clover and total sward HA and nitrogen fixation compared with the resident and Huia-sown swards. Sheep liveweight gain was significantly greater in all systems fertilised with P (438 versus 243 kg/ha for the unfertilised control) and in systems sown with Tahora (425 versus 372 kg/ha for resident and Huia).

Keywords: phosphorus fertiliser, white clover, cultivars, herbage accumulation, animal production

Introduction
The basis for achieving pasture productivity gains in New Zealand hill land lies in the ecological concepts described by Sears (1960) and Levy (1970). Nitrogen (N) is the nutrient most strongly limiting pasture growth in hill pastures, followed usually by phosphorus (P). The classical pasture improvement sequence addresses the N limitation by first reducing the soil P deficiency to create an environment that is favourable for legume growth. The increase in clover in turn stimulates biological nitrogen fixation and plant- and animal-mediated nutrient cycling processes. From this, a cascade of responses ensues, including decrease in the C:N ratio of organic matter, improved soil N availability, improved competitive ability and hence presence in the sward of 'more productive' grass species (as opposed to slower-growing species tolerant of low soil nutrient availability), and higher pasture production (Lambert *et al.* 1983).

Recent trends in land use in New Zealand have created pressure to finish greater numbers of sheep and beef animals on hill country farms because much of the more-productive land previously used for finishing has been converted to dairy production or dairy support. Improved management of animals and the feed-base is key to achieving this. Better feed quality, and an extended seasonal pattern of feed supply from pasture, are two of the critical requirements to achieve the additional 10 kg meat sold per breeding ewe (or equivalent) considered necessary for hill farm viability over the next 15 years (Fennessy *et al.* 2016).

White clover cultivars bred specifically for New Zealand hill environments have been available since the 1980s (Caradus *et al.* 1996), and these add a further tool to assist hill land improvement. However, while there is ample comparative agronomic information available from small-plot studies with white clover cultivars in hill country (e.g. Macfarlane *et al.* 1990; Williams *et al.* 1990), the impacts of cultivar introduction on animal production are not known. Given the range of factors that influence hill land productivity, it is risky to assume that agronomic advantages of cultivars as measured in simple plot experiments will translate into higher animal production in self-contained grazing systems. Furthermore, the impact of cultivar introduction must be assessed against the impact of other inputs, especially P fertiliser, to gain a clearer perspective of the value available from improved clover cultivars in the sequence of hill land improvement.

The objective of the experiment reported here was to compare the animal production response to P fertiliser application with the introduction of white clover cultivars in hill country. Four P fertiliser rates were applied in factorial combination with three pasture type treatments based on different white clover germplasm. Initial results were reported by Chapman *et al*. (1993a) and detailed information on the structure of pasture white clover populations was presented by Chapman *et al.* (1993b).

Materials and methods
Site and experimental design
The experiment was conducted on moderate-steep hill land at Ballantrae Hill Country Research Station, 20 km NE of Palmerston North in the lower North Island of New Zealand. Details of the site and experimental design were presented by Chapman *et al*. (1993b). The mean annual rainfall at the site is 1270 mm, and average temperature is 12.8°C. Before establishment of the experiment, the site displayed characteristics typical of

ISSN 2463-2872 (Print) ISSN 2463-2880 (Online)

unimproved New Zealand hill country. Plant-available soil P, measured by the Olsen P test, averaged 5 mg/kg and soil pH (in water) averaged 5.1. Pastures were dominated by perennial grasses well-adapted to low soil fertility, mainly browntop (*Agrostis capillaris)* and sweet vernal (*Anthoxanthum odoratum)*, comprising 75% of total sward herbage accumulation (HA). Other constituents were: white clover (1% total sward HA), other legumes (mainly *Trifolium dubium* and *Lotus* spp., 5% of total sward HA) and perennial ryegrass (*Lolium perenne*, 4% total sward HA).

The experiment consisted of 48 plots, twelve in each of four replicate blocks. Two replicates faced north with mean slopes of 26° and 17°, one replicate faced south with a mean slope of 21° and one faced east with a mean slope 28°. Each replicate contained six plots of 0.11 ha and six plots of 0.167 ha, covering a total of 1.66 ha. The total land area used in the experiment was 6.65 ha.

Treatments were:

A) P fertiliser application: 1) unfertilised ('control'); 2) mean 8.5 kg/ha citrate-soluble P/year ('P_{cit} 8.5'); 3) mean 22.5 kg/ha citrate-soluble P/year ('P_{cit} 22.5'); and 4) mean 26.5 kg/ha citrate-soluble P/year ('P_{cit} 26.5'). Fertiliser was applied annually, in August, for 7 years from 1988-1994 inclusive.

B) Pasture type: 1) unsown pasture ('resident'); 2) pasture oversown with 'Grasslands Tahora' white clover cultivar (Tahora-sown) bred specifically for hill country; and 3) pasture oversown with 'Grasslands Huia' white clover cultivar (Huia-sown).

One plot of each P fertiliser rate x pasture type combination was located within each replicate in a randomised block design.

P fertiliser regimes changed during the experiment as shown in Table 1. Because different materials were used, with different soluble P concentrations, and for different periods in some cases, the three treatments that received P are defined with reference to the total amount of citrate-soluble P (P_{cit}) that was applied. The P_{cit} 8.5 and P_{cit} 22.5 treatments received the same total amount of P in fertiliser over the 7 years (191 kg/ha), but because only reactive phosphate rock was used in the former, the total amount of soluble P applied was lower. The P_{cit} 26.5 treatment received higher amounts of P in total (245 kg/ha), and in a soluble form. Sulphur was applied annually to ensure each fertiliser treatment received the same amount of sulphur.

Plots to be sown to white clover were sprayed with a mixture of glyphosate (4 L/ha active ingredient, a.i.) and 2,4-D (2.5 L/ha a.i.) on 3rd April 1986. Beginning on 13th May, a herd of 70 breeding cows grazed the sprayed areas at a mean stocking density of 234 cows/ha/day to break up dead herbage and expose bare soil for seed to land on. The day after grazing, plots were hand-sown by spreading seed on the soil surface at a rate equivalent to 8 kg/ha bare seed of the appropriate white clover cultivar. No other species were sown. Seed was coated ('Prillcote", Coated Seeds Ltd., Christchurch), but not inoculated with *Rhizobia*. Sowing was completed on 16th June 1986. In late May, the entire experimental area received a basal dressing of 30 kg/ha P and 14 kg/ha sulphur (S) in the form of partially acidulated phosphate rock with added elemental S, plus 1 t/ha lime. In April 1988, before fertiliser treatments were initiated, the mean Olsen P level of the experimental sites was 6 mg/kg, and had a pH 5.3.

Grazing management and animal measurements

Beginning in winter 1988, the trial area was rotationally grazed by four mobs of sheep, balanced for liveweight (one per fertiliser treatment) at the following stocking rates: 1) early summer to late autumn - 25 lambs (6- to 8-month old animals)/ha; 2) late autumn to early spring -12 hoggets (9- to 12 month old animals)/ha; and 3) early spring to early summer - 25 hoggets (13- to 15-month old animals)/ha. The length of the grazing rotation varied from 18-20 days in spring and summer to 50-60 days in winter.

Grazing management changed in March 1991, when the measurement of animal production responses to treatments began. Two of the four replicate plots for each of the twelve treatment combinations were paired and grazed by two replicate mobs of animals for each combination. Hence, animal production measurements were collected from 24 experimental mobs, while measurements of sward-related variables continued on all 48 plots. After March 1991, animals were swapped between the two plots available to them every 2 weeks, in a simple 2-paddock grazing system with put-and-take (as described below) that approximated continuous grazing in terms of the sward structure that developed.

Stocking density varied throughout the year as determined by a feed budget model. This model used fortnightly actual sward herbage mass (HM) measured by rising plate meter for all 48 plots, combined with expected herbage accumulation rates (HAR), estimated animal intake, and seasonal HM targets to calculate the number of animals required in each mob to keep feed supply and demand in balance, and avoid under- or over-grazing swards. The feed budget model essentially equalised feed availability per animal across all treatment combinations. This allowed differentiation among treatments in their capacity to carry animals (assumed to be related to sward HAR) and in the performance of individual animals grazing on them (kg weight gain per animal, assumed to be related to the quality of herbage available).

Six-month old lambs were introduced to the experiment in March of each year at around 25-28 kg liveweight, and removed in the following February at around 50 kg average liveweight. Three 'tester' animals remained on each treatment for the entire annual measurement period. Additional 'grazer' animals from a buffer group of the same age as the tester animals were added or removed from mobs as required, according to the stocking density estimated by the feed budget model. Tester animals were weighed every 2 weeks before mobs were shifted to the ungrazed plot of each pair. This regimen was repeated for 4 years, concluding in February 1995. Mean herbage mass of swards ranged between approximately 1000 and 2000 kg DM/ha during the year, with lowest mass occurring in late winter, and highest mass occurring in summer (see Figure 1C in Chapman & Caradus (1997) for data on seasonal and annual trends in total sward HM).

Sward and plant measurements

Total sward and white clover HA were measured under one 0.5 m^2 exclosure cage per plot, cut 6-7 times/year to about 2 cm above ground level, and moved to a new trimmed site after each cut. A subsample of herbage from each cage was dissected at each harvest to estimate the proportion of total sward HA that was white clover, perennial ryegrass, other legumes, other grasses, and other broadleaf species. Only data for white clover are presented in detail here. Exclosure cage measurements began in March 1989, and continued until the end of the experiment in February 1995.

Total sward HA was also estimated by difference between fortnightly measurements of herbage mass (HM) on the ungrazed plot of the pair of plots that comprised each replicate of the grazing treatment combinations. HM was measured using a calibrated rising plate meter 2-3 days before animals were weighed and swapped between plots. Thus, the HM of a plot measured just before animals were moved back to graze minus the HM of the same plot measured 2 weeks previously (when it was nearing the end of a 2 week grazing period) gave an estimate of HAR. Total annual HAR was calculated by summing the 26 fortnightly increments.

Nitrogen fixation rate was estimated using the acetylene reduction assay (Ball *et al*. 1979) from October 1990 to September 1992 in all treatment combinations, but in only two of the four replicate blocks. There were 15 measurements in the first year (1990/1991) and 13 measurements in the second year (1991/1992), taken at intervals of between 14 days (in spring/summer) to 60 days (in winter). For further information on the technique used see Chapman & Caradus (1997).

The genetic composition of the white clover plant populations in all Huia-sown and Tahora-sown plots was measured in January 1990 and January 1994 using cyanogenesis as a genetic marker. A full description of the technique can be found in Chapman *et al.* (1993b), which also reports data from the January 1990 sampling. In essence, the resident white clover ecotype, Huia and Tahora all had sufficiently different frequency occurrence of cyanogenesis to allow resident and Huia plants be distinguished from each other in the Huia-sown treatment, and resident and Tahora plants to be distinguished in the Tahora-sown treatment.

Statistical analysis

Data were analysed using ANOVA in Genstat. Variables were analysed as a randomised block design with year, pasture type, fertiliser input, year x pasture, year x fertiliser, and pasture x fertiliser interactions as factors in the model. Four replicates were included for sward-related variables (except for N fixation), and two replicates were included for animal production variables.

Table 1 Description of different P fertiliser types used, their citrate-soluble (cit-sol) P concentration, total amounts applied, and mean kg/ha citrate soluble P and total applied over 7 years 1988-1994 inclusive.

			Fertiliser treatment					
			P_{cit} 8.5		P_{cit} 22.5		P_{cit} 26.5	
P fertiliser material	**% citrate-soluble P**	**Years applied (inclusive)**	**Total P applied (kg/ha)**	**Cit-sol P applied (kg/ha)**	**Total P applied (kg/ha)**	**Cit-sol P applied (kg/ha)**	**Total P applied (kg/ha)**	**Cit-sol P applied (kg/ha)**
Reactive phosphate rock (RPR)	31.6	1988-94	191	60				
Superphosphate/RPR blend	80.5	1988-91			140	113		
Partially-acidulated phosphate rock	68.0	1988-91					140	95
Superphosphate	86.7	1992-94			51	44	105	91
Mean amount of P applied			27.3	8.5	27.3	22.4	35	26.6

Results

There were no significant interactions between fertiliser inputs and pasture type for any of the variables presented below.

White clover herbage accumulation

Tahora-sown pastures accumulated significantly ($P<0.05$) more white clover herbage than Huia-sown or resident pastures when averaged across all 6 years (Table 2). The Tahora-sown pastures accumulated 40% more clover herbage compared to resident pastures, whereas the difference between Tahora-sown and Huia-sown pastures averaged 21%. Phosphate fertiliser application increased mean white clover HA more than three-fold compared with the control treatment which received no P fertiliser ($P<0.05$, Table 2). No significant differences in white clover HA were found among the treatments which received P fertiliser.

Persistence of sown clover cultivars

A significant ($P<0.05$) main effect of fertiliser input on the percentage of white cover plants was identified as true-to-type for the sown cultivar. The highest percentage was recorded in the P_{cit}22.5 treatment, with the lowest percentage in the control treatment, with the other two treatments intermediate (Table 3). A significant interaction ($P=0.001$) was found between year and pasture type in this variable. In 1990, 4 years after sowing, about half of the white clover plants present in pastures sown to Tahora and Huia were identified as having originated from the sown cultivars. At this stage, a significantly higher percentage of the white clover plants sampled from Tahora-sown pastures were estimated to be true-to-type than for clover plants sampled from the Huia-sown pastures (Table 3). By 1994, 8 years after sowing, the percentage of plants sampled from the Huia-sown pastures that were identified as being true-to-type had dropped substantially and was significantly different from the Tahora-sown pastures which retained a true-to-type percentage of above 50%. The apparent loss of Huia plants from the Huia-sown pastures between 1990 and 1994 occurred irrespective of P fertiliser treatment (Table 3).

Nitrogen fixation

Measured for only 2 years, and in two replicates, N fixation rates of the different fertiliser-plant type treatments broadly followed the differences in white clover HA measured over 6 years, as described above. Significant main effects were found for year (44 and 54 kg N/ha /year for 1990/1991 and 1991/1992, respectively, $P<0.05$), fertiliser treatment ($P<0.001$), and pasture type ($P<0.05$). There were no interactions among these factors. Where P fertiliser was applied, N fixation was 2.5-3.2 times greater than where no P fertiliser was applied (Table 4). By contrast, the effect of pasture type was weaker. Estimated N fixation in Tahora-sown pastures was approximately 1.3 times that of the resident and Huia-sown pastures (Table 4).

Total pasture herbage accumulation

Exclosure cage measurements revealed a strong effect of fertiliser ($P<0.001$) driven by 45% higher total annual pasture HA in the treatments where P fertiliser was applied compared to the control treatment (mean of 10 530 kg DM/ha for the three fertiliser inputs versus 7275 kg DM/ha for control). However, when estimated

Table 2 Total annual white clover herbage accumulation (kg DM/ha, mean of 6 years data) of pastures based on the resident white clover ecotype or the cultivars Tahora and Huia, and receiving four fertiliser treatments. Means with the same letter for fertiliser treatment and pasture type do not differ significantly ($P > 0.05$).

Pasture type	Fertiliser treatment				
	Control	P_{cit} 8.5	P_{cit} 22.5	P_{cit} 26.5	Mean
Resident	274	930	1057	1105	841 b
Tahora	557	1478	1506	1157	1174 a
Huia	231	1274	1193	1180	969 b
Mean	354 b	1227 a	1252 a	1147 a	

Table 3 Percentage of plants in white clover populations in pastures sown with the cultivars Tahora or Huia in 1986 that were identified as true-to-type for the sown cultivar 4 (1990) or 8 (1994) years after sowing. Means with the same letter for fertiliser treatment, and for the interaction between year and pasture type, do not differ significantly ($P>0.05$).

Pasture type	Fertiliser treatment								Mean	
	Control		P_{cit} 8.5		P_{cit} 22.5		P_{cit} 26.5			
	1990	1994	1990	1994	1990	1994	1990	1994	1990	1994
Tahora	42.5	33.4	62.3	50.4	65.3	81.9	60.7	58.9	57.7 a	56.2 a
Huia	41.1	13.6	36.5	8.9	46.0	19.1	49.8	13.2	43.4 b	13.7 c
Mean	32.7 c		39.5 bc		53.1 a		45.2 ab			

using exclosure cages, there was no significant effect of pasture type on total pasture HA. Mean estimated total annual pasture herbage accumulation over 6 years was 9600, 10 015 and 9555 kg DM/ha for pasture based on the resident ecotype, Tahora and Huia, respectively.

When estimated using the difference between fortnightly pre- and post-grazing pasture mass measured with a plate meter, summed for each year, the relative difference between treatments where P fertiliser was applied and the control treatment was similar to that estimated using exclosure cages (an additional 3600 kg DM/ha per year or 52%, Table 5, $P<0.05$). Data derived from the plate meter technique revealed a significant effect of pasture type on total annual HA ($P<0.05$, Table 5). Tahora-sown pastures grew an average of 1100-1300 kg more DM/ha/year compared to the Huia-sown and resident pastures, a difference of 12-15%.

Animal stocking density and liveweight gain per hectare

Mean annual animal stocking rate (number of lambs or hoggets/ha, mean of 4 years data) was 37% higher on pasture to which the low P fertiliser treatment (Pcit 8.5) was applied compared with the control, while the higher critic soluble P fertilisers supported 55 and 62% more livestock (Table 6). The effect of pasture type on sheep stocking rate, while statistically significant ($P<0.05$), was much less, with Tahora-sown pastures producing 9 and 10% higher liveweight gain compared to resident and Huia-sown pastures, respectively (Table 6). A similar picture emerges when examining the influence of P fertiliser and pasture type on liveweight gain. Total lamb liveweight gain/year was strongly affected by fertiliser treatments ($P<0.05$). The low P treatment (P_{cit} 8.5) supported 65% greater liveweight gain/ha compared to control, while the two higher critic soluble P application treatments supported between 85 and 90% higher liveweight gain/ha (Table 7). By contrast, the effect of pasture type, while statistically significant ($P<0.05$), was much less. Tahora-sown pastures supported 12% and 17% higher liveweight gain/ha compared with resident and Huia-sown pastures, respectively (Table 7).

Discussion

The results of this experiment were clear. Both P fertiliser addition and white clover cultivar introduction

Table 4 Nitrogen fixation (kg N/ha/year) in 2 years in pastures based on the resident white clover ecotype or the cultivars Tahora and Huia, and receiving four fertiliser treatments. Means with the same letter for fertiliser treatment and pasture type do not differ significantly ($P>0.05$).

Pasture type	Fertiliser treatment								
	Control		P_{cit} 8.5		P_{cit} 22.5		P_{cit} 26.5		
	1990/1	1991/2	1990/1	1991/2	1990/1	1991/2	1990/1	1991/2	Mean
Resident	16.7	17.3	50.2	57	39.9	76.3	44.5	60.9	43.6 b
Tahora	28.3	26.4	63.3	57.3	48.8	70.4	79.3	96.4	58.7 a
Huia	18.4	19.7	42.4	52.5	41.2	45.4	55.9	73.0	45.3 b
Mean	21.1 c		53.6 b		53.7 b		68.3 a		

Pasture type means or fertiliser treatment means with a common letter do not differ significantly ($P > 0.05$)

Table 5 Total annual pasture herbage accumulation (kg DM/ha/year, mean of 4 years of rising plate meter measurements) of pastures based on the resident white clover ecotype or the cultivars Tahora and Huia, and receiving four fertiliser treatments. Means with the same letter for pasture type and fertiliser treatment do not differ significantly ($P>0.05$).

Pasture type	Fertiliser treatment				
	Control	P_{cit} 8.5	P_{cit} 22.5	P_{cit} 26.5	Mean
Resident	6530	9205	10895	9900	9135 b
Tahora	7610	11095	11935	11205	10465 a
Huia	6722	10160	9745	10830	9365 b
Mean	6955 b	10155 a	10860 a	10645 a	

Table 6 Mean annual animal stocking rate (number of lambs or hoggets/ha, mean of 4 years data) on pastures based on the resident white clover ecotype or the cultivars Tahora and Huia, and receiving four fertiliser treatments. Means with the same letter for fertiliser treatment and pasture type do not differ significantly ($P>0.05$).

Pasture type	Fertiliser treatment				
	Control	P_{cit} 8.5	P_{cit} 22.5	P_{cit} 26.5	Mean
Resident	10.4	14.3	17.4	18.8	15.2 b
Tahora	13.4	15.8	18.1	19.0	16.6 a
Huia	10.2	15.9	17.5	17.0	15.1 b
Mean	11.3 c	15.4 b	17.7 a	18.3 a	

significantly increased animal production (measured as liveweight gain/ha/year), and there was no interaction between them. The statistical and absolute effect of fertiliser was much stronger and larger than the effect of white clover cultivar introduction: over all 4 years, fertiliser application increased animal production by an average of 80% compared to the control (unfertilised) treatment, whereas the difference between the best clover cultivar (Tahora) and the pastures based on the resident clover ecotype was only 12%.

The P fertiliser effect was the outcome of a large increase in total white clover HA (Table 2), increased N fixation (Table 4), and an increase in total HA of nearly 50% (Table 5). Because stock numbers allocated to each replicate of fertiliser x pasture treatment were adjusted fortnightly according to the amount of pasture available for grazing, higher stocking rates were achieved on the fertilised pastures (Table 6). This was the major driver of increased animal production (Table 7). Clover comprised a higher proportion of total annual HA in the fertilised treatments compared with the control treatment (11-12% of DM versus 5% of DM). Therefore, the diet consumed by sheep on the former would probably have contained more protein and been higher in digestibility, enabling a further but smaller gain in animal production.

In contrast, there was little difference in the mean clover content of swards among the three pasture types and, therefore, there was unlikely to have been any gain in animal production specifically via better nutritive value of feed in the Tahora- or Huia-sown swards compared with the swards based on the resident clover ecotype. Thus, all of the animal production gain in the Tahora-sown treatment (Table 7) would have come from the higher total annual HA compared with the other two treatments, which was detected by fortnightly pasture plate meter readings (but not under grazing exclosure cages) and was translated into a higher stocking rate.

The source of improvements in total HA in the P fertilised and Tahora-sown swards is more difficult to pinpoint. In the case of fertiliser application, some direct growth response to added P in the dominant pastures species (browntop, etc.) would have been expected even though they are considered to be tolerant of low soil fertility (Grant *et al.* 1981). However, the improved availability of soil N resulting from greater clover growth and higher N fixation (Tables 2, 4) stimulated the growth of more productive grass species such as perennial ryegrass: compared with low fertility-tolerant grasses such as browntop, perennial ryegrass has the potential to grow more herbage on an annual basis (Grant *et al.* 1981), and is more productive in winter when low pasture growth rates commonly limit stocking rates on hill swards (Mackay & Lambert 2011).

Despite significantly higher N fixation rates measured in the Tahora-sown swards (Table 4) there was no significant difference in perennial ryegrass content in the Tahora-sown pasture compared with the other clover treatments (data not presented). An extra 300 kg of white clover DM/ha/year was grown in the Tahora-sown sward compared with the resident, but a further 1000 kg DM/ha/year (approximately) came from other species present. While it is often stated that the abundance of ‘improved’ pasture species must be increased to lift hill pasture productivity, it is salient to note that large increases in clover HA and total annual HA occurred in swards based on the resident clover ecotype (Tables 2, 5). Hence, this clover type is responsive to fertiliser P inputs. Nevertheless, Tahora proved to be even more responsive under the conditions of this experiment, supporting the breeding objectives (Williams *et al.* 1982).

Further support for these breeding objectives was found in the data for the proportion of white clover plants which were true-to-type for the sown cultivar (Table 3). These data clearly show that Huia, the only cultivar available for use in New Zealand hill land before the release of Tahora, did not persist irrespective of whether P fertiliser was used or not. Charlton (1984) also observed poor persistence of Huia in hill country. By year four of the animal production measurements (8 years after sowing), the Huia-sown swards were virtually indistinguishable from the resident swards in terms of clover genotype frequency, whereas more than 50% of clover plants in the Tahora-sown swards were true-to-type for the sown cultivar; this figure did not change between 4 and 8 years after sowing. Tahora demonstrated strong persistence under the conditions of this experiment, indicating that the breeding objectives were achieved.

Table 7 Animal liveweight gain (kg/ha/year, mean of 4 years) from pastures based on the resident white clover ecotype or the cultivars Tahora and Huia, and receiving four fertiliser treatments. Means with the same letter for pasture type and fertiliser treatment do not differ significantly (P>0.05).

Pasture type	Fertiliser treatment				
	Control	P_{cit} 8.5	P_{cit} 22.5	P_{cit} 26.5	Mean
Resident	213	388	476	440	379 b
Tahora	300	436	486	477	425 a
Huia	215	380	417	442	364 b
Mean	243 c	401 b	460 a	453 a	

Practical implications: managing for improved productivity

A mean 12% improvement in animal performance from the introduction of a persistent (Table 3) adapted clover cultivar, at low initial cost, appears to offer an economically viable strategy for improving hill land production. However, there is a caveat to this result, which relates to the ease with which the potential improvement in pasture feed supply from the introduction of an adapted clover cultivar can be captured in hill land farming systems. The use of a put-and-take, variable stocking rate grazing management system and young, growing animals in this experiment, meant that extra feed grown in any treatment was utilised *in situ* by a responsive class of livestock. In this sense, the experiment should be regarded as a test of the potential of treatments to improve animal production. The magnitude of the difference between Tahora-sown and resident clover swards reported here should not be expected in all situations where an adapted cultivar is introduced. For instance, in this experiment, it was possible to fully utilise any extra feed within 2-4 weeks by adjusting stocking rate. This would often not be possible on farms in the short-term because there is usually a fixed number of stock available, although demand does change during the year in the case of lactating animal, to utilise seasonal shifts in herbage availability. In the longer term adjustments in stocking rate could be expected to utilise the additional herbage grown.

In considering hill improvement strategies, it is salient to compare the magnitude of the effects of fertiliser on animal production with the effects of cultivar introduction. The three fertilised treatments produced an average 80% greater liveweight gain/ha compared with the unfertilised treatment, whereas the Tahora-sown treatment resulted in a 12% increase in liveweight gain. Responses to fertiliser are likely to be more reliable across the range of managements and environments that characterise hill land in New Zealand. The established recommendation of viewing cultivar introduction as a complement to fertiliser use, not as a replacement (Chapman & Macfarlane 1985; Lambert *et al.* 1985), therefore remains valid and this principle should be considered in any management decisions concerning improvement strategies for hill land.

ACKNOWLEDGEMENTS

The authors recognise the input of all the science, technical and farm staff and service staff who had an input into this study at the AgResearch Hill Country Research Station, Ballantrae.

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Sediment and nutrient losses under winter cropping on two Manawatu hill country soils

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Abstract

Aerial spraying and surface seeding of winter crops in uncultivable hill country areas is rapidly being adopted as a method of increasing winter feed supply and as a precursor to regrassing. However, there is little research on the sediment and nutrient losses that may result from this practice. In the current study, winter swede crops were established on an imperfectly and on a well-drained soil and these crops were grazed by beef cattle. Soil damage caused by the winter grazing of the swedes generated sediment losses that were 5.5 times greater on the imperfectly drained soil than the well-drained soil. Surface runoff over 3 months (which included crop grazing and the non-grazed crop stubble period) resulted in losses of 1.1 t/ha of sediment, 0.85 kg of phosphorus (P)/ha and 5.4 kg of nitrogen (N)/ha from the poorly drained soil. This key risk period contributed between 88 and 99% of the total annual sediment and total N and P losses, compared to the pre-crop (pasture) and crop establishment phase. A simple comparison with two other sediment and nutrient loss studies located on the same farm as the current study, suggested that the losses associated with winter cropping in this landscape may be extreme. The current study highlights the need for targeted mitigation strategies and/or strategic grazing management to reduce soil and nutrient losses and to minimise the impacts on waterways of winter grazing of hill country crops.

Keywords: winter cropping, hill country, surface runoff, sediment losses, nutrient losses

Introduction

In an effort to boost dry matter production and improve animal performance, more sheep and beef farmers are sowing crops on uncultivable hill country slopes using helicopter spraying and seeding. Despite the increase in the area of hill country that is used to grow crops, there is currently little research on the sediment and nutrient losses that may result from this practice. This is a major concern as these crops are often grown on slopes of ≥20° and the processes of spraying out existing pasture exposes bare soil.

Although studied in a semi-arid environment on shallower slopes (<5º), Silburn *et al.* (2011) reported that runoff volume and suspended sediment load increased with increasing slope, but decreased exponentially as ground cover increased. Subsequent winter grazing increases the risk of treading damage, soil erosion and nutrient loss. Soil physical damage associated with treading damage and cultivation have been shown to increase sediment and nutrient losses in plot-scale and small-scale rainfall simulation studies (e.g. Nguyen *et al.* 1998; McDowell *et al.* 2003b), but few studies have examined sediment and nutrient losses following winter crop grazing. McDowell *et al.* (2003a) measured greater concentrations of sediment and P losses in surface runoff following grazing in a plot-scale study with pasture, cultivated crop, and cultivated crop (grazed) treatments on slopes <11° in South Otago. Orchiston *et al.* (2013) compared sediment and P loss using conventional and strategic grazing techniques for winter crops, also in South Otago. The conventional method involved grazing dairy cattle in the down slope section of the paddock first and then strip-grazing upwards with no back fencing and with free access to gully and swale areas, known as critical source areas (CSA). In the strategic method, dairy cattle strip-grazed from the top of the catchment in the downslope direction using back-fencing, and CSA's were fenced off and only grazed if soil conditions were suitable. Orchiston *et al.* (2013) reported sediment and total P losses following strategic grazing were only ~10 and 20% of those measured using the conventional crop grazing approach. Another sub-catchment study examining the effect of winter crop grazing by dairy cattle on stream water quality (McDowell 2006), showed that crop grazing had minimal impact on P loss, but increased average suspended sediment loss by 75%.

Although these New Zealand studies provide insight with regard to sediment and nutrient losses following the grazing of winter crops, research to date has focussed on cultivatable rolling land used for dairy production. There has been no research quantifying sediment and nutrient losses from hill country cropping, despite it being undertaken on steeper land (slopes of ≥20°) without cultivation. The objectives of the current study was to 1) quantify sediment and nutrient loss in surface runoff from a surface sown hill country winter swede crop which was grazed conventionally and 2) compare

ISSN 2463-2872 (Print) ISSN 2463-2880 (Online)