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THE EFFECT OF SUMMER AND AUTUMN RAINFALL ON LEGUME GROWTH IN THE FOLLOWING SPRING IN SEASONALLY-DRY EAST COAST HILL COUNTRY

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Abstract

The results from a grazing trial measuring the presence of legumes in hill country pastures at Waipawa in Central Hawkes Bay from 1994 to 1999 and a survey in spring 2011 of total legume cover and the presence of legume species on forty seasonally-dry hill country farms from Gisborne to Christchurch were used to develop strategies to improve nutrient use efficiency. At Waipawa, the change in rainfall over the summer (December to February) in any two consecutive years resulted in a similar directional change in the presence of clover measured in the following spring. If summer rainfall increased from one year to the next, then the presence of clover also increased in the spring of the second year. Similarly, when rainfall decreased from summer to summer then the presence of clover decreased in the second spring. The correlation coefficient between the change in summer rainfall and the presence of clover in the next spring was high on easy slopes and moderate on steep slopes. Both white and subterranean clover and other legumes were more abundant on easy slopes and also more responsive to changes in summer rainfall than those on steep slopes.

Above average rainfall from December to February in 1995/96 and 1996/97 at Waipawa increased the presence of white clover on north-easy slopes from 1996 to 1998 but had no effect on north-steep slopes. The presence of subterranean clover increased over this period on north-easy slopes but did not change very much on north-steep slopes. On south slopes, the presence of white clover increased until 1997 before decreasing to 1999 on easy slopes and to 1998 and 1999 on steep slopes. The presence of subterranean clover remained low on both slope classes on the south aspect. On both aspects, the presence of other legumes showed a similar trend over time to white and subterranean clover. The increase in the presence of clover in spring occurred when rainfall for that season was below or similar to the long-term average.

Spring rainfall in 2011 for the east coast regions from Gisborne to Christchurch was only average to below average but was above average in most regions for the preceding December to April period. In spring 2011, the cover of total legume was reasonably uniform over both slopes and aspects in most regions. This result was in contrast to that from earlier research at Waipawa where there was more legume on easy compared with steep and south compared

with north slopes because of better retention of soil moisture. This effect also occurred for the presence of white clover in the on-farm-survey. Although the presence of subterranean clover was only responsive to higher-than-average rainfall in the preceding year on easy slopes on a north aspect in the grazing trial, in the on-farm survey with more measurement sites, subterranean clover was more abundant over all regions on north than south aspects and steep than easy slopes. Other legumes were also more abundant on steep than easy slopes with little difference between aspects. The rational economic approach for a year with around average rainfall is to use variable rate aerial application to apply phosphorus (P) and sulphur (S) only on the easy slopes that grow more legume.

Overall, these research results demonstrate the potential benefits during a wetter than average summer and autumn of applying P and S in the fertiliser application for that year to steep in addition to easy slopes to improve the growth of legume in the following spring.

Introduction

Pasture growth in hill country on the east coast of New Zealand is mainly limited by low and variable rainfall in the summer and autumn with the resulting low soil moisture levels contributing to the lack of legumes to supply N to the soil and pasture. Soil moisture retention is normally better on easy than steep slopes due mainly to greater soil depth and associated water holding capacity and better on south than north-facing slopes due mainly due to less exposure to direct radiation and associated lower soil temperatures (Gillingham 1973) that result in lower evapotranspiration losses. The lack of legume growth is also due to competition for light, moisture and nutrients from low fertility-demanding grasses such as browntop (*Agrostis tenuis* L) that are more tolerant to lower rainfall and more efficient at extracting P than legumes.

Previous research (Gillingham et al. 2004) established an economic basis for variable rate application of P and S on easy slopes that have more legumes and differential application of N on steep slopes that have more grasses on farms with average annual rainfall of less than 1000 mm. Nevertheless, steep slopes especially on south aspects can grow significant amounts of legume when rainfall and soil moisture levels are higher. This necessitates the need for some P and S to replace losses in animal products and the transfer of nutrients from steep to easy slopes.

The summer rainfall patterns and associated clover growth from a grazing trial were compared with those from an on-farm legume survey on North and South Island seasonally-dry east coast hill country to identify any differences in legume growth from the norm that may justify modifying the autumn fertiliser application policy. The results and recommendations are reported here.

Methodology

Waipawa grazing trial

A 48 ha hill country block was divided into 4 farmlets of twelve 1 ha paddocks balanced for slope and aspect at the Waipawa Research Area in Central Hawkes Bay. Treatments applied from 1995 to 2000 were low P (Olsen P of 9 µg/ml maintained), low P + N (30 kg N/ha applied in July), high P (Olsen P increased to near 29 µg/ml and maintained) and high P + N. From each farmlet, 25 pasture tiller cores of 50 mm diameter were taken in

September/October of each year from each aspect x slope and the % presence of white (*Trifolium repens* L), subterranean clover (*Trifolium subterraneum* L) and other legume species (mainly suckling (*Trifolium dubium* L) and red clover (*Trifolium hybridum* L) and Lotus major (*Lotus pedunculatus* L)) were measured.

East Coast on-farm survey

Forty East Coast hill country sheep and beef farms in both the North and South Islands were randomly selected and surveyed from September to November 2011. There were five farms each in the Poverty Bay, Northern, Central and Southern Hawkes Bay, Northern and Southern Wairarapa, Marlborough and North Canterbury regions. On each farm, land units representing either north or south-facing aspects, and either easy (up to 20º slope) or steep (25º plus slope) areas within each aspect were selected. Within each of the four land units a total of 20 points spaced at about 5 m intervals were observed using a small quadrat (100 mm x 100 mm) to record the percentage of the quadrat area covered by any legume (% total legume cover) and the presence (% present within the quadrat) of white and subterranean clover and other legumes. The mean % total legume cover and presence of legumes was an average of all of the quadrat observations on each land unit. Three 'blocks' per farm were measured giving a total of 300 points per farm. In total the survey accumulated nearly 12000 data points. The other legumes were mainly suckling and red clover and Lotus major.

Rainfall

Daily rainfall was recorded at the Waipawa site and the results aggregated from December to February and September to November in each year. NIWA historical records were used to obtain total rainfall from December to April in 2010/11 and September to November in 2011 for Gisborne, Napier, Masterton, Blenheim and Christchurch and compare it with long-term average rainfall from 1981 to 2020 at those sites.

Results

Rainfall

Waipawa grazing trial

The average monthly and aggregated rainfall for December to February is shown in Table 1.

Table 1 Monthly and aggregated rainfall (mm) from December to February for the Waipawa site from 1994/95 to 2001/02.

Month	**1994/95**	**1995/96**	**1996/97**	**1997/98**	**1998/99**	**1999/2000**	**2000/01**	**2001/02**
December	3	60	112	19	36	17	65	161
January	71	104	106	34	153	120	50	109
February	85	112	96	53	16	6	63	108
Total	159	276	314	106	205	143	178	378

In the period 1994/1995 to 2001/2002 (Table 1) the extremes were a low of 106 mm in 1997/98 and a high of 378 mm in 2001/2002. There was a gradual increase in summer rainfall from 1994/95 to 1996/97 followed by a sharp decline in 1997/98 then a gradual increase from 1999/2000 to 2001/2002. The long-term (1994-2009) average aggregated summer rainfall was 206 mm.

During these years, aggregated monthly rainfall from September to November (spring) was below the average long-term rainfall of 169 mm in 1994/95 to 1996/97 and 1998/99 and above-average in the other years.

On-farm survey

The total rainfall from December 2010 to April 2011 and from September to November 2011 from five city meteorological sites is compared with the long-term averages for these sites in Table 2.

Table 2 Aggregated monthly and long-term average rainfall (mm) from five sites

Site	**Summer- autumn (Dec- Apr)**		**Spring (Sept- Nov)**	
	2010 – 2011	**Long-term average**	**2011**	**Long-term average**
Gisborne	561	372	95	214
Napier	641	290	109	170
Masterton	394	323	323	229
Blenheim	304	207	207	187
Christchurch	233	221	176	140

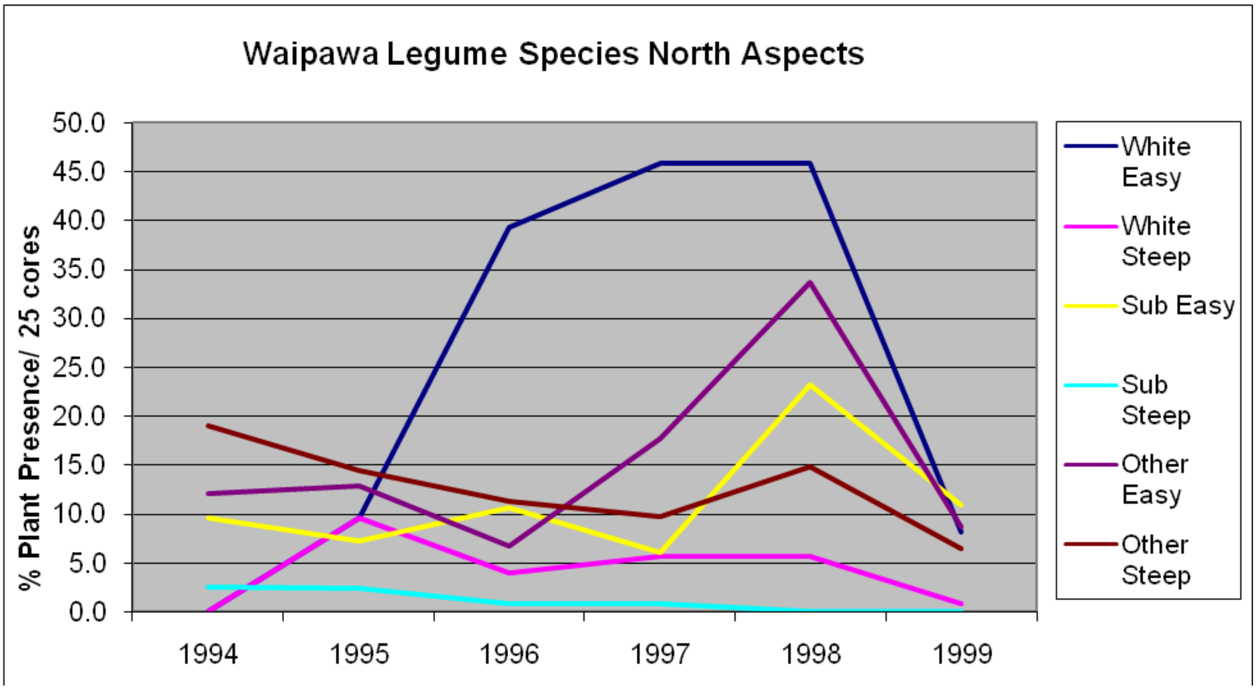
For December 2010 to April 2011, rainfall was above the long-term average for all sites except Christchurch where it was near average. Rainfall was below the long-term average in spring 2011 for Gisborne and Napier but near or above it at the other sites.

Waipawa grazing trial

Presence of legumes

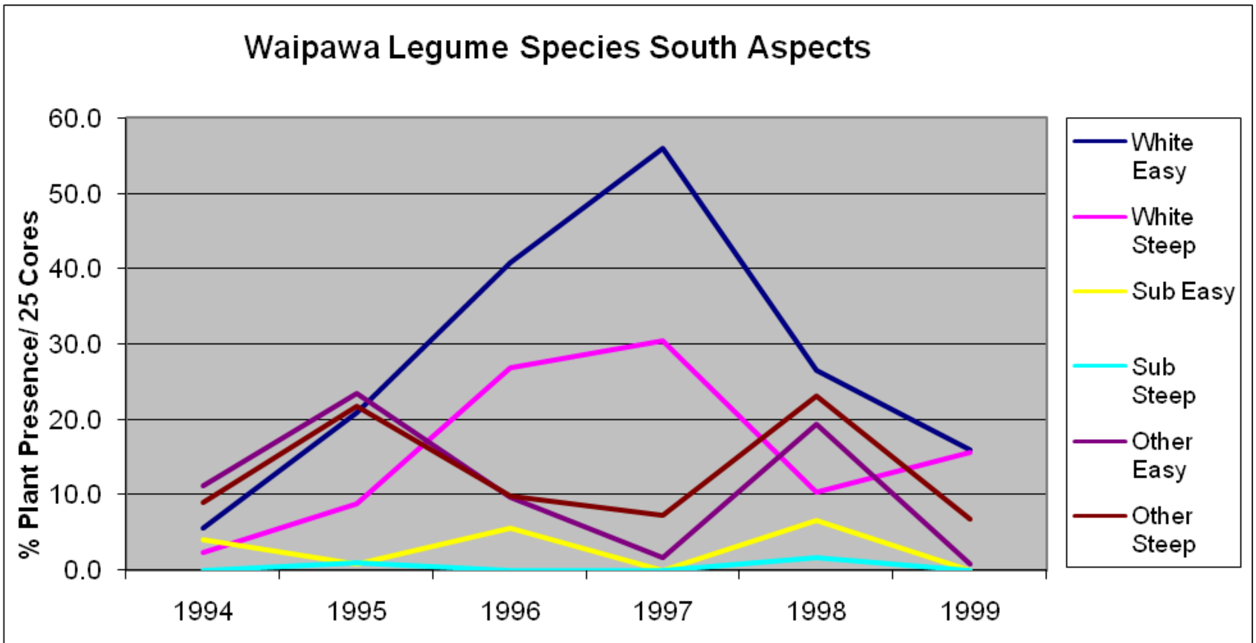
The presence of different legumes from 1994 to 1999 are shown in Figures 1 and 2.

Figure 1 Presence of legumes (%) on north aspects at Waipawa during spring of each year from 1994 to 1999. White = white clover, Sub = subterranean clover, Other = other legumes.



On north aspects, white clover comprised the dominant legume on easy slopes increasing from 10% in 1995 (ie. present in 10% of cores) to 45% in 1997 to 1998, then declining to initial levels in 1999. On steep slopes, the presence of white clover varied from about 5 to 10% during this period. The presence of subterranean clover increased from about 10% in 1994-1997 to 23% in 1998 on easy slopes but then declined to initial levels in 1999 while it remained at near-zero for the whole period on steep slopes. On easy slopes, other legumes maintained a presence of about 10% from 1994 to 1996, peaked at 34% in 1998 and then declined back to initial levels in 1999. On steep slopes, the presence of other legumes remained relatively constant at 7 to 20% between years.

Figure 2 Presence of legumes (%) on south aspects at Waipawa during spring of each year from 1994 to 1999. White = white clover, Sub = subterranean clover, Other = other legumes.

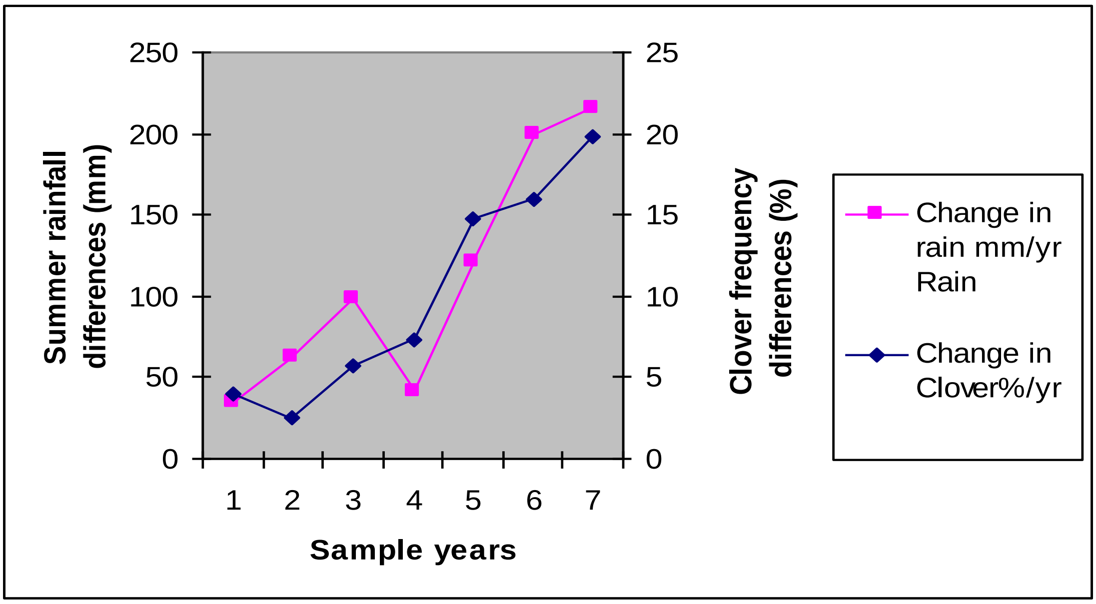


White clover was also the dominant legume on south aspects, where its presence increased from 5% in 1994 to a peak of 56% in 1997 on easy slopes. On south-steep slopes, the presence of white clover increased from an initial 2% to about 30% in 1996-97. The presence of white clover decreased back to near initial levels in 1999 on both slope classes. The presence of subterranean clover remained below 10% on both slope classes within south aspects. Other legumes showed similar changes in presence to white and subterranean clover with troughs of 1 to 10% in 1994, 1997 and 1999 and peaks to about 20% in 1995 and 1998.

Change in presence of clover between years

Figures 3 and 4 shows the relationship between the change in summer rainfall between successive preceding years over the period from 1994-2002, and the associated change in clover presence on easy and steep slopes in the following spring. It should be noted that the sample year numbers do not represent consecutive years but the order of difference in summer rainfall between years.

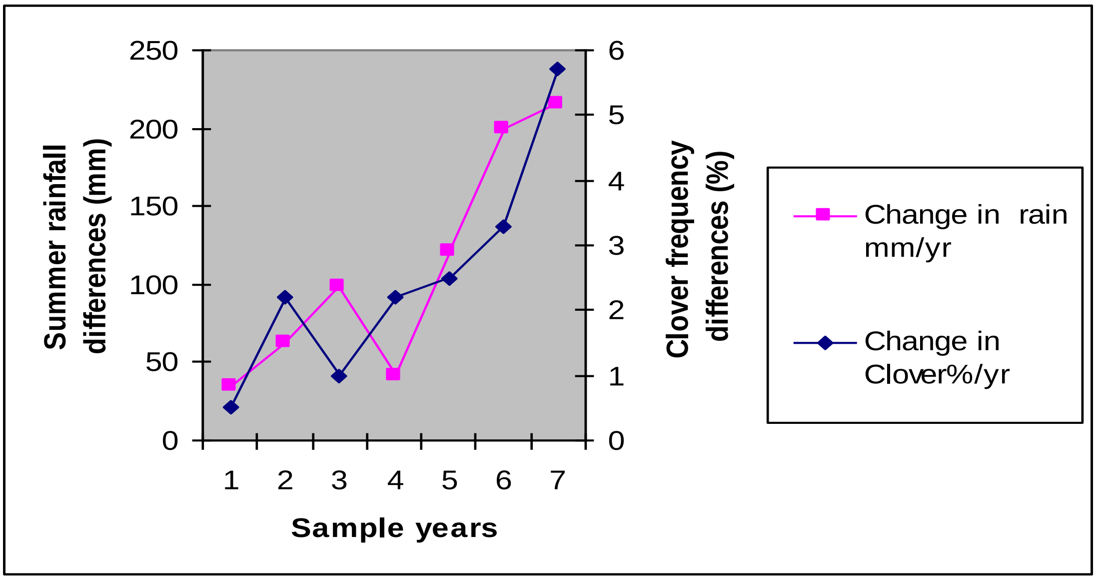
Figure 3 Relationship between the change in rainfall over the two preceding summers, either up or down, and the corresponding change in clover presence (%), either up or down, recorded on easy slopes at Waipawa in the following spring from 1994 to 2000 (Sample years 1 to 7*)



* Sample year 1 = from summer 1999/2000 to 2000/01; Sample year 2 = from summer 1998/99 to 1999/2000;
Sample year 3 = from summer 1997/98 to 1998/99; Sample year 4 = from summer 1995/1996 to 1996/1997;
Sample year 5 = from summer 1994/95 to 1995/96; Sample year 6 = from summer 2000/01 to 2001/02;
Sample year 7 = from summer 1996/97 to 1997/98.

Rainfall in the summer (December to February) of 1995/96 (Sample year 5) was 276 mm and 117 mm greater than in summer 1994/95 (159 mm). The presence of clover, mainly white and subterranean, increased by 15% in the following spring (Figure 3). In contrast summer rainfall in 1997/98 (Sample year 7) was 106mm, being 208 mm less than in summer 1996/97 (314 mm) and clover presence fell by 20% in the following spring. The correlation coefficient between the two factors was $R^2 = 0.81$. ie the change in rainfall between the previous two summers explained 81% of the change in clover presence measured in the following spring. There was about a 10% change in clover presence during spring for every 100 mm rainfall difference between the two previous summers. This was the average for both Low and High fertiliser P farmlets.

Figure 4 Relationship between the change in rainfall over the two preceding summers, either up or down, and the corresponding change in the presence of clover (%), either up or down, recorded on steep slopes at Waipawa in the following spring from 1994 to 2002 (Sample years 1 to 7 – see key in Figure 3)



On steep slopes (Figure 4) there was a similar relationship to easy slopes but the presence of clover was not as responsive to changes in summer rainfall in the preceding two years. This relationship had a correlation coefficient of $R^2 = 0.67$ and thus explained 67% of the variation in the presence of clover in spring on steep slopes from year to year. On steep slopes the rate of change in the presence of white clover was about 2.5% for every 100 mm change in rainfall between the two preceding summers.

East coast on-farm survey

The average cover of total legumes and presence of white and subterranean clover for each region according to slope and aspect is shown in Tables 3 to 8.

Table 3 Cover of total legume (% of quadrat area covered by all legumes) for each region in spring 2011

Slope		**Easy**	**Steep**
Region	**Aspect**		
Poverty Bay	North	13.7	5.6
	South	8.0	5.1
Northern Hawkes Bay	North	19.7	5.9
	South	8.3	4.8
Central Hawkes Bay	North	14.6	5.4
	South	8.6	3.1
Southern Hawkes Bay	North	9.2	11.6
	South	8.1	8.1
Northern Wairarapa	North	7.5	14.0
	South	8.1	9.0
Southern Wairarapa	North	16.0	16.7
	South	9.2	9.1
Marlborough	North	18.8	15.3
	South	14.2	12.3
North Canterbury	North	35.7	28.1
	South	20.5	19.7
SED			4.34

Total legume cover was significantly higher (P<0.05) on north than south aspects in North Canterbury and Southern Wairarapa on both slope classes and in Northern Hawkes Bay on easy slopes only. Easy slopes had significantly more clover cover (P<0.05) than steep slopes on north aspects in Central and Northern Hawkes Bay and Poverty Bay.

Table 4 Effect of aspect x slope on total legume cover (%) averaged across all regions in spring 2011

Slope	**Easy**	**Steep**
Aspect		
North	16.9	12.8
South	10.6	8.9
SED	0.97	

Total legume cover was significantly greater (P<0.05) on north than south aspects for both slopes and easy than steep slopes for both aspects.

Table 5 Presence of white clover (% quadrats containing white clover) for each region in spring 2011

Slope		**Easy**	**Steep**
Region	**Aspect**		
Poverty Bay	North	67.5	26.9
	South	68.3	51.5
Northern Hawkes Bay	North	26.4	9.3

	South	74.9	45.3	
Central Hawkes Bay		North	29.9	5.3
	South	61.9	26.4	
Southern Hawkes Bay	North	82.7	37.9	
	South	78.4	59.7	
Northern Wairarapa	North	60.5	37.6	
	South	75.2	71.7	
Southern Wairarapa	North	37.3	12.3	
	South	61.6	55.7	
Marlborough	North	0.0	0.5	
	South	16.0	7.2	
North Canterbury	North	48.3	23.5	
	South	65.3	51.2	
SED			11.80	

With the exception of Poverty Bay and Southern Hawkes Bay on easy slopes and Marlborough on steep slopes, the presence of white clover was significantly greater (P<0.05) on south than north aspects on both slope classes. On all aspects except the south in Northern and Southern Wairarapa and North Canterbury and both aspects in Marlborough there was a greater presence of white clover on easy than steep slopes. This difference was greater for north than south aspects. Over all regions, Southern Hawkes Bay had the highest and Marlborough had the lowest presence of white clover.

Table 6 Effect of aspect and slope on the presence of white clover (%) in spring 2011

Aspect x slope

Slope	**Easy**	**Steep**
Aspect		
North	44.1	19.2
South	62.7	46.1
SED	2.57	

The order of descending significance for white clover presence (P<0.05) was south/easy>north easy = south steep>north steep.

Table 7 Presence of subterranean clover (%) for each region in spring 2011

Slope		**Easy**	**Steep**
Region	**Aspect**		
Poverty Bay	North	7.2	16.5
	South	3.7	1.9
Northern Hawkes Bay	North	55.7	31.5
	South	9.3	5.60
Central Hawkes Bay	North	44.8	30.1
	South	8.3	13.1
Southern Hawkes Bay	North	2.1	17.9
	South	0.3	1.1
Northern Wairarapa	North	6.7	32.0
	South	2.4	3.2

Southern Wairarapa	North	41.3	61.3
	South	7.4	4.3
Marlborough	North	88.3	81.9
	South	51.5	77.1
North Canterbury	North	42.9	53.9
	South	12.5	28.0
SED		10.2	

Subterranean clover was significantly more abundant on north than south aspects in Northern and Central Hawkes Bay, Southern Wairarapa and North Canterbury on both slopes and Southern Hawkes Bay on steep slopes. Marlborough had the highest presence of subterranean clover and Poverty Bay and Southern Hawkes Bay the lowest.

Table 8 Effect of aspect and slope on the presence of subterranean clover (%) in spring 2011

Aspect x slope

Slope	**Easy**	**Steep**
Aspect		
North	36.1	40.6
South	11.9	16.8
SED	2.58	

For the presence of subterranean clover, the order of descending significance ($P<0.05$) was north steep=north easy>south steep>south easy.

Other legumes

The average presence of other legumes for a unit of region x aspect x slope ranged from 0 to 34% and was highest in Northern and Southern Wairarapa and lowest in Marlborough and North Canterbury (results not shown). Over all regions steep slopes had significantly more other legume ($P<0.05$) than easy slopes but there was no significant difference between aspects.

Discussion

The growth of legumes in hill pastures is critical as a source of fixed N for associated grass growth and higher nutritive value of pasture for grazing animals. However there is a high level of variability in legume content within hill pastures both spatially and temporarily due largely to associated variability in soil moisture availability induced by season, slope and aspect.

The results from the Waipawa grazing trial indicated that the presence of legumes in spring on seasonally-dry east coast hill country was dependent on, and can be predicted from, the change in the amount of rainfall between the preceding two summers. An increase in summer rainfall allowed white clover and other perennial legumes to spread their stolons and more subterranean clover seed to germinate earlier (Olykan et al. 2018). Conversely a decrease in summer rainfall resulted in a subsequent decrease in clover growth in the following spring. This relationship ($R^2 = 0.81$) was stronger on easy slopes with higher moisture status than on associated steep slopes ($R^2 = 0.67$) where soil moisture status is generally lower. These relationships were developed in a climate where summer and autumn rainfall can be very low (eg. 138 mm from December to April in 1997/98 - Table 1), but also much higher as occurred a year earlier (473 mm in 1996/97). This variation between years provides conditions where the presence of legume in spring is highly dependent on the amount of rainfall in the preceding summer and autumn.

The results from the on-farm survey must be interpreted in the light of the greater than average rainfall in the preceding summer and autumn in all regions except North Canterbury. It should be expected then, as predicted by the Waipawa trial results, that pasture legume cover would be expected to be more evenly distributed over slope class and aspect in spring 2011 despite rainfall for that season being mainly lower than or about the long-term average.

In the grazing trial, the effect of more rainfall in the preceding summer increasing the presence of subterranean clover was more apparent on north-easy rather than the other aspects and slopes. For a much greater number of sampling sites over a much wider geographic area in the on-farm survey, the presence of subterranean clover was high on both easy and steep slopes on the north aspect, especially in Northern and Central Hawkes Bay, Southern Wairarapa, Marlborough and North Canterbury. In these regions, subterranean clover would be expected to be more adapted to dry conditions by setting large amounts of seed to provide a bank in the soil before dying (Lucas 2021) and therefore in a better position to respond to higher rainfall during the seed germination phase during summer and autumn. Gillingham et al. (1998) reported that at the Waipawa site, the presence of white clover was significantly greater on easy than steep slopes and on south than north aspects while subterranean clover was significantly more abundant on north rather than south aspects. On higher rainfall with an average of 1600 mm but seasonally dry hill country at Whatawhata Hill Country Research Station in Western Waikato, Gillingham (2016) reported a greater presence of white clover on easy than steep slopes but a smaller difference in the presence of subterranean clover between slope classes.

In contrast to subterranean clover, white clover was present in all regions to a similar degree, except for a lower presence in Marlborough and on north-steep slopes in Northern and Central Hawkes Bay. The greater presence of white clover on south compared with north aspects and easy compared with steep slopes in the on-farm survey was similar to that for the average presence from 1994 to 1999 at Waipawa (Figures 3 and 4). Over all regions though, the legume cover was significantly greater on north than south aspects and on easy than steep slopes although the numerical differences were not large. For subterranean clover in the on-farm survey, there was a greater presence on north than south aspects with little difference between slopes (Table 8). Hence in the on-farm survey, the effects of aspect and slope on the presence of white clover were counter-balanced by the effects on subterranean clover and other legumes resulting in only small differences in total legume cover. The overall results from the on-farm survey supported the contention that above-average rainfall in the preceding summer and autumn encouraged more legume on steep slopes in the following spring.

From the research carried out that forms the basis of variable rate application of fertiliser P and S, the recommendation has been to apply P and S to easy slopes which have more legume in most years and apply N on steep slopes which have less legume with an application of P and S at appropriate intervals to satisfy the lower requirements of the predominant low fertility-demanding grasses (Morton and Gillingham 2017). The results of the two studies in this paper present opportunities to refine when the application of P and S to steep slopes will be more beneficial. When higher than average rainfall occurs over the summer and summer-autumn period as occurred in 1995/96 and 1996/97 at Waipawa and most east coast regions in 2010/2011, then the best decision would be to apply a similar rate of P and S to both steep and easy slopes to allow improved growth from the relatively high presence of legumes in the following spring as occurred in 1997 and 1998 at Waipawa and 2011 in the east coast regions. When summer/autumn rainfall is below-average to average, then P and S should be only applied to easy slopes.

Conclusions

- The results from several years of a grazing trial and an on-farm survey showed that higher rainfall in the preceding summer and autumn on east coast seasonally-dry hill country improved the growth of legumes in the following spring period.
- Conversely, in the grazing trial, a sharp reduction in summer rainfall from the following year reduced clover growth in the subsequent spring.
- There is an opportunity to take advantage of this delayed rainfall effect by the application of P and S fertiliser to both easy and steep slopes during the wet summer and autumn period to grow more legume on these areas in the following spring.

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