Hill country pastures in the southern North Island of New Zealand: an overview

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Abstract
The 4 million ha of hill country pastures in New Zealand grow mostly on steep slopes and soils of naturally low soil fertility. Pastures are based on approximately 25 exotic species introduced within the last 130 years after the forest was cleared and burnt. Despite the environmental constraints and naturalised species, hill country is a major contributor to agricultural exports. The landscape and the pastures are spatially diverse, with slope and aspect strongly influencing the abundance and production of pasture species. The number of pasture species present is relatively stable, but the relative abundance of high fertility grass species (e.g. perennial ryegrass, *Lolium perenne*), low fertility grass species (e.g. browntop, *Agrostis capillaris*) and legumes (e.g. white clover, *Trifolium repens*) can be shifted towards high fertility grass species and legumes through the interaction of phosphate fertiliser application and grazing decisions (that is, sheep versus cattle, stocking rate, grazing management). Increased proportions of desirable species and improved soil fertility and structure can support sustainable farming systems. There are challenges such as soil erosion and nutrient loss into waterways, but these are more readily managed when the pastoral system is productive and profitable.

Keywords: slope, pasture condition, browntop, perennial ryegrass, soil characteristics

Key messages

- Slope and rainfall are the natural factors and fertiliser rate and grazing management are the controllable factors that determine pasture production in hill country
- Soil physical, biological and chemical properties are changed by pasture species, fertiliser application rate and grazing management
- Greater abundance of high fertility pasture species improves the sustainability of hill country pastoral systems.

Overview of the hill country of southern North Island

The hill country has been defined as "all lowland and montane hill and steeplands (slope>15°) classified as land use capability class 5, 6 or 7, and being described in the unit descriptions in the New Zealand Land Resources Inventory as hill country" (Basher *et al.* 2008; Lynn *et al.* 2009). Thus, it comprises grassland farming located in the chain of mountains running south-east – north-west across both the North and South Islands of New Zealand. This overview will focus on the southern North Island. The variety of soil types in the southern North Island include: acidic allophanic brown soil (Taranaki/Manawatu), mottled argillic pallic soil (Wellington/Wairarapa), mottled immature pallic soil (Wellington/Wairarapa), and typic rendzic melanic soil (Wellington/Wairarapa) (Hewitt 2010; Landcare Research 2016), with slope the common feature to all of them (Ledgard & Hughes 2012). The average yearly rainfall varies from 1500 mm in the North to 600 mm in the South so summer drought can occur particularly on the east coast.

Hill country makes a major annual contribution to the New Zealand economy through meat exports and to a lesser extent through wool exports. For example, New Zealand produced 377 000 tonnes of lamb meat and 164 100 tonnes of wool in 2014 (Beef + Lamb New Zealand 2015). There were 19.7 million breeding ewes and 3.6 million cattle (breeding cows, heifers, steers, bulls) in 2014. In 2014, lambing percentage was 119, average lamb carcase weight 18.3 kg, average wool production 5.3 kg/head and the average steer carcase weight 305 kg.

Hill country farming occurs on approximately 4 million ha, 13% of which has average slopes of 16-20° while 32% has slopes greater than 21º (Hodgson *et al.* 2005). Since the indigenous forest was cleared 100-150 years ago to establish pasture, several exotic species have become naturalised to form the base of hill country pastures. There are typically, 25 readily observed species in hill pastures in the southern North Island (Table 1; Nicholas 1999).

The slopes of the hills have a specific micro-relief probably resulting from the combination of the elimination of indigenous forest from the hills, the clearance of tree trunks from the slopes, pasture establishment and animal activities such as grazing and treading. This micro-relief has a high spatial variation at a scale of 1 to 2 m and is characterised by large differences in slope over short distances (Gillingham 1973; Lambert & Roberts 1978; Lambert *et al*. 1983; Lambert *et al*. 1986). There are three broad categories

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of slope, classified as low (LS, 0-12°), medium (MS, 13-25°) and high (HS, >25°), respectively (Lambert *et al.* 1983), which are similar to track-camp, slope and bank proposed by Rumball & Esler (1968).

Slope has a strong influence on soil depth, soil development, nutrient status, moisture retention and the behaviour of grazing animals, including dung and urine deposition (Gillingham & During 1973; Lambert & Roberts, 1978; Lambert *et al.* 1983; Saggar *et al.* 1990; López *et al.* 2003a; López *et al.* 2003b). These characteristics all impact upon pasture botanical composition and production (Gillingham 1973; Lambert *et al*. 1983; López *et al.* 2006). Thus, slope can result in major differences in soil organic matter, nutrient pools, pH, physical properties and biological activity (e.g. the presence and biomass of earthworms), and herbage mass production (Mackay *et al.* 1999; Lambert *et al*. 2000; López *et al*. 2003b; Lambert *et al*. 2014).

A meta-analysis of hill pasture data by Zhang *et al*. (2005) showed that spring rainfall and slope were the two most important factors influencing annual herbage accumulation in hill country (Figure 1). The highest total annual herbage accumulation occurs when spring rainfall is greater than 212 mm, slope is less than 16° and the total phosphate (P) fertiliser applied over 5 years is greater than 145 kg. The lowest annual production occurs when spring rainfall is less than 212 mm, the slope is greater than 22.5° and N fertiliser applied is less than 33.8 kg (Figure 1).

Soil heterogeneity and constraints

Slope differentiates the physical and fertility characteristics of the soil, and thereby influences pasture growth in hill country (Lambert *et al.* 1990; Zhang *et al*. 2005). Microsites with HS have higher water conductivity and soil density, and lower microporosity and water holding capacity than microsites with LS. Thus, HS sites have greater ability to conduct water internally through the soil, but a limited capability to retain water (Figures 1, 2 & 3; López *et al.* 2003b).

The interaction between slope and soil physical attributes has consequences for productivity and sustainability through the supply of available water to the pasture, a major factor that determines botanical composition and pasture growth. When the soil reaches the wettest point in the year, soil water measurements have shown that only the LS meets field capacity, with MS and HS pasture areas permanently in water restriction (López *et al.* 2003b).

Water repellency contributes to pasture water restriction, especially of soils of low soil fertility. There are two water repellence mechanisms: the first prevents water from entering the soil profile, and the second favours water flowing preferentially through large pores to the subsoil, limiting the contact time with small pore sizes and soil aggregates (Wallis *et al.* 1991; Wallis & Horne 1992). These mechanisms are associated with an increase in slope (McGhie 1980) and the complexity of the organic matter particles in the soil (Chan 1992; Hallet & Young 1999). More complex particles, such as those rich in lignins (Posner 1966), confer a higher degree of hydrophobicity (Franco *et al.* 1995).

Table 1 Average percentage cover and standard deviation (SD) of pasture species on hill pastures in the southern North Island of New Zealand (Nicholas 1999).

Botanical name	Common name	%	SD
Agrostis capillaris	Browntop	19.2	4.6
Lolium perenne	Perennial ryegrass	10.0	6.6
Anthoxanthum odoratum	Sweet vernal	7.1	7.0
Cynosurus cristatus	Crested dogstail	5.4	2.4
Rytidosperma spp.	Danthonia	2.6	1.8
Holcus lanatus	Yorkshire fog	1.9	1.0
Poa annua	Annual poa	1.9	1.7
Festuca rubra	Red fescue	0.9	0.8
Dactylis glomerata	Cocksfoot	0.6	1.5
Poa pratensis	Kentucky bluegrass	0.2	0.3
Trifolium repens	White clover	5.0	2.7
Trifolium dubium	Suckling clover	0.7	0.8
Trifolium subterraneum	Subterranean clover	0.3	0.8
Lotus pedunculatus	Greater birdsfoot trefoil	0.4	0.7
Centella uniflora	Centella	0.2	0.2
Nertera setulosa	Nertera	0.6	0.7
Plantago lanceolata	Plantain		
Hypochaeris radicata	Catsear	6.1	4.5
Leontodon taraxacoides	Hawkbit		
Muscii spp.	Moss	5.4	6.0
Achillea millefolium	Yarrow		
Cirsium vulgare	Spear thistle		
Cirsium arvense	Canada thistle	1.3	1.4
Ranunculus repens	Creeping buttercup		
Cerastium glomeratum	Chickweed		
Dead matter		30.2	9.8

Animal behaviour contributes to the modification of soil and pasture attributes in hill country. A paddock can comprise one or more hill faces, thus the animals have the possibility to graze any of the slope categories. The animals mainly camp on the LS, and graze depending on slope category, available herbage mass and individual tiller height. Thus, when there is plenty of available pasture of good quality, such as in spring, the animals mainly graze on the LS, but in winter, when pasture availability is low, the animals graze through all the microsites. LS pasture is intensively grazed during the whole year, maintaining a height of 1 to 3 cm and a high tiller density, contrary to HS microsites (López *et al.* 2003a).

Grazing and camping behaviour increase fertility levels in the LS due to deposition of urine and faeces, and contribute to nutrient transfer from, and depletion of, HS and MS areas (Saggar *et al.* 1990; López *et al.* 2003b). Grazing animals constitute a major source of redistribution of the P and N amongst microsites (Saggar *et al.* 1990; Mackay & Lambert 2011). For example, 60% of the P from dung is deposited on microsites with less than 12° slope, which is only 30% of the grazed area (Saggar *et al.* 1990). There is also nutrient redistribution due to water runoff moving sediments and anion and cation leaching, such as sulphate (SO_4-S) and magnesium (Mg^{2+}) (Lambert *et al.* 1986; Saggar *et al.* 1990; Mackay & Lambert 2011). Sulphate, K^+, Ca^{2+}, Mg^{2+} and soil total exchangeable bases also accumulate on LS areas, with the grazing animal being the major factor causing redistribution of these nutrients amongst microsites (Gillingham & During 1973; Mackay & Lambert 2011).

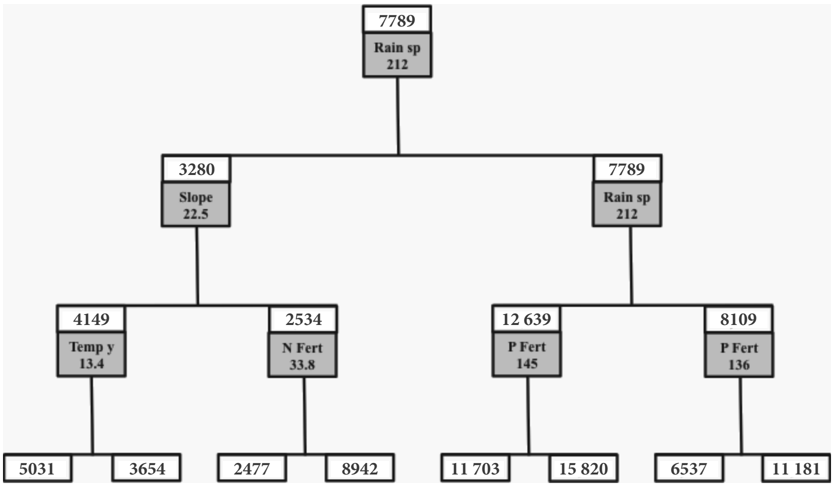


Figure 1 Hierarchy of the main variables that determine hill country annual pasture production according to the first three levels of the decision tree model (Zhang *et al.* 2005). Predicted production (kg DM /ha/year) is shown in the unshaded rectangles, splitting variables and split-points are in the shaded rectangles. Prediction goes to the left-side branch when splitting variable < split-point, and goes to the right-side branch when the splitting variable ≥ split point. Abbreviations are defined in Appendix 1.

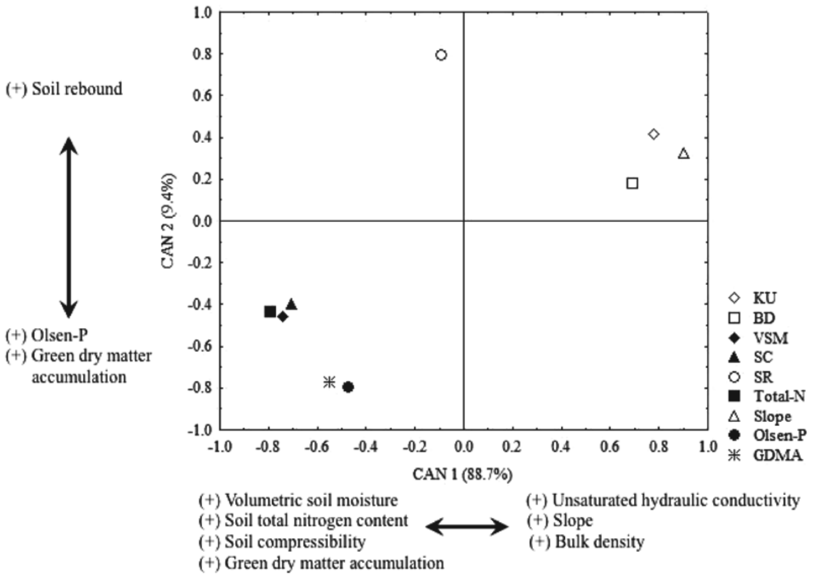


Figure 2 Soil variables that lead to soil microsite differentiation on hill slopes as a result of a canonical variate analysis (CAN). KU, unsaturated hydraulic conductivity (<750 mm); BD, bulk density; VSM, volumetric soil moisture (<30 mm); SC, soil compressibility; SR, soil rebound; Total-N, soil total nitrogen content; Olsen-P, soil phosphorus content; GDMA, green dry matter accumulation (López *et al.* 2003b).

Pasture heterogeneity and production

There is a strong relationship between pasture composition and growth and soil physical and chemical properties. The movement of soil particles and nutrients from HS areas to LS areas, due to erosion and grazing animals, exacerbates soil and pasture differences between both microsites and influences water flow and retention (Lambert *et al.* 1996). Water shortage strongly affects hill country pasture growth. Increasing slope, aspect and summer rainfall accentuate water deficits for and restrict pasture growth (Bircham & Gillingham, 1986). Pasture species that colonise HS microsites are able to tolerate permanent water restriction and low soil nutrient supply. Therefore, they are able to survive and slowly grow under constantly stressful soil conditions (Campbell, 1990; Davis *et al.* 1994; López *et al.* 2006). Examples include *Hypochaeris radicata*, *Leontodon taraxacoides*, *Anthoxanthum odoratum*, *Agrostis capillaris*, *Rumex acetosella* and *Festuca rubra* (López *et al.* 2006).

Meanwhile, LS areas have water and soil nitrogen (N) accumulation and an improved physical state, allowing fast growing species to contribute to higher annual herbage accumulation rates (Table 2; Figure 3). Soil in LS areas hold more available water for a longer period into the summer, so pasture has a longer growing season (Lambert *et al.* 1983). Pasture species that dominate LS are mainly competitors, such as *Lolium perenne*, *Poa trivialis* and *Holcus lanatus*, that are able to sustain high growth rates, and high dry matter production with high nutritive value only if their growth requirements are fulfilled (López *et al.* 2006). These species have high rates of water and nutrient uptake from the soil.

The environmental conditions described for the HS and MS areas support herbage accumulation rates of approximately 3-7 tonnes DM/ha/year, while for the LS sites can support 10 tonnes DM/ha/year or higher (López *et al.* 2003b). Based on the long term study (1975-1987) at AgResearch's Ballantrae Hill Country Research Station (located in southern Hawke's Bay), maximum annual herbage accumulation data, modelled according to increasing soil Olsen-P status, is around 15 tonnes DM/ha/year for LS areas and 9 tonnes DM/ha/year for HS areas (Lambert *et al.* 2014).

Sustainable management of the pastoral system

Before taking action towards improving hill country pastures, it is necessary to determine the factors that can be controlled by farmers and the response that they will confer to the whole system in terms of pasture production, stocking rate and profitability. Fast growing pasture species, such as *Lolium perenne* and *Trifolium repens* have potentially high herbage accumulation rates and nutritive value. These species respond to regular application of P fertiliser and to grazing management that keeps the pasture cover under control (Lambert *et al*. 1986; Wan *et al*. 2009).

Fertiliser application stimulates pasture growth and soil biological activity, thus soil from fertilised paddocks holds more water in the pore sizes <300 µm, <150 µm, <60 µm and <30 µm than soil from non-fertilised paddocks (López *et al.* 2003b). This is relevant for pasture growth, since the available water for plants is held in pores between 0.2 µm and 60 µm (Thomasson 1978). The unsaturated hydraulic conductivity (KU) indicates that water flows more slowly through the fertilised soil for the pore sizes <1500 µm and <750 µm. This suggests that the more fertile soil may not have complete pore continuity.

Table 2 Soil physical and fertility features and pasture herbage accumulation in hill country as influenced by fertiliser and slope. VSM: volumetric soil moisture. LL: non-fertilised paddock, HH: fertilised paddock (1), LS: Low slope, MS: Medium slope, HS: High slope (López *et al.* 2003b).

	Total Soil Porosity (%)	Bulk density (g/cm³)	Field VSM (V/V%)	Total N (ppm)	Soil Total Exchangeable Bases (meq 100/g ds)	Annual Herbage Mass (kg DM/ha)	Slope (°)
Paddock							
LL	67.6	0.86	0.37	87.2	8.0	4280	24
HH	68.3	0.84	0.45	148.2	7.7	10285	22
s.e.m.	0.42	0.01	0.02				1.0
Significance	n.s.	n.s.	n.s.	*			*
Slope							
LS	70.7 a	0.78 c	0.52 a	275.5 a	10.8 a	12568 a	8 c
MS	68.3 b	0.84 b	0.38 b	106.3 b	6.8 b	5806 b	24 b
HS	65.0 c	0.93 a	0.32 b	50.2 c	6.6 b	4003 c	40 a
s.e.m.	0.52	0.01	0.02				1.2
Significance	***	***	***	***	***	***	***

(1) Fertilisation: LL: 11 kg P/ha /year between 1975-1980, no fertiliser after 1980; HH: 57 kg P/ha/year between 1975-1980, 60 kg P/ha/year after 1980.
*= P<0.05; ***P<0.001; ns, not significant.

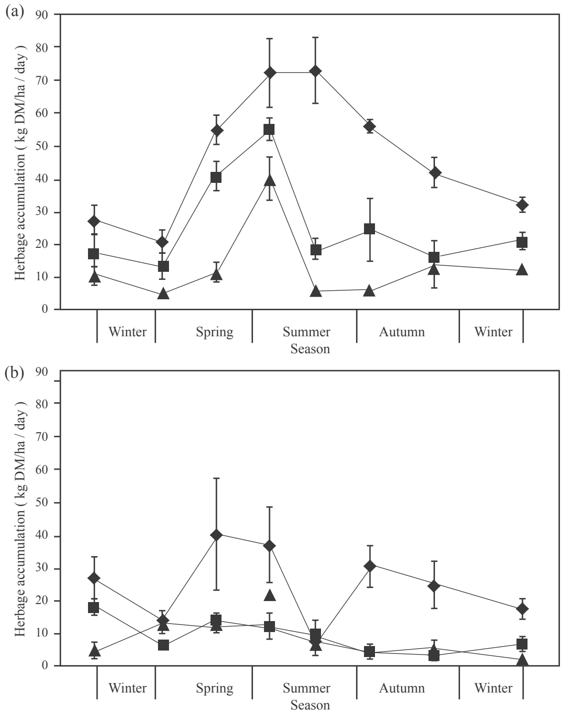


Figure 3 Mean seasonal herbage accumulation rate of different slope categories (low slope (LS), ■; medium slope (MS), ◆; high slope (HS), ▲) of (a) fertilised (HH) and (b) non-fertilised (LL) hill country pastures. Vertical bars represent the standard error of the mean (n=4) (López *et al.* 2003b).

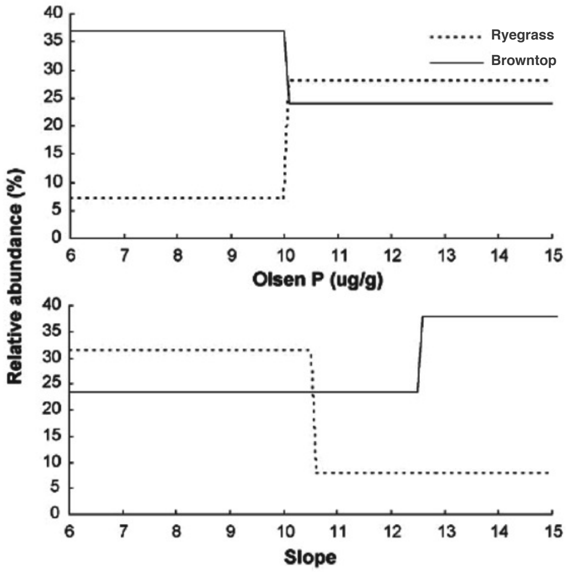


Figure 4 The average responses of perennial ryegrass (*Lolium perenne*) and browntop (*Agrostis capillaris*) to Olsen P and slope gradients (Wan *et al.* 2009).

Thus, improvements in volumetric soil moisture (VSM) and in soil chemical properties with fertiliser addition, combined with decreased slope, result in improved soil development (López *et al*. 2003b). Soil micro-aggregate status and total N content (19 kg/ha/year), and biological N fixation, all improve due to greater white clover abundance and growth, and greater earthworms populations and activity (Grant & Lambert 1979; Mackay *et al*. 1999; Lambert *et al*. 2000; Lambert *et al.* 2014). However, at the same time, pore continuity and function are reduced as a result of the constant treading by grazing animals on fertilised soils associated with a higher stocking rate, especially in low slope areas (López *et al*. 2003a).

In non-fertilised pastures, soil nutrients constrain pasture production, especially in HS and MS microsites. Fertiliser application allows the faster growing species to increase in abundance and express their productive potential (Figure 3).

As a result of fertiliser application soil environmental constraints diminish enabling changes in the pasture botanical composition such as decreased abundance of stress tolerating pasture species and increased abundance of faster-growing species, thereby increasing herbage accumulation and stocking carrying capacity. Increasing the soil Olsen-P levels over 10 ppm results in *Lolium perenne* abundance increasing relative to *Agrostis capillaris* (Figure 4; Wan *et al*. 2009).

In addition, the application of lime increases the content of soil exchangeable bases and triggers mechanisms that increase soil moisture retention and mineralisation of organic N, encouraging legume growth, high annual herbage accumulation rates, and increased earthworm activity (Morton *et al.* 2005; Lambert *et al.* 2014).

Herbage and animal production and ecosystem sustainability

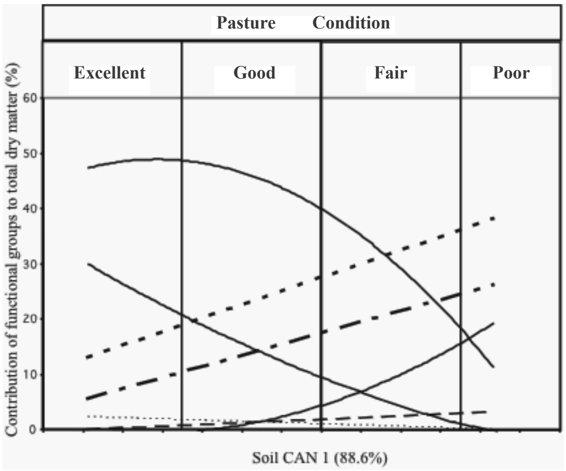
Although the indigenous forest on hill country was replaced with hill pasture based on exotic pasture species, the pasture vegetation can be maintained in a stable and sustainable state provided the slope is not highly susceptible to soil erosion. This is essential, as the wider public nationally and internationally demand that farm systems be environmentally sustainable. The demand to be sustainable along with the need for farmers to have profitable farm businesses has bought changes to hill country pastoral farming. More trees are being incorporated into the landscape, both as forests and as widely spaced plants, to better manage soil erosion on the slopes and the consequent entry of sediment and nutrients into waterways (Gillingham & Gray 2006). Nutrient budgeting (e.g. OVERSEER; Wheeler *et al*. 2003) is being used to manage nutrient losses from farms through controlled use of fertiliser, keeping livestock out of waterways, and restricting cattle grazing on wet soils. Also, the importance of carbon sequestration in soils and trees has been recognised, and in the case of trees is a potential source of income (Lambert *et al*. 2000; Guevara-Escobar *et al*. 2002).

The number of species in permanent hill pastures is stable and is highly resistant to change. A long term trial at Ballantrae Research Station from 1969 to 1995 showed no changes in the number of pastures species present, but the relative abundance of individual species did change (Nicholas 1999). The interaction of grazing management and fertiliser application changes the relative contribution of key pasture species over time (Lambert *et al*. 1986; López 2000; Wan *et al*. 2009). As a result of increased soil P and N and regular defoliation of pasture, the abundance of high fertility-competitor grass species (*L. perenne*, *H. lanatus*, *Poa* spp.) and *T. repens* increase, resulting in greater pasture and animal production from all the microsites on the hills, particularly in LS areas (Lambert *et al*. 1986; López *et al*. 2006; Wan *et al*. 2009). This improvement of pasture through management creates a more productive and profitable pastoral system yet maintains the stability of the pasture across all microsites.

In a heterogeneous environment, such as hill country, a diverse pasture allows the species and their ecotypes to grow according to their own requirements, and their relative abundance (diversity between and within species) is the result of the interactions between environmental conditions and the genetic capability of each individual to survive and grow under those conditions (Wedderburn *et al.* 1990; Nichols & Crush 2015). Therefore, a highly heterogeneous environment requires a highly diverse pasture, with sufficient population plasticity to allow adjustments to environmental changes (López & Valentine 2003).

Pasture condition and functional groups

The close relationship between the environment and pasture botanical composition means the degree of development or degradation of the pasture system can be evaluated visually. Species that use a similar quantity of resources or respond in a similar manner to disturbances can be grouped together into plant functional groups (Gitay & Noble 1997). Plants in each functional group have similar internal requirements or phenotypic responses. An additional concept is that of "Pasture Condition", defined as the actual pasture dry matter production of a site in relation to the maximum possible herbage that can accumulate at that site (potential production) (Gastó *et al.* 1993; Pieper 1994). The potential pasture production of a site depends on: 1) the permanent environmental attributes (non controllable factors), such as climate, landform, soil depth and texture, and 2) the non-permanent attributes (controllable factors), such as soil nutritional status, at a level that they do not constitute a limitation to plant species presence or growth for a given site (Dyksterhuis 1949; Dyksterhuis 1958; Noble 1973; Archer & Smeins 1991; Gastó *et al.* 1993).



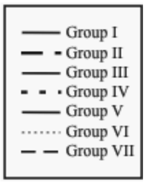


Figure 5 Changes in botanical composition according to pasture condition for hill country pastures (López 2000). Group I (Low Fertility species): *Rytidosperma* sp., *Festuca rubra, Muscii* sp., *Hypochaeris radicata*, *Leontodon taraxacoides* and *Trifolium dubium*; Group II (Medium Fertility species): *Anthoxanthum odoratum*, *Cynosurus cristatus* and *Trifolium repens*; Group III (High Fertility grasses): *Holcus lanatus*, *Poa annua* and *Poa trivialis*; Group IV (Generalist Type A): *Agrostis capillaris*; Group V (Generalist Type B): *Lolium perenne*; Group VI (High Fertility dicotyledons): *Cirsium arvense*, *Cerastium glomeratum* and *Plantago lanceolata*; Group VII (species with Low Presence): *Cymbalaria muralis*, *Centella uniflora* and *Sagina procumbens*.

Pasture condition was used to evaluate the impact of grazing pressure on pasture performance, with plant species grouped according to their species changes over time (Dyksterhuis 1949; Dyksterhuis 1958; Noble 1973). Alternatively, pasture condition can be determined according to the species present in a site, when the plant functional groups that the species belong to are known (López & Valentine 2003).

A pasture in excellent condition is dominated by fast-growing pasture species, which improves soil porosity and pore continuity, water infiltration, water holding capacity, root growth mass, soil biological activity and herbage accumulation (Lambert *et al.* 1990; Lambert *et al.* 1996; Wedderburn *et al.* 2010; Reid & Crush 2013).

Pasture condition in hill country can be assessed by statistical analysis of changes in herbage mass of 7 functional groups (7 groups) in relation to changes in soil physical and fertility properties (Figure 5). Such an analysis reveals that:

- at each pasture condition level, pasture diversity is maintained;
- changes in the percentage of pasture groups are

closely related to variations in soil physical and chemical state; and

- presence and abundance of functional groups reflects the availability of environmental resources, including soil nutrients and water (López *et al*. 2006).

Summary

There is high spatial variation in environmental conditions and pastures over short distances and this heterogeneity drives functionality and stability of the whole system. Grazing animals, fertiliser application and grazing management decisions stimulate changes in soil and pasture attributes, such that flat areas accumulate soil particles and nutrients that have been transferred from the steeper slope areas, accentuating differences in soil and herbage across slope categories. The interaction between slope position and soil development, and subsequently on herbage accumulation rate, are highly relevant for the development of hill country pastoral systems. Today's challenge is to efficiently use the typically fertile soil and productive pasture found in the flat areas and to continue improvement of soil and pasture on the slopes in a sustainable manner, allowing the resilience and productivity of hill pastures as a whole to increase.

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Variable symbol	Units	Variable description
pH	$-\log_{10}[H^+]$	Soil pH
BD	g/cm^3	Soil bulk density
Olsen P	µg/g	Soil Olsen P
P_fert	kg/ha/year	Annual P fertilizer input
P_fert5	kg/ha	Five-years cumulative P fertilizer input
Temp_y	°C	Annual mean daily temperature
Temp_sp	°C	Spring mean daily temperature
Temp_su	°C	Summer mean daily temperature
Temp_au	°C	Autumn mean daily temperature
Temp_wi	°C	Winter mean daily temperature
Rain_y	mm	Annual rainfall
Rain_sp	mm	Spring rainfall
Rain_su	mm	Summer rainfall
Rain_au	mm	Autumn rainfall
Rain_wi	mm	Winter rainfall
Rain_warm	mm	Sum of spring and summer rainfall
Slope	°	Hill slope angle
G_animal	s, c,	Grazing animal species: sheep (s), cattle (c).

Appendix 1 Input variables used in the decision tree analyses presented in the Figures (Wan *et al.* 2009).