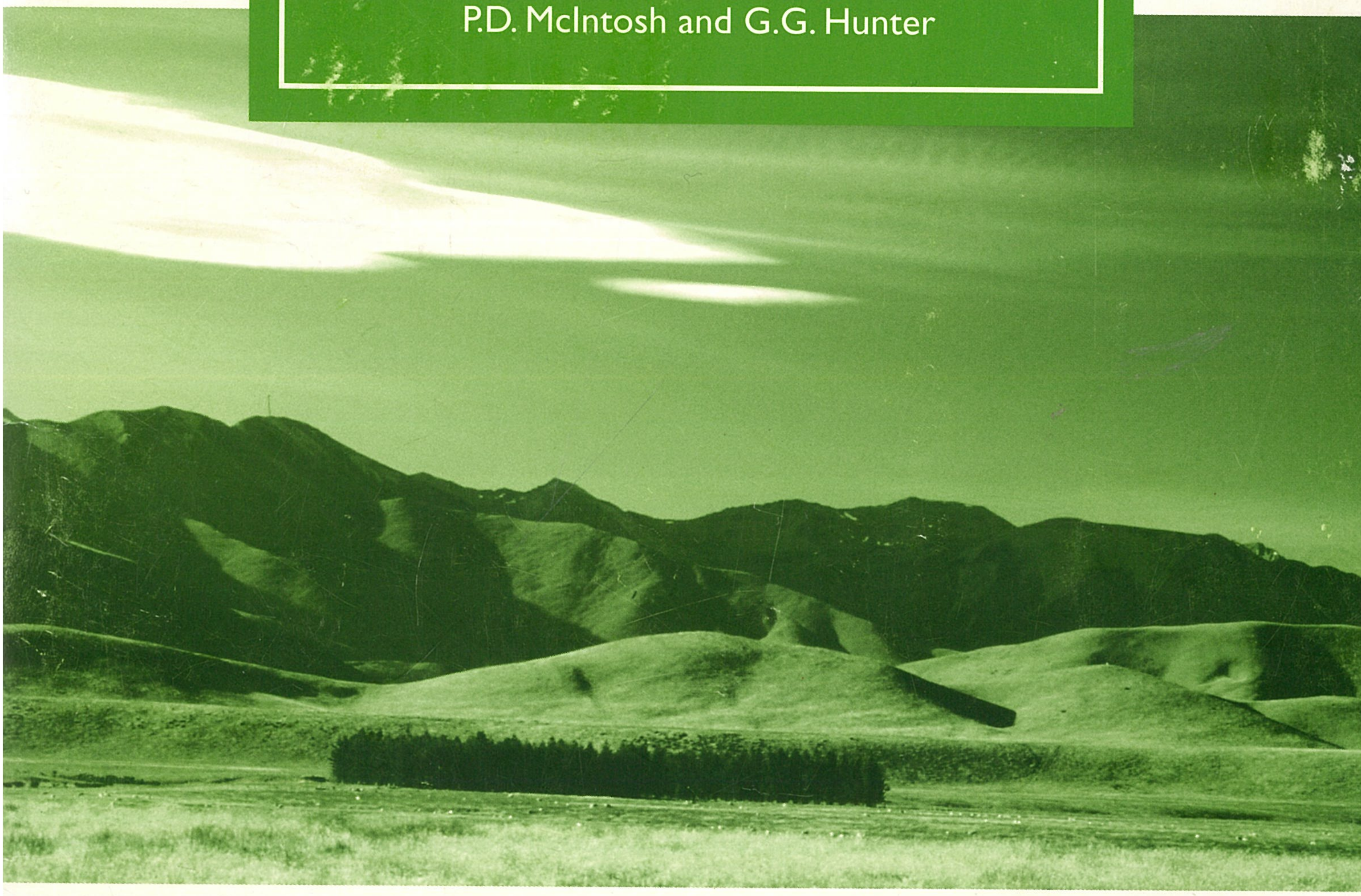
Soils and Land-Use Issues in the Mackenzie Hill Country

P.D. McIntosh and G.G. Hunter



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Contents

Summary

The Mackenzie hill country is defined as the hilly and steep land surrounding the Mackenzie basin of South Canterbury. Soil-landscape models for land below 1500 m altitude are described, and the questions of sustainable pastoral land use in the Mackenzie hill country, and potential for forestry, are addressed.

Thirty-nine soils are identified and the predominant soils are grouped into land systems. Fourteen soils are described in soil "factsheets".

Two land systems predominate in the dry eastern hill country (mean annual rainfall less than 800 mm): the Grampians-Meyer-Omarama-Tengawai land system and the Quailburn-Benmore land system. Three land systems are described in the moist western hill country (mean annual rainfall greater than 800 mm): the Mesopotamia-Tekapo-Cass land system, the Tekoa land system (consisting of phases of Tekoa soils) and the Kaikoura land system (consisting of phases of Kaikoura soils).

Soil chemical patterns in the drier and moister areas are described and fertiliser requirements for pastures reviewed. The main sustainability issues for pastoral use are identified as: (1) loss of topsoil organic matter over time; (2) loss of nutrients over time; (3) soil acidification; (4) erosion. The effects of burning and grazing on N losses in tall tussock grasslands are calculated. Forestry is considered to be a viable option on some soils and a provisional classification of soils for forestry, based on soil moisture availability, is presented.

Introduction

2.1 Land-use issues

The Mackenzie hill country is a term coined for the hilly and steep land surrounding the Mackenzie basin of South Canterbury, New Zealand. This land has been used for extensive grazing since the 1850s. Earlier this century McGillivray (1929) remarked "It is unfortunate that there are no definite records of the progress of events that have led up to the present state of the Mackenzie Country, and still more so that remedial measures were not taken at an earlier date." Although McGillivray was referring to the Mackenzie basin, he might equally well have been referring to the surrounding hilly and steep land. Despite McGillivray's plea, and years of scientific research, little has been done to determine whether farming practices in the Mackenzie hill country are sustainable in the long term.

To be sustainable, agricultural and forestry use in the Mackenzie hill country must maintain or enhance the soil resource. The first step in deciding whether an agricultural or forestry system is sustainable is to define the nature and extent of the soil resource, i.e., to determine the assets in the "soil bank". These assets include the bulk of the soil material, the quality and quantity of organic matter, nutrients, and soil structure. We need to know how these properties vary from place to place. The second step is to measure how these properties change as a result of using the land for primary production.

In the last 50 years the effects of grazing and rabbits on soils and whole ecosystems have become clearer. In some areas the sustainability of pastoralism has been brought into question. New land uses such as commercial forestry have been suggested, and the option of separating land more suitable for conservation from land that can continue to be used for primary production is being considered. Knowledge about soil resources, management of soils, and soil fertility is useful for resolving these issues since the soil resources are the assets on which all primary production is based. This report summarises information available for the soils of the Mackenzie hill country. It is written for farmers, foresters, conservationists, consultants, and local authorities with an interest in sustainable land uses. It is complementary to the report on soils and land use on the flat to rolling land in the Mackenzie basin (Webb 1992).

2.2 Objectives

The objectives of this report are to:

- Summarise present knowledge on the soils and soil distribution in the Mackenzie hill country.
- Bring together information on soil limitations for increasing pastoral and forestry production.
- Clarify the main land use sustainability issues.

2.3 Area

The Mackenzie hill country includes both the hilly and steep land around the margin of the upper Waitaki basin (**Figure 1** see page 6). This report considers the more productive land below about 1500 m altitude receiving < 1600 mm rainfall.

2.4 Geology and parent materials

Rocks are predominantly greywacke and argillite of medium induration (Chlorite Subzone 1), with belts of tuffaceous greywacke east of the Tekapo River (Mutch 1963; Gair 1967). Weakly schistose non-foliated greywacke and argillite (Chlorite Subzone 2) occur west of the Ahuriri River, on the Ewe Range south of Omarama, in the Ben Ohau Range, on Haldon Station, and north of Burkes Pass. Gravelly colluvium is an extensive parent material on hill slopes that have not been glaciated. Moraine occurs on hill slopes on the sides of glaciated valleys, particularly in the Ben Ohau Range. Fan alluvium occurs but is generally covered with more than 45 cm of loess, mixed with boulders and stones. On other landforms loess is mostly patchy and less than 45 cm thick.

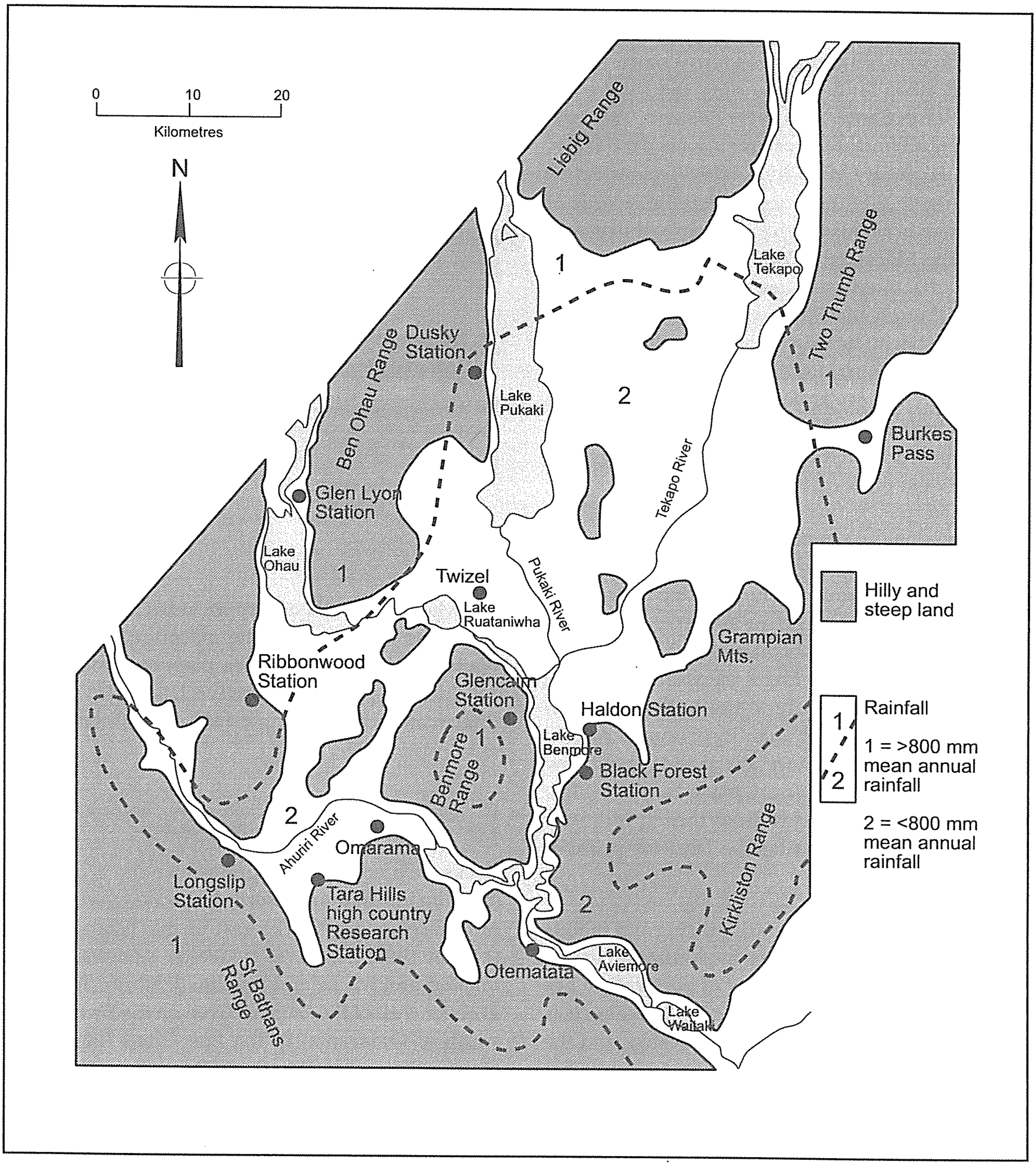


Figure 1. The Mackenzie hill country area, with approximate rainfall zones based on Belton and Ledgard (1984) and N.Z. Meteorological Service (1973).

2.5 Climate

Belton and Ledgard (1984) summarised the climate of the Mackenzie Basin. Their rainfall zones, and rainfall estimates based on isohyet maps produced by N.Z. Meteorological Service (1973), have been applied to the Mackenzie hill country (**Figure 1**).

Two broad rainfall zones are distinguished: (1) a humid region having >800 mm mean annual rainfall, west of the basin; and (2) a subhumid region having 500–800 mm mean annual rainfall, east of the basin, in the rainshadow of the western ranges. Within the humid region subhumid land may occur in the foothills, and in the subhumid region humid land may occur on the tops of the ranges.

The rainfall pattern is variable: annual rainfall at Tara Hills, for example, has varied from 384 mm to 770 mm, the mean being 533 mm (Webb 1992). Snow may fall in any month. The outstanding extreme snowfall was in November 1967 when over 1 m of snow fell over the region (Hughes 1969).

Detailed temperature records are available only for drier sites in the Mackenzie basin. At Tara Hills, altitude 488 m, mean annual temperature is 9.3°C and at Lake Tekapo, altitude 683 m, it is 8.8°C (N.Z. Meteorological Service 1984). Seasonal variation is large: mean monthly temperature at Tara Hills in January is 15.8°C, and in July is 1.3°C. Intense radiation cooling occurs at night and is reflected in extreme ranges of temperature: air temperatures of 34.6°C and –17.9°C have been recorded at Tara Hills. However, extreme frosts probably do not occur on lower altitude hill slopes, because of cool air drainage.

2.6 Vegetation

Before Polynesian and European settlement vegetation is likely to have been dominated by Hall's totara (*Podocarpus hallii*), matai (*Prumnopitys taxifolia*) and kowhai (*Sophora microphylla*) on lower-altitude hill country in the east, and beech forest (*Nothofagus solandri* var. *cliffordiodes*) and Hall's totara in the west (Burnett 1927; R.B. Allen and B.P.J. Molloy, personal communication). Tall tussock (*Chionochloa rigida*) and *Chionochloa macra* occurred above the tree line. Plant communities dominated by tall tussock replaced the forest communities after Polynesian fires (Connor 1964). Early European explorers, stock drovers and pastoralists described a largely unforested area and drew attention to the thorny wild Irishman (*Disearia toumatou*), spaniard (*Aciphylla* sp.) and rank tall tussock as major barriers to travel in the valley floors and lower slopes (Haast 1879; Burnett 1927). Intensive grazing and burning by European pastoralists have resulted in replacement of much of the lower-altitude tall tussock grassland by short tussock and herb communities. These communities are made up of grasses such as hard tussock (*Festuca novae-zelandiae*), silver tussock (*Poa cita*) blue tussock (*Poa colensoi*) and many introduced species, for example, *Bromus tectorum*, sweet vernal (*Anthoxanthum odoratum*), *Vulpia bromioides* and hawkweed (*Hieracium pilosella* and *H. praealtum*).

2.7 General soil pattern and previous studies

The general soil pattern mapped by N.Z. Soil Bureau (1968) is shown in **Figure 2**. The distribution of soils is broadly related to climate. Brown-grey earths occur under the lowest mean annual rainfall (less

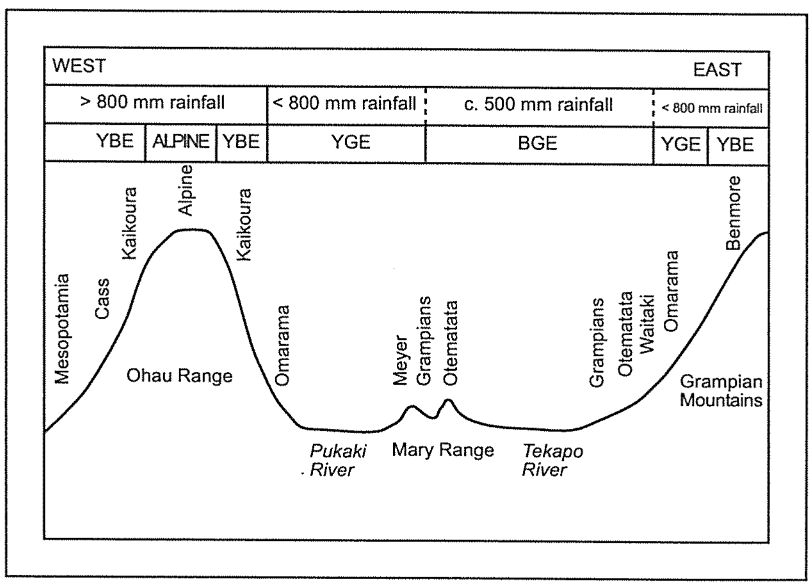


Figure 2. Diagrammatic representation of soil sets mapped in the Mackenzie hill country, from N.Z. Soil Bureau (1968). Puketeraki soils (on mid-altitude rolling tops) not shown. YBE = yellow-brown earth; YGE = yellow-brown earth; BGE = brown-grey earth.

than about 500 mm) and are very drought-prone. They are the least leached of the soils and have the highest pH and available nutrients for plants (although some elements derived from rainfall, *e.g.*, sulphur and selenium may be very deficient). Yellow-grey earths occur under slightly higher mean annual rainfall (approximately 500–800 mm) and often experience droughts. They have moderate to high nutrient status. Yellow-brown earths occur under higher mean annual rainfall and rarely experience severe droughts. They are more leached of nutrients and more acid than the other two soil groups.

The 1968 soil map is not detailed enough for land-use planning at the farm scale. In addition, several soils are not well described, which makes interpretation difficult. Since 1968, detailed surveys, using the New Zealand Soil Classification (Hewitt 1992; Clayden and Webb 1994) have been made on Tara Hills High Country Research Station, and parts of the Benmore Range, Ohau Range, Ahuriri Valley, and the mountains east of Lake Benmore (McIntosh *et al.* 1992 and Landcare Research, unpublished data). This report brings together the new information and presents soil-landscape models and land-use interpretations.

Soil classification enables soil information to be extrapolated from one area to another. If the soil at one location has the same classification as the soil at another location, and climate and landform are also similar, then it can be assumed, with some confidence, that options for land management and land-use potential will be similar at both locations. In this report the New Zealand Soil Classification (Hewitt 1992; Clayden and Webb 1994) is used. **Brown** soils are broadly equivalent to soils previously classified as yellow-brown earths; **Pallic** and **Recent** soils together are broadly equivalent to soils previously classified as yellow-grey earths and brown-grey earths.

Table 1 lists the most commonly occurring soils, and shows which soils are described in detail in this report (see the accompanying factsheets). Several soils not described in factsheets are closely related to described soils, for example, Omarama, weathered phase is a **Recent** soil differing from the Omarama soil in having a more weathered B horizon. To understand the soil patterns it is convenient to group soils that commonly occur together into land systems. The main land systems in the Mackenzie hill county are described below.

	CODE	SUBGROUP	GROUP	ORDER	PM CLASS	RELATED SET	SET PHASE	EQUIVALENT SERIES	NOTES	SOIL FACT SHEET NO	RAINFALL (mm)	SOIL DROUGHT RISK CLASS Sunny	Shady	Estimated RAW	Estimated TAW	Profile ID
Pallic Soils																
*	**PIT Md**	**Typic**	**Immature**	**Pallic**	**stoneless**	**Mesopotamia**		**Mesopotamia**	**in deep loess**		**800-1000**	**3**	**4**	**52**	**121**	**R18**
	PIT Mr	Typic	Immature	Pallic	rounded-stony	Grampians		Glenrock	on old fans		400-600	1	2	37	99	G53
	PJA Mr	Aged	Argillic	Pallic	rounded-stony	Dalgety		n.d.	on old fans		400-600	1	2	28	74	G11
*	**PJT Ma**	**Typic**	**Argillic**	**Pallic**	**angular-stony**	**Tengawai**		**Tengawai**	**in angular colluvium**		**600-800**	**2**	**3**	**35**	**90**	**H12**
	PLT Md	Typic	Laminar	Pallic	stoneless	Otematata		n.d.	in deep loess		400-600	1	2	45	138	G50
*	**PXCN Ms**	**Calcareous-sodic**	**Fragic**	**Pallic**	**with stones**	**Grampians**		**Grampians**	**in loess and colluvium on fans**		**400-600**	**1**	**2**	**27**	**73**	**T5**
Recent soils																
	RFT Ma	Typic	Fluvial	Recent	angular-stony	Tasman		n.d.	on recent fans		400-600	1	2	24	64	THW
	RFT Ms	Typic	Fluvial	Recent	with stones	Tasman		n.d.	in deep silt on recent fans		400-600	1	2	35	96	THW
	ROA Ma	Acidic	Orthic	Recent	angular-stony	Meyer	acid	n.d.	in angular colluvium		800-1000	3	4	42	71	G58
	ROA Ml	Acidic	Orthic	Recent	lithic	Omarama	acid	n.d.	in shallow angular colluvium		800-1000	2	3	12	35	G102
	ROAW Ma	Weathered	Acidic-orthic	Recent	angular-stony	Alpine		n.d.	in colluvium on uplands		800-1000	3	4	64	164	G61
	ROAW Mr	Weathered	Acidic-orthic	Recent	rounded-stony	Dalgety		Dalgety	on old fans		400-600	1	2	24	63	G10
*	**ROAW Ms**	**Acidic-weathered**	**Orthic**	**Recent**	**with stones**	**Kaikoura**	**recent**	**Kaikoura**	**in silty colluvium**		**>1000**	**4**	**4**	**64**	**164**	**R7**
*	**ROT Ma**	**Typic**	**Orthic**	**Recent**	**angular-stony**	**Meyer**	**deep**	**Meyer (deep)**	**in angular colluvium**		**400-600**	**1**	**2**	**42**	**81**	**similar to G56**
*	**ROT Ma**	**Typic**	**Orthic**	**Recent**	**angular-stony**	**Meyer**		**Meyer**	**in angular colluvium**		**400-600**	**1**	**2**	**40**	**70**	**T8**
*	**ROT Ml**	**Typic**	**Orthic**	**Recent**	**lithic**	**Omarama**		**Omarama**	**in shallow angular colluvium**		**400-600**	**1**	**2**	**10**	**30**	**G108, G28, T9**
	ROT Ms	Typic	Orthic	Recent	with stones	Tasman		n.d.	in protected basins		400-600	1	2	44	122	G105
	ROW Ma	Weathered	Orthic	Recent	angular-stony	Meyer	weathered	n.d.	in angular colluvium		600-800	2	3	42	107	G54, G55, G56, G67
	ROW Md	Weathered	Orthic	Recent	stoneless	Tasman	weathered	n.d.	in deep silt in protected basins		400-600	1	2	72	137	G37
	ROW Ml	Weathered	Orthic	Recent	lithic	Omarama	weathered	n.d.	in shallow colluvium		400-600	1	2	14	37	G43
	ROW Ms	Weathered	Orthic	Recent	with stones	Tasman	weathered	Streamlands	in protected basins		400-600	1	2	35	96	G47, G49
	RXA Ml	Acidic	Rocky	Recent	lithic	Benmore	shallow	n.d.	eroded shallow soils		600-800	1	2	13	39	similar to G63
Brown soils																
*	**BFA Ms**	**Acidic**	**Firm**	**Brown**	**with stones**	**Tekapo**		**n.d.**	**in loess and colluvium**		**800-1000**	**3**	**4**	**47**	**140**	**R23**
	BFAL Ma	Acidic-allophanic	Firm	Brown	angular-stony	Benmore		n.d.	in angular colluvium		800-1000	3	4	26	54	G41
*	**BLA Ma**	**Acidic**	**Allophanic**	**Brown**	**angular-stony**	**Kaikoura**	**allophanic**	**n.d.**	**in angular colluvium**		**>1000**	**4**	**4**	**33**	**125**	**R20**
*	**BLA Mm**	**Acidic**	**Allophanic**	**Brown**	**moderately deep**	**Tekoa**	**allophanic**	**n.d.**	**in angular colluvium**		**800-1000**	**3**	**4**	**50**	**150**	**R6**
*	**BLAD Mm**	**Acidic-pedal**	**Allophanic**	**Brown**	**moderately deep**	**Tekoa**	**allophanic, firm**	**n.d.**	**in angular colluvium**		**800-1000**	**3**	**4**	**47**	**140**	**R5**
*	**BLT Ma**	**Typic**	**Allophanic**	**Brown**	**angular-stony**	**Cass**		**n.d.**	**thin loess over moraine**		**800-1000**	**3**	**4**	**53**	**160**	**R21**
	BOAP Ma	(Acidic)-pallic	Orthic	Brown	angular-stony	Benmore		n.d.	in angular colluvium		600-800	2	3	58	138	G40
	BOA Ma	Acidic	Orthic	Brown	angular-stony	Benmore		Quailburn (deep)	in silt and angular colluvium		600-800	2	3	60	124	G66
*	**BOA Ma**	**Acidic**	**Orthic**	**Brown**	**angular-stony**	**Benmore**		**Quailburn**	**in angular colluvium**		**600-800**	**1**	**3**	**34**	**84**	**T4**
	BOA Mf	Acidic	Orthic	Brown	fragmental	Benmore	scree	n.d.	in angular colluvium		600-800	1	2	13	39	not described
	BOA Ml	Acidic	Orthic	Brown	lithic	Benmore	shallow	n.d.	in shallow colluvium		600-800	1	2	37	88	G24
	BOAP Ml	(Acidic-)pallic	Orthic	Brown	lithic	Benmore	shallow	n.d.	in shallow colluvium		600-800	1	2	19	50	G39
*	**BFP Ma**	**Pallic**	**Firm**	**Brown**	**angular-stony**	**Benmore**		**Benmore**	**in angular colluvium**		**600-800**	**2**	**3**	**44**	**135**	**T2**
	BOP Ma	Pallic	Orthic	Brown	angular-stony	Benmore		n.d.	in angular colluvium		600-800	1	3	28	81	G31
	BOT Ma	Typic	Orthic	Brown	angular-stony	Benmore		n.d.	in angular colluvium		600-800	1	3	33	92	G64, G65
	BOT Ml	Typic	Orthic	Brown	lithic	Benmore	eroded	n.d.	in angular colluvium		600-800	1	2	12	32	G63
	BOT Mm	Acidic	Orthic	Brown	moderately deep	Benmore		n.d.	in angular colluvium		600-800	1	3	25	73	G62
Podzols																
*	**ZXQ Ma**	**Ortstein**	**Pan**	**Podzol**	**angular-stony**	**Kaikoura**	**podzol**	**n.d.**	**in angular colluvium**		**>1000**	**2**	**4**	**17**	**30**	**R8**

n.d. = series not defined
RAW = Readily Available Water
TAW = Total Available Water

Table 1. Soils of the Mackenzie hill country. Asterisked soils in bold type are those described in this report.

For soil drought risk classes see Table 9, page 40.

Soils of the dry eastern hill country

A distinct assemblage of soils occurs in the dry hill country east and south of the Mackenzie basin. The soils are classified as **Recent** and **Pallic** soils at lower altitudes. At higher altitudes, where rainfall may be slightly higher, and evapotranspiration less, the soils are classified as **Brown** soils. The low-altitude soils were previously mapped in the Meyer, Otematata, Omarama and Waitaki sets, whereas those at higher altitude were mapped in the Benmore, Puketeraki and Kaikoura sets (**Figure 2** see page 7).

The **Recent** and **Pallic** soils of the drier lower altitude zone form the *Grampians-Meyer-Omarama-Tengawai* land system and the **Brown** soils of the moister, higher altitude zone the *Quailburn-Benmore* land system. The approximate boundary between these two land systems is the transition from short tussock to tall tussock grassland. However, the position of this transition zone is influenced by grazing pressure and fire history, so it is only an indication of the land systems boundary.

Land systems are described below. Individual soils are described in the soil factsheets accompanying this publication.

3.1 The Grampians-Meyer-Omarama-Tengawai land system

This land system of **Recent** and **Pallic** soils (**Figure 3**), described by McIntosh *et al.* (1992), occurs in the drier parts of the landscape (lower and mid-altitude sunny slopes and lower shady slopes), below 1000 m, in rainfall zone 2 (**Figure 1**) see page 6).

Grampians soils (Webb 1987, 1992; McIntosh *et al.*1992), are **Pallic** soils formed in deep loamy silt (loess) on fans and on footslopes of hills. They may contain stones and boulders. Meyer soils (McIntosh *et al.* 1992), are **Recent** soils. They occur on hilly and steep slopes, and are formed in angular greywacke or subschist colluvium overlying jointed rock at greater than 45 cm depth. Omarama soils (McIntosh *et al.* 1992), are also **Recent** soils, formed in angular greywacke or subschist colluvium, but jointed rock occurs at less than 45 cm depth. Both Meyer and Omarama soils often occur on sunny slopes associated with rock outcrops. Tengawai soils (Ives 1974; McIntosh *et al.* 1992) are formed in more than 45 cm of angular greywacke or subschist colluvium overlying jointed rock. They are classified as **Pallic** soils because they have clay accumulation in the lower parts of profiles. They occur mostly on steep shady slopes or on slightly wetter or higher altitude slopes than Meyer and Omarama soils.

Omarama soils are the most droughty soils in the Mackenzie hill country and offer few possibilities for pastoral or forestry development. Locally, erosion can be severe (**Photo 1** see page 11). Meyer soils are less droughty and are therefore more suitable for improved pastures, but the drought-proneness of these soils probably means that commercial forestry is unlikely to be economic. Tengawai soils are deep and water-retentive and probably offer the best

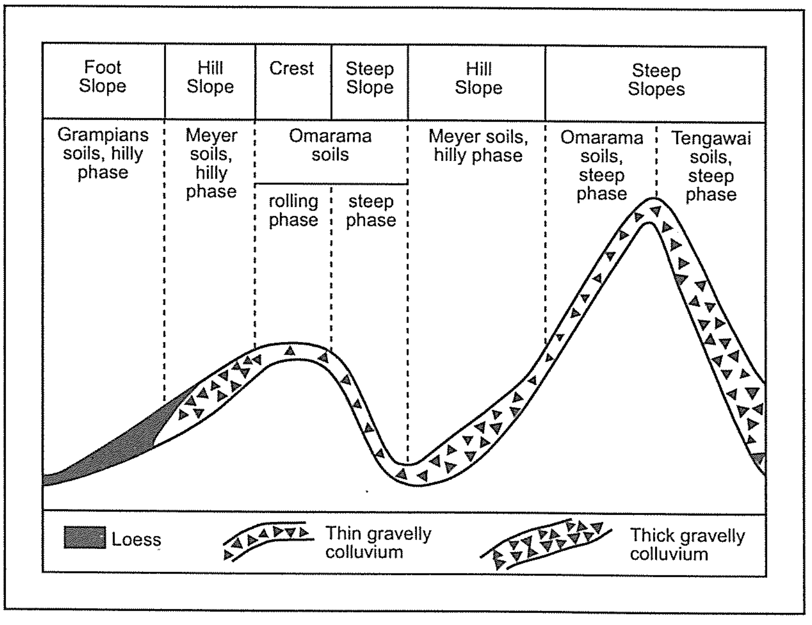


Figure 3. Soil-landscape relationships in the Grampians-Meyer-Omarama-Tengawai land system. From McIntosh et al. *(1992). These soils were formerly mapped in the Meyer, Otematata, Omarama and Waitaki sets.*

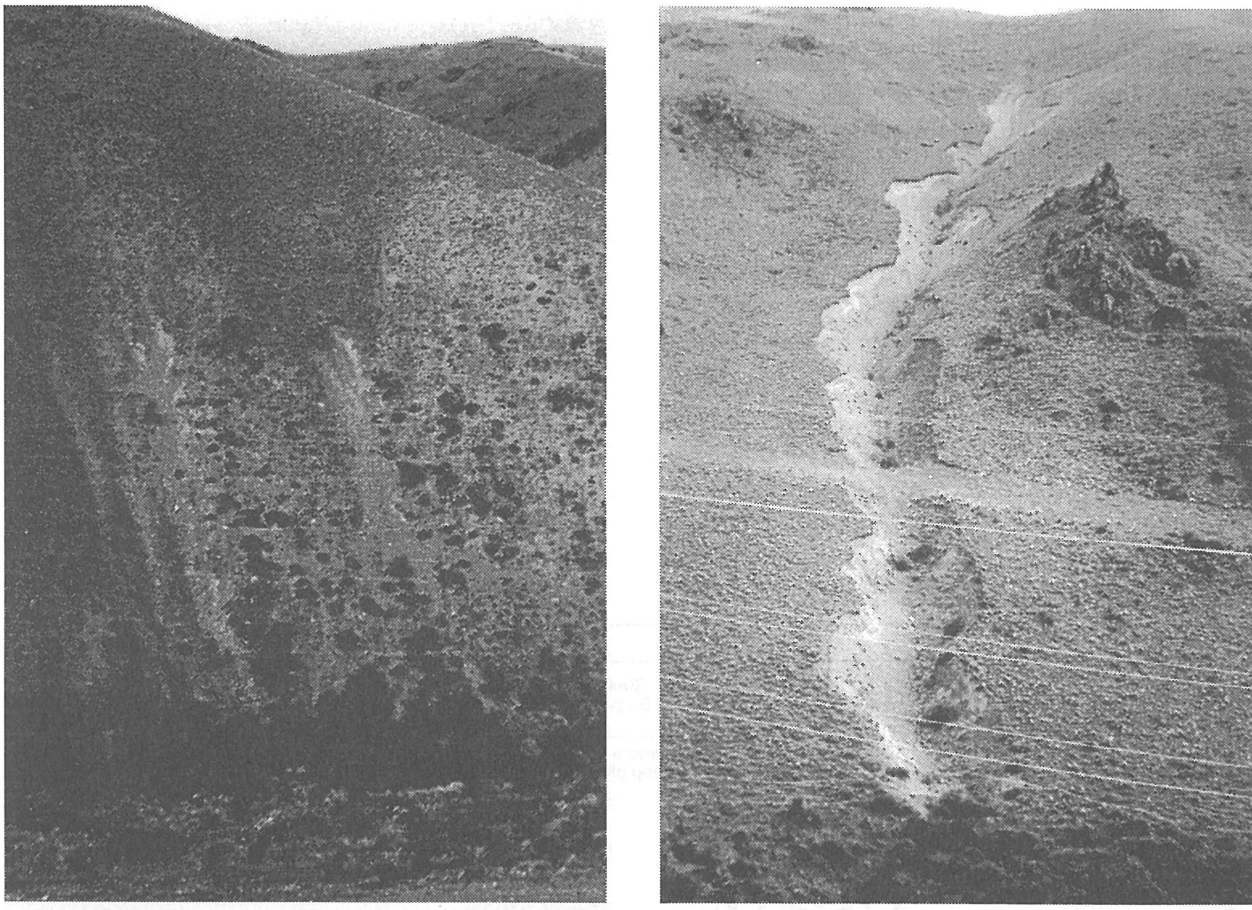


*Photo 1. In **Pallic** and **Recent** soils of the drier areas of the Mackenzie hill country erosion can be severe. Erosion like that illustrated in the photograph on the right is probably triggered by short-term events like thunderstorms but overgrazing of vegetation and subsequent topsoil degradation have almost certainly made the soils more prone to erosion. Better vegetation cover is crucial for preserving soil resources. Relief from grazing should be the primary objective for reducing erosion. Oversowing and topdressing, if affordable, would accelerate the vegetation recovery and soil stabilisation.*

opportunities for pastoral farming and forestry in the drier hill country. Grampians soils are suitable for irrigation. However the poor structure of the soils means that care must be taken to prevent soils becoming saturated with water, otherwise tunnel gully erosion could occur..

3.2 The Quailburn-Benmore land system

This land system of **Brown** soils (**Figure 4** see page 12) (McIntosh *et al*. 1992) occurs in the moister parts of the landscape, mostly at altitudes from 1000 m to 1500 m, in rainfall zone 2 (**Figure 1** see page 6).

Benmore soils occur in deep angular colluvium, mostly on hilly and steep slopes. In areas where the soil parent material is very gravelly (for example close to ridge crests, or in areas remote from loess sources, such as the east side of the Benmore Range), the soils are more leached and more acid, and **Acidic Orthic Brown** soils (Quailburn soils) occur. On sunny slopes within the land system erosion is locally severe, and the topsoil (A horizon) may be missing (**Photo 2** see page 13).

These soils are generally not economic to oversow and topdress, although legumes can be established successfully. For example, on Tara Hills, oversown

Maku lotus topdressed with 200 kg/ha S-superphosphate has persisted for 6 years with no maintenance fertiliser. Where tall tussock dominates pastures, the soils are used for late summer grazing. Management for pastoral use must be designed to maintain tussock dominance, both for soil conservation reasons and to guard against invasion of *Hieracium* and woody weeds, which would lower the value of vegetation on the land system as a low-cost feedbank. The soils are mostly too exposed and too cold for commercial forestry.

3.3 Conclusions

- Soils in the dry eastern hill country can be grouped into two land systems, one consisting of **Pallic** and **Recent** soils, and the other of **Brown** soils.
- Tengawai soils, which occur mostly on steep shady slopes at lower altitude, have the best attributes for pastoral and forestry use.
- The **Brown** soils are generally uneconomic to oversow and topdress and are too cold and too exposed for commercial forestry. If tussock cover is maintained, and *Hieracium* and woody weeds are excluded, the vegetation on the **Brown** soils has value as a low-cost feedbank for grazing stock.

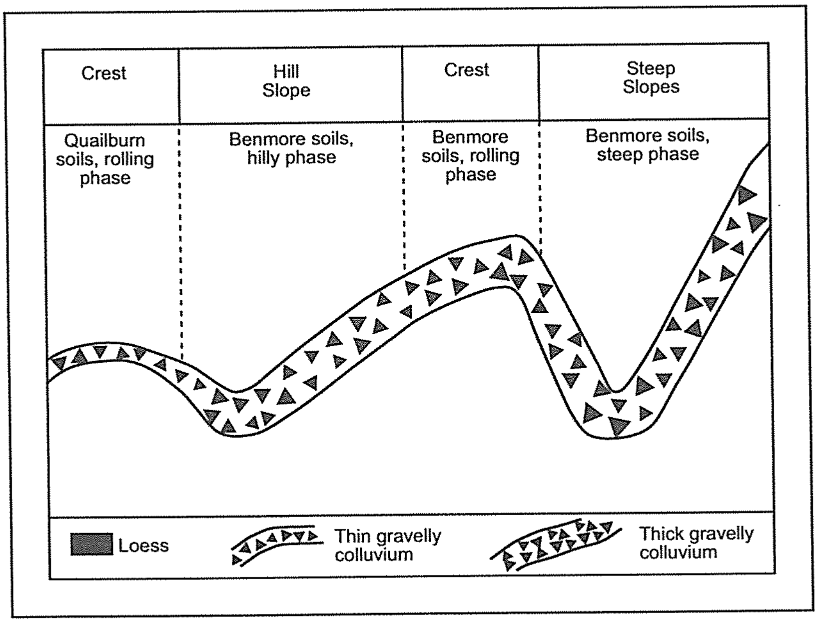


Figure 4. Soil-landscape relationships in the Quailburn-Benmore land system. From McIntosh et al. *(1992). Note that Kirkliston soils described by McIntosh* et al. *(1992) are now included with Benmore soils. These soils were formerly mapped in the Puketeraki and Kaikoura sets.*

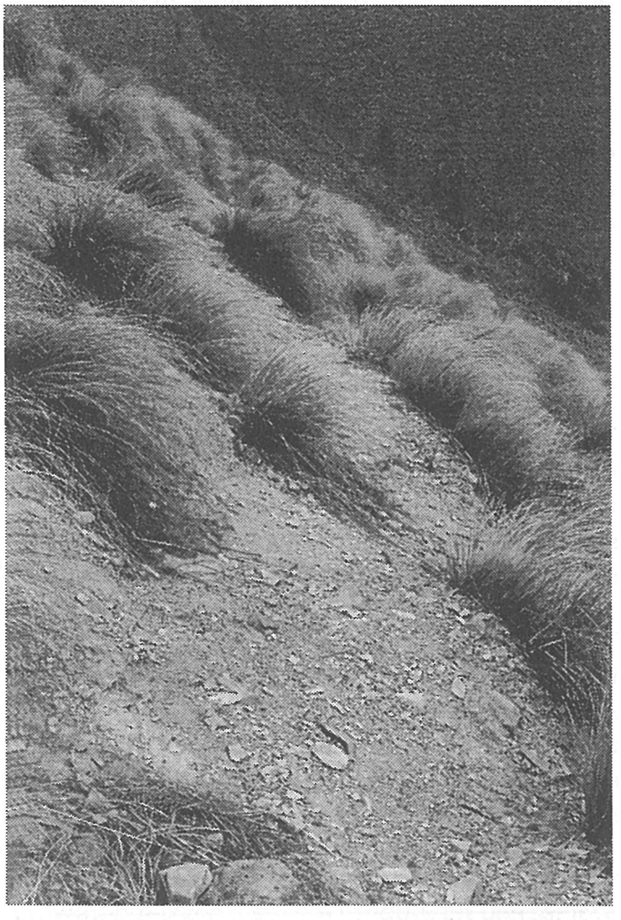
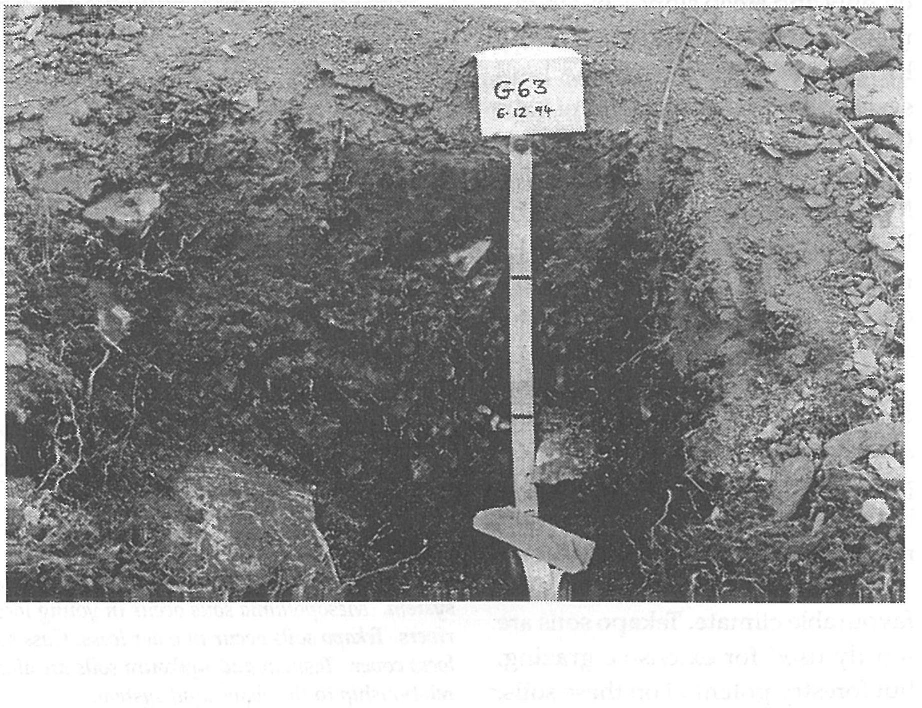


*Photo 2. Erosion is not limited to **Pallic** and **Recent** soils. This **Brown** soil on a sunny slope at 1150 m altitude has lost its topsoil, probably by wind erosion. With vegetation cover of < 50%, low organic matter contents (< 2% total C) and shallow soils in which plants are under moisture stress in summer, **Brown** soils on sunny slopes are as fragile as the **Pallic** and **Recent** soils at lower altitude.*



Soils of the moist western hill country

Soils of the moist hill country were previously mapped by N.Z. Soil Bureau (1968) in the Mesopotamia, Tekapo, Cass, and Kaikoura sets. There are no detailed published maps of the humid hill country, nor have formal soil series been defined, but recent mapping (Landcare Research, unpublished data) has identified the main soils. Although provisional, this new soil information is given here as it represents a significant advance in our knowledge of soil patterns and properties.

Three land systems have been distinguished. The individual soils have not been given formal names, but are currently named after the soil set which they most closely relate to (*e.g. Kaikoura*). Where a second name is added, it illustrates the main distinguishing feature of the soil (*e.g. Kaikoura Recent*).

4.1 The Mesopotamia-Tekapo-Cass land system

The *Mesopotamia-Tekapo-Cass* land system (**Figure 5**) of **Pallic** and **Brown** soils occurs on dissected fans and terraces, and hilly and steep moraines with variable loess cover, up to 1100 m altitude. The soils occur on rolling and strongly rolling land, as well as on hilly and steep slopes, but in this report all the soils described are on hilly and steep slopes. The land system is most extensive east of Lake Ohau and Lake Pukaki, with small areas occurring in the Ahuriri Valley. Mesopotamia soils occur on young loess, Tekapo soils occur on older more weathered loess and Cass soils occur in thin loess overlying moraine.

Mesopotamia soils are outstanding soils for commercial Douglas fir production (see section 8), probably because of their excellent soil moisture storage as well as their occurrence in an area with a favourable climate. Tekapo soils are mostly used for extensive grazing, but forestry potential on these soils, at lower altitudes, is likely to be similar to that of Mesopotamia soils. Cass soils at lower altitudes offer excellent opportunities for forestry, as they occur mostly on readily accessible hilly land, are well drained and friable, and occur in a favourable rainfall zone, but above about 800 m steeper slopes, difficult access, cool temperatures and exposure all limit commercial forestry potential.

4.2 The Tekoa land system

Tekoa soils occur in very gravelly greywacke colluvium, 45–90 cm deep. They are the characteristic soils of the lower altitude hilly and steep slopes of the moist western hill country that is mantled with colluvium rather than moraine.

The soils developed under beech forest, but except for occasional forest remnants in gullies, only isolated beech trees remain. Present vegetation is mostly tall and short tussock and associated plants such as spaniards (*Aciphylla* sp.), *Leucopogon colensoi*, *Dracophyllum* sp., *Drapetes* and *Hieracium praealtum*.

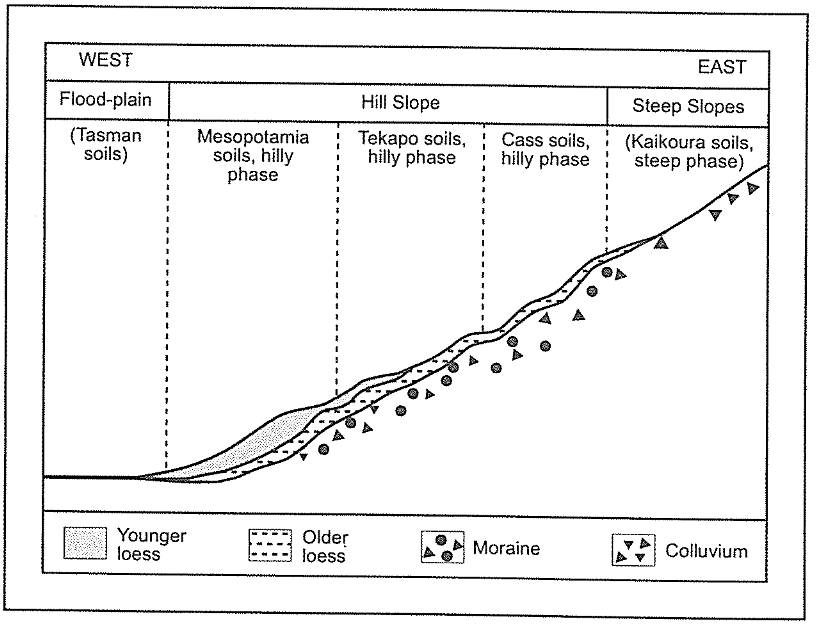


Figure 5. Soil landscape-relationships in the Mesopotamia-Tekapo-Cass land system. Mesopotamia soils occur in young loess close to floodplains of major rivers. Tekapo soils occur in older loess. Cass soils occur in moraine with thin loess cover. Tasman and Kaikoura soils are also shown, to indicate their relationship to the above land system.

Above 1100 m, which is approximately the altitude of the former treeline, soils of the Tekoa land system give way to soils of the Kaikoura land system.

Mapping in the Ben Ohau Range has established the tentative soil distribution, and soils here have been informally named. *Tekoa Allophanic* soils occur on shady slopes. These are **Acidic Allophanic Brown** soils, identified by having a subsoil horizon with a strong or very strong reaction to the NaF field test, and high P retention values. *Tekoa Allophanic Firm* soils occur on sunny slopes. These are distinguished by their slightly firm subsoils, and are classified as **Acidic-pedal Allophanic Brown** soils. These soils are less acid than their counterparts on shady slopes.

Inclusions of **Pallic Firm Brown** soils (*Tekoa Firm*) also occur among the Tekoa soils, on drier sunny faces. These soils have firm massive subsoils resembling fragipans. It appears that at particular sites seasonal drying has caused subsoil consolidation.

Because of the allophanic minerals in Tekoa soils, and their high P retention values, Tekoa soils are likely to require high rates of S-superphosphate and lime to support legume-based pastures. On lower slopes the soils and climate are well suited to conifer growth, but steep slopes with difficult access, low temperatures, and exposure to wind are limitations for commercial forestry at higher altitudes.

4.3 The Kaikoura land system

Kaikoura soils occur mostly on steep land above 1100 m. The complete absence of beech in gullies suggests that Kaikoura soils formed above the treeline, under grassland rather than beech cover. Like Tekoa soils they are formed in gravelly colluvium. In some soils there is evidence of periods of slope instability in the form of buried soils. On slightly concave stable footslope sites, soils are podzolised. Above 1500 m the proportion of bare ground and scree increases and soils above this altitude are not considered in this report.

Three Kaikoura soils were described in the Ben Ohau Range. As with soils of the Tekoa set, they have been given informal names, pending detailed mapping and definition of soil series. The sites chosen were representative of the wetter and drier sides of the western ranges, and of upland basins, but further work is required before the pattern of soils previously mapped in the Kaikoura set can be established with confidence.

Kaikoura Allophanic soils occur in thin loess over very gravelly colluvium on stable sites, under tall tussock grassland. They are **Acidic Allophanic Brown** soils. *Kaikoura Recent* soils occur on erosion-prone steep sunny slopes on the east (drier) side of the ranges. Vegetation cover is depleted and soil profiles have buried topsoils, showing that there have been periods of slope instability. The soils are classified as **Acidic-weathered Orthic Recent** soils. *Kaikoura Podzol* soils occur on footslopes of valley sides in old scree deposits, now stabilised. The soils are classified as **Ortstein Pan Podzols** because they have a thin, hard, iron-cemented pan. The pan restricts root and water penetration.

Soils of the Kaikoura land system are strongly acid and extremely leached and infertile. Commercial forestry is excluded because of cool temperatures and exposure associated with high altitudes. Because the soils contain too few nutrients to support plant growth, the vegetation should be either protected from grazing or grazed only at very low intensity (less than 0.2 stock units per hectare) to prevent depletion of tall tussock cover and minimise the risk of erosion. For the same reasons, fire should not be used for tussock management.

4.4 Conclusions

- The soils of the moist western hill country have been grouped into three land systems, containing **Pallic** and **Brown** soils.
- Soils occurring at lower altitudes in the Mesopotamia-Tekapo-Cass and Tekoa land systems offer excellent opportunities for forestry. Douglas fir appears to be ideally suited to Mesopotamia soils. Soil acidity and high P retention values limit oversowing and topdressing potential on these land systems, particularly at higher altitudes.
- Soils of the Kaikoura land system occur at altitudes that are too high for economic oversowing and topdressing or commercial forestry. The soils need very careful management to maintain vegetation cover and prevent tussock depletion and erosion.

Soil chemical patterns

In the high country, fertiliser and management decisions are usually made on the basis of easily-recognised landscape units (*e.g.* lower sunny faces, fans). Many of these units have distinctive soil chemistry and in certain areas the pattern of soil chemistry has been described. In this section we summarise the available information on how soil chemistry varies between landscape units, to enable managers to target their farm management more effectively.

5.1 Benmore Range

In the **Pallic** and **Recent** soils of the dry eastern hill country at 400–800 m on the east side of the Benmore Range, soil carbon and nitrogen, and several measures of soil fertility are strongly related to aspect (**Table 2; Figures 6, 7** and **8** see pages 18, 19 and 20). The higher total Pi in soils on shady slopes (**Table 2; Figure 8** see page 20) than on sunny slopes results from their higher organic Pi (Po) values, because a moister soil environment favours organic matter accumulation on shady slopes. The possibility of Po also being added to topsoil on shady slopes following topsoil erosion of sunny slopes cannot be discounted as Hewitt (1995, 1996) has demonstrated, in a semi-arid area, that such erosion can occur.

Above 800 m on shady slopes, and above 1000 m on sunny slopes, the soils are **Brown** soils (**Figure 6** see page 18). Total C is below 2% on all sunny slopes from 440—1220 m, even in **Brown** soils. In contrast, on shady slopes total C values increase progressively with increasing altitude, from 2.1% at 440 m, to 8.3% at 1220 m altitude (**Figure 6** see page 18). Total N, Pi, Po, and P retention values are all higher, and pH values lower, on shady aspects. Cation exchange capacity values are higher, and base saturation values and pH values are lower, on shady slopes than on sunny slopes (**Figure 6** and **Figure 9** see pages 18 and 21). Estimated total available water (TAW) and readily available water (RAW) are consistently higher on shady slopes, because these soils are deeper and contain more organic matter.

The low percentage of carbon in soils on sunny slopes of the Benmore Range (**Table 2** and **Figure 6** see pages 17 and 18), and A horizons which are thin (15–17 cm) or absent (**Photo 2** see page 13) indicate that wind erosion has occurred. These soils, which have up to 60% bare ground, are prone to further erosion.

	Mean shady slope	Mean sunny slope
Acidity		
pH	6.2	6.4
Phosphorus status		
Olsen P (μg/g)	19	20
P retention (%)	20	13
Pa (μg/g)	389	357
Pi (μg/g)	1056	728
Po (μg/g)	667	371
Organic matter		
C (%)	2.7	1.9
N (%)	0.29	0.19
C/N	9.5	10.0
Exchangeable cations		
Exch. K (me.%)	1.04	0.95
Exch. Ca (me.%)	11.5	8.5
Exch. Mg (me.%)	1.97	1.5
TEB (me. %)	14.4	11.0
CEC (me.%)	14.6	10.4
BS (%)	96	100

Pa = P soluble in 0.5 *M* H_2SO_4, air-dry soil
Pi = P soluble in 0.5 *M* H_2SO_4, ignited soil
Po (organic P) = Pi– Pa
TEB = Total Exchangeable Bases
CEC = Cation Exchange Capacity
BS = Base Saturation $\frac{(TEB \times 100)}{CEC}$
Each value is the mean of 12 observations

Table 2. *The relationship of topsoil chemical properties to aspect on unfertilised soils, 400—800 m altitude, in the dry eastern hill country (Benmore Range) (mean annual rainfall 500—600 mm. Data from McIntosh* et al. *(1981).*

ALTITIUDE (m)

1220	1220
1150	1150*
1000	1000
770	770
440	440

A HORIZON DEPTH (cm)

48	22
37	0*
25	27
22	10
17	17

CLASSIFICATION

BOT Ma	BOT Ma
BOT Mm	BOT Ml*
BOA Ma	ROW Ma
ROW Ma	ROW Ma
ROW Ma	PIT Mr

0-7.5 CM VALUES

pH (H_2O)

5.0	5.9
5.2	6.0*
5.3	6.2
5.8	6.3
5.4	5.8

pH (Ca Cl_2)

4.4	5.0
4.5	5.1*
4.6	5.5
nd	nd
nd	nd

C (%)

8.3	1.7
5.0	1.4*
4.5	1.5
3.3	1.7
2.1	1.7

N (%)

0.47	0.11
0.30	0.10*
0.27	0.12
0.32	0.15
0.16	0.15

Pa (µg/g)

130	220
160	170*
130	260
380	450
330	230

Pi (µg/g)

1450	580
940	550*
990	580
1080	850
820	570

Po (µg/g)

1320	360
780	380*
860	320
700	410
500	340

Pret (%)

47	20
43	21*
30	10
17	11
21	11

BS(%)

27	40
20	37*
42	70
71	82
58	75

PROFILE DATA

Profile ID

65	64
62	63*
66	67
55	56
54	53

RAW (mm)

73	46
40	12*
60	31
54	39
50	37

TAW (mm)

170	113
117	32*
124	81
140	98
128	99

Figure 6. *Physical and chemical attributes of soils on the east side of the Benmore Range. Values are given for analyses of soils sampled at 0–7.5 cm depth, for sunny (clear blocks) and shady (shaded blocks) midslopes in an altitude sequence. * indicates a shallow profile that has lost its A horizon by wind erosion (see* ***Photo 2****).*

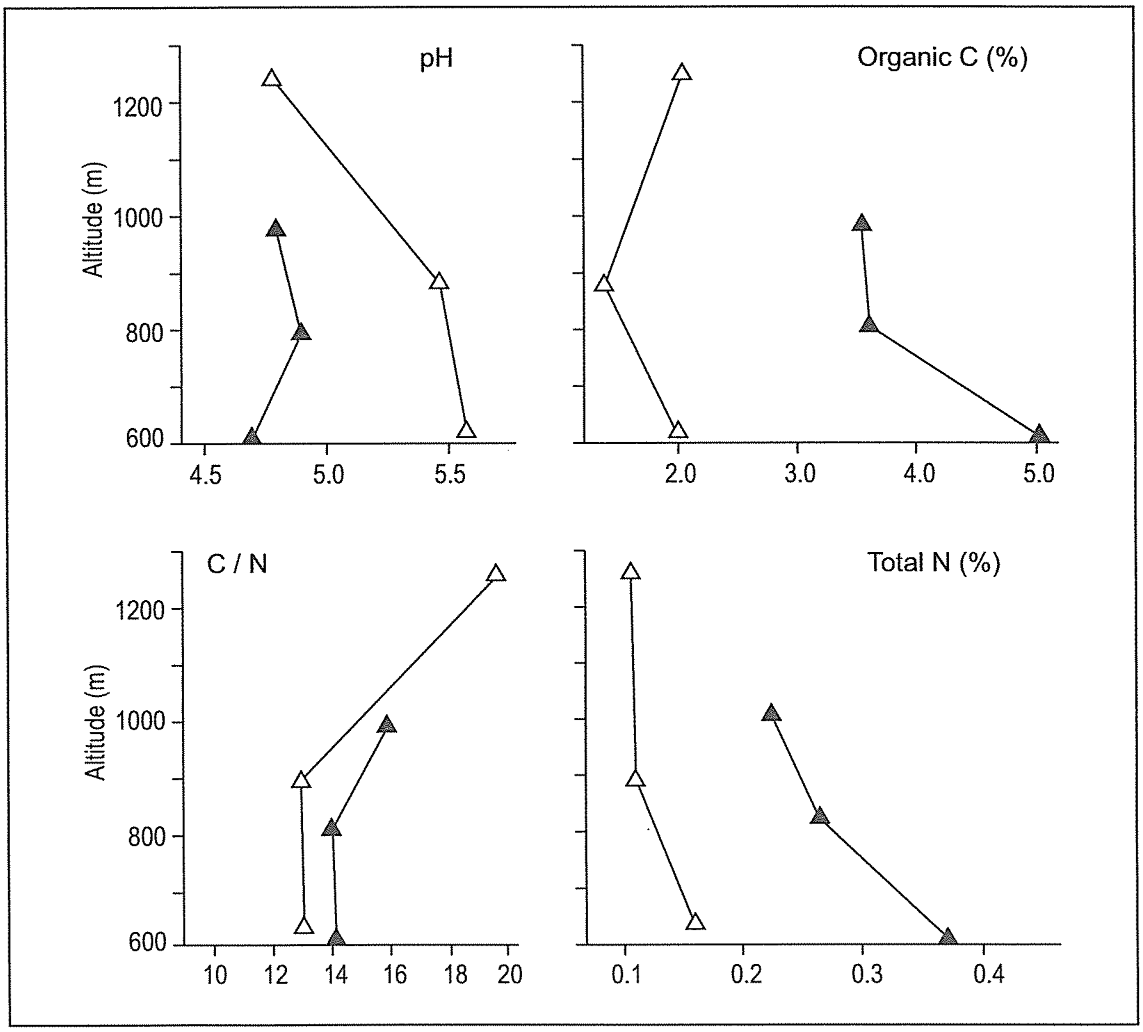


Figure 7. Trends of topsoil (0–7.5 cm) organic C, total N and pH on the Benmore Range. Data for shady slopes (solid triangles); Data for sunny slopes (open triangles)

5.2 Ahuriri Valley

In the **Pallic, Recent,** and **Brown** soils at 730–1190 m in the Ahuriri valley, a marked effect of aspect on several soil properties was noted in untopdressed soils that span the boundary between the dry and moist hill country (**Table 3** see page 22). Fertility, as measured by Olsen P, Pa, exchangeable K, exchangeable Ca, exchangeable Mg, total exchangeable bases and base saturation, was higher in soils on sunny slopes, and P retention and Po were lower. In contrast to the drier hill country, Po values were not significantly higher on shady slopes, perhaps because of the overall moister status of the soils, and possibly less wind erosion of topsoils on sunny slopes.

Trends with altitude were not strong but fertility, as measured by the above criteria, tended to be lower under tall tussock than under short tussock associations (McIntosh *et al.* 1981). Under tall tussock (above about 1000 m) Olsen Pa values were 10 μg/g or less and acid-soluble Pa values were 250 μg/g or less. In contrast, under short tussock associations Olsen Pa values were as high as 30 μg/g and acid-soluble P values as high as 490 μg/g. In soils under tall tussock about 80% of the total P(Pi) was in the relatively

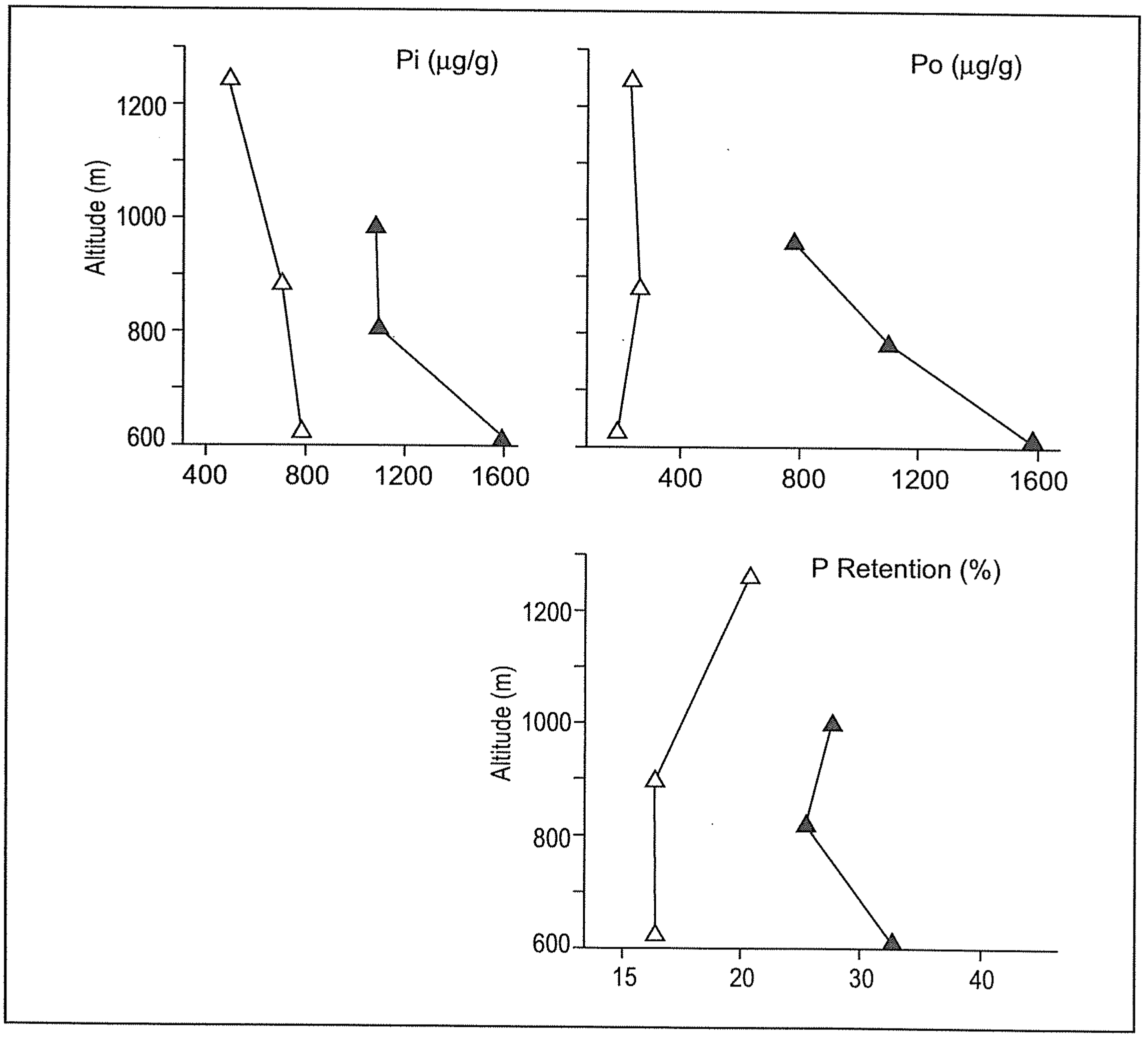


Figure 8. *Trends of (0–7.5 cm) P and P retention on the Benmore Range. Data for shady slopes (solid triangles); Data for sunny slopes (open triangles).*

unavailable organic form, but under short tussock associations this percentage was about 65%. Soils on steep sunny aspect sites had the highest values of exchangeable K, exchangeable Mg, total exchangeable bases, base saturation and Olsen P. McIntosh *et al.* (1981) suggested that soils without tall tussock cover had been rejuvenated both by erosion processes and by depletion (mineralisation) of organic P (Po). Higher CaP values (measured by the method of Williams *et al.* 1967) in unfertilised shallow soils on steep sunny faces (McIntosh *et al.* 1981) supported the erosion hypothesis because Ca P occurs in apatite, a mineral that is present in weakly weathered rocks (Williams *et al.* 1967). Mineralisation of organic matter could occur by raising of soil temperature following burning and grazing (McSweeney 1983). As the short tussock – tall tussock boundary has been pushed to higher altitudes by a combination of grazing pressures and fires, and as tall tussock almost certainly formerly covered all hilly sites in the Ahuriri valley, the lower percentage of organic P under short-tussock indicates an effect associated with the removal of tall tussock cover rather than a preference of tall tussock for sites with more organic P. The inference is that farming activities (grazing and burning) have

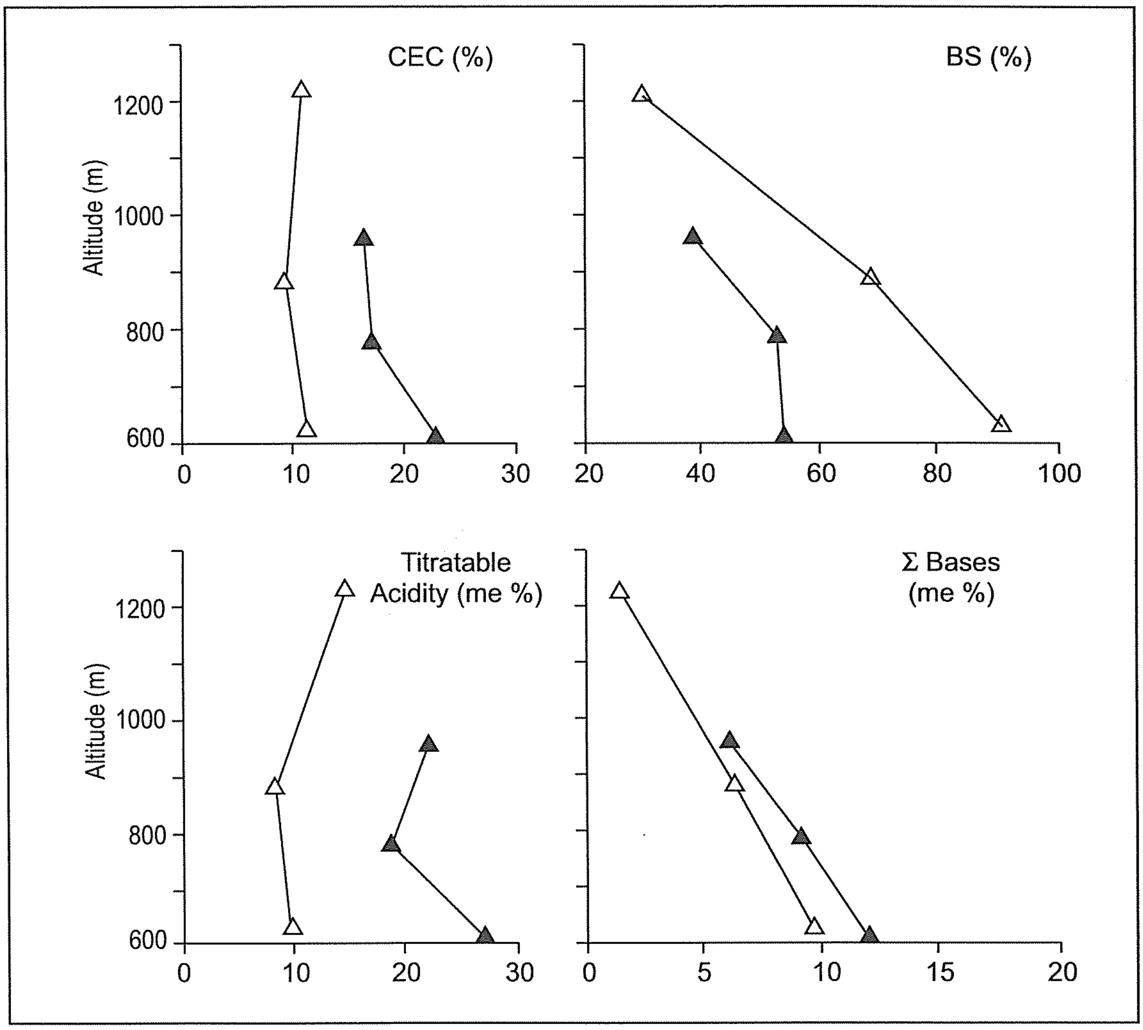


Figure 9. Topsoil (0–7.5 cm) trends of CEC, base saturation, titratable acidity and total exchangeable bases on the Benmore Range. Data for shady slopes (solid triangles); Data for sunny slopes (open triangles).

resulted in mineralisation (breakdown) of organic P and its release into more labile forms. The more labile forms were identified as "surface" Al-P and Fe-P which were present in much higher amounts under short tussock vegetation than under tall tussock (McIntosh *et al.* 1981).

5.3 Drier and moister soils compared

Mean topsoil data (**Table 4** see page 23) indicate the differences between unfertilised sites on drier and moister hill country. Fertility, as measured by pH, Olsen P, Pa, exchangeable K, Ca, Mg, total exchangeable bases and base saturation, is higher in the drier soils, but organic C is lower, indicating that the drier soils are likely to be more prone to erosion and structural damage (Hewitt and McIntosh 1996). The 500–600 mm mean annual rainfall at the drier site minimises leaching losses of cations but the longer drier season induces mineralisation of organic matter and is unfavourable for organic matter accumulation. Consequently the drier soils need more careful management to preserve or enhance nutrients, organic matter and moisture-holding capacity.

	Mean shady slope	Mean sunny slope
Acidity		
pH	5.7	5.9
Phosphorus status		
Olsen P (µg/g)	9	14
P retention (%)	42	26
Pa (µg/g)	186	256
Pt (µg/g)	816	839
Po (µg/g)	631	583
Organic matter		
C (%)	3.3	3.1
N (%)	0.26	0.26
C/N	13	12
Exchangeable cations		
Exch. K (me.%)	0.77	1.02
Exch. Ca (me.%)	2.5	4.8
Exch. Mg (me.%)	0.57	0.99
TEB (me. %)	3.81	6.80
CEC (me.%)	15.3	12.5
BS (%)	26	54

For explanation of symbols, see **Table 2**.
Each value is the mean of 19 observations.

Table 3. *The relationship of topsoil chemical properties to aspect on unfertilised soils at 700—1200 m altitude, in the moist western hill country (Ahuriri valley) (mean annual rainfall 700—1000 mm). Data from McIntosh* et al. *(1981).*

	Ahuriri valley	Benmore Range
Acidity		
pH	5.8	6.3
Phosphorus status		
Olsen P (µg/g)	11	19
P retention (%)	34	16
Pa (µg/g)	221	373
Pi (µg/g)	828	891
Po (µg/g)	607	519
Organic matter status		
Total C (%)	3.2	2.3
Total N (%)	0.26	0.24
C/N	12.3	9.7
Exchangeable cations		
Exch. K (me. %)	0.89	0.99
Exch. Ca (me.%)	3.62	10.0
Exch. Mg (me.%)	0.78	1.7
TEB (me.%)	5.29	12.7
CEC (me.%)	13.9	12.5
BS (%)	40	98

Figures for Ahuriri valley are means of 38 observations; figures for Benmore Range are means of 24 observations.
For explanations of symbols, see **Table 2**.

Table 4. *Differences between mean topsoil chemical properties for unfertilised sites in the moister hill country (Ahuriri valley; mean annual rainfall c. 700—1000 mm) and in the drier hill country (Benmore Range; mean annual rainfall 500—600 mm). From McIntosh* et al. *(1981).*

5.4 Conclusions

- On typical untopdressed dry eastern hill country there is a marked effect of aspect on nearly all soil properties, including pH, organic C, total N, measures of P status, and available water.
- On dry eastern hill country topsoil C is uniformly low (less than 2%) on sunny slopes, even on **Brown** soils, but on shady slopes topsoil C is more than 2% and increases with increasing altitude.
- On typical untopdressed moist western hill country aspect differences are less pronounced, but the phosphorus chemistry of soils with short tussock cover indicates that these soils have been rejuvenated.
- Fertility is higher in the dry soils but organic C and total N are higher in topsoils of the moist soils.
- The drier soils need most careful management.

Nutrient deficiencies and pasture establishment

The predominant nutrient deficiencies for introduced pastures are nitrogen (N), molybdenum (Mo), phosphorus (P) and sulphur (S) (During 1972), and in practice these deficiencies are corrected by oversowing with legumes and fertilising.

6.1 Nitrogen and molybdenum

Nitrogen is naturally deficient in all New Zealand natural grasslands. Nitrogen is added in rainfall, but in dry inland areas rainfall contributes less than 0.2 kg/ha/yr (Cossens 1970). Nitrogen fixation rates from non-symbiotic sources (*e.g.*, cyanobacteria) may be 1.6 kg/ha/yr in upland inland areas (Line and Loutit 1973). These additions are insignificant in relation to the total N requirement for maximum production: trials using N for pasture establishment in the Mackenzie basin soils have indicated a dry matter (DM) response to up to 800 kg/ha of applied N (Scott and Maunsell 1981). Elsewhere in the high country, near Lake Wakatipu, pasture responses to fertiliser N were 27% to 146% higher than those achieved with P and S fertilisers alone (McIntosh

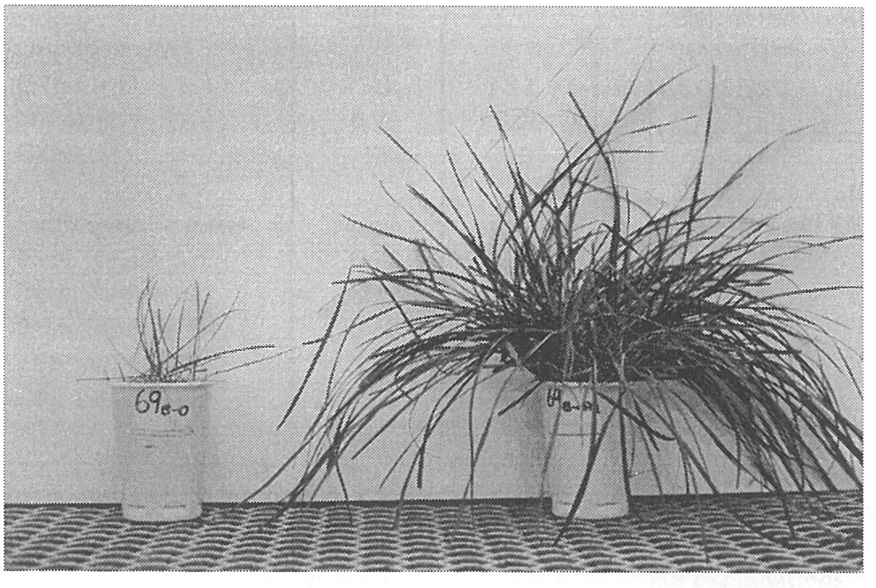
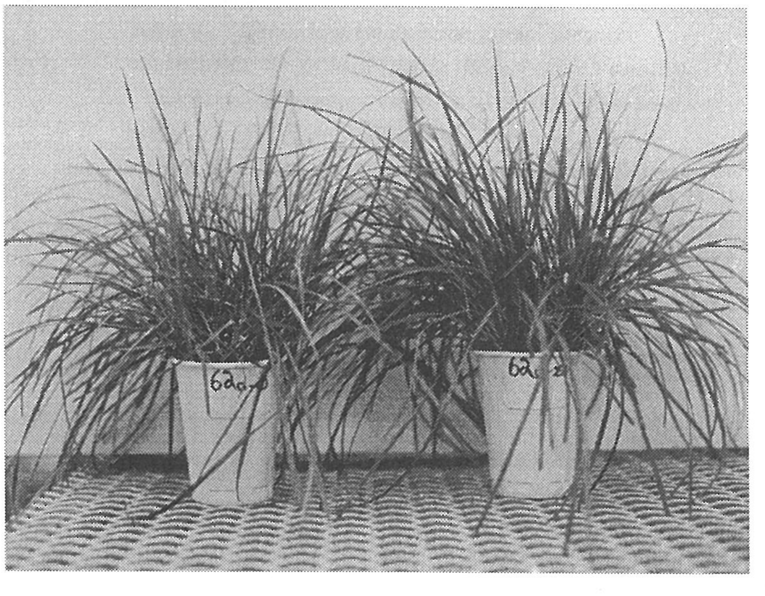


*Photo 3. (top) P response in a **Brown** soils (Ahuriri valley) and (right) in a **Recent** soil on the Benmore Range. In each photograph the pot on the right has received all nutrients, including P, while the pot on the left has received all nutrients except P. Note that the ryegrass growing in the **Brown** soil is much more responsive to added P than the ryegrass growing in the **Recent** soil.*



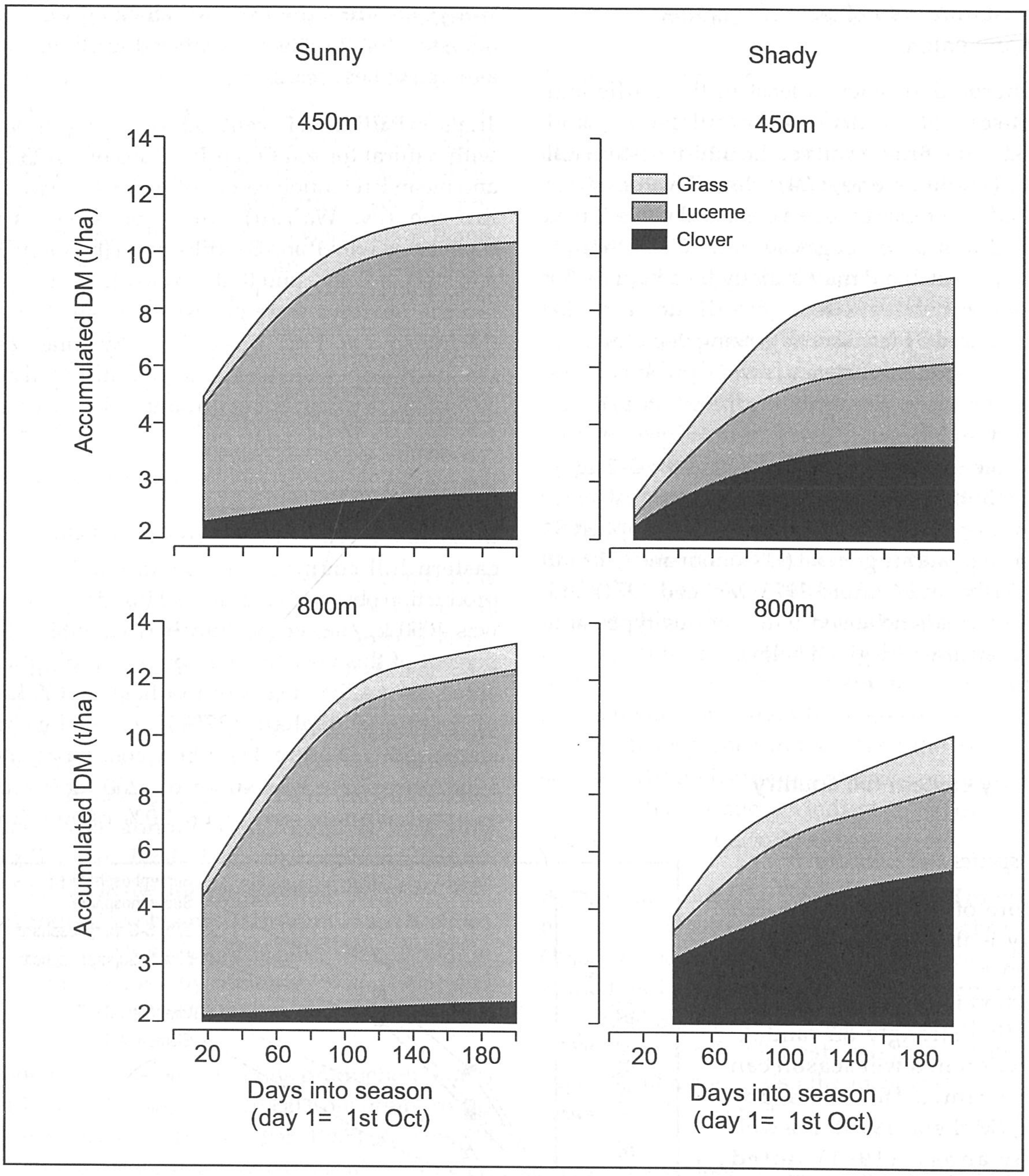


Figure 10. *Relative proportions of clover, lucerne and grass on four trials on sunny and shady aspects and two altitudes on the Benmore Range. Redrawn from Boswell and Swanney (1991), with permission.*

and Wales 1989). Although similar responses can be expected from grasses on the Mackenzie hill country, direct N application is uneconomic, and the traditional way of improving pastures is oversowing of legumes and fertilising with P and S. However, strategic application of N at rates of 50–150 kg/ha may help grasses establish (Pollock 1989).

The importance of Mo for legume growth was established by Walker *et al.* (1955). It is now standard practice to include Mo in fertiliser mixes for initial legume establishment.

6.2 Phosphorus, sulphur, and pasture improvement

Phosphorus deficiency is least in the **Pallic** and **Recent** soils of the dry eastern hill country and greatest in the **Brown** soils of the moist western hill country (**Photo 3** see page 24). Olsen P values show a marked difference between drier and wetter areas (**Tables 2 and 3** see pages 17 and 22). Although naturally-available P may initially be adequate for legumes on drier sites, it will need to be supplemented by fertiliser as grazing depletes the P resource. Sulphur deficiency is widespread because of the very low amounts supplied in rainfall (Ledgard and Upsdell 1991). Natural phosphate-extractable SO_4–S values are mostly in the 0–2 μg/g range in both topsoils and subsoils (McIntosh *et al.* 1981). Consequently, strong responses to applied S-superphosphate are general (O'Connor and Clifford 1966; Vartha and Clifford 1973; McLeod 1974) and details of yields achieved with various types and rates of fertiliser are given below.

6.2.1 Dry eastern hill country

Yields, species and cultivars

A feature of the dry eastern-hill country is that on fertilised land maximum dry matter (DM) production is extremely variable, depending strongly on rainfall: production in a wet season can be five times that of a dry season (McLeod 1974). Boswell and Swanney (1991) noted similar variability: at 4 sites mean maximum production was 11 000 kg/ha and mean minimum production was 3040 kg/ha. Production on shady slopes was always higher than that on sunny slopes, except in one particularly moist year (1983/84), when it was higher on sunny slopes. These unpredictable production peaks in wet years stress the need for stocking rates to be adjusted for the "lean" years rather than for the average or best years.

Trials on **Pallic** and **Recent** soils (yellow-grey earths) with natural topsoil Olsen P values of 10–23 μg/g and mean P retention values of 10–23% showed that lucerne (cv. Wairau) could be successfully established with P and S fertilisers on the sunny hilly and steep country, and that red clover (cv. Pawera)–lucerne mixtures were persistent on shady slopes (McIntosh *et al.* 1985; Boswell and Swanney 1991). On shady slopes resident grasses contributed about 30% of the dry matter, but on sunny slopes less than 10% (**Figure 10** see page 25).

Responses to fertiliser

In the first 3 years of trials covering 5 sites on dry eastern hill country soils mean maximum DM production obtained with annual P and S application was 4050 kg/ha/yr (McIntosh *et al.* 1985). Sixty percent of this was obtained by one application of either 330 kg/ha of superphosphate, or 159 kg/ha of S-superphosphate (27%S), or 98 kg/ha of elemental S (**Figure 11**). On a cost basis the S-superphosphate was superior: 200 kg/ha of S-superphosphate produced 70% of maximum

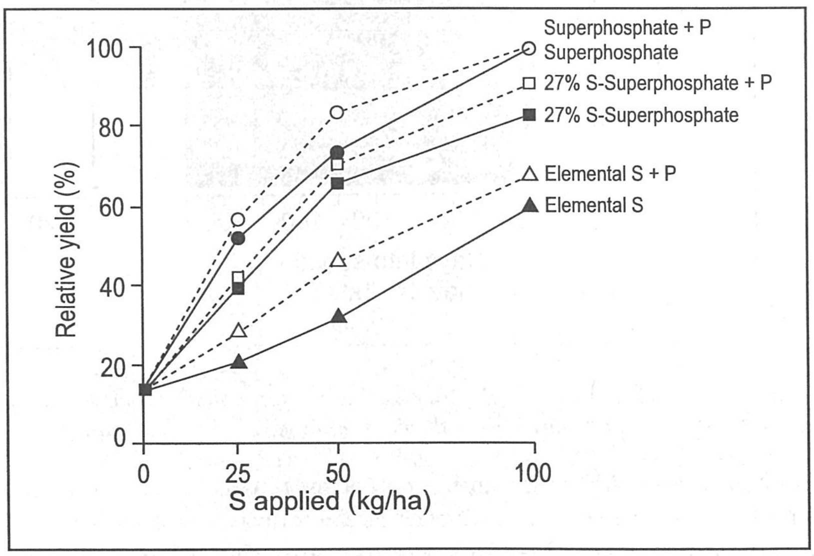


*Figure 11. Production over 3 years from improved pastures on **Pallic** and **Recent** soils topdressed with elemental S, S-superphosphate (27% total S) and superphosphate in comparison with production on plots receiving annual P and S applications. From McIntosh* et al. *1985.*

possible production over 3 years and was suggested as the minimum initial rate for legume introduction on these soils. However, because this rate of S-superphosphate gave only 50% of maximum production in year 3 of the experiment, McIntosh *et al.* (1985) recommended that this rate of fertiliser application should be repeated after 2 years. After running the trials for a further 3 years Boswell and Swanney (1991) calculated mean annual yield to be 5900 kg/ha/yr and reached a similar conclusion regarding fertiliser rates. However, Boswell and Floate (1992) made the general recommendation of 150 kg/ha of molybdenum S-superphosphate every 2–3 years for yellow-grey earths (**Pallic** and **Recent** soils). The above evidence indicates that such a rate would be insufficient to achieve 70% of maximum production.

McLeod's earlier experiments on Omarama steepland soils at a site with 625 mm mean annual rainfall (McLeod 1974) showed that over 5 years mean annual production without fertiliser was less than 1000 kg DM/ha. Annual application of 185 kg/ha of molybdic S-superphosphate (28% S) produced 6200 kg DM/ha. The same fertiliser applied only once produced 62% of the production obtained from annual applications. By applying 185 kg/ha of molybdic S-superphosphate followed by 92.5 kg/ha in the third and subsequent years, 90% of the production obtained from annual applications was achieved. These fertiliser rates were similar to those recommended by McIntosh *et al.* (1985) and Boswell and Swanney (1991).

On Tengawai soils on Tara Hills production of less than 1000 kg DM/ha/yr is typical from unimproved short tussock associations (Allan 1985). When soils were oversown with white clover, alsike clover, cocksfoot and ryegrass and topdressed with S-superphosphate (33% S) at the rate of 125 kg/ha every 3 years, production was increased to 3000–4000 kg/ha/yr, but the evidence from field trials, summarised above, indicated that higher fertiliser application rates would have yielded more.

6.2.2. Moist western hill country

Responses to fertiliser

Trials were laid down on **Brown** soils at an altitude of 1065 m in the Ahuriri Valley (McIntosh *et al.* 1985). The soils had Olsen P values of 6–7 µg/g in topsoils, and P retention values of 31–42%. The natural vegetation was dominated by tall tussock. Clover-based pastures produced a maximum of 1270 kg DM/ha when annually topdressed with S and P, but because of the severe P deficiency (**Photo 3** see page 24) even 1000 kg/ha of superphosphate, applied initially, was insufficient to produce more than 50% of potential DM over 3 years, and elemental S was useless. McIntosh *et al.* (1985) concluded that P deficiency in these soils over 1000 m altitude was more severe than in the **Brown** soils previously investigated by Ludecke and Leamy (1972) in Central Otago, and by Douglas and Kinder (1975) on Tara Hills. These authors recommended 250 kg of S-superphosphate (9% P, 19% S) every 2 years on yellow-brown earths (**Brown** soils) but such a recommendation would have given less than 30% of potential legume production on the **Brown** soils studied. The high rates of fertiliser required and the low potential production indicated that oversowing above 1000 m is unlikely to be economic.

Appropriate rates for lower-altitude **Brown** soils may be deduced from the work of Craighead *et al.* (1990) who found that at 800 m on a **Brown** soil south of the Lindis Pass, 205 kg/ha of S-superphosphate (37% total S) applied in years 1 and 3 of a 4-year trial produced highest pasture yields. S-superphophate was also the most cost-effective of several fertilisers used.

On a site overlooking Lake Pukaki (mean annual rainfall 1000 mm) McLeod (1974) investigated the effects of various rates of molybdic S-superphosphate (28% total S) on dry matter yields of pastures on a Cass soil (topsoil pH 5.5) (**Table 5**). The site was on rolling land but trial results are included here as they are some of the few obtained

Fertiliser rate	Mean annual DM production (kg/ha)	% of Maximum production
No fertiliser	1300	23
185 kg/ha year 1	3600	63
185 kg/ha years 1, 2, 3, and 4	5700	100
185 kg/ha years 1 and 3	5300	93
185 kg/ha years 1 and 4	4500	79
185 kg/ha year 1 + 92.5 kg/ha years 2, 3, and 4	5600	99
185 kg/ha year 1 + 92.5 kg/ha year 3	5100	89
185 kg/ha year 1 + 92.5 kg/ha year 4	3900	69

Fertiliser was S-superphosphate containing 18% added elemental S.

Table 5. *Mean annual dry matter (DM) production over 4 years for legume-based pastures under different fertiliser regimes on Cass soils near Lake Pukaki. From McLeod (1974).*

on Cass soils. The trial was run for 4 years. Production was extremely variable because of one very wet season. Production without fertiliser was 1300 kg DM/ha yr. Highest production was achieved with 185 kg/ha of fertiliser applied annually, but 185 kg/ha of molybdic S-superphosphate followed by half this rate every second year gave about 90% of maximum production. Delaying this second application by 1 year reduced annual production to 70% of potential, indicating that application of 92.5 kg/ha S-superphosphate every 3 years could well be the most cost-effective maintenance fertiliser option for improved pastures on Cass soils.

Appropriate policies for oversowing and topdressing depleted fescue tussock grassland on steepland soils of the Ohau set were also investigated at a site overlooking Lake Pukaki by Vartha and Clifford (1973). Topsoil pH was in the range 5.0–5.5. Sites sown with alsike clover, red clover, white clover, perennial ryegrass, cocksfoot, tall fescue and yorkshire fog had very variable DM production of 2000–7000 kg DM/ha when fertilised with 380 kg/ha of molybdic S-superphosphate (28% total S) in the first year followed by 190 kg/ha of the same fertiliser in the third and fifth years. A notable feature of the trials was the high clover production (more than 3000 kg/ha) in the first 3 years of the experiment but the collapse of clover production to less than 500 kg/ha in subsequent drier years. Although grass production exceeded clover production in years 4 and 5, it did not compensate for the loss of clover. Consequently, in years 4 and 5 total production did not exceed 3000 kg/ha under any fertiliser treatment. Anecdotal evidence from farmers suggests that peaking of legume production after oversowing, followed by a "levelling off" is widespread.

Alternative legumes, lime

On severely P-deficient **Brown** soils, at an altitude of 660 m and mean annual rainfall 845 mm in the Ashburton catchment, Davis (1991) found that the perennial tree lupin (*Lupinus arboreus*) produced more than 10 000 kg DM/ha in a single season without added P and did not respond to fertiliser (**Figure 12** see page 29). On the same site alsike clover *(Trifolium hybridum)* and red clover *(Trifolium pratense)* produced similar yields to tree lupins but required the equivalent of about 2500 to 5000 kg/ha of superphosphate (applied 16 months previously) to achieve this (Davis 1991). Davis remarked that "lupins are able to exploit a source of soil phosphorus which is not available to either white clover or lotus." The trial showed that at low P application rates the lupins fixed more N than pasture legumes. He suggested that tree lupins could be used more widely for fixing N in conventional plantation forests. However, because only a few plants survived a droughty summer, this plant is more suited to P-deficient sites with dependable summer rainfall.

Excessive levels of available Al in soils are not only toxic to some plants but also interfere with P uptake.

In their trials Nordmeyer and Davis (1977) found that Maku lotus responded to superphosphate applied at rates up to 1600 kg/ha, and clovers responded to rates of up to 2400 kg/ha. These rates are very high, and are never likely to be economic to apply for production purposes. Another factor

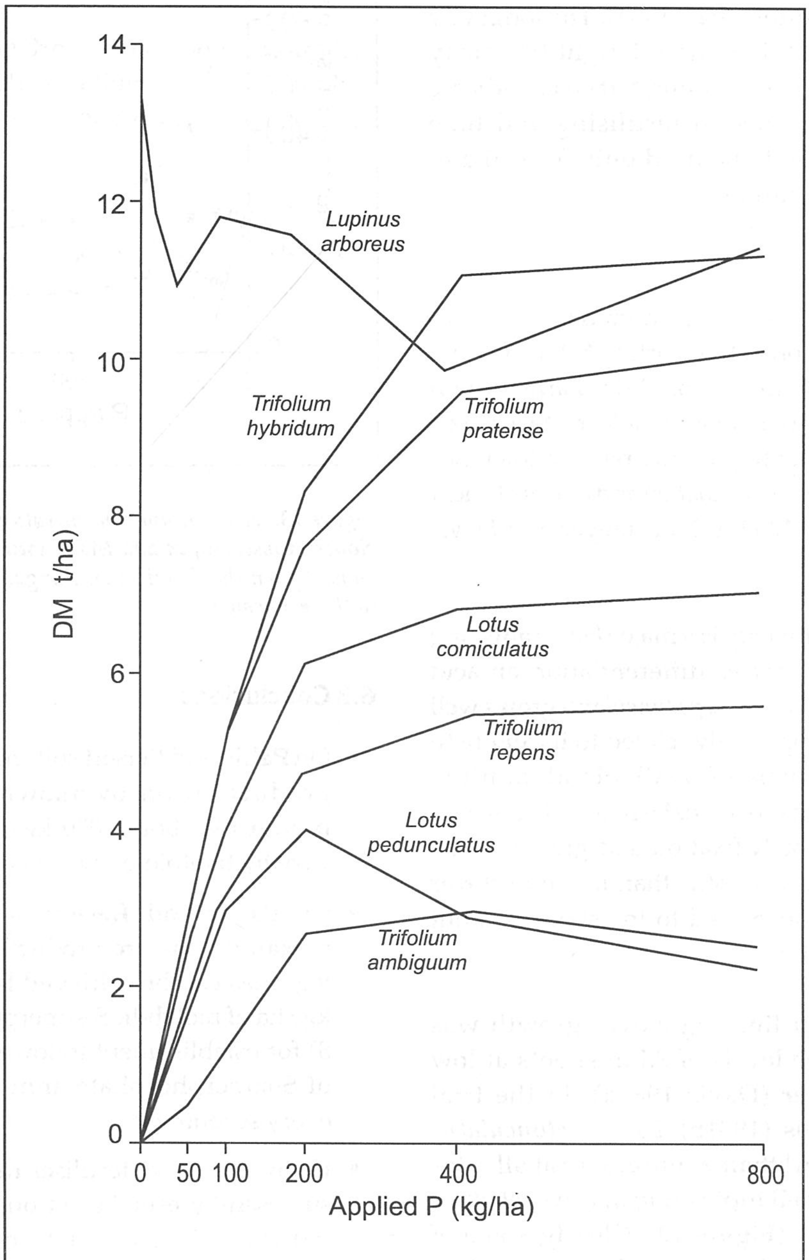


Figure 12. *Responses of various legumes, 16 months after sowing, to P applied to a* ***Brown*** *soil (altitude 660 m, rainfall 845 mm). From Davis (1991), with permission.*

against pasture development with lotus is the difficulty of managing lotus pastures, because they cannot be mob-stocked for long periods, and therefore require fencing into smaller blocks than are common in the high country. Other studies have shown that addition of lime may lower P requirements (*e.g.* Davis 1981c; Haynes and Ludecke 1981; McIntosh *et al.* 1984). The longevity of the liming effect (Floate and Enright 1991) may mitigate the high cost of liming but costs indicate that on land over 1000 m fertilising and lime application is likely to be used only for soil and vegetation rehabilitation.

Aluminium toxicity

The question of Al toxicity in the humid high country has received attention in the work of A. Nordmeyer and others, working mainly on **Allophanic Brown** soils in the Cragieburn Range, outside the Mackenzie hill country. Commenting on the relative tolerance of Maku lotus (*Lotus pedunculatus*) and clovers to acid subsoils on sites at 1200 m Nordmeyer and Davis (1977) remarked:

"It appears that Al toxicity is a major factor affecting plant growth and species differentiation on acid subsoils. The reasons why *L. pedunculatus* grows well on these soils are apparently related to its ability to withstand high levels of available aluminium combined with an ability to make relatively efficient use of fertiliser P for N fixation and growth. Total uptake of Al is lower in lotus than in white clover and the amount transported to the shoot is about half that of white clover."

The effect of Al in limiting clover growth was shown by the toxic levels of Al in shoots at low rates of P fertiliser (Davis 1981a). In the trial described by Davis (1981b) *Lotus pedunculatus* accumulated less Al than white clover at all rates of P, values in Russell lupins (*Lupinus polyphyllus*) being intermediate (**Figure 13**). Clearly, some of the applied P was being used to neutralise available Al in the soil. Both lotus and lupins appeared to be suitable for improving the fertility of the soil.

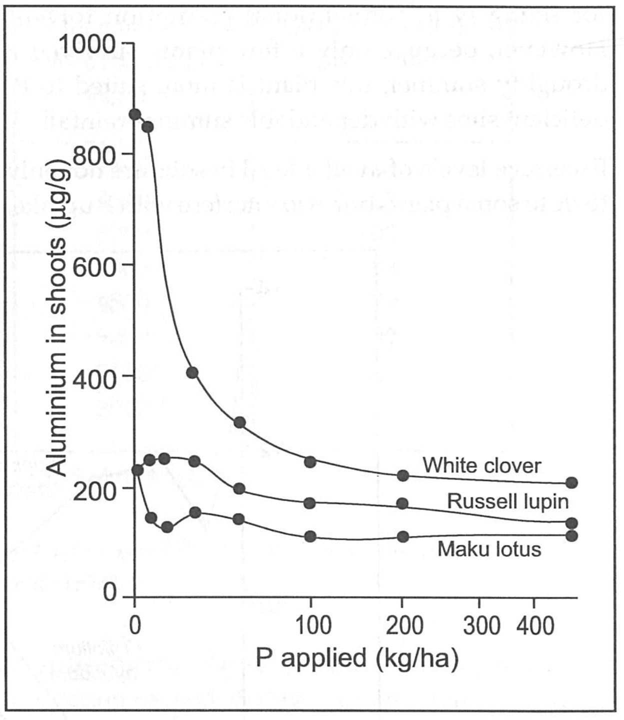


Figure 13. *Aluminium concentrations in shoots of white clover, Russell lupin and Maku lotus growing on a Bealey subsoil from the Cragieburn Range. From Davis (1981a), with permission.*

6.3 Conclusions

- On **Pallic** and **Recent** soils mean maximum DM production on oversown and topdressed pastures is about 6000 kg/ha. Production can vary by fivefold between wet and dry years.
- On **Pallic** and **Recent** soils about 70% of maximum pasture production from oversown legumes can be achieved by using about 200 kg/ha of molybdic S-superphosphate (27% total S) for establishment followed by 90-100 kg/ha of S-superphosphate annually, or 200 kg/ha every second year.
- Using the above fertiliser rates, lucerne can be successfully established on sunny slopes, and red clover-lucerne mixtures on shady slopes. With the passage of time, resident grasses contribute about 30% of the dry matter on shady slopes, but only about 10% of the dry matter on sunny slopes.

- On **Brown** soils above 1000 m even 1000 kg/ha of superphosphate is insufficient to give more than 50% of potential yield with clovers and oversowing above this altitude is unlikely to be economic. Maku lotus can be established at these altitudes but requires very high rates of superphosphate.
- On lower altitude **Brown** soils about 185 kg/ha of S-superphosphate followed by 92.5 kg/ha every 3 years is likely to be the most cost-effective option
- Tree lupins can produce more that 10 000 kg/ha of DM on **Brown** soils at 660 m altitude, without P fertiliser, but droughts can kill plants.

Sustainability issues for pastoral use

In the mid-1980s cheap loans and subsidies for high country 'development' were withdrawn, concurrently with the invasion of weeds like *Hieracium* and briar, and periodic explosions of rabbit populations. These events highlighted the question of the sustainability of many high country farming practices. The issues of sustainability were raised by O'Connor and Harris (1991) who, for the first time, estimated the net loss of the major nutrients N, P, K, and S from high country soils since 1850. The issues were also raised in three government reports (Hughes 1991, 1995; Martin *et al.* 1994). In 1994, the first reports of farm-scale pH declines were published (McIntosh *et al.* 1994a, b) suggesting that continued grazing on hilly and steep high country soils might eventually lead to lime being required, to arrest soil acidification. In addition, farm monitoring has shown that, where grazing is not accompanied by topdressing, topsoil nutrient loss occurs (McIntosh *et al.* 1996).

In parallel with the government and research emphasis on environmental and sustainability issues, the legislative requirements of the Resource Management Act (1991) require local authorities to ensure that land uses are sustainable. Consequently it has become important to establish ways of measuring the sustainability of farming practices.

7.1 Measuring sustainability

To assess land-use sustainability, trends of soil properties over time need to be measured and understood. Land use is probably sustainable if the chemical, biological, and physical status of the soil improves or at least remains constant over time, and is unsustainable if their status declines. Soil erosion is the most obvious observable effect indicating unsustainability of a land use (**Photo 1** and **2** see pages 11 and 13). Erosion, however, is merely the end point of more subtle changes which, if detected early by soil monitoring, can give a warning of soil trends requiring correction.

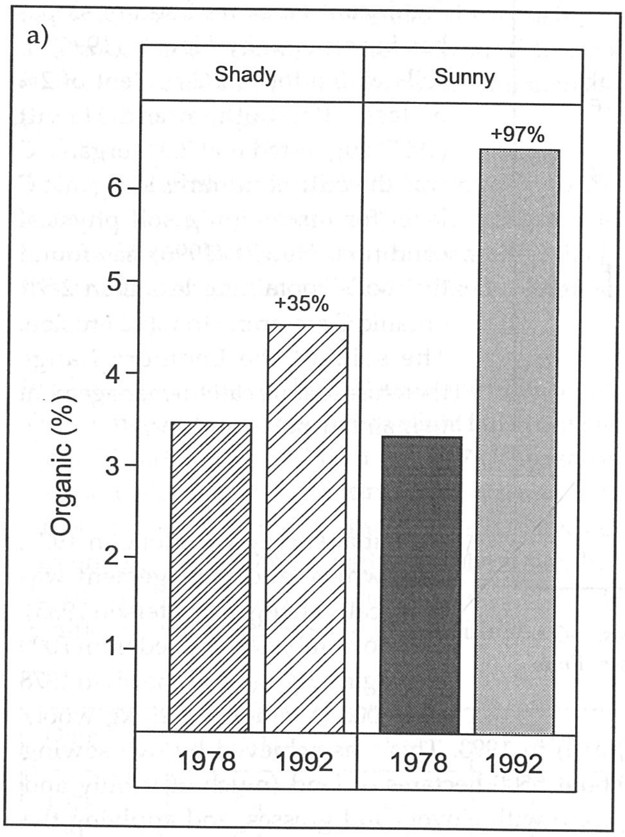
There are two approaches to assessing soil changes: (1) by temporal measurements, that is noting changes over time; or (2) by spatial comparisons, that is noting soil properties in areas of changed land use and comparing them with soil properties in a nearby area having soils still under a land use previously common to both areas. The first method requires well-identified sites and careful attention to ensure consistency of sampling and analytical procedures over the monitoring period. The second method generally requires reference areas, which typically will be reserves or areas with some protected status. Reference areas are scarce in the pastoral high country (Lands and Survey 1984) and soil monitoring must therefore be predominantly by temporal measure-ments.) Two examples of assessment of soil changes in the Mackenzie hill country are given below.

7.2 Two case studies

Temporal changes of soil chemistry in soils on hilly and steep country on the Benmore Range and in the Ahuriri valley were studied by comparing topsoil (0–7.5 cm) analyses from grid surveys conducted in 1978 and 1979 and repeated in 1992 and 1993. The Benmore area is at 440–810 m, has a rainfall of 500–600 mm, and has **Pallic** and **Recent** soils, previously mapped in the Meyer and Omarama sets. The Ahuriri area studied is at 685–1190 m altitude, has a rainfall of 700–1000 mm and has **Brown** and **Pallic** soils, the latter on lower-altitude sunny slopes. Soils were previously mapped in the Kaikoura and Omarama sets. The soil patterns in both areas were described by McIntosh *et al.* (1981) and are summarised on pages 17–23.

Benmore area

Since 1978 the Benmore area has been grazed but not topdressed. The mean organic C value of 24 sites was 2.3% in 1978 and declined by 10% between 1978 and 1993; the C decline was larger on sunny slopes (20%) than on shady slopes (4%) (**Figure 14** see page 33). Soil N declined by 25% between 1978 and 1993, from 0.24% N to 0.18% N (**Figure 15** see page 33), and pH declined by 0.43 units, from 6.30 to 5.87 (**Figure 16** see page 34). These soil changes were associated with an increase in the proportion of bare ground, *Hieracium* and briar cover. *Hieracium*



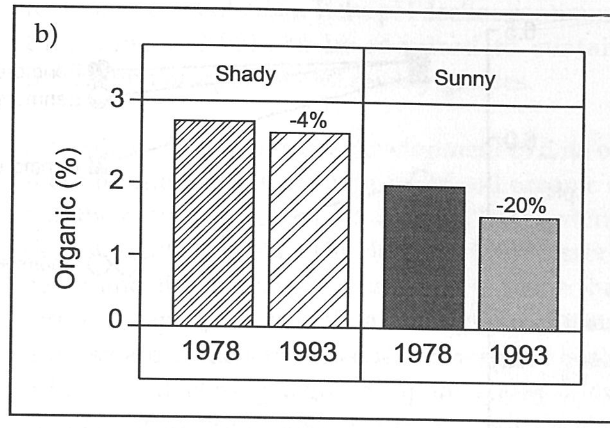


Figure 14. *Organic C changes in topsoils on sunny and shady slopes on a ridge (a) in the Ahuriri valley and (b) on the Benmore Range. Ahuriri data based of mean of 19 points per bar graph. Benmore data based on mean of 12 points per bar graph.*

compounded the acidification problem with soils under *Hieracium* patches on average being more acid by 0.5 pH unit than soils under native vegetation (McIntosh and Allen 1993; McIntosh *et al.* 1995).

Since 1978 exchangeable calcium, magnesium and potassium levels have also declined in 0–7.5 cm soils and BS values have fallen as a consequence (**Table 6** see page 34). Nutrient decline has been greatest on shady slopes. McIntosh *et al.* (1996) calculated that nutrient loss was greater than could be explained solely by sheep uptake and nutrient transfer, and suggested that erosion, nutrient removal by rabbits, or organic matter mineralisation (breakdown) could be partly responsible for nutrient losses.

Grazing has clearly affected topsoil chemistry, with sunny slopes being more prone to organic matter changes. The results from fenced trial areas showed that preventing grazing by sheep or rabbits could arrest soil C and N decline, but that to lift soil C and

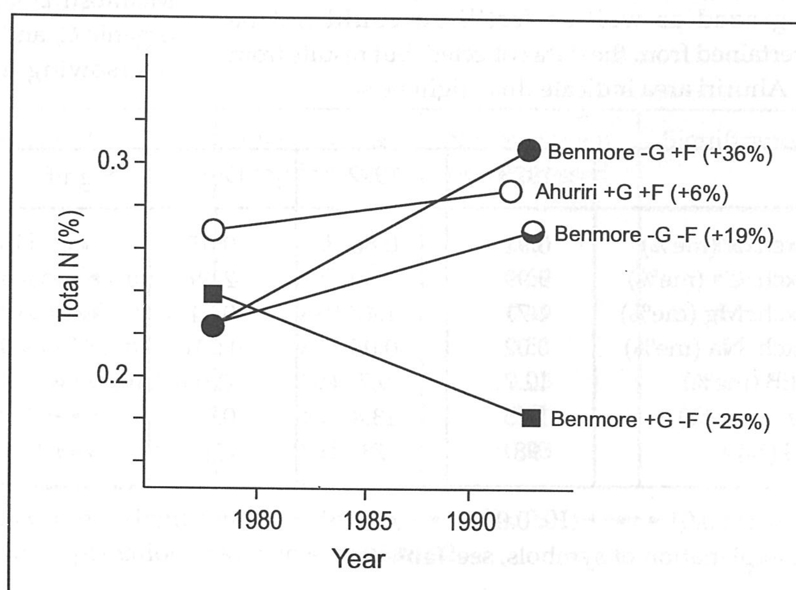


Figure 15. *Changes of mean total N in 0–7.5 cm soils since 1978 in Ahuriri and Benmore areas. -G = no grazing; +G = with grazing; -F = no fertiliser; +F = with fertiliser. From McIntosh* et al. *(1994b).*

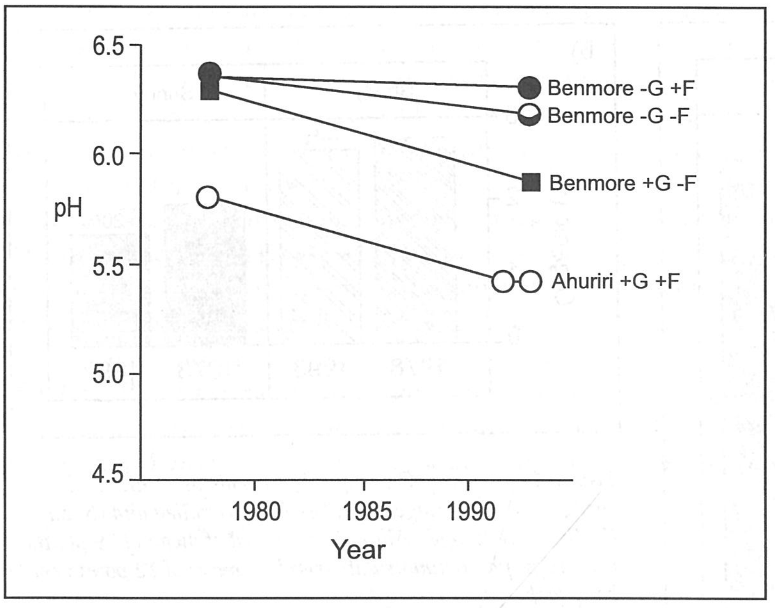


Figure 16. *pH changes since 1978 in the Ahuriri and Benmore areas. -G = no grazing; +G = with grazing; -F = no fertiliser; +F - with fertiliser. From McIntosh* et al. *(1994b).*

N, fertiliser application was necessary (McIntosh *et al.* 1994b, and unpublished). However, Ross *et al.* (1993) considered fertiliser application to be uneconomic, so restoration of soil condition by improving soil C and N status may require subsidies. Whether soil C and N would rise if pastures were to be grazed as well as fertilised could not be ascertained from the data collected, but results from the Ahuriri area indicate this might be so.

	1978	1992	Diff.	Signif.
Exch. K (me%)	0.91	0.86	–0.05	••
Exch. Ca (me%)	9.99	7.30	–2.69	•••
Exch. Mg (me%)	1.71	1.47	–0.24	•••
Exch. Na (me%)	0.02	0.05	0.03	•••
TEB (me%)	12.7	9.7	–3.0	•••
CEC (me%)	12.5	13.4	0.9	•••
BS (%)	98	73	–25	•••

•• = P< 0.01 ••• = P< 0.001

For explanation of symbols, see **Table 2**.

Table 6. *Changes of mean values of exchangeable cations, CEC and BS, in topsoils (0–7.5 cm) of 24 sites on the Benmore Range between 1978 and 1992. From McIntosh* et al. *(1992).*

Significant erosion of sunny slopes has been noted by Hewitt (1996) in soils with a topsoil C content of 2% or less. Parshotham and Hewitt (1995) suggested that 2.5% organic C was the critical minimum organic C level for maintaining soil physical condition. Hewitt (1996) has found that soils containing less than 2.5% organic C are prone to wind erosion. The soils of the Benmore Range therefore require careful management to maintain soil condition.

Ahuriri area

An initial survey was done in 1978, after which land management was drastically changed (Patterson 1985). Merino numbers increased from 7000 (averaging 3.4 kg wool/head) in 1978 to 18 000 (averaging 4.25 kg wool/head) in 1993. This was achieved by oversowing about 5500 hectares of land (much of it hilly and steep) with clovers and grasses, and applying the equivalent of 100 kg/ha of 28% S-superphosphate each year since 1979. No lime was applied.

McIntosh *et al.* (1994a, b) described the soil pH, organic C, and total N changes resulting from the oversowing and topdressing policy. Mean soil organic C values at upper midslope and near-ridge sites rose by 67% (from 3.3% C to 5.5% C) between 1978 and 1992. The increase was larger on sunny slopes (97%) than on shady slopes (35%) (**Figure 14** see page 33). Soil N values increased only slightly over this time period, from 0.27% N to 0.29% N (**Figure 15** see page 33) but this overall figure masked a 13% decrease of total N on shady slopes and a 26% increase of total N on sunny slopes. Mean pH declined by 0.41 units, from 5.81 to 5.40 (**Figure 16**), with the lowest recorded value being 4.9. These soil changes were associated with a decrease in the amount of bare ground, a decrease in snow tussock cover, an increase in legume cover, and an increase in sites with *Hieracium*.

The pH decline was attributed primarily to the organic C increase, but nitrate leaching and application of elemental S in fertiliser are also likely to have contributed to soil acidification (McIntosh *et al.* 1994a).

In contrast, at 7 sites on lower landscape units under similar management, there was a slight fall in organic C and N and no change in pH (**Table 7**). The reason for the different "behaviour" of the sites in low landscape positions may be that these sites have net carbon loss, i.e., sheep eat herbage at these sites but deposit dung elsewhere. Further work on soil trends in different landscape positions is required.

Date	pH	C	N
1978	5.4	4.6	0.31
1992	5.4	4.0	0.28

Table 7. *Mean pH, C, and N analyses from 0—10 cm soils from 10 trial sites in lower landscape positions, Ahuriri valley. From McIntosh* et al. *(1994a).*

The causes of acidification of soils under pastures are well known and have been documented in New Zealand and Australia (Chartres *et al.* 1990; Bolan *et al.* 1992; Donald and Williams 1955; Helyar and Porter 1989; Kohn *et al.* 1977; Sinclair *et al.* 1994; White 1991; Williams and Donald 1957; Williams 1980; Williams *et al.* 1993). However, acidification has not previously been recognised as a problem in the South Island high country and the extent of acidification and the processes determining it require further attention. If the pH decline continues, then lime is likely to be required to sustain production of legumes and quality grasses.

A positive effect of pasture development to date on these moister soils is the increase of soil organic C and the reduction in the percentage of bare ground (McIntosh *et al.* 1994a). The decline of tall-tussock cover and the increase of *Hieracium* indicate that fertiliser application to maintain a vigorous clover/grass sward is likely to be needed on a regular basis, otherwise declining legume vigour could allow *Hieracium* to dominate. Another positive also development has been the increased fertility of sunny slopes resulting from the oversowing and topdressing programme (**Table 9** see page 36).

A comparison of ten topdressed and oversown sites in the Ahuriri valley with ten unfertilised sites having the same altitude and aspect and similar soils, also demonstrated the marked effect of oversowing and topdressing on soil organic matter and nutrients over a 15-year period (**Table 8**). The oversown and topdressed soils had higher fertility and accumulated more organic matter. There was no apparent effect of management on soil pH.

Property	Oversown & topdressed	Not oversown or topdressed	Significance
pH	5.3	5.3	NS
Exch. Ca (me%)	3.32	1.69	•••
Exch. K (me%)	0.79	0.49	•••
Exch. Mg (me%)	0.79	0.51	••
Exch. Na (me%)	0.04	0.03	•
C (%)	5.2	3.7	••
N (%)	0.35	0.23	••

NS = not significant; • = $P < 0.05$; •• = $P < 0.01$; ••• = $P < 0.001$
For explanation of symbols, see Table 2.

Table 8. *Comparison of chemical properties of oversown and topdressed topsoils (0-7.5 cm) in the Ahuriri valley with soils neither oversown or topdressed. Each value is the mean of 10 sites. From McIntosh* et al. *(1996).*

Cation	Shady aspect				Sunny aspect				Mean			
	1978	1992	Diff.	Sig.	1978	1992	Diff.	Sig.	1978	1992	Diff.	Sig.
Exch. K (me%)	0.82	0.77	–0.05	NS	1.10	1.33	23	••	0.96	1.00	0.04	NS
Exch. Ca (me%)	3.23	3.42	0.19	NS	4.91	7.10	2.19	•••	4.07	5.26	0.19	•••
Exch. Mg (me%)	0.66	0.66	0	-	1.02	1.34	0.32	•	0.84	1.00	0.16	•
Exch. Na (me%)	0.00	0.02	0.02	-	0.00	0.01	0.01	-	0.00	0.02	0.02	-
Σ cations (me%)	4.75	4.86	0.11	NS	7.07	9.78	2.71	•••	5.91	7.31	1.40	••
CEC (me%)	15.4	16.8	1.4	NS	12.6	19.1	6.5	•••	14.0	18.0	4.03	•••
BS (%)	31	29	–2	NS	55	50	-5	•	43	40	–3	•

NS = not significant; = $P < 0.05$; = $P < 0.01$; = $P < 0.001$
For explanation of symbols, see **Table 2**.

Table 9. *Mean changes of exchangeable cations in topsoils (0 – 7.5 cm) on 38 sites in the Ahuriri valley, 1978-1992 showing the effect of aspect on soil changes on fertilised land. From McIntosh* et al. *(1996).*

Implications

The results show that soil monitoring networks covering a range of soils, altitudes, aspects and managements can give useful information about the sustainability of high country pastoralism and future options. With the exception of pH decline, soil effects from oversowing and topdressing are mostly positive. Soils in the drier hill country appear to be especially sensitive to the effects of grazing, and if pastoral use is to continue, measures will have to be taken to maintain soil pH, organic matter and nutrient levels. On the drier hill country subsidies may be required to achieve an improvement in soil condition, as it is doubtful whether soil improvement can be consistently financed from farm incomes.

7.3 Burning and grazing

It is accepted by farmers on lowlands that regular fertiliser and lime application is necessary to replace nutrient losses that occur by soil leaching, by soil immobilisation, by inefficient return of nutrients by animals, and to counter soil acidification (brought about by cation removal, organic matter accumulation and nitrate leaching). However, in some areas of the high country, burning and grazing of tussock, without adding fertiliser to make up for resulting losses, is still practised. Burning and grazing without fertiliser and lime application must inevitably cause vegetation change and nutrient decline, since nutrients are lost to the atmosphere, to sheep products, and by nutrient transfer in the landscape. Under such circumstances tussock vigour will decrease and a different vegetation type attuned to the lower fertility soils will take over (*e.g.* tussock grasses may die and *Hieracium* may increase).

To assess the effects of burning and grazing, a nutrient balance, in which inputs are assessed against losses, can be calculated. The nutrient balance considers inputs and losses arising from both chemical processes (*e.g.*, leaching) and physical processes (*e.g.*, soil erosion). As natural grasslands are extremely N deficient, determining an N balance in tussock grasslands is important for determining the sustainability of management practices. A nitrogen balance is calculated to show how management can affect soil and vegetation resources in "unimproved" high country tussock grasslands.

The nitrogen economy of burnt and grazed tussock grasslands

The principle components of the N cycle in tussock grasslands were presented by O'Connor (1983) but figures for the various components were not estimated. In calculating this balance, several assumptions were made: (1) on hill country sheep deposit about 60% of their dung and 55% of their urine on campsite areas which may occupy only 15–31% of the land area (Saggar *et al.* 1988; Williams and Haynes 1991; Rowarth *et al.* 1992); (2) the stocking rate is 0.3 sheep/ha, one sheep eats 1.1 kg of dry matter per day and the sheep's diet consists of a mixture of tall tussock, short tussock, and herbfield vegetation; (3) the dry matter eaten contains 1.2% N, which is the mean of the N content of green tall tussock leaves (0.76%) (Williams *et al.* 1977) and the N content of mixed herbfield-short tussock vegetation (1.7%) (mean of 32 unpublished results, Landcare Research); (4) the tussock cover is burnt at 20-year intervals.

Because of the intermittent burning, it is convenient to base calculations on a 100-year period:

N losses:

The total ingested N is 145 kg/ha per century. Losses in sheep products and urine transfer are estimated to be 55% of the ingested N which equals **80 kg/ha** per century.

Losses from burning vegetation were estimated from the N content (243 kg/ha) of above-ground components of previously burnt tall tussock stands (Williams *et al.* 1977; Basher *et al.* 1990), assuming a 70% loss after burning (Raison 1979). Total loss from one burn is 0.7 x 243 kg/ha = 170 kg/ha. Assuming five burns per century, and regrowth to previous stature between burns, the total N loss is **850 kg/ha** per century.

Soil N loss from actual burning of the soil is assumed to be low. There may be indirect effects of burning on soil losses as soil temperature extremes are greater when vegetation cover is depleted (Johnston *et al.* 1971; McSweeney 1983) and therefore mineralisation of topsoil organic matter can be expected (Daubenmire 1968), especially in drier areas. There are no measurements of mineralisation losses for tussock grasslands, so losses by this pathway have not been estimated.

Losses caused by urine leaching or volatilisation are not known. It may be assumed that leaching losses are low in the unfertilised highly N-deficient soils of the high country. N losses by volatilisation may occur in drier grasslands (Floate 1981; Watson and Lapins 1969) but no figures for New Zealand tussock grasslands have been measured. Losses from both these sources are conservatively estimated to be about **100 kg/ha** per century.

Losses from soil erosion have not been estimated in this calculation as they are likely to be very variable and site-specific.

The total N loss from all the above sources is **1030 kg/ha** per century, which is probably an underestimate because it does not include any mineralisation or erosion losses.

N gains:

Woodmansee *et al.* (1981) estimated that N fixation from non-symbiotic, free-living bacteria in natural grasslands is about 1–2 kg/ha/yr. In the South Island the average measured N fixation from similar sources in tall tussock/hard tussock grasslands is 1.6 kg/ha/yr (Line and Loutit 1973), i.e., **160 kg/ha** per century.

As legumes are generally absent in unfertilised tall tussock grasslands, and other N-fixing plants like the shrubs matagouri (*Discaria taumaton*) and *Coriaria* sp. are normally of very local extent, inputs from these sources are considered to be insignificant.

Gains from rainfall in dry areas (460 mm mean annual rainfall) amount to **20 kg/ha** per century (Cossens 1970).

The total N gain per century from the above sources is **180 kg/ha.**

N balance:

The N balance is minus 850 kg/ha per century, i.e., a net N loss of 8.5 kg ha/yr could occur under a traditional burning and extensive grazing regime. Thus for a soil containing 4000 kg/ha of total N in the topsoil, if all the N loss is made up from topsoil sources, burning and grazing will result in the topsoil N reserve declining by 21% over a century.

Effect of changing management

If the stocking rate is doubled to 0.6 sheep per hectare the N loss rises to 930 kg/ha, giving a 23% decline of soil N over a century; at 1.2 sheep per hectare the N loss is 1030 kg/ha, giving a 26% decline of soil N over a century. Thus the actual sheep diet, and stocking rate (within the above limits) have a relatively small effect on N loss compared to the effects of burning. For example, increasing the frequency of burning from five to eight burns per century, while grazing at 0.3 sheep per hectare, will increase topsoil N depletion from 21% to 34%.

The above figures are illustrative, using estimates from the published literature. Actual figures will depend on stocking rate, frequency of burning, tussock stature, and soil N reserves. However, calculation shows that burning is likely to result in a significant net loss of N from tussock grassland ecosystems.

7.4 Conclusions

- Temporal soil monitoring over periods of 15 years or more, using networks of observation sites covering a range of landscape positions, is an effective method of showing changes over time in soils on hilly and steep land.
- Fertilising the moist western hill country results in a large increase of soil C and a decline of pH on some land, but land in lower landscape positions seems to be unaffected.
- Grazing, without fertilising on the dry eastern hill country leads to soil nutrient and C decline, and soil acidification.
- *Hieracium* progressively acidifies soils as it invades short tussock grassland and herbfield.
- Regular burning of tall tussock grassland and grazing at a rate of less than 1 sheep/ha is estimated to result in the loss of about 850–1000 kg/ha of N from tussock grassland ecosystems over a century. Such a loss is equivalent to 20–25% of the topsoil N reserves of a typical soil of the moister high country.
- For grazing of tussock grasslands to be sustainable, nutrients lost must be replaced, and organic matter levels must be maintained or increased, by oversowing and applying fertiliser. Sooner or later acidification will require correction by lime application.

The forestry option

In 1913 the Royal Commission on Forestry observed that the Mckenzie area "was virtually a desert below a certain altitude" and recommended that certain areas of the Mackenzie be afforested. More recently, Belton (1991a,b,c, 1993) has argued strongly for forestry, both for economic and soil conservation reasons, and suggested that there was 374 500 ha of land suitable for forestry in the Canterbury high country.

Belton (1991a,b,c), Ledgard (1980, 1986) and Ledgard and Belton (1985) discussed the most suitable plantation species for the high-country. Maximum stemwood volume increments for Corsican pine (*Pinus nigra),* a conifer well suited to the climate of the inland high country, were estimated to range from <9.0 m^3/ha/yr under <600 mm rainfall to 24 m^3/ha/yr under 1200–1400 mm rainfall, but for Douglas fir maximum growth rates can be over 30 m^3/ha/yr. At one site, on Mesopotamia soils (**Typic Immature Pallic** soils, see page 14) near Lake Ohau, mean growth rates have been about 40 m^3/ha/yr, with growth from age 42-53 yrs being 65 m^3/ha/yr per year (Belton 1993). These very high growth rates compare with the national average for radiata pine of about 23 m^3/ha/yr.

Belton (1993) estimated that on an annualised basis the Lake Ohau forest has increased in value by $4000/ha/yr. He compared this to returns from topdressed and oversown pastures, which by his estimates returned about $150 to $250/ha/yr. Much of the land considered suitable by Belton (1991c) is hilly and steep with difficult access. Problems of plantation management, including access, harvesting costs and wilding control may not have been fully taken into account when calculating returns.

Belton (1993) cautioned that growth rates such as those recorded on Mesopotamia soils were not likely to be repeated everywhere. Nevertheless, the Lake Ohau site epitomises the advantages of the high country environment for tree growth: low humidity which limits disease and allows needles to be retained on conifers for up to 3 years; photosynthesis throughout the year, with complete suppression only when soil temperatures are close to freezing (Benecke and Havranek 1980); a large diurnal range of temperature, limiting energy loss by respiration at night (Benecke 1985); and (locally) deep silty soils with high water holding capacity.

In the discussion of the suitability of land for forestry, there has been little consideration of the likely effect of soils on tree performance or species selection. Ledgard and Belton (1985) noted much higher growth rates on the "moister" soil groups (N.Z. Soil Bureau 1968) but as the 1968 soil group classification is linked to climate this finding was not surprising. There were indications that for species other than radiata pine moisture stress limited production on some sites (Ledgard and Belton 1985) but the lack of soil water data precluded any rigorous analysis of performance against soil factors. In the following section we assess the main factors controlling forest growth, and present a preliminary site classification scheme.

8.1 Assessment for forestry using soil moisture

The factors affecting forestry suitability are chiefly climatic and physical. The climatic limitations may be divided into those which directly affect growth (temperature and moisture) and those that affect tree and timber quality (risk of heavy snow and exposure). The temperature and exposure limitations are recognised by the approximate upper altitude limit of 900 m for commercial forestry plantations in this region.

The prediction of moisture deficits for forestry in the Mackenzie hill country is hampered by lack of information on rainfall and evaporation rates. Apart from the study of Radcliffe and Lefever (1981), which only looked at gravimetric moisture at 0–10 cm depth and did not go as far as compiling a water balance, the moisture status of South Island hilly and steep land is virtually undocumented.

To help assess the possible limitation of soil water on forestry production, total available water (10–1500 kPa) was estimated from data for the Tekapo soil (Landcare Research, unpublished data) and for the Streamlands soil (McIntosh 1992).

The Tekapo soil has a texture representative of the **Brown** soils of the moister western Mackenzie basin and the Streamlands soil has a texture representative of the **Pallic** soils of the eastern Mackenzie basin. Total available water (TAW) was estimated to a depth of 100 cm or to a rock contact or rooting impediment (pan). The volume of stones and gravels observed in soil profiles was taken into account. **Table 1** (see page 9) presents the estimated TAW class of the typical profiles described.

Using the TAW classes and rainfall isohyet maps four very broad soil drought risk classes are proposed (**Table 10**). Soils were given a drought risk class for sunny and shady slopes (1 = maximum risk; very droughty; 4 = minimum risk; very seldom droughty). Soils with drought risk classes 3 and 4 are considered suitable for commercial forestry, if they occur at low altitudes. From **Table 1** it can be seen that all but the shallowest or stoniest **Brown** soils on shady slopes are suitable for forestry, but among the **Pallic** and **Recent** soils only the deeper Mesopotamia, Tengawai and Meyer soils are suitable. The authors acknowledge that these drought risk classes are indicative only, and that much more information is required on the availability of water for commercial plantations in the Mackenzie hill country, and high country in general. In particular, the drought risk classes need to be calibrated against actual growth rates of commercial stands.

		RAINFALL							
		400–600 mm		600–800 mm		800–1000 mm		> 1000 mm	
	TAW Class	Sunny	Shady	Sunny	Shady	Sunny	Shady	Sunny	Shady
A	Soils having < 40 mm TAW	1	1	1	2	2	3	2	4
B	Soils having 40–100 mm TAW	1	2	1	3	2	4	3	4
C	Soils having > 100 mm TAW	1	2	2	3	3	4	4	4

Table 10. *Proposed drought risk classes for Mackenzie hill country soils, as predicted from TAW, rainfall and aspect. 1 = very droughty in most years (maximum risk); 4 = very seldom droughty (minimum risk).*

8.2 Nutrient deficiencies in trees

Few if any trials have been established to investigate nutrient requirements for trees in the Mackenzie hill country. Therefore limited work in South Canterbury has to be extrapolated to similar soils of the Mackenzie hill country. Ill-health in a Douglas fir stand on a high country yellow-brown earth (**Brown** soil) in South Canterbury was primarily due to P deficiency; soil exchangeable Al levels were high and Al toxicity may have compounded P deficiency problems (Belton and Davis 1986). Application of P in field trials raised foliar N content. These results are likely to be applicable to similar soils having more than 1000 mm rainfall (*e.g.* Cass and Cragieburn soils). On such soils, where climate is apparently suitable for Douglas fir, Al may restrict growth. The high growth rate on adjacent Mesopotamia soils (Ledgard and Belton 1985; Belton 1993) is explained by the fact that these **Pallic** soils are less weathered because they are developed in relatively young loess deposits (see Factsheet 7), and insufficient Al has been released by the soils to interfere with P uptake by plants.

Rainfall zone (mm)	Corsican pine						Douglas fir					
	Growth (m^3/ha/yr)	N	P	K	Mg	Ca	Growth (m^3/ha/yr)	N	P	K	Mg	Ca
		(kg/ha/yr)						(kg/ha/yr)				
500-600	9	9	1	6	1	7	-	-	-	-	-	-
600-700	12	12	2	8	2	10	13	12	3	13	1	5
700-800	14	14	2	10	2	12	16	14	3	16	1	6
800-1000	18	17	3	13	3	14	21	18	4	20	1	8
1000-1200	21	21	3	15	3	18	26	23	5	26	2	10
1200-1400	24	24	3	17	4	20	31	28	6	30	2	12

Derived from the wood and bark analyses of Nordmeyer and Ledgard (1993) and the growth rates of Ledgard and Belton (1985).

Table 11. *Estimated annual nutrient content of logs from 15-year-old stands of Corsican pine and Douglas fir.*

8.3 Nutrient removals

Tree plantations generally acidify the soil as nutrients are transferred to the wood fibres and leaves. Although soil acidification is often perceived as negative, it must be remembered that most of the Mackenzie hill country was previously under forest vegetation and a similar process occurred under the natural cover. Many of the nutrients in trees remain on site when logs are removed. Net removal of nutrients after logging of a 45-year-old Corsican pine stand has been estimated to be 80 kg N/ha, 25 kg P/ha, 167 kg K/ha, 50 kg Mg/ha, and 190 kg Ca/ha (Belton 1991c). These levels are small in comparison with the losses resulting from grazing and burning (O'Connor and Harris 1991). However, Belton's (1991c) figures were taken from a stand with an annual rainfall of 650 mm and cannot be regarded as typical of high country forest in general. Nutrient removal in logs from various rainfall zones can be calculated using the nutrient contents and bark: stemwood ratios of the 15-year-old Cragieburn stands assessed by Nordmeyer and Ledgard (1993) in conjunction with growth rates (Ledgard and Belton 1985). **Table 11** shows that logging of 15-year-old stands in the wetter climatic zone could remove up to 410 kg N/ha, 90 kg P/ha, 450 kg K/ha, and 32 kg Mg/ha. These figures are approximate, as they assume that the bark: stemwood ratios at the Cragieburn site apply across all climate zones and stand ages. Older trees may have lower rates of nutrient removal, as the heartwood: sapwood ratio of trees increases with age. However, even with these provisos, it is clear from **Table 11** that in the wetter climate zones losses of nutrients from plantations have the potential to be greater than the calculated losses (O'Connor and Harris 1991) resulting from pastoral use.

It is unlikely that soil weathering can replenish such nutrient losses. Therefore, for forestry to be sustainable, such nutrient losses must be replaced by using fertilisers.

8.4 Benefits

Belton (1991b) listed the benefits of forestry as: (1) increasing inputs of soil organic matter because forests have 10 to 50 times higher biological activity than depleted rangelands; (2) positive effects on soil temperatures (elimination of extremes); (3) decreased wind exposure and protection from erosion; (4) mobilisation of soil nutrients; (5) ability to maintain production through droughts; (6) financial returns 10 to 60 times those of pastoral agriculture (1991 prices). He concluded with the following challenge:

"while forestry is uniquely positioned to address the ecological and economic problems of high country landuse and could play a major role in landuse diversification away from traditional pastoralism, high country forestry on a significant scale will only occur if attitudinal, institutional and financial barriers are overcome".

It remains to be seen whether diversification into forestry will become an acceptable and profitable land use in the Mackenzie hill country.

8.5 Conclusions

- Mean growth rates for commercial forestry range from less than 9 m^3/ha/yr for Corsican pine at a site with less than 600 mm rainfall, to over 30 m^3/ha/yr for Douglas fir at a site with more than 800 mm rainfall. In comparison the national average for radiata pine is about 23 m^3/ha/yr.
- Highest growth rates for Douglas fir are recorded on Mesopotamia soils.
- Nutrient loss by log removal is estimated to be less than that resulting from grazing in the dry eastern hill country, and greater than that resulting form grazing in the moist western hill country. For forestry to be sustainable, these nutrient losses must be replaced with nutrients in fertilisers.

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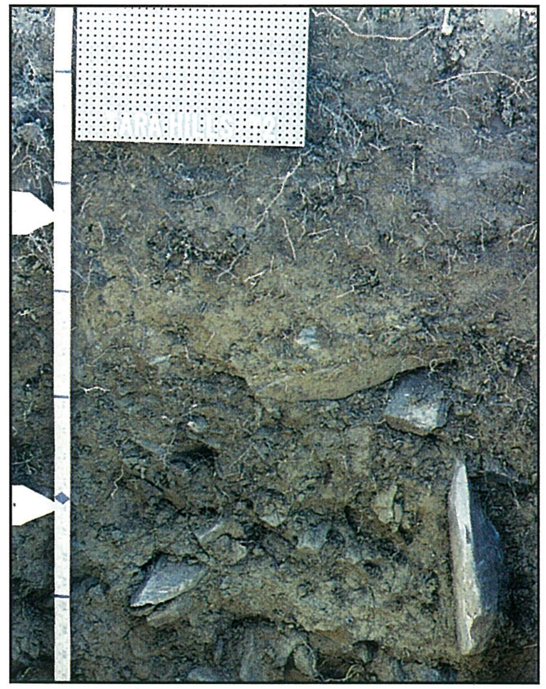
SOIL FACT SHEET 1
MACKENZIE HILL COUNTRY

soil name	:	**BENMORE**
related set	:	Benmore
equivalent series	:	Benmore
subgroup, parent material class	:	**Pallic Firm Brown Soil, angular-stony**
typical particle size class	:	silty over skeletal
typical permeability	:	moderate over rapid

SOIL PROFILE



12-90(3)-10

KEY FEATURES

- deep profiles formed in silty and gravelly colluvium
- subsoils slightly firm with few roots
- moderately acid profiles, very infertile

LANDSCAPE

12-90(3)-12

TYPICAL FEATURES

- above natural treeline (> 1000 m)
- mostly on steep slopes
- patchy tall tussock cover
- rainfall probably 600–800 mm
- 30% bare ground
- 10% surface stones
- rock outcrops

SOIL NOTES

Benmore soils are **Pallic Firm Brown** Soils that occur mainly on drier hilly and steep slopes. They commonly have gravels and boulders on the soil surface and up to 50% bare ground. Typical vegetation is narrow-leaved tall tussock, blue tussock, *Hieracium praealtum* and *Leucopogon fraseri*. There is widespread evidence of frost action, for example, orientation of boulders with long axes downslope, very friable topsoils with profuse spheroidal peds, and bouldery scree deposits. The bouldery screes appear to be inactive at present and may have formed under a colder climate, possibly during the last glaciation.

Very low base saturation values in subsoils, P retention of 45% in the Bw1 horizon, and high KCl-Al values and very low values for MAF Quick Tests all indicate strong leaching.

The soils are deep, and have slightly firm subsoils below 50 cm. Total available water is estimated to be about 135 mm in the rooting zone .

Moderately to strongly acid soils, high KCl-Al values, steep slopes and associated cool climate severely limit the land-use options. Opportunities for pastoral development are limited. Climate limits the range of trees that can be grown, and frost heave affects the establishment of seedlings. Grazing and use of fires must be carefully controlled to prevent tall tussock depletion.

The high percentage of bare ground and presence of *Hieracium* suggest that land use that maintains tussock cover is appropriate on these soils, otherwise weeds may spread, production may decline and erosion may become a risk. Legumes may be successfully established but require regular fertiliser inputs if invasion of unpalatable species or reversion to bare ground is to be avoided.

SUMMARY OF CHEMICAL PROPERTIES

	A horizon	Subsoil to 6 0 cm
pH	5.1	5.7
P retention	medium	medium
Exch. Ca	very low	very low
Exch. Mg	very low	very low
Exch. K	very low	very low
CEC	low	low
BS%	very low	very low
Organic C	–	–

SUMMARY OF PHYSICAL PROPERTIES

Ped development	strong
Soil depth	> 100 cm
Effective rooting depth	> 100 cm
Readily available water (est.)	42 mm
Total available water (est.)	135 mm
Drought risk class (1 = max.; 4 = min.)	
sunny	2
shady	3
Horizon with slow hydraulic conductivity	Bw2 horizon
Erosion risk	moderate (wind)
Drainage	well drained

LAND USE

Typical vegetation	tall tussock, blue tussock, hard tussock, *Leucopogon fraseri, Hieracium*.
Predominant land use	extensive grazing
Maximum pastoral production	not known
Fertiliser requirement for pasture	P, S, lime
Forestry options	none: too high, too exposed
Weed problems	risk of *Hieracium pilosella* invasion if tussock cover depleted by overgrazing or burning
Soil problems	wind erosion, aided by frost heave; could become worse if vegetation is depleted
Conservation values	intact areas of tall tussock and short tussock grassland

PROFILE DESCRIPTION

Horizon	Depth	Description
Ah	0–23 cm	Brown to dark brown slightly gravelly loamy silt; very weak soil strength; strongly developed spheroidal peds; NaF 1/5.
Bw1	23–51 cm	Light olive brown moderately gravelly loamy silt; weak soil strength; moderately developed medium blocky peds; NaF 2/5.
Bw2	51–75 cm	Light yellowish brown very gravelly loamy silt; slightly firm soil strength; weakly developed blocky peds; NaF 3/5.
BC	75–100+ cm	Light yellowish brown very gravelly loamy silt; slightly firm soil strength; brittle failure; massive; NaF 2/5.

Profile ID: Field No: T2
Lab. No: IS00118
Grid reference: NZMS 260 H39 655191

ANALYTICAL DATA

Horizon	Depth (cm)	C (%)	N (%)	Cation Exchange (me%) Ca	Mg	K	Na	∑cations	CEC	BS (%)	P retn (%)	SO_4-S (μg/g)
Ah	0–23	–	–	0.3	0.1	0.2	0.1	11.9	0.7	6	40	6
Bw1	23–51	–	–	0.2	0.1	0.2	0.0	8.2	0.5	6	45	3
Bw2	51–75	–	–	0.2	0.0	0.1	0.1	7.7	0.4	5	37	3
BC	75–100	–	–	0.2	0.0	0.1	0.1	5.6	0.4	6	26	4

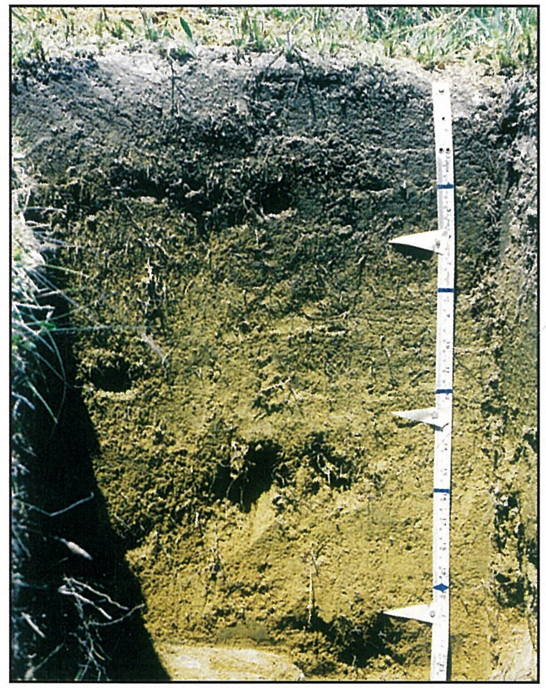
Horizon	Depth (cm)	Stones (%) by wt.	In <2mm fraction Sand	Silt	Clay	pH (H_2O)	Ag Research Quick Tests Ca	P	K	Mg	Na
Ah	0–23	–	24	65	11	5.1	1	3	2	5	2
Bw1	23–51	–	26	62	12	5.7	1	2	2	3	2
Bw2	51–75	–	29	63	8	5.8	1	3	1	3	2
BC	75–100	–	35	58	7	5.9	1	7	1	3	2

Author: P.D. McIntosh, Landcare Research, Dunedin

SOIL FACT SHEET 2
MACKENZIE HILL COUNTRY

soil name	:	**CASS**
related set	:	Cass
equivalent series	:	not defined
subgroup, parent material class	:	**Typic Allophanic Brown Soil, angular-stony**
typical particle size class	:	silty
typical permeability	:	moderate

SOIL PROFILE



12-92(3)-17

KEY FEATURES

- formed on loess over bouldery moraine
- strongly developed spheroidal peds
- P retention values medium
- moderately acid
- strong or very strong reaction to the NaF test
- low fertility

LANDSCAPE

12-92(3)-15

TYPICAL FEATURES

- hummocky moraine topography
- rainfall 800–1000 mm
- tall tussock cover
- on rolling, hilly and steep slopes at 600–100 m

SOIL NOTES

Cass soils are formed in moraines covered with a variable thickness of loess. They are classified as **Brown** soils because they are weathered, and as **Typic Allophanic Brown** soils because they have allophanic properties *viz.*: abundant spneroidal peds in subsoils and a strong reaction to the NaF field test.

In the Ben Ohau Range Cass soils occur up to 1000 m altitude, on landforms forming a series of steps, typical of moraines on hillsides. Consequently, although the overall slope is hilly, most individual slopes are rolling or steep. Vegetation at higher altitudes is dominated by narrow-leaved tall tussock and fescue tussock. *Leucopogon fraseri* and *Hieracium praealtum* occur in inter-tussock spaces. At lower altitudes, especially where cattle have grazed, tussock cover is depleted and introduced plants including sweet vernal and clovers are widespread.

The analysed profile has a curiously high Olsen P value in the gravelly subsoil, possibly a result of weathering of the phosphate-rich mineral apatite.

Estimated total available water in Cass soils is about 160 mm although this figure will vary, depending on the proportion of boulders. The soils offer excellent opportunities for forestry, being generally on hilly rather than steep land, being well drained and friable, and occurring in a favourable rainfall zone.

SUMMARY OF CHEMICAL PROPERTIES

	A horizon	Subsoil to 60 cm
pH	5.2	5.6
P retention	low-medium	medium
Exch. Ca	low	very low
Exch. Mg	low	very low
Exch. K	medium	very low
CEC	–	–
BS%	–	–
Organic C	low	very low

SUMMARY OF PHYSICAL PROPERTIES

Ped development	strong
Soil depth	> 90 cm
Effective rooting depth	> 90 cm
Readily available water (est.)	53 mm
Total available water (est.)	160 mm
Drought risk class (1 = max.; 4 = min.)	
sunny	3
shady	4
Horizon with slow hydraulic conductivity	not present
Erosion risk	slight
Drainage	well drained

LAND USE

Typical vegetation	tall tussock, fescue tussock, *Leucopogon fraseri, Hieracium praealtum*
Predominant land use	extensive grazing
Maximum pastoral production	not known
Fertiliser requirement	P, S
Forestry options	Douglas fir (snow risk for other species)
Weed problems	burning and overgrazing could lead to *Hieracium* invasion.
Soil problems	high cost of applying fertiliser and lime probably precludes oversowing and topdressing
Conservation values	contains many areas of tall tussock grassland in good condition

PROFILE DESCRIPTION

Horizon	Depth	Description
Ah	0–15 cm	Brown to dark brown silt loam; strongly developed spheroidal peds; NaF test 0/5.
AhBw	15–32 cm	Brownish yellow silt loam; 20% brown inclusions; strongly developed spheroidal and polyhedral peds; NaF test 2/5.
Bw	32–53 cm	Brownish yellow silt loam; strongly developed spheroidal peds; NaF test 4/5.
2Bw	53–74 cm	Brownish yellow bouldery silt loam; weakly developed spheroidal peds; NaF test 4/5.
C	74–90 cm	Olive very gravelly sandy loam; single grain; NaF test 4/5.

Profile ID: Field No: R21
Lab. No: IS00381
Grid reference: NZMS 260 H38 622678

ANALYTICAL DATA

Horizon	Depth (cm)	C (%)	N (%)	Cation Exchange (me%) Ca	Mg	K	Na	∑cations	CEC	BS (%)	P retn (%)	SO_4-S (µg/g)
Ah	0–15	2.5	0.19	2.7	0.7	0.3	0.0	–	–	–	29	4
Bw	15–43	1.0	0.07	1.3	0.1	0.0	0.1	–	–	–	34	5
2Bw	43–65	1.1	0.07	0.5	0.1	0.1	0.1	–	–	–	63	3

Horizon	Depth (cm)	Stones (%) by wt.	In <2mm fraction Sand	Silt	Clay	pH (H_2O)	Ag Research Quick Tests Ca	P	K	Mg	Na
Ah	0–15	–	–	–	–	5.2	–	7	–	–	–
Bw	15–43	–	–	–	–	5.5	–	9	–	–	–
2Bw	43–65	–	–	–	–	5.7	–	39	–	–	–

Author: P.D. McIntosh, Landcare Research, Dunedin

SOIL FACT SHEET 3
MACKENZIE HILL COUNTRY

soil name	:	**GRAMPIANS, bouldery phase**
related set	:	Grampians, bouldery
equivalent series	:	Grampians
subgroup, parent material class	:	**Calcareous-sodic Pallic Soil, with stones**
typical particle size class	:	silty
typical permeability	:	slow

SOIL PROFILE

12-90(2)-16

KEY FEATURES

- silty parent material (loess) with boulders
- compact fragipan below 60 cm depth
- weakly developed peds: limited rooting volume
- high fertility (except S)
- salts and carbonate in subsoils
- erosion-prone (wind, tunnel gully)
- low topsoil carbon

LANDSCAPE

12-90(2)-20

TYPICAL FEATURES

- old fans and lower toeslopes of hills at 400–600 m altitude
- undulating to strongly rolling
- few stones or boulders
- rainfall 440–600 mm
- up to 30% bare ground

SOIL NOTES

Grampians soils are **Pallic** soils formed in deep loamy silt (loess) on fans and on footslopes of hills. The loess was probably blown in from adjacent floodplains. The bouldery phase includes soils or boulders in the silty parent material. In the undeveloped state the soils typically have about 30% bare ground and a cover of silver tussock, matagouri, sweet briar, ryegrass, cocksfoot, sorrel, annual clovers and scabweed.

A fragipan (Btx horizon) with clay bands (clay-enriched zones) and eluvial bands (depleted of clay) is present. Permeability is slow to very slow in the fragipan, and a mottled Bg horizon may overlie it. When the soils are irrigated, water may collect above the fragipan. Below the fragipan lime has accumulated. Lime is a product of soil weathering, and under dry conditions it has accumulated because insufficient water passes through soil to leach it out. Estimated total available water is 73 mm.

The soils are slightly acid in upper horizons, and alkaline in subsoil horizons, because of the lime accumulation. Natural fertility, expressed as base saturation (BS) is very high but cation exchange capacity (CEC) is low or very low because of low or very low organic carbon and clay content. The soils are extremely S deficient.

SUMMARY OF CHEMICAL PROPERTIES

	A horizon	Subsoil to 60 cm
pH	6.5	7.8
P retention	very low	very low
Exch. Ca	medium	very low
Exch. Mg	medium	medium
Exch. K	high	very low
CEC	–	–
BS%	very high	very high
Organic C	very low	very low

SUMMARY OF PHYSICAL PROPERTIES

Ped development	weakly developed
Soil depth	> 100 cm
Effective rooting depth	60 cm
Readily available water (est.)	27 mm
Total available water (est.)	73 mm
Drought risk class (1 = max.; 4 = min.)	
sunny	1
shady	2
Horizon with slow hydraulic conductivity	Btx horizon
Erosion risk	moderate
Drainage	well drained

LAND USE

Typical vegetation	silver tussock, cocksfoot, sorrel, scabweed, *Hieracium*, matagouri, sweetbriar
Predominant land use	extensive grazing
Maximum pastoral production	not known
Fertiliser requirement for pasture	c. 200 kg/ha S-superphosphate every 3 years
Forestry options	Corsican pine
Weed problems	briar, *Hieracium*
Soil problems	poor structure, low carbon, wind erosion, droughtiness
Conservation values	vegetation strongly modified

PROFILE DESCRIPTION

Horizon	Depth	Description
Ah	0–22 cm	Dark greyish brown slightly gravelly silt loam; weakly developed blocky peds breaking to polyhedral peds.
AhBw	22–35 cm	Light olive brown slightly gravelly silt loam; slightly firm soil strength; weakly developed blocky peds breaking to polyhedral peds (introduced by earthworms).
E	35–58 cm	Light yellowish brown moderately gravelly loamy silt; firm soil strength; slightly sticky; dilatant; prismatic peds; light olive brown silt coats on faces of peds.
Btx	58–73 cm	Light yellowish brown moderately gravelly silt loam with boulders; very firm soil strength; prismatic peds; yellowish brown clay coats on faces of peds; extremely fine light olive brown sub-parallel lamellae.
Btk	73–85 cm	Light olive brown moderately gravelly silt loam with boulders; very hard soil strength; weakly developed blocky peds; olive brown clay coats on faces of peds; very few extremely fine white bifurcating carbonate veins; many extremely fine olive brown bifurcating lamellae.

Profile ID: Field No: T5
Lab. No: IS00191
Grid reference: NZMS 260 H39 660244

ANALYTICAL DATA

Horizon	Depth (cm)	C (%)	N (%)	Cation Exchange (me%)						BS (%)	P retn (%)	SO_4-S (µg/g)
				Ca	Mg	K	Na	∑cations	CEC			
Ah	0–22	–	–	4.7	1.6	1.1	0.1	7.5	8.4	89	7	0
AhBw	22–35	–	–	3.7	1.8	0.3	0.3	6.0	6.6	91	7	1
E	35–58	–	–	2.9	1.4	0.0	1.8	6.2	4.8	100	5	0
Btx	58–73	–	–	3.3	2.0	0.1	4.1	9.5	6.3	100	5	1
Btk	73–85	–	–	6.9	6.0	0.1	9.2	22.2	11.5	100	12	2

Horizon	Depth (cm)	Stones (%) by wt.	In <2mm fraction			pH (H_2O)	Ag Research Quick Tests				
			Sand	Silt	Clay		Ca	P	K	Mg	Na
Ah	0–22	–	21	65	14	6.5	7	7	18	37	5
AhBw	22–35	–	20	65	15	6.8	7	4	4	49	15
E	35–58	–	23	68	9	8.6	7	2	2	39	95
Btx	58–73	–	20	74	6	9.5	8	4	2	56	235
Btk	73–85	–	12	61	27	9.6	14	6	5	120	260

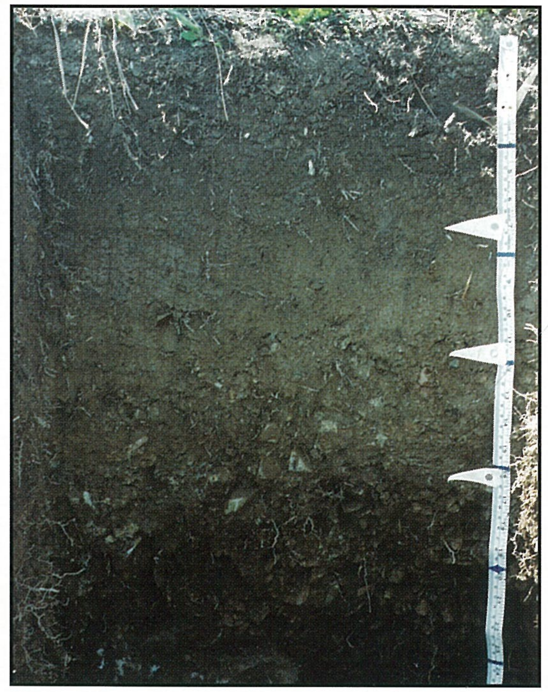
Author: P.D. McIntosh, Landcare Research, Dunedin

SOIL FACT SHEET 4
MACKENZIE HILL COUNTRY

soil name	:	**KAIKOURA, allophanic phase***
related set	:	Kaikoura
equivalent series	:	not defined
subgroup, parent material class	:	**Acidic Allophanic Brown Soil, angular-stony**
typical particle size class	:	silty
typical permeability	:	moderate

*provisional name

SOIL PROFILE



12-92(3)-12

KEY FEATURES

- formed in thin loess over very gravelly colluvium
- high to very high P retention in subsoils
- dark yellowish brown subsoils
- strongly developed spheroidal peds
- very strong reaction to NaF test
- strongly acid and very infertile
- loose gravels in subsoil

LANDSCAPE

TYPICAL FEATURES

- > 1000 m altitude
- above natural treeline
- good tussock cover
- steep slopes
- surface stones and boulders
- rainfall > 1000 mm

SOIL NOTES

A profile was described on a steep west-facing slope at 1200 m on the west (wetter) side of the Ben Ohau Range. The parent material was thin loess over very gravelly colluvium (probably an old scree). The 4.2% carbon in the gravelly subsoil may represent a buried topsoil. The gravelly subsoil has a very strong reaction to the NaF field test and the P retention of the gravelly horizons is high to very high (76-91%). These properties and the soil's good drainage mean the soil is classified as an **Allophanic Brown** soil, and because pH is in the range 5.0 to 5.4 the soil subgroup is **Acidic**. Vegetation at the sampling site was narrow-leaved snow tussock, *Aciphylla* sp., *Hieracium praealtum*, *Lycopodium* and sweet vernal, with 20% bare ground and stones.

The soils are infertile and altitude precludes intensive pastoral or forestry use. Grazing should probably be limited to about 0.2 S.U. per hectare (averaged over the year), to maintain tall tussock cover and prevent exposure of inter-tussock areas and the resulting risk of erosion and *Hieracium* invasion. For the same reasons, fire should not be used for tussock management.

SUMMARY OF CHEMICAL PROPERTIES

	A horizon	Subsoil to 60 cm
pH	5.2	5.2
P	low	medium
retention	very low	very low
Exch. Ca	low	very low
Exch. Mg	low	very low
Exch. K	–	–
CEC	–	–
BS%	low	low
Organic C		

SUMMARY OF PHYSICAL PROPERTIES

Ped development	strong
Soil depth	> 90 cm
Effective rooting depth	> 90 cm
Readily available water (est.)	33 mm
Total available water (est.)	125 mm
Drought risk class (1 = max.; 4 = min.)	
sunny	4
shady	4
Horizon with slow hydraulic conductivity	not present
Erosion risk	severe if vegetation depleted
Drainage	well drained

LAND USE

Typical vegetation	tall tussock grassland
Predominant land use	extensive grazing, many areas retired
Maximum pastoral production	not known
Fertiliser requirement for pasture	P, S, lime
Forestry options	none – too exposed, too steep
Weed problems	burning and overgrazing could lead to *Hieracium* invasion
Soil problems	risk of severe erosion if vegetation cover depleted
Conservation values	extensive areas of tall tussock grassland

PROFILE DESCRIPTION

Horizon	Depth	Description
Ah	0–17 cm	Dark brown silt loam; moderately developed spheroidal peds; NaF test 0/5.
Bw	17–30 cm	Dark yellowish brown silt loam; strongly developed spheroidal peds; NaF test 1/5.
2Bw	30–41 cm	Dark yellowish brown moderately gravelly silt loam; strongly developed spheroidal peds; NaF test 2/5.
2Bh1	41–73 cm	Dark brown extremely gravelly greasy silt loam; loose; NaF test 5/5.
2Bh2	73–90 cm	Dark yellowish brown extremely gravelly greasy silt loam; NaF test 5/5.

Profile ID: Field No: R20
Lab. No: IS00380
Grid reference: NZMS260 H58 625678

ANALYTICAL DATA

Horizon	Depth (cm)	C (%)	N (%)	Cation Exchange (me%)						BS (%)	P retn (%)	SO_4-S (µg/g)
				Ca	Mg	K	Na	∑cations	CEC			
Ah	0–17	2.7	0.10	1.5	0.6	0.4	0.0	–	–	–	27	3
Bw	17–30	2.1	0.20	0.8	0.3	0.2	0.0	–	–	–	35	4
2Bw	30–41	1.7	0.12	0.2	0.1	0.1	0.0	–	–	–	41	3
2Bh1	41–73	4.2	0.18	0.3	0.1	0.1	0.1	–	–	–	91	2
2Bh2	73–90	2.5	0.14	0.2	0.0	0.0	0.2	–	–	–	76	2

Horizon	Depth (cm)	Stones (%) by wt.	In <2mm fraction			pH (H_2O)	Ag Research Quick Tests				
			Sand	Silt	Clay		Ca	P	K	Mg	Na
Ah	0–17	–	–	–	–	5.2	–	7	–	–	–
Bw	17–30	–	–	–	–	5.0	–	4	–	–	–
2Bw	30–41	–	–	–	–	5.0	–	6	–	–	–
2Bh1	41–73	–	–	–	–	5.4	–	7	–	–	–
2Bh2	73–90	–	–	–	–	5.4	–	6	–	–	–

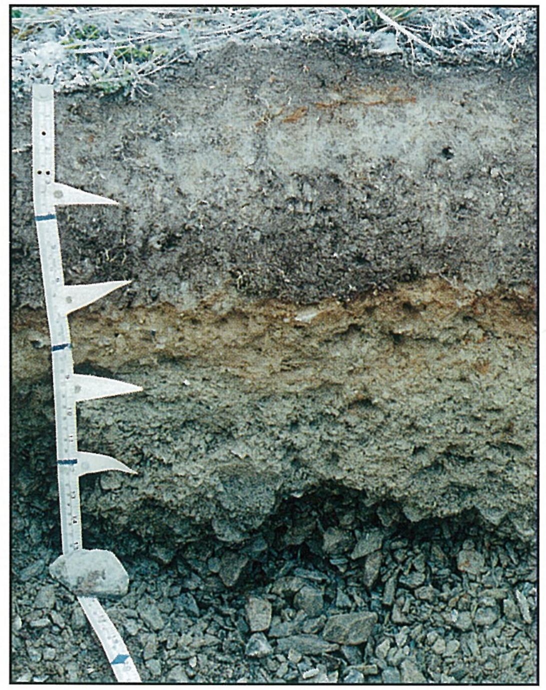
Author: P.D. McIntosh, Landcare Research, Dunedin

SOIL FACT SHEET 5
MACKENZIE HILL COUNTRY

soil name	:	**KAIKOURA, podzol phase***
related set	:	Kaikoura
equivalent series	:	not defined
subgroup, parent material class	:	**Ortstein Pan Podzol, angular-stony**
typical particle size class	:	silty
typical permeability	:	moderate over slow

*provisional name

SOIL PROFILE



12-92(2)-27

KEY FEATURES

- distinct Fe pan, sharp upper boundary
- thin loess over extremely gravelly subsoils
- loose gravels in subsoils
- strongly acid profiles
- extremely low fertility
- strong to very strong reaction to the NaF test

LANDSCAPE

12-92(2)-17

TYPICAL FEATURES

- on stable talus slopes on lower valley sides (see centre of photo)
- unvegetated screes upslope
- above treeline
- > 1000 m altitude
- rolling to steep
- rainfall > 1000 mm

SOIL NOTES

A profile was described on a steep sunny site at 1380 m altitude on a concave footslope in a valley on the east (drier) side of the Ben Ohau Range. It is likely to be typical of Kaikoura soils developed in more stable colluvium, but the range of soil variation needs to be established. The parent material is loose gravelly colluvium, probably an old scree deposit, now stabilised. The soil is classified as an **Ortstein Pan Podzol** because it has a thin, hard iron-cemented pan. The pan restricts root and water penetration. Consequently the rooting depth is only about 20 cm. The soils are strongly acid and extremely leached and infertile. Commercial forestry is excluded because of high altitude. Because the soil contains so few nutrients to support plant growth, the vegetation should be either protected from grazing or grazed only at very low intensity (less than 0.2 S.U. per hectare) to prevent depletion of tall tussock cover and the risk of erosion. For the same reasons, fire should not be used for tussock management.

SUMMARY OF CHEMICAL PROPERTIES

	A horizon	Subsoil to 60 cm
pH	4.8	4.9
P retention	medium	medium
Exch. Ca	very low	very low
Exch. Mg	very low	very low
Exch. K	very low	very low
CEC	–	–
BS%	–	–
Organic C	low	very low

SUMMARY OF PHYSICAL PROPERTIES

Ped development	weak
Soil depth	> 45 cm
Effective rooting depth	17 cm
Readily available water (est.)	10 mm
Total available water (est.)	17 mm
Drought risk class (1 = max.; 4 = min.)	
sunny	2
shady	4
Horizon with slow hydraulic conductivity	Bfm horizon (pan)
Erosion risk	high
Drainage	well drained

LAND USE

Typical vegetation	tall tussock, *Aciphylla*, *Hieracium*, *Dracophyllum*
Predominant land use	extensive grazing
Maximum pastoral production	not known
Fertiliser requirement for pasture	P, S, lime
Forestry options	none: too high, too cold, snow risk
Weed problems	risk of *Hieracium* invasion if tussock burnt or overgrazed
Soil problems	very high erosion risk if vegetation depleted
Conservation values	vegetation and landscape is relatively unmodified by human influence

PROFILE DESCRIPTION

Horizon	Depth	Description
Ah	0–8 cm	Pale brown very slightly gravelly loamy silt; few strong brown mottles (strongly weathered gravels); massive; NaF test 0/5.
Ahw	8–17 cm	Brown to dark brown very slightly gravelly silt loam; weakly developed polyhedral peds; NaF test 2/5.
Bfm	17–23 cm	Brown slightly gravelly silt loam (top 2 mm), strong brown (below top) silt loam; hard; massive; NaF test 5/5.
BC	23–30 cm	Light yellowish brown moderately gravelly loamy silt; massive; NaF test 4/5.
2BC	30–45+ cm	Light yellowish brown extremely gravelly sand; 95% angular greywacke gravels, loose; NaF test 3/5.

Profile ID: Field No: R8
Lab. No: IS99374
Grid reference: NZMS 260 H38 662668

ANALYTICAL DATA

Horizon	Depth (cm)	C (%)	N (%)	Cation Exchange (me%) Ca	Mg	K	Na	∑cations	CEC	BS (%)	P retn (%)	SO_4-S (µg/g)
Ah	0–8	2.1	0.12	0.5	0.2	0.3	0.0	–	–	–	37	3
ABw	8–17	2.9	0.13	0.0	0.0	0.2	0.0	–	–	–	60	2
Bfm	17–23	1.5	0.04	0.2	0.0	0.1	0.0	–	–	–	58	2
BC	23–30	0.43	0.02	0.0	0.0	0.0	0.0	–	–	–	27	2
2BC	30–45	0.66	0.03	0.1	0.0	0.1	0.1	–	–	–	30	2

Horizon	Depth (cm)	Stones (%) by wt.	In <2mm fraction Sand	Silt	Clay	pH (H_2O)	Ag Research Quick Tests Ca	P	K	Mg	Na
Ah	0–8	–	–	–	–	4.8	–	3	–	–	–
ABw	8–17	–	–	–	–	4.8	–	3	–	–	–
Bfm	17–23	–	–	–	–	4.9	–	1	–	–	–
BC	23–30	–	–	–	–	5.0	–	4	–	–	–
2BC	30–45	–	–	–	–	4.9	–	13	–	–	–

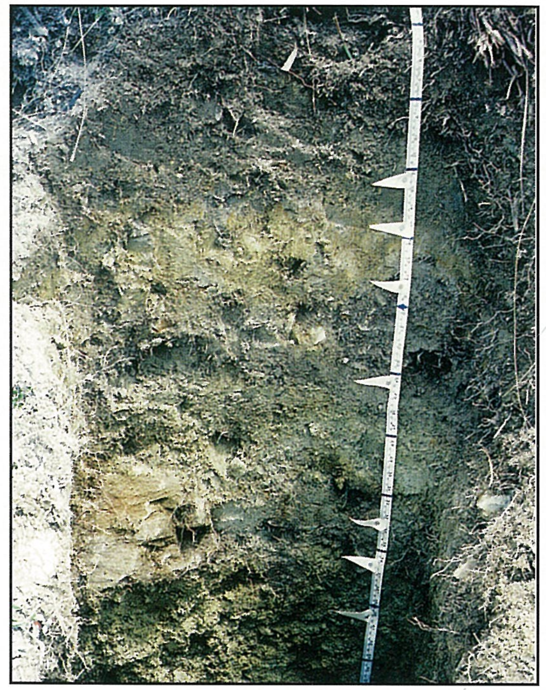
Author: P.D. McIntosh, Landcare Research, Dunedin

SOIL FACT SHEET 6
MACKENZIE HILL COUNTRY

soil name	:	**KAIKOURA, recent phase***
related set	:	Kaikoura
equivalent series	:	not defined
subgroup, parent material class	:	**Acidic-weathered Orthic Recent Soil, with stones**
typical particle size class	:	silty
typical permeability	:	moderate

*provisional name

SOIL PROFILE



12-92(2)-19

KEY FEATURES

- thin topsoils
- buried topsoils in profile
- irregular carbon percentage down profile
- strongly acid and infertile
- medium P retention
- alternating gravelly and silty layers
- strong to very strong reaction to NaF test

LANDSCAPE

12-92(2)-22

TYPICAL FEATURES

- > 1000 m altitude
- steep slopes
- 20% bare ground
- stones on surface
- mostly on sunny slopes
- many rock outcrops
- rainfall > 1000 mm

SOIL NOTES

A profile was described on a steep sunny site at 1200 m on the east (drier) side of the Ben Ohau Range. The parent material is gravelly colluvium. Two buried topsoils are evident in the soil profile, showing that there have been periods of instability at the sampling site. The presence of buried topsoils mean that the soil is classified as a **Recent** soil, and the pH of less than 5.5 in all subsoil horizons and lack of other distinguishing characteristics mean that the soil is an **Acidic-weathered Orthic Recent** soil.

At the sampling site narrow-leaved snow tussock is dominant. *Leucopogon colensoi*, *Gaultheria* sp. and *Hebe* sp. occur in inter-tussock spaces, and there is 20% bare ground.

The soils are strongly acid and infertile and altitude precludes intensive pastoral or forestry use. Grazing should be very limited, so that snow tussock cover is maintained. The risk of erosion of these soils is high and fires should not be used as a tussock management tool.

SUMMARY OF CHEMICAL PROPERTIES

	A horizon	Subsoil to 60 cm
pH	4.9	4.7
P retention	medium	medium
Exch. Ca	very low	very low
Exch. Mg	very low	very low
Exch. K	low	very low
CEC	–	–
BS%	–	–
Organic C	low	low

SUMMARY OF PHYSICAL PROPERTIES

Ped development	strong to none
Soil depth	> 100 cm
Effective rooting depth	> 100 cm
Readily available water (est.)	64 mm
Total available water (est.)	164 mm
Drought risk class (1 = max.; 4 = min.)	
sunny	4
shady	4
Horizon with slow hydraulic conductivity	not present
Erosion risk	high
Drainage	well drained

LAND USE

Typical vegetation	tall tussock, *Gaultheria, Hebe, Aciphylla, Leucopogon fraseri*
Predominant land use	extensive grazing
Maximum pastoral production	not known
Fertiliser requirement for pasture	P, S, lime
Forestry options	none – too high, too exposed, too steep
Weed problems	*Hieracium* if vegetation depleted by burning or overgrazing
Soil problems	severe erosion a risk if vegetation is depleted
Conservation values	tall tussock vegetation appears to be partly depleted, but this may be its natural state

PROFILE DESCRIPTION

Horizon	Depth	Description
Ah	0–32 cm	Dark yellowish brown slightly gravelly silt loam; strongly developed spheroidal peds; NaF test 1/5.
BC	32–38 cm	Brown slightly gravelly silt loam; massive; NaF test 1/5.
BC(g)	38–47 cm	Olive yellow moderately gravelly silt loam; massive 20% greyish brown mottles; NaF test 1/5.
bAh	47–62 cm	Greyish brown slightly gravelly silt loam; massive; NaF test 2/5.
2bBC(g)	62–85 cm	Pale yellow very gravelly silt loam; 20% dark yellowish brown mottles; massive; NaF test 3/5.
3bAh	85–93 cm	Olive brown slightly gravelly silt loam; massive; NaF test 4/5.
3bBw	93–102 cm	Light yellowish brown slightly gravelly silt loam; 10% angular greywacke gravels; massive; NaF test 4/5.
3bBC	102–120 cm	Light olive brown slightly gravelly silt loam; 30% light olive brown mottles (clay-organic coats); structureless; NaF test 4/5.

Profile ID: Field No: R7
Lab. No: IS00373
Grid reference: NZMS 260 H38 673669

ANALYTICAL DATA

Horizon	Depth (cm)	C (%)	N (%)	Cation Exchange (me%)						BS (%)	P retn (%)	SO_4-S (µg/g)
				Ca	Mg	K	Na	∑cations	CEC			
Ah	0–32	4.1	0.19	0.4	0.2	0.3	0.0	–	–	–	34	5
BC	32–38	2.9	0.15	0.2	0.1	0.2	0.0	–	–	–	46	3
BCg	38–47	2.5	0.14	0.1	0.1	0.1	0.0	–	–	–	49	3
bAh	47–62	2.3	0.12	0.0	0.1	0.1	0.0	–	–	–	46	2
2bBC(g)	62–85	1.6	0.08	0.0	0.0	0.1	0.0	–	–	–	42	1
3bAh	85–93	2.2	1.09	0.0	0.0	0.1	0.0	–	–	–	55	1
3bBw	93–102	1.5	0.07	0.1	0.0	0.0	0.0	–	–	–	48	1
3bBC	102–120	1.0	0.04	0.0	0.0	0.0	0.0	–	–	–	43	2

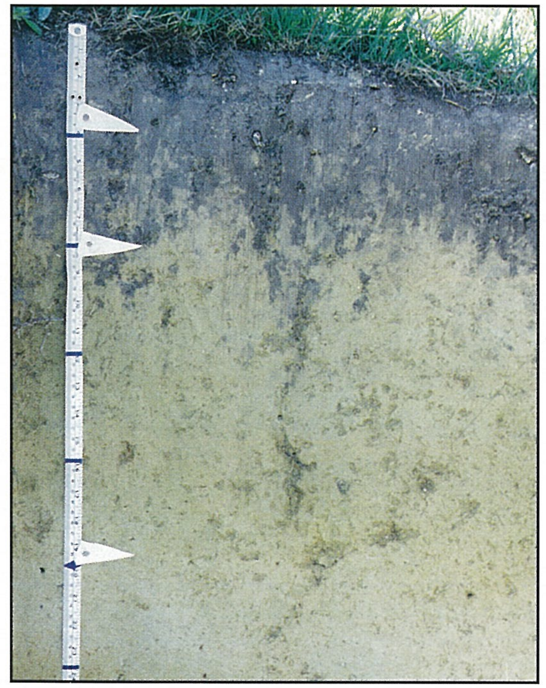
Horizon	Depth (cm)	Stones (%) by wt.	In <2mm fraction			pH (H_2O)	Ag Research Quick Tests				
			Sand	Silt	Clay		Ca	P	K	Mg	Na
Ah	0–32	–	–	–	–	4.9	–	3	–	–	–
BC	32–38	–	–	–	–	4.7	–	1	–	–	–
BCg	38–47	–	–	–	–	4.6	–	1	–	–	–
bAh	47–62	–	–	–	–	4.7	–	1	–	–	–
2bBC(g)	62–85	–	–	–	–	4.8	–	1	–	–	–
3bAh	85–93	–	–	–	–	4.8	–	0	–	–	–
3bBw	93–102	–	–	–	–	4.9	–	0	–	–	–
3bBC	102–120	–	–	–	–	4.8	–	3	–	–	–

Author: P.D. McIntosh, Landcare Research, Dunedin

SOIL FACT SHEET 7
MACKENZIE HILL COUNTRY

soil name	:	**MESOPOTAMIA**
related set	:	Mesopotamia
equivalent series	:	Mesopotamia
subgroup, parent material class	:	**Typic Immature Pallic Soil, stoneless**
typical particle size class	:	silty
typical permeability	:	moderate over slow

SOIL PROFILE



12-92(3)-9

KEY FEATURES

- pale-coloured profiles
- formed in deep loess
- firm subsoils
- high RAW and TAW
- buried soils present
- moderately acid

LANDSCAPE

12-90(3)-6

TYPICAL FEATURES

- on rolling or hilly land near floodplains
- at 400–800 m altitude
- rainfall 800–1000 mm
- beech remnants, scrub

SOIL NOTES

Mesopotamia soils occur to the south and east of floodplains of major rivers, and were described on slopes in the 540 m to 700 m range, on lower slopes northeast of Lake Ohau. They are formed in thick loess that has been blown off nearby floodplains by northwesterly winds, and has accumulated on fans, terraces and moraines downwind. The loess is a young deposit, as shown by its pale colour and the fact that it has buried older soils. The pale colours and firm subsoils are typical of **Immature Pallic Soils**. The buried soil in the described profile (at 64 cm depth) is marked by a change in colour to brownish yellow and an increase in P retention from 25% above the boundary to 53% below it, indicating that the older, lower horizon is considerably more weathered.

Natural vegetation has been largely modified. East of Lake Ohau the soils support short tussock grassland, scrub species, introduced clovers, and exotic conifer forest.

The soils are moderately acid and are not naturally fertile, as Olsen P and exchangeable calcium, magnesium and potassium levels are all low to moderate. The higher P retention in the buried horizon below 64 cm depth appears to have trapped sulphate in rainfall and consequently SO_4-S values in this horizon are medium.

Mesopotamia soils are outstanding soils for commercial Douglas fir production probably because of their excellent soil moisture storage as well as their occurrence in an area with favourable climate.

SUMMARY OF CHEMICAL PROPERTIES

	A horizon	Subsoil to 60 cm
pH	5.2	5.3
P retention	low	low
Exch. Ca	low	very low
Exch. Mg	medium	low
Exch. K	low	very low
CEC	–	–
BS%	–	–
Organic C	low	very low

SUMMARY OF PHYSICAL PROPERTIES

Ped development	moderate
Soil depth	> 100 cm
Effective rooting depth	> 100 cm
Readily available water (est.)	52 mm
Total available water (est.)	121 mm
Drought risk class (1 = max.; 4 = min.)	
sunny	3
shady	4
Horizon with slow hydraulic conductivity	C horizon
Erosion risk	slight
Drainage	well drained

LAND USE

Typical vegetation	fescue tussock grassland, bracken fern and minor areas of exotic conifer and beech forest
Predominant land use	extensive grazing, plantation forestry
Maximum pastoral production	not known
Fertiliser requirement for pasture	P, S
Forestry options	Douglas fir – very high growth rates
Weed problems	matagouri, scrub invasion
Soil problems	no serious problems
Conservation values	remnant areas of beech forest

PROFILE DESCRIPTION

Horizon	Depth	Description
Ah	0–9 cm	Greyish brown silt loam; moderately developed polyhedral peds; NaF test 1/5.
Ah/Bw	9–20 cm	Olive yellow silt loam; 40% greyish brown inclusions of horizon above; moderately developed polyhedral peds; NaF test 0/5.
Bw	20–49 cm	Olive yellow silt loam; prismatic peds breaking to blocky peds; slightly firm; NaF test 2/5.
C	49–64 cm	Pale yellow loamy silt; coarse blocky peds; firm; NaF test 0/5.
bBw	64–90 cm	Brownish yellow clay loam; 20% light grey mottles; friable; massive; NaF test 3/5.
2bBC	90–100+ cm	Reddish yellow very gravelly sandy loam.

Profile ID: Field No: R18
Lab. No: IS00379
Grid reference: NZMS 260 H38 601644

ANALYTICAL DATA

Horizon	Depth (cm)	C (%)	N (%)	Cation Exchange (me%)						BS (%)	P retn (%)	SO_4-S (µg/g)
				Ca	Mg	K	Na	∑cations	CEC			
Ah	0–9	3.9	0.26	4.9	1.3	0.4	0.0	–	–	–	15	3
Ah/Bw	9–20	1.9	0.13	2.7	0.8	0.2	0.0	–	–	–	27	2
Bw	20–49	0.67	0.05	0.4	0.2	0.1	0.0	–	–	–	27	2
C	49–64	0.30	0.03	0.5	0.2	0.1	0.0	–	–	–	25	3
bBw	64–90	0.56	0.04	0.2	1.0	0.1	0.1	–	–	–	53	25

Horizon	Depth (cm)	Stones (%) by wt.	In <2mm fraction			pH (H_2O)	Ag Research Quick Tests				
			Sand	Silt	Clay		Ca	P	K	Mg	Na
Ah	0–9	–	–	–	–	5.2	–	6	–	–	–
Ah/Bw	9–20	–	–	–	–	5.3	–	1	–	–	–
Bw	20–49	–	–	–	–	5.3	–	0	–	–	–
C	49–64	–	–	–	–	5.2	–	0	–	–	–
bBw	64–90	–	–	–	–	5.6	–	1	–	–	–

Author: P.D. McIntosh, Landcare Research, Dunedin

SOIL FACT SHEET 8
MACKENZIE HILL COUNTRY

soil name	:	**MEYER**
related set	:	Meyer
equivalent series	:	Meyer
subgroup, parent material class	:	**Typic Orthic Recent Soil, angular-stony**
typical particle size class	:	silty
typical permeability	:	rapid

SOIL PROFILE

12-90(1)-12

KEY FEATURES

- formed in slope colluvium 45–90 cm thick over rock
- very gravelly
- moderately fertile (except for S)
- low RAW and TAW; very drought-prone
- pale Bw horizon
- erosion-prone
- low topsoil carbon
- moderately to slightly acid

LANDSCAPE

5-91-0

TYPICAL FEATURES

- at 400–800 m altitude
- mostly on hilly and steep slopes
- sunny and shady aspects
- rainfall < 800 mm
- common surface stones and outcrops; up to 30% bare ground

SOIL NOTES

Meyer soils, are **Recent** soils formed in moderately deep angular greywacke or subschist colluvium and overlying jointed rock. A pale Bw horizon is present but the soils have neither the brown subsoils characteristic of **Brown** Soils nor the clay banding characteristic of **Pallic** soils.

The soils occur mainly on sunny hill slopes and are often associated with the shallower Omarama soils which occur mainly on steep slopes. The soil surface is typically gravelly or bouldery with up to 30% bare ground. The soils are prone to wind erosion. Vegetation is typically vipers bugloss, cocksfoot, sweet vernal, blue tussock, haresfoot trefoil and white clover

The soils are moderately fertile but have low natural SO_4-S levels. In the analysed profile SO_4-S levels, and probably Olsen P levels also, reflect topdressing. The pH levels are lower than those prevailing in undeveloped natural soils.

Meyer soils occur mostly below 800 m and almost invariably are droughty in summer. Deep-rooting perennial legumes such as lucerne and birdsfoot trefoil will persist, but are difficult to establish. Without topdressing and oversowing, yields from the semi-natural cover range from 0.5 to 1.0 t DM/ha. At Tara Hills, yields have been increased to about 1.5 t/ha with topdressing and oversowing, using maintenance fertiliser rates of 125 kg/ha of 33% S-superphosphate every three years, but under experimental conditions potential yields are larger. Grass species suitable for Meyer soils include ryegrass and cocksfoot. Because of the dry climate neither Argentine stem weevil nor grass grubs are a problem.

The soils are deeper than adjacent Omarama soils and may be the most favourable sunny slope sites for trees for shade and shelter. Corsican pine, Ponderosa pine and *Eucalyptus gunnii* may be suitable, but require assessment. Commercial timber production is unlikely to be economic because of slow growth rates, and bad tree form resulting from exposure to northwesterly winds.

SUMMARY OF CHEMICAL PROPERTIES

	A horizon	Subsoil to 60 cm
pH	5.6	5.7
P retention	low	very low
Exch. Ca	low	very low
Exch. Mg	low	low
Exch. K	low	very low
CEC	low	very low
BS%	medium	medium
Organic C	low	very low

SUMMARY OF PHYSICAL PROPERTIES

Ped development	weakly developed
Soil depth	45–90 cm
Effective rooting depth	45–90 cm
Readily available water (est.)	40 mm
Total available water (est.)	70 mm
Drought risk class (1 = max.; 4 = min.)	
sunny	1
shady	2
Horizon with slow hydraulic conductivity	not present
Erosion risk	wind
Drainage	well drained

LAND USE

Typical vegetation	vipers bugloss, cocksfoot, sweet vernal, blue tussock, silver tussock, haresfoot trefoil
Predominant land use	extensive grazing
Maximum pastoral production	3 t/ha/yr
Fertiliser requirement for pasture	c. 125 kg/ha S-superphosphate every three years
Forestry options	Corsican pine, Pondersosa pine (conservation planting)
Weed problems	briar
Soil problems	poor structure, low carbon, wind erosion, acidification, droughtiness
Conservation values	vegetation strongly modified

PROFILE DESCRIPTION

Horizon	Depth	Description
Ah	0–15 cm	Dark brown moderately gravelly silt loam; very weak soil strength; weakly developed polyhedral and spheroidal peds.
AhBw	15–28 cm	Light olive brown very gravelly silt loam; very weak soil strength; weakly developed polyhedral peds.
Bw	28–46 cm	Light olive brown very gravelly loamy silt; very weak soil strength; weakly developed blocky.
Cu	46–85 cm	Light yellowish brown extremely gravelly loamy silt; very weak soil strength; massive.
R	85+ cm	Jointed subschist.

Profile ID: Field No: T8
Lab. No: IS00194
Grid reference: NZMS 260 633230

ANALYTICAL DATA

Horizon	Depth (cm)	C (%)	N (%)	Cation Exchange (me%) Ca	Mg	K	Na	∑cations	CEC	BS (%)	P retn (%)	SO_4-S (µg/g)
Ah	0–15	–	–	2.8	0.7	0.4	0.0	3.9	–	53	12	8
AhBw	15–28	–	–	2.0	0.6	0.3	0.1	2.9	–	47	11	7
Bw	28–46	–	–	1.5	0.5	0.2	0.1	2.1	–	37	10	3
Cu	46–85	–	–	2.0	0.8	0.2	0.1	3.0	–	58	5	3

Horizon	Depth (cm)	Stones (%) by wt.	In <2mm fraction Sand	Silt	Clay	pH (H_2O)	Ag Research Quick Tests Ca	P	K	Mg	Na
Ah	0–15	–	32	58	10	5.6	5	12	10	19	2
AhBw	15–28	–	35	54	11	5.5	4	8	5	16	3
Bw	28–46	–	45	49	6	5.6	3	15	3	15	4
Cu	46–85	–	40	56	4	5.9	5	3	5	26	7

Author: P.D. McIntosh, Landcare Research, Dunedin

SOIL FACT SHEET 9
MACKENZIE HILL COUNTRY

soil name	:	**MEYER, deep phase***
related set	:	Meyer
equivalent series	:	Meyer
subgroup, parent material class	:	**Weathered Orthic Recent Soil, angular-stony**
typical particle size class	:	silty
typical permeability	:	rapid

*provisional name

SOIL PROFILE

10-92(2)-22

KEY FEATURES

- deep soils, > 90 cm depth
- very gravelly
- moderately fertile (except for S)
- low RAW and TAW
- pale Bw horizon
- erosion-prone
- low topsoil carbon
- slightly acid to near-neutral

LANDSCAPE

12-92(2)-34

TYPICAL FEATURES

- at 400–1000 m altitude
- mostly on steep slopes
- sunny and shady aspects
- rainfall 400–600 mm
- surface stones and boulders
- up to 30% bare ground

SOIL NOTES

Meyer soils, deep phase are **Recent** soils formed in deep angular greywacke or subschist colluvium and overlying jointed rock. A pale Bw horizon is present but the soils have neither the brown subsoils characteristic of **Brown** Soils nor the clay banding characteristic of **Pallic** soils.

The soils occur mainly on both sunny and shady slopes and are often associated with the shallower Omarama soils. The soil surface is typically gravelly or bouldery with up to 30% bare ground. The soils are prone to wind erosion. Vegetation is typically silver tussock, vipers bugloss, cocksfoot, sweet vernal, blue tussock, haresfoot trefoil and white clover.

The soils are moderately fertile but have very low natural SO_4-S levels.

Meyer soils occur mostly below 800 m and almost invariably are droughty in summer. Deep-rooting perennial legumes such as lucerne and birdsfoot trefoil will persist, but are difficult to establish by oversowing because of droughtiness. Without topdressing and oversowing, yields from the semi-natural cover range from 0.5 to 1.0 t DM/ha. At Tara Hills yields have been increased to about 1.5 t/ha with topdressing and oversowing, using maintenance fertiliser rates of 125 kg/ha of 33% S-superphosphate every three years, but under experimental conditions potential yields are larger. Grass species suitable for Meyer soils include ryegrass and cocksfoot. Because of the dry climate neither Argentine stem weevil nor grass grubs are a problem.

The soils are deeper than adjacent Omarama soils and may be the most favourable sunny slope sites for trees for shade and shelter. Corsican pine, Ponderosa pine and *Eucalyptus gunnii* may be suitable, but require assessment. Commercial timber production is unlikely to be economic because of slow growth rates, and bad tree form resulting from exposure to northwesterly winds.

SUMMARY OF CHEMICAL PROPERTIES

	A horizon	Subsoil to 60 cm
pH	6.6	6.4
P retention	low	very low
Exch. Ca	medium	medium
Exch. Mg	medium	medium
Exch. K	medium	low
CEC	low	low
BS%	very high	very high
Organic C	very high	low

SUMMARY OF PHYSICAL PROPERTIES

Ped development	weak
Soil depth	> 45 cm
Effective rooting depth	> 45 cm
Readily available water (est.)	39 mm
Total available water (est.)	98 mm
Drought risk class (1 = max.; 4 = min.)	
sunny	1
shady	2, some 3
Horizon with slow hydraulic conductivity	not present
Erosion risk	high
Drainage	well drained

LAND USE

Typical vegetation	silver tussock, sweet vernal
Predominant land use	extensive grazing
Maximum pastoral production	c. 4t/ha/yr
Fertiliser requirement	c. 200 kg/ha S-superphosphate every three years
Forestry options	not economic; Corsican pine for soil conservation
Weed problems	briar
Soil problems	low carbon; erosion; droughtiness
Conservation values	most vegetation is strongly modified

PROFILE DESCRIPTION

Horizon	Depth	Description
Ah	0–10 cm	Dark brown loamy silt; weak soil strength; massive.
2Ah/Bw	10–23 cm	Dark brown moderately gravelly silt loam; weak soil strength; weakly developed blocky peds.
2Bw	23–37 cm	Yellowish brown very gravelly loamy silt; weak soil strength; weakly developed blocky peds.
2BCt	37–78 cm	Light olive brown very gravelly loamy silt; weak soil strength; massive; dark yellowish brown clay lamellae 5 mm thick.
3C	78–94 cm	Light olive brown moderately gravelly loamy silt; slightly firm; massive; clay cutans in pores.

Profile ID: Field No: G56
Lab. No: IS655a-e
Grid reference: NZMS 260 H39 836453

ANALYTICAL DATA

Horizon	Depth (cm)	C (%)	N (%)	Cation Exchange (me%) Ca	Mg	K	Na	∑cations	CEC	BS (%)	P retn (%)	SO_4-S (µg/g)
Ah	0–10	1.7	0.14	6.98	1.42	0.58	0.03	9.01	9.9	91	10	1
2Ah/Bw	10–23	1.1	0.10	5.61	1.22	0.60	0.03	7.46	8.7	86	11	2
2Bw	23–37	0.54	0.06	4.97	1.44	0.34	0.08	6.83	7.4	92	9	1
2BCt	37–78	0.23	0.02	4.71	2.23	0.13	0.07	7.14	6.9	100	7	0
3C	78–94	0.14	0.02	6.34	4.92	0.06	0.25	11.57	8.8	100	6	0

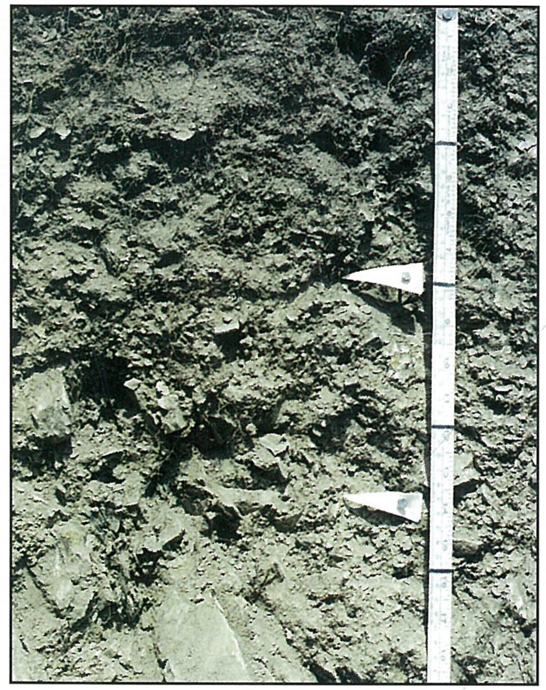
Horizon	Depth (cm)	Stones (%) by wt.	In <2mm fraction Sand	Silt	Clay	pH (H_2O)	Ag Research Quick Tests Ca	P	K	Mg	Na
Ah	0–10	–	39	44	17	6.6	–	–	–	–	–
2Ah/B	10–23	–	37	41	21	6.3	–	–	–	–	–
2Bw	23–37	–	44	44	12	6.3	–	–	–	–	–
2BCt	37–78	–	32	52	16	6.6	–	–	–	–	–
3C	78–94	–	27	60	13	7.1	–	–	–	–	–

Author: P.D. McIntosh, Landcare Research, Dunedin

SOIL FACT SHEET 10
MACKENZIE HILL COUNTRY

soil name	:	**OMARAMA**
related set	:	Omarama
equivalent series	:	Omarama
subgroup, parent material class	:	**Typic Orthic Recent Soil, lithic**
typical particle size class	:	skeletal
typical permeability	:	rapid

SOIL PROFILE

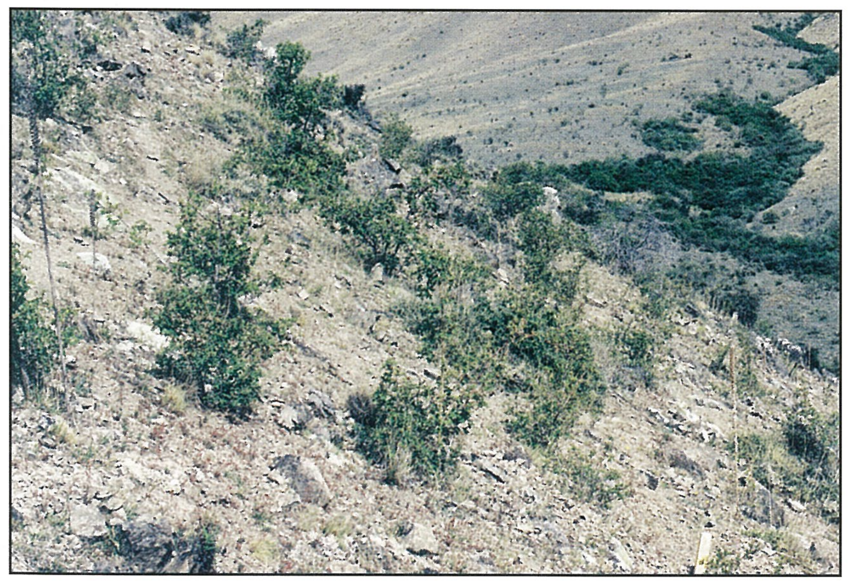


12-90(1)-17

KEY FEATURES

- shallow stony soils, < 45 cm to rock
- extremely drought-prone
- moderate fertility, slightly acid
- low topsoil carbon
- weakly developed peds
- pale Bw horizon
- erosion-prone
- associated with rock outcrops

LANDSCAPE



11-93-24

TYPICAL FEATURES

- 400–1000 m altitude
- mostly on steep slopes
- mostly on sunny aspects
- rainfall < 800 mm
- rocks and boulders on surface
- up to 40% bare ground

SOIL NOTES

Omarama soils, are **Recent** soils formed in up to 45 cm of angular greywacke or subschist colluvium over jointed rock. As in Meyer soils, a Bw horizon is weakly developed but the soils have neither the colours characteristic of **Brown** soils nor the clay accumulation features of **Pallic** soils.

Omarama soils occur mostly on sunny steep slopes, but also on convex ridge crests and hills and planar steep shady slopes. The soil surface is often gravelly or bouldery and commonly has about 30% bare ground. Thin A horizons at some sites indicates topsoil erosion. Cocksfoot, vipers bugloss, blue tussock, haresfoot trefoil, silver tussock, clover, mullein, sweet briar, matagouri and *Hymenanthera* are characteristic plant covers.

Omarama soils have high natural fertility (except for pronounced S deficiency) and are slightly acid. The soils fall into two altitude zones requiring different management. Below 800 m altitude the soils are extremely droughty and establishment of perennial legumes is very difficult. Haresfoot trefoil, suckling clover and subterranean clover are valuable N-fixers, but dry-matter production is in the range 1.0 to 2.5 t/ha. Above 800 m white, alsike and red clover in association with cocksfoot and ryegrass can be established, giving higher production of 2.0 to 3.5 t/ha. Correction of S deficiency is required before legumes will successfully establish. Production is greatest in the spring and varies greatly from season to season because of the low amounts of total available soil water. On Tara Hills the maintenance fertiliser used is the same as on Meyer soils, *i.e.* 125 kg/ha of 33% S-superphosphate every three years.

Commercial timber production is not economic. Corsican pine, Ponderosa pine and *Eucalyptus gunnii* may be suitable shade species, but require assessment. Most eucalypts are likely to be unsuitable because of the risk of unseasonal frosts. The low cation exchange capacity means that soil acidification is a risk.

SUMMARY OF CHEMICAL PROPERTIES

	A horizon	Subsoil to 60 cm
pH	6.1	6.4
P retention	low	low
Exch. Ca	low	low
Exch. Mg	medium	medium
Exch. K	low	low
CEC	low	low
BS%	high	very high
Organic C	very low	very low

SUMMARY OF PHYSICAL PROPERTIES

Ped development	weak
Soil depth	< 45 cm
Effective rooting depth	< 45 cm
Readily available water (est.)	15 mm
Total available water (est.)	35 mm
Drought risk class (1 = max.; 4 = min.)	
sunny	1
shady	2
Horizon with slow hydraulic conductivity	not present
Erosion risk	high
Drainage	well drained

LAND USE

Typical vegetation	cocksfoot, vipers bugloss, haresfoot trefoil, silver tussock, mullein, sweet briar, matagouri
Predominant land use	rough grazing
Maximum pastoral production	2–3.5 t/ha/yr
Fertiliser requirement for pasture	c. 125 kg/ha S-superphosphate every three years
Forestry options	Corsican pine, Ponderosa pine (for soil conservation only)
Weed problems	briar
Soil problems	poor structure, low carbon, wind erosion, acidification, droughtiness
Conservation values	vegetation strongly modified

PROFILE DESCRIPTION

Horizon	Depth	Description
Ah	0–19 cm	Dark brown very gravelly silt loam; weak soil strength; weakly developed polyhedral and spheroidal peds.
Ah/Bw	19–36 cm	Yellowish brown and dark brown very gravelly silt loam; weak soil strength; weakly developed polyhedral peds.
Cu/R	36–46 cm	Yellowish brown very gravelly silt loam; firm soil strength; weakly developed peds.
R	46+ cm	Jointed rock.

Profile ID: Field No: T9
Lab. No: IS00195
Grid reference: NZMS 260 H39 637233

ANALYTICAL DATA

Horizon	Depth (cm)	C (%)	N (%)	Cation Exchange (me%) Ca	Mg	K	Na	∑cations	CEC	BS (%)	P retn (%)	SO_4-S (µg/g)
Ah	0–19	1.6	0.15	4.7	1.0	0.4	0.0	6.1	7.9	77	10	5
Ah/Bw	19–36	0.90	0.11	4.2	1.1	0.3	0.0	5.6	7.0	80	11	4
Cu/R	36–46	–	–	3.7	1.1	0.3	0.0	5.0	6.0	84	8	1

Horizon	Depth (cm)	Stones (%) by wt.	In <2mm fraction Sand	Silt	Clay	pH (H_2O)	Ag Research Quick Tests Ca	P	K	Mg	Na
Ah	0–19	–	40	51	11	6.1	7	6	8	29	2
Ah/Bw	19–36	–	36	51	13	6.3	7	4	5	30	2
Cu/R	36–46	–	35	54	11	6.6	7	3	5	35	3

Author: P.D. McIntosh, Landcare Research, Dunedin

SOIL FACT SHEET 11
MACKENZIE HILL COUNTRY

soil name	:	**QUAILBURN**
related set	:	Benmore
equivalent series	:	Quailburn
subgroup, parent material class	:	**Acidic Orthic Brown Soil, angular-stony**
typical particle size class	:	silty
typical permeability	:	moderate

SOIL PROFILE

12-90(2)-7

KEY FEATURES

- profiles 45–90 cm deep
- no firm horizon: friable throughout
- parent material is loess over colluvium
- weak to moderate reaction to NaF test
- moderately acid profiles

LANDSCAPE

12-90(3)-14,15

TYPICAL FEATURES

- rolling ridge crests
- tall tussock cover
- > 1000 m altitude
- up to 50% bare ground
- rainfall 600–800 mm

SOIL NOTES

Quailburn soils are **Brown** soils formed in moderately deep angular schist or greywacke colluvium on rolling or hilly land. Subsoils have a pH less than 5.5 in the Bw horizon and therefore the soils are classified as an **Acidic Orthic Brown** soils.

Quailburn soils generally occur on convex ridge crests, but also occur on hilly and steep slopes. In their natural state they have a cover of narrow-leaved snow tussock, introduced grasses and short tussock with up to 50% bare ground.

The soils have higher clay content and P retention values, and lower base saturation and pH values than Omarama or Meyer soils in equivalent landscape positions at lower altitude, which shows that Quailburn soils are more leached and weathered.

The main limitations for pasture are cool climate, short growing season and P and S deficiency. Low temperatures and exposure to wind and snow damage means the soils are unsuitable for forestry.

These soils are susceptible to wind erosion and weed invasion if tall tussock cover is depleted, so grazing must be carefully controlled. If fire is used as a management tool, intervals between fires should be at least 14 years.

SUMMARY OF CHEMICAL PROPERTIES

	A horizon	Subsoil to 60 cm
pH	5.4	5.4
P retention	low	low
Exch. Ca	low	very low
Exch. Mg	medium	low
Exch. K	low	very low
CEC	medium	low
BS%	low	low
Organic C	–	–

SUMMARY OF PHYSICAL PROPERTIES

Ped development	moderate
Soil depth	45–90 cm
Effective rooting depth	c. 60 cm
Readily available water (est.)	60 mm
Total available water (est.)	124 mm
Drought risk class (1 = max.; 4 = min.)	
sunny	2
shady	3
Horizon with slow hydraulic conductivity	not present
Erosion risk	moderate (wind)
Drainage	well drained

LAND USE

Typical vegetation	tall tussock and fescue tussock grassland, with introduced grasses
Predominant land use	extensive grazing
Maximum pastoral production	not known
Fertiliser requirement for pasture	P, S, lime
Forestry options	none: too high, too exposed
Weed problems	risk of *Hieracium pilosella* invasion if tussock burnt or overgrazed
Soil problems	wind erosion, if vegetation cover depleted
Conservation values	in many areas the vegetation has been modified

PROFILE DESCRIPTION

Horizon	Depth	Description
Ah	0–23 cm	Dark brown very slightly gravelly silt loam; weak soil strength; moderately developed spheroidal and polyhedral peds.
AhBw	23–36 cm	Brown to dark brown moderately gravelly loamy silt; weak soil strength; moderately developed spheroidal and polyhedral peds.
Bw	36–47 cm	Yellowish brown very gravelly loamy silt; weak soil strength; weakly developed spheroidal and polyhedral peds.
Cu/R	47–60 cm	Light yellowish brown extremely gravelly loamy silt; massive; 90% *in-situ* jointed subschist.

Profile ID: Field No: T4
Lab. No: IS00190
Grid reference: NZMS 260 H39 642206

ANALYTICAL DATA

Horizon	Depth (cm)	C (%)	N (%)	Cation Exchange (me%)						BS (%)	P retn (%)	SO_4-S (µg/g)
				Ca	Mg	K	Na	∑cations	CEC			
Ah	0–23	–	–	3.5	1.1	0.4	0.0	4.9	12.6	39	24	3
AhBw	23–36	–	–	1.8	0.7	0.2	0.1	2.8	11.7	24	34	1
Bw	36–47	–	–	1.3	0.5	0.1	0.1	2.0	11.4	18	41	2

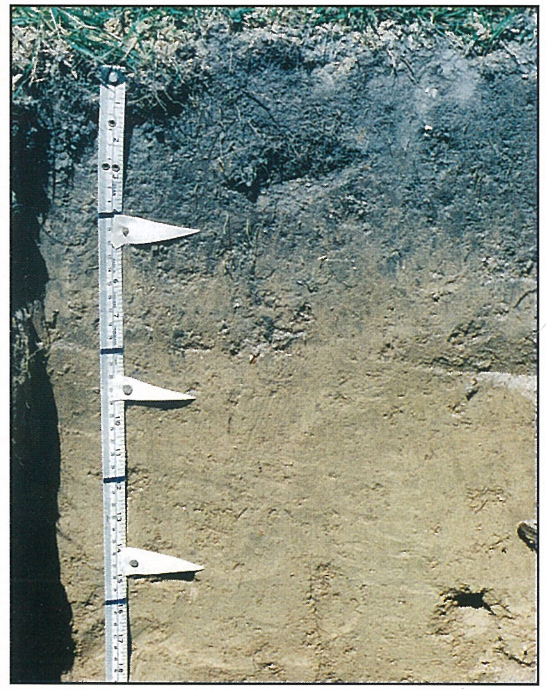
Horizon	Depth (cm)	Stones (%) by wt.	In <2mm fraction			pH (H_2O)	Ag Research Quick Tests				
			Sand	Silt	Clay		Ca	P	K	Mg	Na
Ah	0–23	–	20	60	20	5.4	4	21	6	23	2
AhBw	23–36	–	19	64	17	5.4	3	8	5	18	7
Bw	36–47	–	24	61	15	5.4	2	11	2	15	5

Author: P.D. McIntosh, Landcare Research, Dunedin

SOIL FACT SHEET 12
MACKENZIE HILL COUNTRY

soil name	:	**TEKAPO**
related set	:	Tekapo
equivalent series	:	Tekapo
subgroup, parent material class	:	**Acidic Firm Brown, with stones**
typical particle size class	:	silty
typical permeability	:	moderate over slow

SOIL PROFILE



12-92(3)-19

KEY FEATURES

- formed in moderately deep silt over moraines
- slightly firm subsoils
- moderate P retention
- moderately acid

LANDSCAPE

TYPICAL FEATURES

- on rolling or hilly land
- hummocky moraine topography
- 700–900 m
- good tussock cover, or developed pasture
- rainfall 800–1000 mm

SOIL NOTES

Tekapo soils are well-drained soils formed in loess. The soil parent material is older than that of Mesopotamia soils, which may occur in similar landscape positions. Consequently the soils are more weathered, and are classified as **Brown** soils. Slightly firm subsoil horizons having pH less than 5.5 mean that they are classified as **Acidic Firm Brown** soils.

The soils typically occur on terraces, low-angle fans and moraines, mostly at 550 m to 650 m altitude but extending up to 800 m. They are mostly used for extensive grazing and support vegetation such as sweet vernal, browntop and fescue tussock grassland, with matagouri scrub. Some areas improved for agriculture support clovers.

Estimated total available water is >100 mm to 1 m depth, and there is no physical impediment to root penetration. As expected in **Brown** soils, P retention values are medium, except in the A horizon. Olsen P values are low but SO_4-S values are medium in subsoil horizons. With phosphate topdressing the soils will support improved pasture. Forestry potential at lower altitudes is likely to be similar to that of Mesopotamia soils, i.e. high growth rates can be expected.

SUMMARY OF CHEMICAL PROPERTIES

	A horizon	Subsoil to 60 cm
pH	5.3	5.3
P retention	low	medium
Exch. Ca	medium	very low
Exch. Mg	medium	very low
Exch. K	very low	very low
CEC	–	–
BS%	–	–
Organic C	medium	very low

SUMMARY OF PHYSICAL PROPERTIES

Ped development	strong
Soil depth	> 90 cm
Effective rooting depth	> 90 cm
Readily available water (est.)	47 mm
Total available water (est.)	140 mm
Drought risk class (1 = max.; 4 = min.)	
sunny	3
shady	4
Horizon with slow hydraulic conductivity	Bw horizon
Erosion risk	slight
Drainage	well drained

LAND USE

Typical vegetation	short tussock grassland, introduced grasses, matagouri scrub
Predominant land use	extensive grazing; some areas developed
Maximum pastoral production	c. 5–6 t/ha/yr
Fertiliser requirement for pasture	P, S, Mo
Forestry options	Corsican pine, Douglas fir
Weed problems	scrub, *Hieracium*
Soil problems	few – erosion risk slight
Conservation value	contains remnant areas of tall tussock grassland

PROFILE DESCRIPTION

Horizon	Depth	Description
Ah	0–11 cm	Dark greyish brown silt loam; abundant spheroidal peds; slightly firm; NaF test 0/5.
Ah/Bw	11–23 cm	Yellowish brown loamy silt; 20% inclusions of horizon above; common polyhedral peds; slightly firm; NaF test 0/5.
Bw1	23–37 cm	Brownish yellow silt loam; common polyhedral peds; slightly firm; NaF test 1/5.
Bw2	37–54 cm	Brownish yellow silt loam; 20% reddish yellow mottles; many polyhedral peds; slightly firm; NaF test 1/5.
Bw3	54–70 cm	Reddish yellow silt loam; massive; weak soil strength; NaF test 2/5.
2Bw	70–90 cm	Brownish yellow very gravelly silt loam; massive; weak soil strength; abundant spheroidal peds.
2C	90–100+ cm	Olive extremely gravelly sand.

Profile ID: Field No: R23
Lab. No: IS00382
Grid reference: NZMS 260 H38 613680

ANALYTICAL DATA

Horizon	Depth (cm)	C (%)	N (%)	Cation Exchange (me%)						BS (%)	P retn (%)	SO_4-S (μg/g)
				Ca	Mg	K	Na	∑cations	CEC			
Ah	0–11	4.5	0.31	8.1	1.7	0.2	0.2	–	–	–	24	6
Ah/Bw	11–23	1.8	0.12	2.8	0.6	0.1	0.0	–	–	–	39	3
Bw1	23–37	0.87	0.05	0.4	0.1	0.0	0.1	–	–	–	33	5
Bw2	37–54	0.61	0.05	0.2	0.1	0.1	0.1	–	–	–	44	19
Bw3	54–70	0.62	0.05	0.3	0.1	0.1	0.1	–	–	–	53	8
2Bw	70–90	0.69	0.06	0.1	0.0	0.0	0.1	–	–	–	51	21

Horizon	Depth (cm)	Stones (%) by wt.	In <2mm fraction			pH (H_2O)	Ag Research Quick Tests				
			Sand	Silt	Clay		Ca	P	K	Mg	Na
Ah	0–11	–	–	–	–	5.3	–	10	–	–	–
Ah/Bw	11–23	–	–	–	–	5.1	–	2	–	–	–
Bw1	23–37	–	–	–	–	5.3	–	1	–	–	–
Bw2	37–54	–	–	–	–	5.4	–	1	–	–	–
Bw3	54–70	–	–	–	–	5.5	–	4	–	–	–
2Bw	70–90	–	–	–	–	5.6	–	4	–	–	–

Author: P.D. McIntosh, Landcare Research, Dunedin

SOIL FACT SHEET 13
MACKENZIE HILL COUNTRY

soil name	:	**TEKOA, Allophanic phase***
related set	:	Tekoa
equivalent series	:	not defined
subgroup, parent material class	:	**Acidic Allophanic Brown Soil, moderately deep**
typical particle size class	:	silty
typical permeability	:	moderate

*provisional name

SOIL PROFILE

12-92(2)-15

KEY FEATURES

- 45–90 cm deep, on greywacke rock
- dark topsoils with strongly developed spheroidal peds
- friable throughout; weak soil strength; easily penetrated by roots
- strong reaction to NaF test in subsoil – indicative of allophanic minerals
- P retention medium to high
- very infertile
- strongly acid and leached of nutrients

LANDSCAPE

12-92(2)-34

TYPICAL FEATURES

- on hilly and steep slopes at 700–1200 m altitude (below previous tree line)
- mostly on shady slopes
- tall tussock grasslands; good vegetation cover
- occasional beech remnants
- rainfall 800–1000 mm

SOIL NOTES

Tekoa soils occur in greywacke colluvium. They are the characteristic soils of the hilly and steep slopes of the moist hill country west of the Mackenzie basin. The colluvium is generally 45–90 cm deep and in subsoil horizons angular gravels make up 35-70% of the soil volume.

The soils probably developed under beech forest, but except for occasional forest remnants in gullies, only isolated beech trees remain. Above about 1200 m, which is approximately the altitude of the treeline, soils of the Tekoa association give way to soils of the Kaikoura association. Present vegetation is mostly tall tussock grassland and associated plants such as *Aciphylla*, *Leucopogon colensoi*, *Dracophyllum*, *Drapetes* and *Hieracium praealtum*.

Soils here have been informally named, based on the mapping in the Ben Ohau Range. *Tekoa Allophanic* soils described in this fact sheet occur on shady slopes. These are **Acidic Allophanic Brown** soils and have a subsoil horizon with a strong or very strong reaction to the NaF field test, and high P retention values. *Tekoa Allophanic, Firm* soils occur on sunny slopes. These are distinguished by their slightly firm subsoils, and are classified as **Acidic-pedal Allophanic Brown** soils. These soils have P retention of 60% or more in some subsoil horizon, but are less acid than their counterparts on shady slopes.

Inclusions of **Pallic Firm Brown** soils *Tekoa Firm* also occur among the Tekoa soils, on drier sunny faces. These soils have firm massive subsoils resembling fragipans. It appears that at particular sites seasonal wetting and drying has caused subsoil consolidation.

Tekoa soils are likely to require high rates of S-superphosphate and lime to support legume-based pastures. On lower slopes the soils and climate are well suited to conifer growth, but at higher altitudes, steep slopes, low temperatures and exposure limit commercial forestry.

SUMMARY OF CHEMICAL PROPERTIES

	A horizon	Subsoil to 60 cm
pH	4.7	4.9
P retention	medium	medium
Exch. Ca	very low	very low
Exch. Mg	low	very low
Exch. K	low	very low
CEC	–	–
BS%	–	–
Organic C	medium	very low

SUMMARY OF PHYSICAL PROPERTIES

Ped development	strong
Soil depth	85 cm
Effective rooting depth	85 cm
Readily available water (est.)	50 mm
Total available water (est.)	150 mm
Drought risk class (1 = max.; 4 = min.)	
sunny	3
shady	4
Horizon with slow hydraulic conductivity	none
Erosion risk	slight
Drainage	well drained

LAND USE

Typical vegetation	*Dracophyllum* scrub, narrow-leaved tall tussock grassland, *Hieracium*, minor areas of beech forest
Predominant land use	extensive grazing
Maximum pastoral production	not known
Fertiliser requirement for pasture	P, S
Forestry options	Douglas Fir, Corsican pine
Weed problems	overgrazing/burning will allow weed invasion, especially *Hieracium*
Soil problems	lime required for improved pasture, but probably uneconomic to apply
Conservation values	extensive areas of indigenous grassland, scrub and remnant forest

PROFILE DESCRIPTION

Horizon	Depth	Description
Ah	0–9 cm	Dark yellowish brown slightly gravelly silt loam; strongly developed spheroidal peds; weak soil strength; NaF test 0/5.
ABw	9–25 cm	Yellowish brown slightly gravelly silt loam; strongly developed spheroidal peds; weak soil strength; NaF test 0/5.
Bw	25–55 cm	Strong brown moderately gravelly silt loam; abundant spheroidal, polyhedral and blocky peds; weak soil strength; NaF test 5/5.
BC	55–85 cm	Light yellowish brown very gravelly silt loam; single grain; weak soil strength; NaF test 5/5.

Profile ID: Field No: R6
Lab. No: IS00372
Grid reference: NZMS 260 H38 677675

ANALYTICAL DATA

Horizon	Depth (cm)	C (%)	N (%)	Cation Exchange (me%)						BS (%)	P retn (%)	SO_4-S (µg/g)
				Ca	Mg	K	Na	∑cations	CEC			
Ah	0–9	4.0	0.24	1.7	0.7	0.5	0.0	2.9	–	–	47	9
ABw	9–25	2.1	0.12	0.8	0.2	0.1	0.0	1.1	–	–	59	3
Bw	25–55	1.9	0.08	0.2	0.0	0.1	0.1	0.4	–	–	64	2
BC	55–85	1.1	0.05	0.0	0.0	0.1	0.0	0.1	–	–	47	2

Horizon	Depth (cm)	Stones (%) by wt.	In <2mm fraction			pH (H_2O)	Ag Research Quick Tests				
			Sand	Silt	Clay		Ca	P	K	Mg	Na
Ah	0–9	–	–	–	–	4.7	–	6	–	–	–
ABw	9–25	–	–	–	–	4.8	–	1	–	–	–
Bw	25–55	–	–	–	–	5.0	–	10	–	–	–
BC	55–85	–	–	–	–	5.1	–	4	–	–	–

Author: P.D. McIntosh, Landcare Research, Dunedin

SOIL FACT SHEET 14
MACKENZIE HILL COUNTRY

soil name	:	**TEKOA, Allophanic, Firm phase***
related set	:	Tekoa
equivalent series	:	not defined
subgroup, parent material class	:	**Acidic-pedal Allophanic Soil, angular-stony**
typical particle size class	:	silty
typical permeability	:	moderate over slow

*provisional name

SOIL PROFILE

12-92(2)-11

KEY FEATURES

- moderately deep, on rock
- friable soils, becoming firmer with increasing depth
- strongly developed spheroidal peds
- P retention medium to high
- very infertile
- moderately acid
- moderate to strong reaction to NaF test in subsoils

LANDSCAPE

12-92(2)-12

TYPICAL FEATURES

- on hilly and steep slopes at 700–1200 m altitude
- good vegetation cover
- occasional beech remnants
- narrow-leaved tall tussock grasslands
- mostly on sunny slopes
- rainfall 800–1000 mm

SOIL NOTES

Tekoa soils occur in greywacke colluvium. They are the characteristic soils of the hilly and steep slopes of the moist, hill country west of the Mackenzie basin. The colluvium is generally 45–90 cm deep and in subsoil horizons angular gravels make up 35-70% of the soil volume.

The soils probably developed under beech forest, but except for occasional forest remnants in gullies, only isolated beech trees remain. Above about 1200 m, which is approximately the altitude of the treeline, soils of the Tekoa association give way to soils of the Kaikoura association. Present vegetation is mostly tall tussock, fescue tussock and associated species including *Aciphylla*, *Leucopogon colensoi*, *Dracophyllum* sp., *Drapetes* and *Hieracium praealtum*.

Mapping in the Ben Ohau Range has established the tentative soil pattern, and soils here have been informally named. *Tekoa Allophanic* soils occur on shady slopes. These are **Acidic Allophanic Brown** soils and have a subsoil horizon with a strong or very strong reaction to the NaF field test, and high P retention values. *Tekoa Allophanic, Firm* soils described in this fact sheet occur on sunny slopes. These are distinguished by their slightly firm subsoils, and are classified as **Acidic-pedal Allophanic Brown** soils. These soils have P retention of 60% or more in some subsoil horizons, but are less acid than their counterparts on shady slopes.

Inclusions of **Pallic Firm Brown** soils (*Tekoa Firm*) also occur among the Tekoa soils, on drier sunny faces. These soils have firm massive subsoils resembling fragipans. It appears that at particular sites seasonal wetting and drying has caused subsoil consolidation.

Tekoa soils are likely to require high rates of S-superphosphate and lime to support legume-based pastures. On lower slopes the soils and climate are well suited to conifer growth, but at higher altitudes, slopes, low temperatures and exposure are limitations for commercial forestry.

SUMMARY OF CHEMICAL PROPERTIES

	A horizon	Subsoil to 60 cm
pH	5.4	5.2
P retention	medium	high
Exch. Ca	low	very low
Exch. Mg	low	very low
Exch. K	medium	very low
CEC	–	–
BS%	–	–
Organic C	medium	low

SUMMARY OF PHYSICAL PROPERTIES

Ped development	strong
Soil depth	60 cm
Effective rooting depth	60 cm
Readily available water (est.)	47 mm
Total available water (est.)	140 mm
Drought risk class (1 = max.; 4 = min.)	
sunny	3
shady	4
Horizon with slow hydraulic conductivity	Bw horizon
Erosion risk	slight slips
Drainage	well drained

LAND USE

Typical vegetation	tall tussock, fescue tussock and *dracophyllum* scrub
Predominant land use	extensive grazing
Maximum pastoral production	not known
Fertiliser requirement for pasture	P, S
Forestry options	Douglas fir, Corsican pine
Weed problems	overgrazing/burning will allow weed invasion
Soil problems	lime required for improved pasture, but uneconomic to apply
Conservation values	contains areas of native grassland and scrub

PROFILE DESCRIPTION

Horizon	Depth	Description
Ah	0–9 cm	Dark yellowish brown slightly gravelly silt loam; strongly developed spheroidal peds; weak soil strength; NaF test 0/5.
ABw	9–25 cm	Yellowish brown slightly gravelly silt loam; strongly developed spheroidal peds; weak soil strength; NaF test 0/5.
Bw	25–55 cm	Strong brown moderately gravelly silt loam; weakly developed spheroidal, polyhedral and blocky peds; weak soil strength; NaF test 5/5.
BC	55–85 cm	Light yellowish brown very gravelly silt loam; single grain; weak soil strength; NaF test 5/5.

Profile ID: Field No: R5
Lab. No: IS00371
Grid reference: NZMS 260 H38 677677

ANALYTICAL DATA

Horizon	Depth (cm)	C (%)	N (%)	Cation Exchange (me%) Ca	Mg	K	Na	∑cations	CEC	BS (%)	P retn (%)	SO_4-S (µg/g)
Ah	0–9	4.0	0.24	1.7	0.7	0.5	0.0	–	–	–	47	9
ABw	9–25	2.1	0.12	0.8	0.2	0.1	0.0	–	–	–	59	3
Bw	25–55	1.9	0.08	0.2	0.0	0.1	0.1	–	–	–	64	2
BC	55–85	1.1	0.05	0.0	0.0	0.1	0.0	–	–	–	47	2

Horizon	Depth (cm)	Stones (%) by wt.	In <2mm fraction Sand	Silt	Clay	pH (H_2O)	Ag Research Quick Tests Ca	P	K	Mg	Na
Ah	0–9	–	–	–	–	4.7	–	2	–	–	–
ABw	9–25	–	–	–	–	4.8	–	0	–	–	–
Bw	25–55	–	–	–	–	5.0	–	0	–	–	–
BC	55–85	–	–	–	–	5.1	–	0	–	–	–

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SOIL FACT SHEET 15
MACKENZIE HILL COUNTRY

soil name	:	**TENGAWAI**
related set	:	Tengawai
equivalent series	:	Tengawai
subgroup, parent material class	:	**Typic Laminar Pallic Soil, angular-stony**
typical particle size class	:	Tengawai
typical permeability	:	moderate

SOIL PROFILE

12-90(2)-22

KEY FEATURES

- moderately deep and deep soils
- moderately stony
- clay bands in subsoil
- fertile; moderately to slightly acid
- low to medium topsoil carbon
- generally good vegetation cover

LANDSCAPE

12-90(1)-9

TYPICAL FEATURES

- 400–1000 m altitude
- on hilly and steep slopes
- mostly on shady aspects
- few surface boulders
- rainfall 600–800 mm

SOIL NOTES

Tengawai soils are formed in moderately deep and deep angular greywacke or subschist colluvium overlying jointed rock. They are classified as **Pallic** soils because they have clay accumulation in the lower parts of profiles, and as **Typic Laminar Pallic** because the clay accumulation is in the form of lamellae.

The soils occur predominantly on shady, hilly and steep slopes. They commonly have about 15–25% bare ground. Surface gravels or boulders are generally fewer than on Omarama and Meyer soils. The soils often have short tussock vegetation, induced from tall tussock (*C. rigida*) by grazing and burning. In the unimproved state, species present include blue tussock, fescue tussock, silver tussock, browntop, sweet vernal and native grasses. However, the soils are very prone to invasion of *Hieracium*, having more available moisture than Omarama and Meyer soils.

Tengawai soils are the most valuable soils for pasture in the lower-altitude zone, as the moderately deep and deep profiles hold an estimated total available water of about 90 mm. The clay accumulation is insufficient to impede roots, and evaporation losses are less than on Omarama and Meyer soils. In their natural state the soils are fertile (except for P and S) and moderately to slightly acid. With oversowing, adequate fertiliser to correct deficiencies, and subdivision and fencing, the stocking rate can be as high as 3 SU/ha/yr.

The soils offer the best sites for forestry in the dry, eastern hill country. Douglas fir, European larch, Corsican pine, and Ponderosa pine are likely to be suitable. However the expense of planting, weed control, roading and harvesting on steep slopes may have a major influence on forestry economics. Both species performance and the economics of forestry on hilly and steep Tengawai soils require further research.

SUMMARY OF CHEMICAL PROPERTIES

	A horizon	Subsoil to 60 cm
pH	6.0	6.5
P retention	low	low
Exch. Ca	medium	medium
Exch. Mg	medium	medium
Exch. K	low	very low
CEC	low	low
BS%	high	very high
Organic C	low-medium	very low

SUMMARY OF PHYSICAL PROPERTIES

Ped development	moderate
Soil depth	> 100 cm
Effective rooting depth	> 100 cm
Readily available water (est.)	35 mm
Total available water (est.)	90 mm
Drought risk class (1 = max.; 4 = min.)	
sunny	1
shady	3
Horizon with slow hydraulic conductivity	not present
Erosion risk	slight-moderate
Drainage	well drained

LAND USE

Typical vegetation	blue tussock, fescue tussock, silver tussock, sweet vernal and introduced grasses, *Hieracium*
Predominant land use	rough grazing
Maximum pastoral production	c. 4t/ha/yr
Fertiliser requirement	c. 200 kg/ha S–superphosphate every three years
Forestry options	Douglas fir, Corsican pine
Weed problems	*Hieracium*
Soil problems	wind erosion; soil acidification
Conservation values	where not heavily grazed, there are some areas of short tussock associations in good condition

PROFILE DESCRIPTION

Horizon	Depth	Description
Ah	0–10 cm	Very dark greyish brown loamy silt; weakly developed spheroidal peds; weak soil strength.
Bw	10–27 cm	Dark brown loamy silt; weakly developed spheroidal peds; weak soil strength.
2Bw	27–45 cm	Light olive brown very gravelly loamy silt; weakly developed spheroidal peds; weak soil strength.
2BCt	45–100 cm	Olive very gravelly loamy silt; massive; yellowish brown clay lamellae 1–2 mm thick; weak soil strength.

Profile ID: Field No: H12
Lab. No: IS385a-d
Grid reference: NZMS 260 H39 636237

ANALYTICAL DATA

Horizon	Depth (cm)	C (%)	N (%)	Cation Exchange (me%)						BS (%)	P retn (%)	SO_4-S (μg/g)
				Ca	Mg	K	Na	∑cations	CEC			
Ah	0–10	3.9	0.34	10.5	2.01	0.51	0.04	13.1	19.3	68	18	0
Bw	10–27	2.5	0.27	9.42	1.68	0.27	0.05	11.4	15.5	74	20	1
2Bw	27–45	0.87	0.11	4.69	1.33	0.15	0.17	6.34	10.1	63	18	3
2BCt	45–100	0.21	0.04	3.21	1.79	0.04	0.12	5.16	7.9	65	11	1

Horizon	Depth (cm)	Stones (%) by wt.	In <2mm fraction			pH (H_2O)	Ag Research Quick Tests				
			Sand	Silt	Clay		Ca	P	K	Mg	Na
Ah	0–10	–	–	–	–	5.4	–	20	–	–	–
Bw	10–27	–	–	–	–	5.9	–	8	–	–	–
2Bw	27–45	–	–	–	–	6.0	–	9	–	–	–
2BCt	45–100	–	–	–	–	5.9	–	5	–	–	–

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