Section

2

2. Soil Patterns, Landuse and Climate

Key Learning Objective

After studying this section you should be able to identify the key landscape features that have particular influences on nutrient management.

General Background

The soil resource of New Zealand is finite. Of the 27 million ha of the New Zealand landmass, about half is used for agriculture and horticulture, of which about two-thirds is mostly sown grassland and the remainder is native grassland used for grazing livestock. The following slope classes are used to group land-use:

1. Slopes of <15° – generally land that can be easily cultivated by machine and usually referred to as arable land
2. Slopes between 15° and 25° – commonly referred to as hill country and mapped as hill soils
3. Slopes > 25° – comprising the steepland of New Zealand.

Nearly half of New Zealand comprises steepland, which is disproportionately abundant in the South Island. The North Island has about equal areas of land in each slope class. When subdividing the land on the basis of altitude, one's attention is drawn to the fact that more than 50% of New Zealand is above an altitude of 300 m, emphasising the rugged nature of this country's landmass.

A study of soil patterns will assist in the management of soil as a productive and protective resource. Due to the high capital costs of fertilisers and the potential impact they have on the wider environment, it is important for farm managers to understand why fertiliser is required, the fate of nutrients after application to the soil, and their efficiency in maintaining the supply of nutrients to plants. Also, when managed correctly, soil has the potential to be a remarkable filtering and cleansing agent for solutions passing through it, thus forming a major resource for the discharge of effluent, particularly from dairy sheds and factories throughout the country.

Soil Orders

Studies of soils within New Zealand over the last century have resulted in a recently revised classification system (Hewitt, 1993). For the purposes of this course, we are only interested in the top-level hierarchy (the fifteen Soil Orders). The relationships between them are shown in Figure 2.1

Allophanic soils

Soils that are dominated by allophane - iron and aluminium oxides resulting from the weathering of iron and magnesium-rich minerals. This mineral coats the sand and silt grains and maintains a porous, low-density structure with weak strength. Allophane has a strong affinity for phosphate so that higher amounts of soluble fertiliser P are required to raise the amount of P sorbed on the soil surface to overcome any limiting value of solution P concentration. They occur predominantly in North Island volcanic ash, in the weathering products of volcanic rocks, and from greywacke and schist in the South Island high country. They cover 5% of New Zealand.

Anthropic soils

Soils that have been constructed by, or drastically disturbed by people. They include soil materials formed by stripping of the natural soil, deposition of refuse or spoil, or by severe soil mixing. The original character and normal properties of the soil has been lost. These soils are found extensively in urban and mining areas and cover less than 1% of New Zealand.

Brown soils

Soils that have a brown or yellow-brown subsoil below a dark grey-brown topsoil. The brown colour is caused by a thin coating of iron oxide weathered from the parent material. These soils occur in places where summer drought is uncommon and which are not water-logged in winter. They cover 43% of New Zealand.

Gley soils

Soils that are strongly affected by water-logging and have been chemically reduced during weathering. They have light grey subsoils, usually with reddish-brown or brown mottles. The grey colours usually extend to more than 90 cm depth. Water-logging usually occurs in winter and spring, and some soils remain wet all year. These soils occur throughout New Zealand in low parts of the landscape where there are high groundwater tables or where there are seepages. They cover 3% of New Zealand.

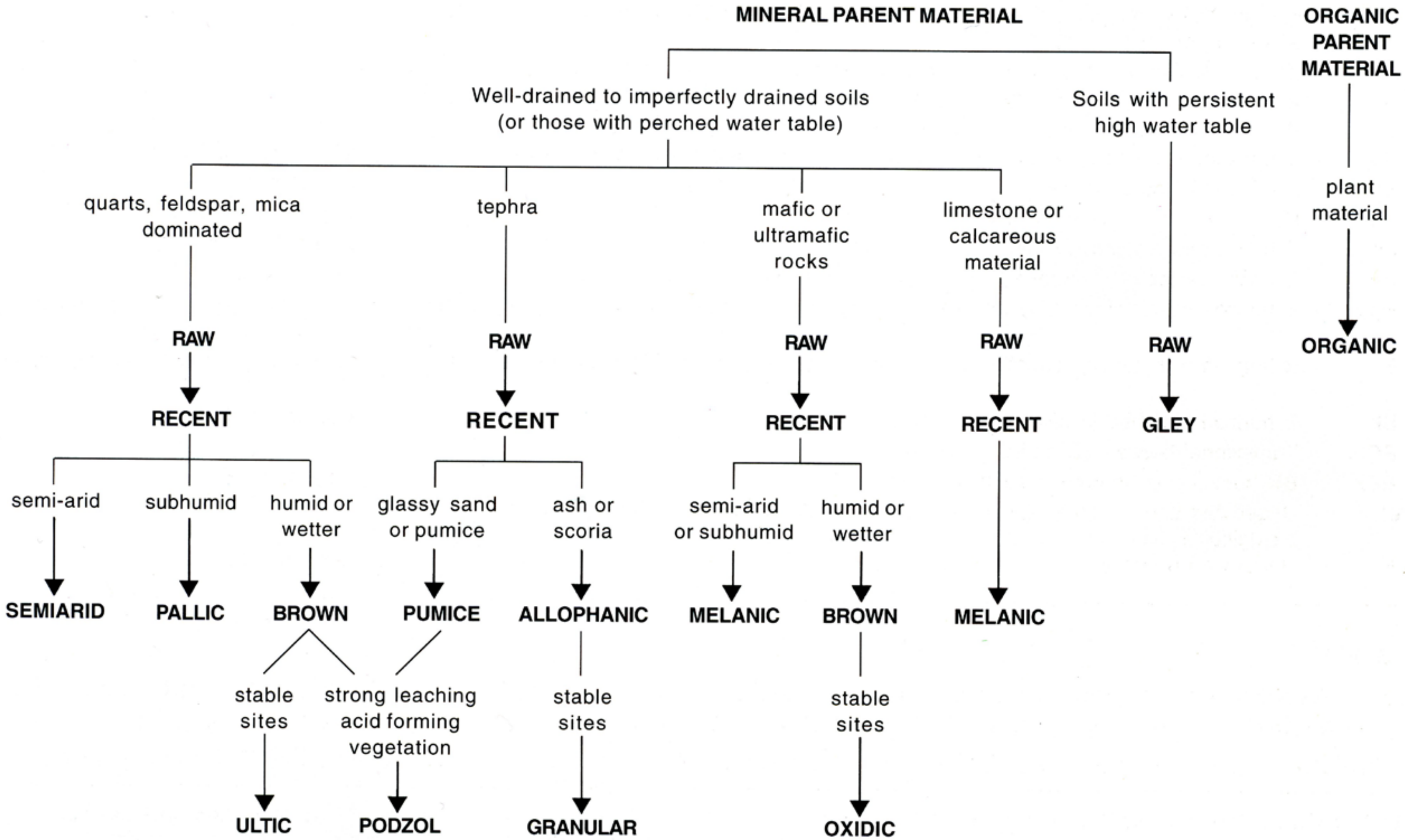


Figure 2.1 The relationships between the 15 soil orders of the New Zealand soil classification system (from Molloy, 1998). Soils will only proceed the whole way down a soil formation pathway on relatively stable sites. Reprinted with permission of NZSSS.

Granular soils

Soils that have a high clay component formed from materials derived by strong weathering of volcanic ash or rocks. Dry or moist samples may be easily parted into small hard fragments. When wetted and rubbed between the fingers, the clay becomes sticky and may be easily remoulded with little cracking. They occur only in the northern North Island, particularly in the lowlands of the Waikato and South Auckland regions. Parent materials are usually strongly weathered tephras, mostly older than 50000 years. They cover 1% of New Zealand.

Melanic soils

Soils that have black or dark grey topsoils that are well-structured. The subsoil either contains lime, or has well-developed structure and is neutral or only slightly acid. These soils occur in small areas scattered throughout New Zealand, in association with lime-rich rocks or dark (basic) volcanic rocks. They cover 1% of New Zealand.

Organic soils

Soils that have formed in the partly decomposed remains of wetland plants (peat) or forest litter. Some mineral material may be present but the soil is dominated by organic matter. These soils occur in wetlands in most parts of New Zealand, or under forests that produce acid litter in areas with high rainfall. They cover 1% of New Zealand.

Oxidic soils

Soils that have a high clay component formed as a result of the weathering of volcanic ash or dark volcanic rock over long periods of time. Despite the high clay content, the soils are friable with low plasticity and fine structure. They contain appreciable amounts of iron and aluminium oxides. They occur only in the Auckland and Northland regions. Parent materials are derived from strongly weathered andesite, dolerite, or basaltic rock or ash. They cover less than 1% of New Zealand.

Pallic soils

Soils that have pale coloured subsoils, due to low contents of iron oxides. They have weak structure and high density in subsurface horizons. Pallic soils are dry in summer and wet in winter and occur predominantly in the seasonally dry eastern part of the North and South Islands, and in the Manawatu. Parent materials are commonly loess derived from schist or greywacke. They cover 12% of New Zealand.

Podzols

Soils that are strongly acid and that usually have a bleached horizon immediately beneath the topsoil. This horizon is the source of aluminium and iron oxides that have accumulated, in association with organic matter, in an underlying dark or reddish coloured horizon. These soils occur in areas of high rainfall and are usually associated with forest trees with an acid litter. The soils occur mainly in materials from silica-rich rocks. They cover 13% of New Zealand.

Pumice soils

Soils that are sandy or gravelly and dominated by pumice with a high content of natural glass. Drainage of excess water is rapid but the soils are capable of storing large amounts of water for plants. They occur in tephras ranging from 700 to 3500 years old and are found predominately in the central North Island, particularly in the Volcanic Plateau. They cover 7% of New Zealand.

Raw soils

Soils that are very young. They lack distinct topsoil development or are fluid at a shallow depth. They occur in environments where the development of soils is prevented by rockiness, by active erosion, or deposition. These soils are scattered throughout New Zealand, particularly in association with high mountains, braided rivers, beaches, and tidal estuaries. They cover 3% of New Zealand.

Recent soils

Soils that are weakly developed, showing limited signs of soil-forming processes. A distinct topsoil is present but a B horizon is either absent or only weakly expressed. These soils occur throughout New Zealand on young land surfaces, including alluvial floodplains, unstable steep slopes, and slopes mantled by young volcanic ash. Their age varies depending on the environment and soil materials, but most are less than 1000 to 2000 years old. They cover 6% of New Zealand.

Semiarid soils

Soils that are dry for most of the growing season. Rain is not sufficient to leach through the soil, so that lime and salts accumulate in the lower subsoil. Nutrient levels are relatively high, but the soils must be irrigated to produce a crop. These soils occur in the inland basins of Otago and southern Canterbury, where annual rainfall is less than 500 mm. They cover 1% of New Zealand.

Ultic soils

Soils that are strongly weathered and have a well-structured, clay-enriched subsoil horizon. An E horizon, which is relatively depleted in clay, frequently occurs immediately beneath the topsoil. The soils are acid and strongly leached, with generally low levels of calcium and other basic cations. They occur in clay or sandy clay material derived by strong alteration of quartz-rich rocks over long periods of time. They are most commonly found in the northern North Island, and the Wellington, Marlborough, and Nelson regions. They cover 3% of New Zealand.

The formation of soils from their parent materials (various types of rocks) is strongly influenced by a number of environmental factors (the soil forming environment), and is often strongly associated with landscape units. These factors and the landscape units are examined in more detail in the next section.

Recognising Soil Patterns in the Landscape

Learning to recognise commonly occurring landscape units is an important skill that will assist you in the sustainable management of the soil resource. In this section you are given examples of questions you should ask in relation to landscapes in order for you to identify the key landscape features that have a particular influence on nutrient management and on soil development. For example, you will already be aware that the rate of phosphorus (P) fertiliser application to soils can be influenced by the soil's ability to fix P in non-plant available forms. It is common to expect moderately to strongly weathered soils derived from volcanic materials to have high P fixation capacities. Also, strongly weathered sedimentary rocks, exposed to warm and wet climates, can develop high P fixation. An example is the horticulturally important Levin soils in the Horowhenua, which are formed from loess that is derived from greywacke-argillite sedimentary rocks.

Decision Tree For Landscape Interpretation

The key landscape features that will influence the properties and productivity of the soil and, in turn, your decision on the form, amount, placement, and frequency of fertiliser application are:

1. ***Parent material:*** Locate where you are in New Zealand *(see Lower North Island example later in this section)* to identify the predominant parent materials in the landscape:
    - Northland (sedimentary rocks, scoria cones, basalt).
    - Central North Island (sedimentary rocks, air-fall ash and volcanic alluvium, coarse rhyolitic pumice).
    - Lower North Island (sedimentary rocks, alluvial sediments and loess derived from sedimentary rocks).
    - South Island (sedimentary rocks, basalt, granites, schists).

    Notes on volcanic parent materials:
    - Parent rocks: basalt, andesite, rhyolite, dacite.
    - Parent materials: tephra, ignimbrite, alluvium, volcaniclastic (e.g. lahars).
    - Rhyolitic and andesitic tephra is the most widespread volcanic material.
    - Rhyolite volcanoes are Taupo and Okataina.
    - Andesite volcanoes are Ruapehu/Tongariro and Taranaki.
    - Basalt volcanoes are found in Northland, Auckland, South Auckland, Banks Peninsula, Timaru and Dunedin.

- Volcanic parent materials are most prevalent from Central North Island to Auckland. Soils with some influence of volcanic ash extend south to Levin and northern Wairarapa.

The dominant constituent of volcanic parent materials is an alumino-silicate glass, which weathers to form allophane in free draining soil or to halloysite in poorly draining soil. Allophane is a non-crystalline clay, which specifically adsorbs P and therefore has a high P retention and a high P requirement. Allophanic soils tend to be well drained with stable structure, good physical and good biological fertility. In contrast, soils with halloysite (a crystalline mineral found in the clay fraction of soils) can be poorly drained with poor physical properties. Allophane eventually weathers to halloysite (e.g. Allophanic soils weathering to Granular soils).

2. ***Soil forming environment:*** The five main factors that influence differences in soil type are:
   - climate
   - vegetation and animals
   - relief or topography
   - parent materials and rocks
   - time: age of parent materials

In general, parent material is often the most influential soil forming factor and is the primary determinant of its fertility. For example, there are substantial differences between soils derived from volcanic parent materials compared with those from non-volcanic parent materials. However, the relative importance of the soil forming factors varies from region to region. Refer to Table 2.1 (and Figure 2.1) for information on a selection of New Zealand soils; their parent materials, their distribution and the rainfall conditions under which they were formed. Also, refer to Fig. 2.2 which provides a map of the soil order distribution in New Zealand.

(Consult Molloy, 1998, Soils in the New Zealand landscape – the living mantle, for more detail on soil parent materials and soil-forming processes that may be relevant to your landscape)

3. ***Interactions with climate and topography factors*** that are relevant for decision-making on fertiliser use.
   - Climate
     - o rainfall and its distribution
     - o "summer-safe" versus "summer-dry"

- relationship between rainfall, evapotranspiration and moisture storage
- exposure to winds
- frosts
- soil temperatures

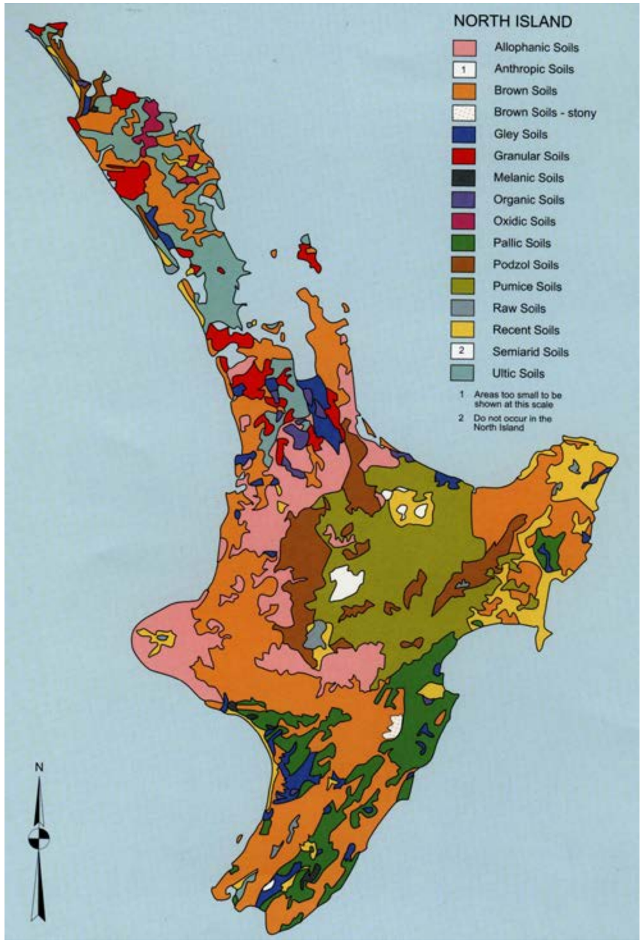
- Topography
  - relationship between parent material, slope and the type and degree of erosion
  - slope versus soil depth
  - aspect (e.g. seasonal differences in pasture production for northern slopes versus southern slopes)

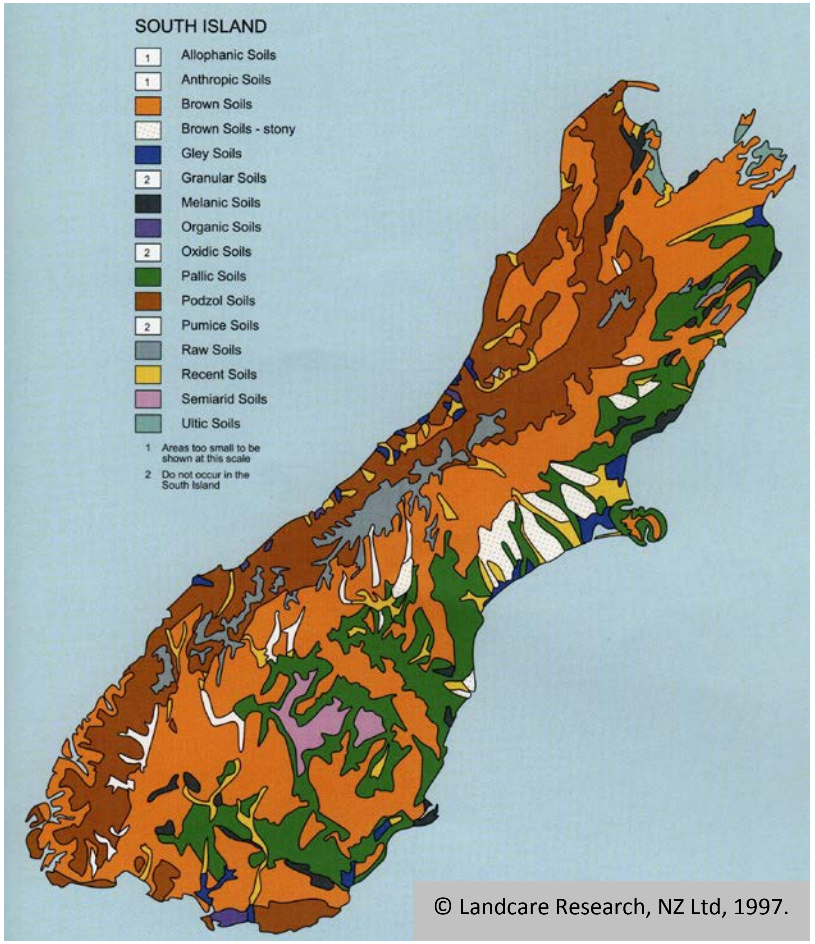
4. *Other features* in the landscape that are relevant for decision-making on fertiliser use. For example:

- Differences in farm management, stocking rate, and land-use.
- Placement of fertiliser in relation to:
  - water ways
  - native vegetation
  - neighbouring properties
  - grazing stock

Table 2.1 A selection of New Zealand soils; their parent materials, their distribution and the rainfall conditions under which they were formed.

Old Name On Soil Maps	Molloy (1998)	New Soil Order Name (Hewitt, 1993)	Distribution	Approximate Average Annual Rainfall (mm)
1. Soils developed from sedimentary rocks and loess, alluvium or colluvium derived from them:				
Brown-grey earths	Semi-arid soils	Semi-Arid Soils	Central Otago	300-500
Yellow-grey earths	Dense grey soils	Pallic Soils	East Coast, both Islands	500-1100
Yellow-brown earths	Brown soils	Brown Soils	Nationwide	800-2000*
Northern yellow-brown earths	Brown clays	Ultic Soils	Northland	1000-2000
Podzols	Podzols	Podzols	West coast, both Islands	>2000
2. Soils developed from volcanic rocks and loess, alluvium or colluvium derived from them:				
Yellow-brown Pumice soils	Pumice Soils	Pumice Soils	Central North Island, Bay of Plenty, Hawkes Bay	1200-2000
Yellow-brown loams	Volcanic loams	Allophanic Soils	Waikato, Bay of Plenty, Taranaki, Central N.I.	1100-2000
Brown-granular loams	Volcanic loamy clays	Granular Soils	Northern Waikato, Auckland, Northland	1100-2000
Brown-granular clays	Volcanic clays	Oxidic Soils	Northland	1100-2000
Red and Brown loams	Volcanic loams	Allophanic Soils Granular Soils	Northland	1100-2000
3. Soils developed from unusual parent materials:				
High water table Gleys	Gleys	Gley Soils	Common wherever water table is high	300-10 000
Coastal sands Yellow-brown sands	Coastal sands	Brown Soils	Manawatu, Bay of Plenty, Waikato, Northland	800-2000
Young parent materials Recent Soils	Recent Soils	Recent Soils	Common Nationwide	300-10 000





Derived from the New Zealand Land Resource Inventory and National Soils Database using the Soil Classification (Hewitt, A.E. 1993)

Fig. 2.2 ***Map of the distribution of soil orders of New Zealand Soil Classification in the North and South Islands of New Zealand (Reprinted with permission of Landcare Research NZ Ltd).***

Examples of Interpreting Soil Properties and Processes

AIM

For the following two landscape examples, use the lecture information and your general knowledge of farming to identify:

- landforms that vary in their productive potential and fertiliser requirements, and
- landforms and features in the landscape to which the application of fertiliser poses an environmental risk.

EXAMPLE 1: CENTRAL NORTH ISLAND DAIRY FARM

Background

A dairy farm located in the Bay of Plenty, near Katikati. Figure 2.3 shows a view of a landscape of a dairy farm and the surrounding area.

Figure 2.3 Central North Island landscape located near Katikati, Bay of Plenty.

Step 1: Parent materials on the Bay of Plenty landscape example:

- Figure 2.6 shows that this landscape is within the range of airfall tephra.
- Close proximity to the tephra source indicates that the ash layer is likely to be deep (consult more detailed soil maps).
- Likely to have received significant alluvial volcanic ash via rivers which could form alluvial flats.
- Underlying sedimentary rocks unlikely to be exposed.

Step 2: Soil forming environment.

- Rainfall about 1400 mm annually (moderate to strong weathering regime), therefore, ash has weathered to form allophane and has very strong P retention characteristics (Table 2.1)

Step 3: Erosion

- Soils formed on eroded slopes generally have lower fertility and are shallower compared to those on flatter surfaces. Some older ashes also have poorer fertility being formed from ash showers lower in nutrients.
- Deposition surfaces:
  - o *Uneroded tephras* – Stronger weathering has produced some of the better structured and more productive soils.
  - o *Alluvial flats* – moderate to stronger weathering has produced productive soils.

Step 4: Areas to avoid fertiliser application (Figure 2.4)

- Waterways
- Neighbouring properties (e.g. residential housing, organic farms, grazing stock)

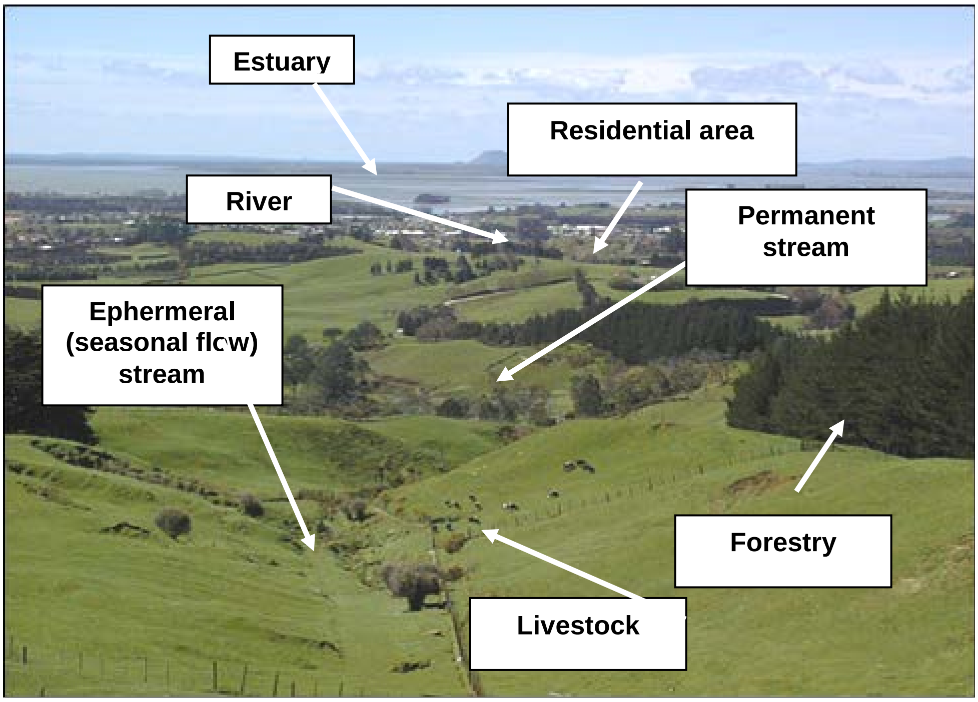


Figure 2.4 Features in the landscape that should be considered when applying fertiliser

EXAMPLE 2: LOWER NORTH ISLAND SHEEP AND BEEF FARM

Background

A sheep and beef station (Bramerton) located in the Wairarapa, 13 km East of Masterton on the Masterton-Castlepoint road (27 km from the coast). Figure 2.5 shows a view of a landscape on part of the farm.

Figure 2.5 Lower North Island landscape.

Step 1: Parent materials:

- Figure 2.6 shows that the location of this landscape is beyond the range of significant air-fall tephra and will not have received significant alluvial volcanic ash because rivers in this area do not source from regions receiving air-fall tephra.
- Parent rocks are mudstone, siltstone, and sandstone. Most soils are formed in these rocks, or alluvium and colluvium derived from them. The local river has also laid down greywacke gravels to form terraces.
- Geological faulting can induce sudden changes in the landscape and soil patterns.

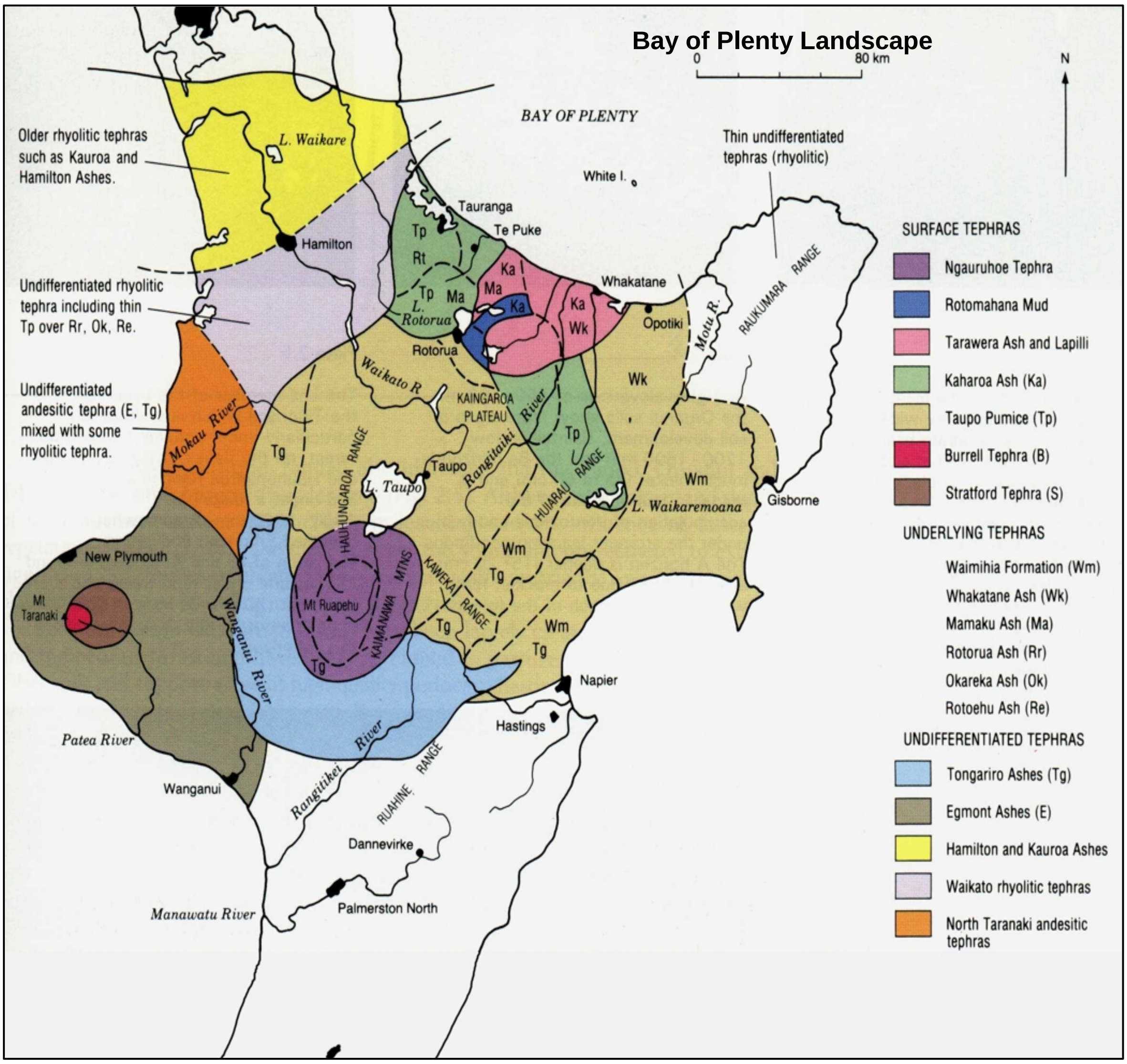


Figure 2.6 *Map of soil-forming tephras in the Central North Island and Taranaki (Molloy, 1998; reprinted with permission of NZSSS).*

Step 2: Soil Forming Environment:

- Rainfall about 850 mm annually.
- Erosion:
  - o Eroded surfaces; younger shallow soils on steeper slopes low in organic matter and low moisture-holding capacity.
  - o Deposition materials:
    - i. *Colluvium* – erosion products collect at the foot of slopes.
    - ii. *Alluvium* – well-sorted stream or river-carried materials that now form flats on terraces of different ages. Drainage characteristics depend on the particle size deposited and the age of deposits since soil-forming processes began. Free-draining soil is often the most productive in the landscape (can cover a wide range of moisture regimes).

- o Apparently un-eroded surfaces or non-alluvial flats or gently rolling surfaces with small ephemeral streams.
  - i. Soils formed on bedrock. Older soils in the landscape.
  - ii. Soils formed from loess close to large abraided riverbeds. Can be very dense soils with poor drainage qualities (e.g. perched water-tables).

Step 3: Slope/aspect interactions (Figure 2.7):

- Steepland (> 25°) – South versus North facing.
  - o North facing – warmer, higher evapotranspiration, dryer, poorer plant establishment (less clover), marked seasonal growing (late autumn/winter/early spring period).
  - o South facing – cooler, low evapotranspiration, wetter, long growing season extending into summer, slow to negligible growth in winter due to shade/low sunshine hours.
- Hill country (15-25°). Similar slope and aspect relationships controlling soil moisture as with the steep slopes, but not as extreme.
- Flats (< 15°). No interaction with slope and aspect, but some positions (e.g. valley bottoms) can collect cold air and be susceptible to more frequent frosts.

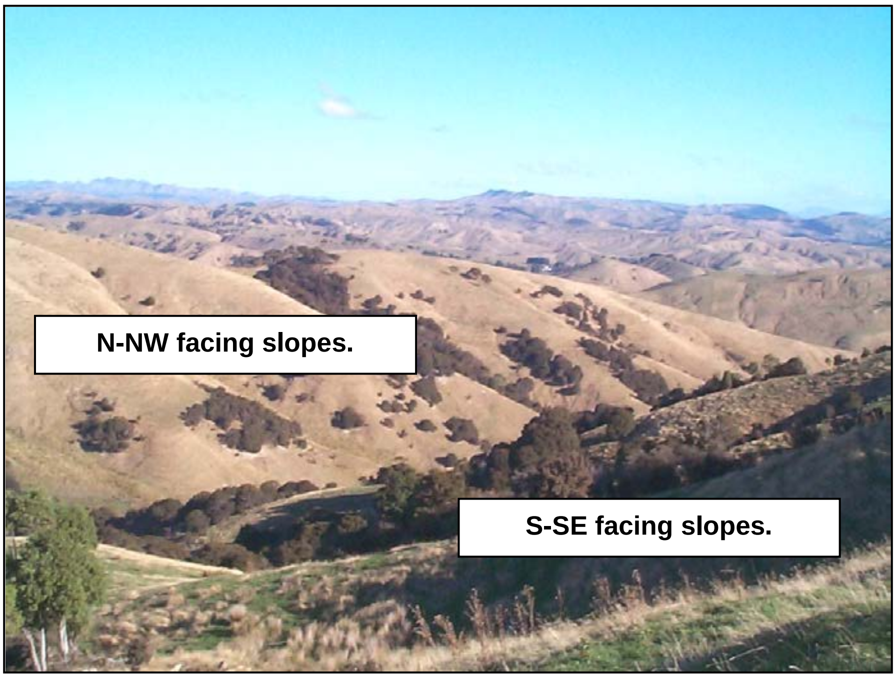


Figure 2.7 The effect of aspect on pasture growth in hill country during summer. N-NW aspects receive higher amounts of solar radiation throughout the year. Accordingly, higher evapotranspiration rates dry out the soil more quickly on these slopes and pastures brown off more quickly during summer and autumn dry periods. The drying process may be further exacerbated by the onset of soil water repellency.

Table 2.2 Summary of productivity ranking

Land units	Productivity	Use
Flats Gentle slopes on Northern aspects	High	Intensive grazing, hay, silage, crops
Gentle slopes on Eastern/Western aspects Medium slopes on Northern aspects	Medium	Intensive grazing
Gentle slopes on Southern aspects Medium slopes on Eastern/Western aspects	Medium-Low	Lower stocking rates
Medium slopes on Southern aspects Steep slopes on Northern/Eastern/Western aspects	Low	Retire from grazing, use for forestry

Step 4: Areas on which to avoid fertiliser application (Figure 2.8):

- Steep, poorly vegetated slopes.
- Waterways.
- Native vegetation.
- Neighbouring properties (e.g. residential housing, organic farms, grazing stock).

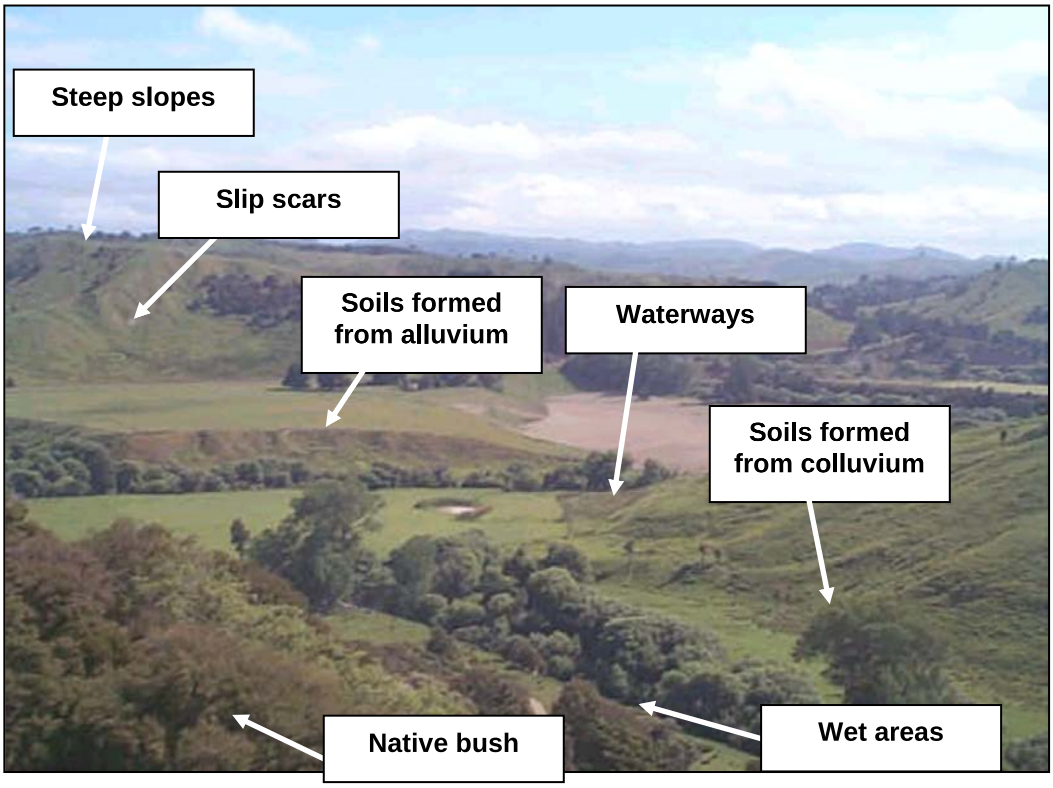


Figure 2.8 Landscape features that should be considered when applying fertiliser

Test Your Knowledge

1. Tirau silt loam (an Allophanic soil) and Tokomaru silt loam (a Pallic soil) are examples of contrasting soils formed from different parent materials and developed under different climatic regimes. Compare and contrast their physical and chemical properties in terms of their suitability for dairy farming.

2. Rivers are major transporters of soil parent materials, with the town of Ngaruawahia sited at the confluence of the Waipa and Waikato rivers. Use Google Earth to identify 3 major landscape units around Ngaruawahia and suggest the types of soils that may have formed on those units subsequent to the rhyolitic Hamilton ash falls about 180000 years ago.

Glossary (most definitions sourced from Molloy, 1998)

Alluvium
Material such as sand, silt or gravel which has been deposited by rivers, streams, and other running water.

Andesite
A dark coloured volcanic rock intermediate in composition between rhyolite and basalt. Molten andesite flows slowly and eruptions usually consist of both lava flows and tephra.

Argillite
A rock formed by the hardening of mudstone or siltstone.

Basalt
A type of volcanic rock which is rich in iron and magnesium but poor in silica (SiO_2). Molten basalt flows easily and it usually gives rise to lava flows with little ash being formed.

Bedrock
The solid rock that underlies soil or other loose material.

Clay
Soil material which consists of particles less than 0.002 mm in diameter.

Colluvium
Material such as rock fragments and soil which has accumulated at the base of steep slopes as a result of gravity.

Dacite
A lighter-coloured volcanic rock intermediate in composition between andesite and rhyolite.

Evapotranspiration
The sum of evaporation and plant transpiration of water from the soil surface to the atmosphere.

Fragipan
Subsoil horizon which has a high bulk density and which is relatively hard when dry but softens when wet. Usually impedes downward movement of water.

Gleying
Processes that occur mostly in wet, poorly drained soils, and that involve the reduction of iron and result in grey or bluish-grey colours. Gleying may be induced by groundwaters rising up through the soil, or by surface or 'perched' water which comes down from above but which is held up by a relatively impervious horizon in the soil.

Greywacke
A dark grey sandstone, flecked with dark angular fragments of finer rock; formed by the hardening of deposits in ancient ocean basins; the major rock type of central New Zealand.

Humus
Well decomposed organic matter in a soil.

Ignimbrite
Thick sheets of rock formed by the welding together of extremely hot particles of rhyolitic ash during volcanic eruptions.

Lahar
A flow of volcanic material, both ash and coarser products, mixed with water.

Leaching
The removal of dissolved materials from the soil by water.

Loam
A soil with desirable physical properties for plant growth, usually containing approximately equal proportions of sand, silt, clay, and organic matter.

Loess
A blanket deposit of silt-sized material – usually carried by wind from dry river beds or outwash plains (e.g. Canterbury).

Mafic
Describes a silicate rock or mineral which is rich in iron and magnesium.

Mudstone
Soft sedimentary rock formed from material which contains a large proportion of clay.

Pumice
A soft, light-coloured, frothy, glassy rock with the appearance of a sponge; usually formed by the trapping of bubbles of volcanic gases in molten rhyolite.

Rhyolite
A type of volcanic rock which is rich in silica (SiO_2), but poor in iron and magnesium. Molten rhyolite is very stiff and it usually gives rise to explosive volcanic eruptions with the emission of large quantities of ash.

Sand
Material which consists of particles between 0.05 and 2.0 mm in diameter.

Sedimentary rocks
Rocks resulting from the consolidation of loose material that has accumulated in layers, usually on the bed of a sea, in lakes, or in rivers.

Silt
Soil material which consists of particles between 0.05 and 0.002 mm in diameter.

Siltstone
Sedimentary rock formed mainly from silt.

Tephra
General term for all solid material (not molten material) which has been ejected from a volcano during an eruption.

Volcanic ash
Fine, ash-like rock particles ejected from volcanoes during eruptions; may be transported large distances by wind.

Acknowledgements

We thank Nathan Heath for providing the information and photographs for the Bramerton Station example.

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