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# **Soil Spatial Variability in Northern Manawatu, New Zealand**

**A thesis presented in partial fulfilment of the requirements for  
the degree of Doctor of Philosophy in Soil Science  
at Massey University  
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**Massey University**

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*This Thesis is Dedicated to My Loving Mother and  
to the Memory of My Loving Father.*

## Abstract

A detailed soil survey (1:25,000 scale) was conducted in northern Manawatu, near Kiwitea village, covering 2000 ha of terraced lands having three major terraces; a low river terrace, a last-glacial intermediate terrace and loess covered upper terrace. The area is characterized by warm and dry summers and wet and mild winters. The annual rainfall ranges from 900-1200 mm and the mean annual temperature ranges from 12°-13.5°C.

The parent materials are recent alluvium for the soils of the lower terrace; a mixture of alluvium, colluvium, loess and tephra for the soils of the intermediate terrace and Ohakean loess intermixed with tephra for the soils of the upper terrace. The loess originated from the local alluvium. The alluvium is derived mainly from greywacke, which is non calcareous and quartzo-feldspatic in mineralogy, and local early Pleistocene sands and mud.

In the soil survey, soils with gley profile form are considered poorly drained; with mottled profile form are considered imperfectly drained; with redox-mottled horizon below 60 cm are considered moderately well drained and; with no reductimorphic horizon or redox-mottled horizon within 80 cm are considered well drained. According to these drainage criteria the Ohakea and Marton series are redefined. Five new soil series are identified. Thirteen soil types are mapped.

The soil survey revealed that there is little relationship between soil drainage and topography. Chemical and mineralogical analysis of the soils revealed that there is a strong relationship between soil drainage, clay mineralogy and phosphate retention (P-retention).

Three parameters important for soil management were studied in detail in a window area (2000 m by 300 m) selected from the intermediate terrace. These three parameters were drainage status, P-retention and penetration resistance (PR) of the topsoil.

When mapped at 1:25,000 scale the window area comprised three different soil map units having well, moderately well and imperfect drainage. A small window area

(300 m by 250 m) from each map unit was selected and again mapped at 1:10,000 (100 m by 100 m grid) and 1:5,000 (50 m by 50 m grid) scales.

The simple soil pattern represented at 1:25,000 scale map is more complex when mapped at 1:10,000 scale. At least three different soil types (drainage classes) were identified in each of the blocks at 1:10,000 scale. When mapped at 1:5,000 scale little new information was found, but the drainage class boundaries could be shown more accurately. P-retention and PR of the topsoil are highly variable within the soil map units at all different mapping intensities. Variability of PR is dependent on the soil type and the land use, whereas P-retention is influenced by soil type alone.

Soil maps at 1:25,000 or smaller scale are not capable of readily delineating drainage status of this particular soil complex. A 1:10,000 scale soil map is the smallest scale that portrays reliable information.

No clear relationship could be established between soil drainage and landscape features, or depth to underlying river gravels. Therefore, a grid method is most suitable for conventional soil surveys in the area. An electromagnetic sensor (Em38) linked to a GPS can successfully be used to map soil drainage classes reliably, rapidly and cost effectively.

There is a good relationship between P-retention and soil drainage. Low P-retention values are associated with poorly drained soil conditions whereas high P-retention values are associated with well-drained soil conditions. The relationship is not as strong with moderately well drained and imperfectly drained soils. A majority of the observations on the imperfectly drained soils have medium P-retention values whereas a majority of the observations on the moderately well drained soils have P-retention values that range from medium to high.

The relationship between P-retention and soil type allows soil maps to be used effectively to identify areas likely to have low and high P-retention in the field. Soil maps at 1:10,000 scale are more suitable for identifying the areas reliably. However, some uncertainty exists within imperfectly and moderately well drained areas.

There is a good relationship between the PR and soil types as for the P-retention. The PR of the topsoil is relatively low in poorly drained soils and gradually increases through imperfect, moderately well to well drained soils. Soil maps at 1:5,000 are the most suitable for delineating PR classes.

The spatial scale of the variability of the three soil properties was quantitatively investigated using variogram models. The spatial variability of the three soil properties is anisotropic over the intermediate terrace. The variability is greater across the terrace than along the terrace. The maximum variability occurs at shorter lags (100-200 m) across the terrace and at longer lags (250 – 500 m) along the terrace.

Soil drainage and the tephra mixed parent material are the driving force behind the spatial variability of the three soil properties. Under well drained conditions, volcanic glass present in the tephra weathers to allophane and kandite and under imperfect and poorly drained conditions into kandite alone. P-retention is high in allophane-rich, well-drained soils and low in kandite-rich imperfectly and poorly drained soils. Variability of soil drainage within short distances is attributed to the minor textural differences responsible for the different hydraulic conductivity properties in the original alluvial sediments from which the soils developed.

The implications of spatial scale of soil variability for soil mapping, land use, soil management and land suitability evaluation are discussed

A summary of the study, research findings, recommendations and further research needs are given.

A soil survey report of Kiwitea district including formation, distribution, properties, limitations and the management of soils is written in simple English for non-technical people and is included as an appendix.

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## CHAPTER 1

# Introduction

The northern Manawatu Region of the North Island is an important agricultural area in New Zealand. The region has had a proud agricultural history for nearly 150 years since the 1860's. The traditional land use pattern in the area used to be pastoral farming, fattening of sheep, dairy and beef. However, this has gradually been diversified over the last few years into other agricultural uses such as cut flowers and bulbs, maize, barley, dairy conversion and contract vegetables for Heinz-Watties.

Development and expansion of Feilding and Marton townships within the northern Manawatu region has caused additional land use issues. Regional Councils, District Councils and City Councils may need to find suitable soils for non-farm uses such as housing, factories, storage houses, waste disposal sites, recreation etc. Real estate agencies, investors and the other agencies dealing with land-based enterprises may need to consult soil maps to evaluate and estimate land value and make decisions about their investment. Reliable soil maps at a suitable scale and easily interpreted soil reports are the essential base materials for these purposes. Unfortunately there are no soil maps available at suitable scale for the area. The most detailed coverage available is the 1:63,360-scale land use capability map (NZ land Resource Inventory, 1979). Therefore, the soil resources of the area need to be mapped and understood in order to increase farm productivity and make decisions on non-farm use of soils, while conserving soil resources and the surrounding environment.

In the New Zealand landscape topography, climate, geology, parent materials, hydrology and soils are highly variable. Jenny (1941) pointed out that soils are formed through the interaction of five major factors: climate, organisms, topography, parent

material and time. The relative influence of each factor varies from place to place and therefore soils also vary.

Soil variability affects soil management practices. Where there are large differences between soil properties, all land cannot usually be managed in the same way. Therefore, in soil surveys, soil scientists try to separate the heterogeneous landscape into more or less homogeneous segments or map units in order to adopt better soil management practices. A map unit is an area or group of areas in which the soil is less variable than in the larger landscape (Beckett and Webster, 1971).

Although map units are thought to be more or less homogeneous, some variability exists within soil map units that are segments of the natural landscape. Diagnostic properties used in soil mapping are usually soil physical properties. Therefore, there may be variability within non-diagnostic soil properties in a soil map unit. With the implementation of Soil Taxonomy it was found that the cartographic units representative of soil series seldom comprise more than 40-50% of soils designated in the map unit name (Powell and Springer, 1965; Wilding *et. al.*, 1965; McCormark and Wilding, 1969; Amos and Whiteside, 1975). However, this is a measure of the magnitude of fit between the taxonomic system and the cartographic units. Many of the soil inclusions in map units are not sufficiently different from the central concept to detract significantly from the interpretative value of the maps for soil performance. It is evident that the taxonomic purity of map units is not a proper measure of quality or precision of a soil survey (Miller *et al.*, 1979). More emphasis should be placed on the interpretative accuracy of soil map units.

Traditionally, soil management and land use planning have been the main broad aims of soil survey at all scales. Recently non-farm use of the soil resource has increased rapidly. This has exerted a great need for information about the effects on soils on these non-farm uses. Non-farm soil interpretations require different information. Some soil properties that are not important for growth of plants are very important in evaluating soils for their suitability for building sites, waste disposal systems, highways, pipelines and recreation (Soil Survey Staff, 1993).

Soil related environmental problems such as nitrate leaching and groundwater contamination, phosphate losses and eutrication of water bodies, and accumulation of

heavy metals and other contaminants in soils have become serious problems in some agricultural areas. New Zealand farmers are concerned about their clean and green image; therefore good soil health is one of their major concerns. Recently precision agricultural management has become a common practice to minimize the environmental hazards related to agriculture while maximizing production.

With the inception of precision agriculture and other non-farm use of soil, concern about soil variability became a more and more significant issue. Moreover soil variability studies gradually moved from qualitative to more quantitative measurements. It is evident that quantitative measurements of spatial soil variability are becoming more and more important in dealing with soil related problems. Quantitative methods enable precise statements to be made about the soil. The methods are collectively categorized in the emerging field of soil science known as pedometrics (McBratney *et al.*, 2000).

The variations in soils represent a continuum from a megascopic to a microscopic level of resolution (Wilding, 1985). However, the detailed soil survey conducted in the Kiwitea study area revealed that soil drainage, phosphate retention of the topsoil and pugging in the wet seasons are three important soil properties which are important in soil management practices and also highly variable over the landscape. Therefore, investigation of the magnitude of spatial variability of these three soil properties is one of the major objectives of this thesis.

The spatial variability study started with a detailed soil survey at 1:25, 000 scale in a representative area of about 2000 ha of terraced lands near Kiwitea village in the northern Manawatu Region. The arrangement of chapters is as follows.

Chapter 2 gives an overview of the study area as to its location, previous soil survey work and physical environment. Chapter 3 describes the methods used in soil mapping and characterization. Chapter 4 discusses the morphological, physical, chemical and mineralogical properties of the soils of the area. Chapter 5 is devoted to discuss the spatial variability of soil drainage, phosphate retention of the topsoil and penetration resistance of the topsoil of the intermediate terrace. Chapter 6 demonstrates use of geostatistics in quantification of spatial scale of variability of the three soil properties considered in the study. Chapter 7 discusses the possible reasons for the spatial variability of the three soil properties. Chapter 8 discusses the implications of soil

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variability. Chapter 9 gives a summary, research findings, recommendations and suggestions for future research to be conducted. The following flowchart (Figure.1.1) explains the structure of the thesis in more detail. Most soil survey reports are written for technically literate people. Farmers and non-technical people have difficulties in interpreting and using them. Therefore, a user-friendly soil report is included in appendix 14 to publish as a soil bulletin.

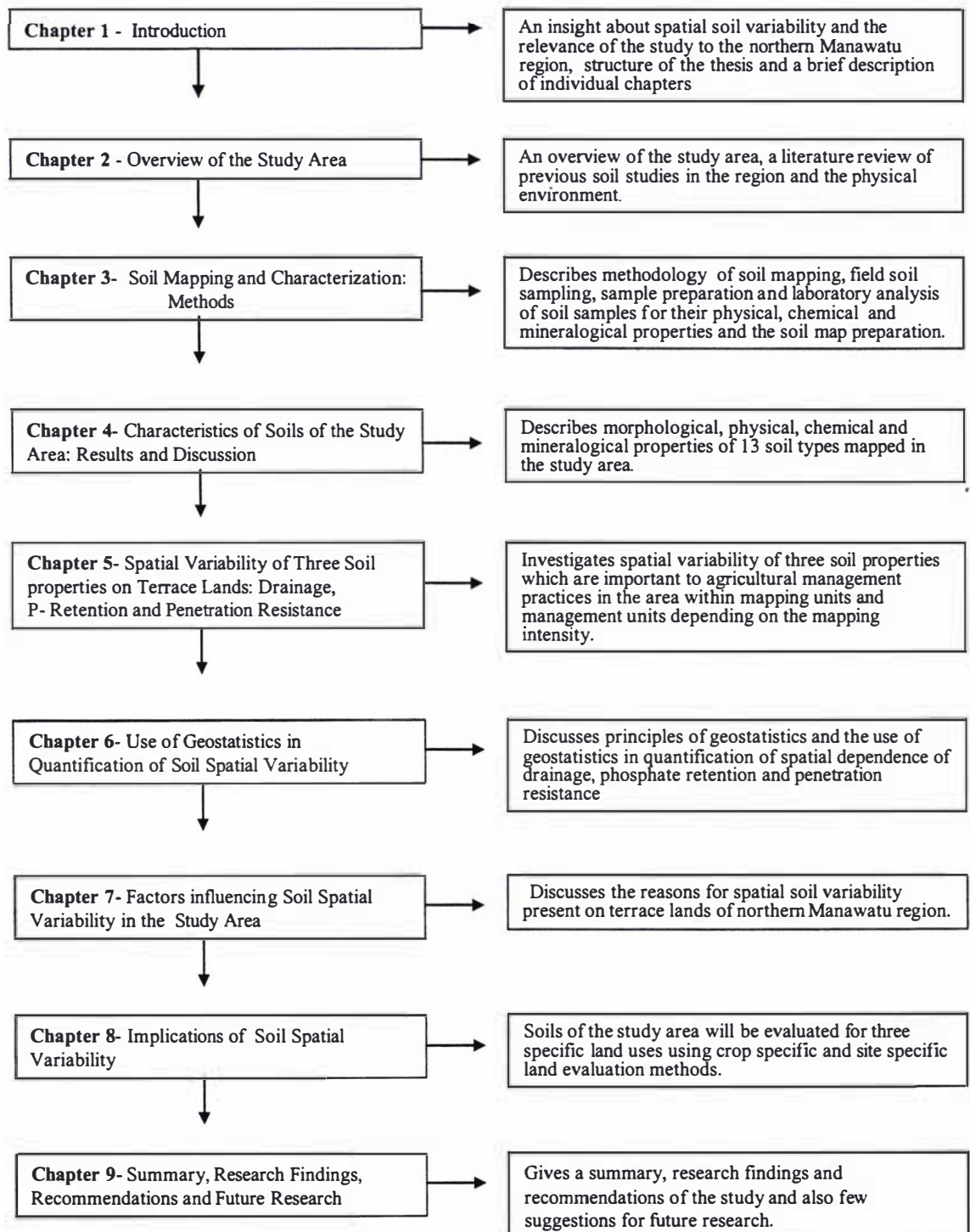


Figure 1.1 The structure of the thesis.

## **Overview of the Study Area**

### **2.1. Introduction**

The study area is located in the former KIWITEA County, one of the regions of the northern Manawatu where there is little detailed soil information available after the General Soil Survey of the North Island in 1954 (NZ Soil Bureau, 1954) and the New Zealand Land Resources Inventory Survey conducted in 1979 (NZ Land Resource Inventory, 1979). Therefore, the initial step of this study was to conduct a detailed soil survey in a selected representative area of about 2000 ha near KIWITEA village.

The objectives of this chapter are:

- to provide a review of previous soil studies in this region since 1954, and
- to provide background to the study area as to its location and the physical environment.

### **2.2. Location and General Description of the Study Area**

The location of the study area, near KIWITEA village, in northern Manawatu district of North Island is shown in Figure 2.1. KIWITEA village is located 40 km. north of Palmerston North, the principal city of the Manawatu Region. The total area covers 2000 ha. and is situated within the catchments of KIWITEA Stream and the Oroua River near KIWITEA village on the Cheltenham-Kimbolton road. The nearest urban area, Feilding, is situated 20 km south of KIWITEA (Figure 2.2 and NZMS 260 T23).

Kiwitea is easily accessed through State Highway 54. The survey area is well served with a local sealed and metalled road network. Farm tracks provide easy access to all the other parts of the farm properties (Figure 2.3).

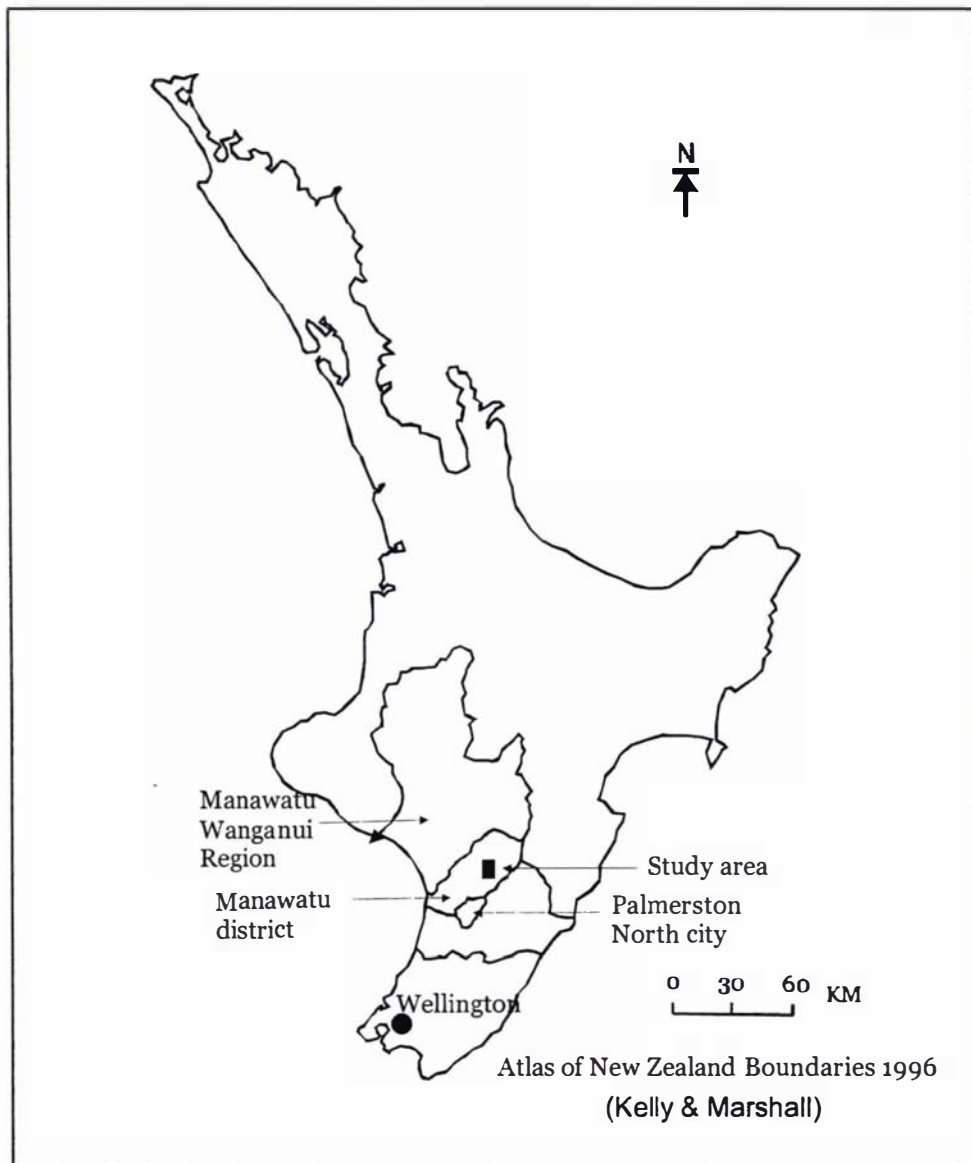


Figure 2.1 Location of the study area within the Manawatu district, North Island of New Zealand.

Terrace lands and river flats are the major landforms of the area. There are three distinct terrace levels; upper, intermediate and lower terraces. They are covered with loess

mixed with volcanic ashes, alluvium and colluvium mixed with volcanic ashes and alluvial materials respectively. The soils are the weathering products of these materials.

The landscape is flat to undulating and rolling on the upper terrace and flat to gently sloping on the intermediate terrace and lower terrace. The elevation ranges from 180 m at the lower terrace to 300 m on the highest part of the upper terrace.

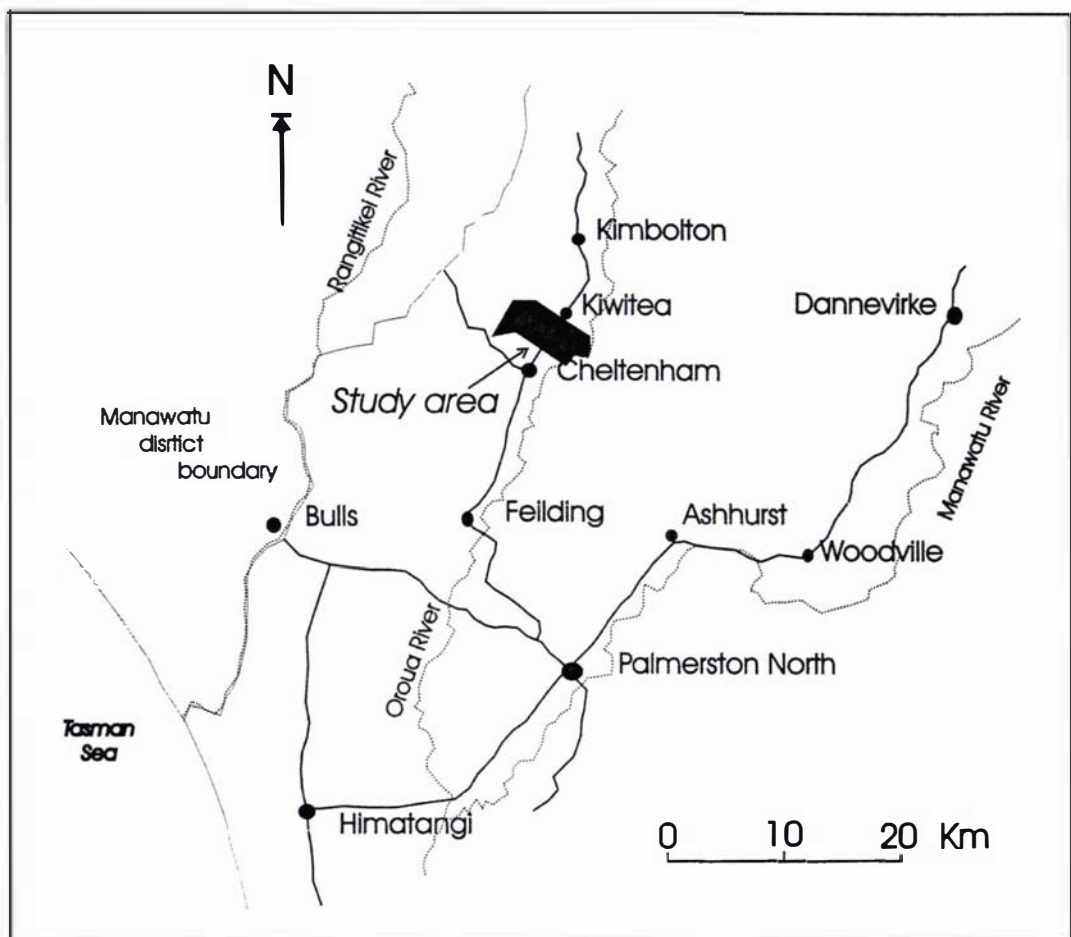


Figure 2.2 Location of the study area in relation to other urban areas, major roads and river catchments of the northern Manawatu.

A number of active and ephemeral streams running through the landscape drain into KIWITEA Stream and in turn into the Oroua River. The terraces generally slope gently from northeast to southwest off the Pohangina Anticline.

The annual rainfall ranges from 900 mm to 1200 mm with relatively dry summers and wet winters. Mean temperatures are around 7° C in winter and 18° C in summer.

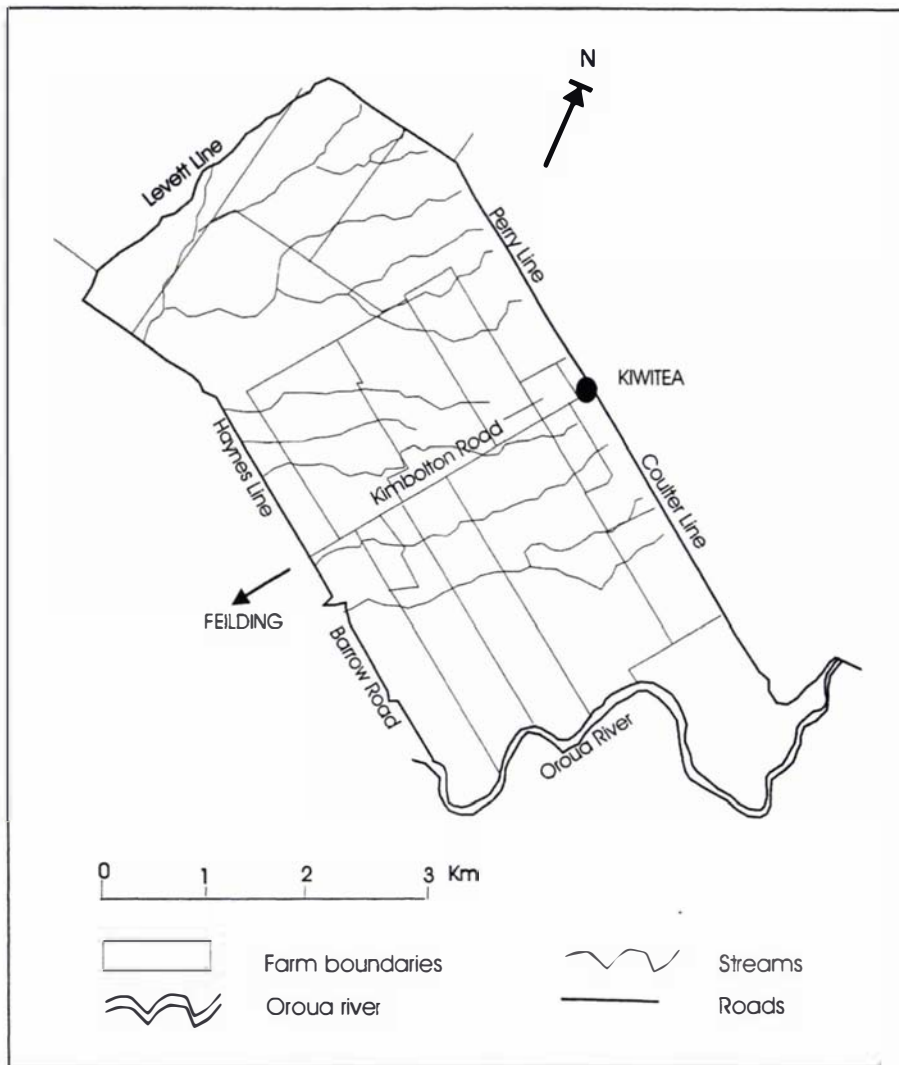


Figure 2.3 The study area near Kiwitea showing the road network, streams and farm boundaries.

The land is mainly used for pastoral farming especially dairy, beef, sheep and deer. Some farms have partially or fully been diversified into other agricultural land uses such as cropping, cut flowers and bulbs.

### 2.3. Previous Soil Studies in the Manawatu Region

Soil maps and reports available for the Manawatu Region have mostly been published on a county basis, a former administrative unit (Figure 2.4). The present Manawatu district (Figure 2.5) more or less covers the former (1) Rangitikei, (2) Manawatu, (3)

Kairanga, (4) Oroua, (5) Pohangina and (6) Kiwitea counties. The present study area is part of what was previously known as Kiwitea County.

A complete list of soil maps and reports published on a county basis, for the North and South Islands of New Zealand has been compiled and published as the “Directory of New Zealand Soil Survey Maps” by Fenwick and Tangelder (1983). This report gives a complete picture of the available soil studies in any part of the country up to that time.

The primary source of information available on soils in the Manawatu area dates back to 1954. The General Survey of the Soils of North Island, New Zealand (N.Z. Soil Bureau, 1954) covers the entire region. The objective of this study was to obtain an overall picture of North Island soils and their fertilizer needs and an approximate estimate of the productive potential of soil resources. This was a cooperative project of the Soil Bureau, Department of Scientific and Industrial Research and of the Extension Division, Department of Agriculture. The soil distribution pattern is shown on the Soil Map of New Zealand (NZ Soil Bureau, 1954) at 4 miles to an inch scale. The soils are grouped into "soil sets" which are convenient groupings of soils with like properties or a like assemblage of properties.

The second important source of information available for the Manawatu Region is the New Zealand Land Resource Inventory (1979). Land resource maps are published at 1:63,360 scales. The map units bear information about rock type, soil types, slope, degree and type of erosion and vegetation. It is important to note that little new soil information was gathered for the Land Resource Inventory. Rather, there was a reliance on interpretation of existing published and unpublished soil surveys.

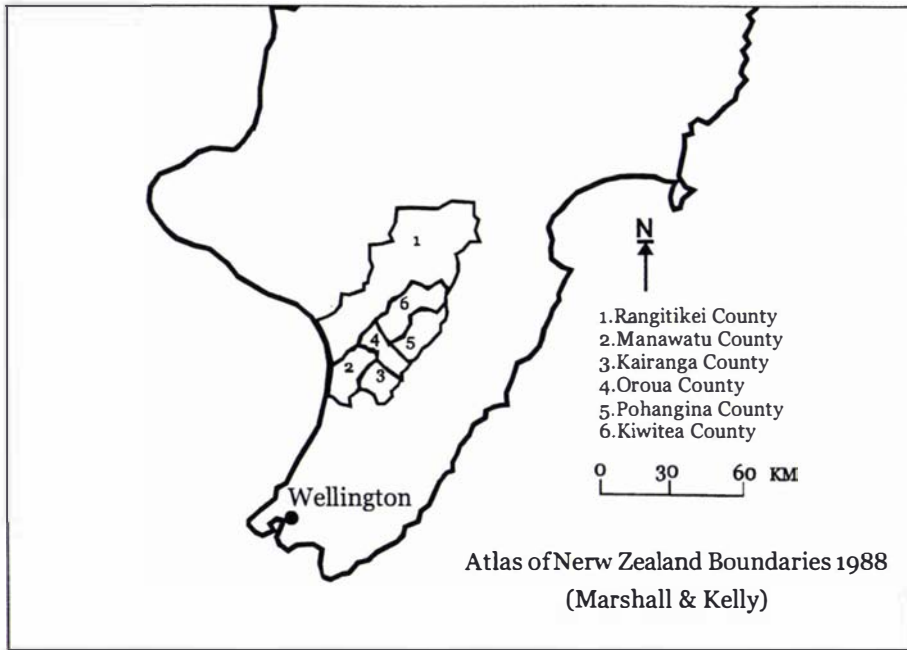


Figure 2.4 Former counties of the Manawatu Region

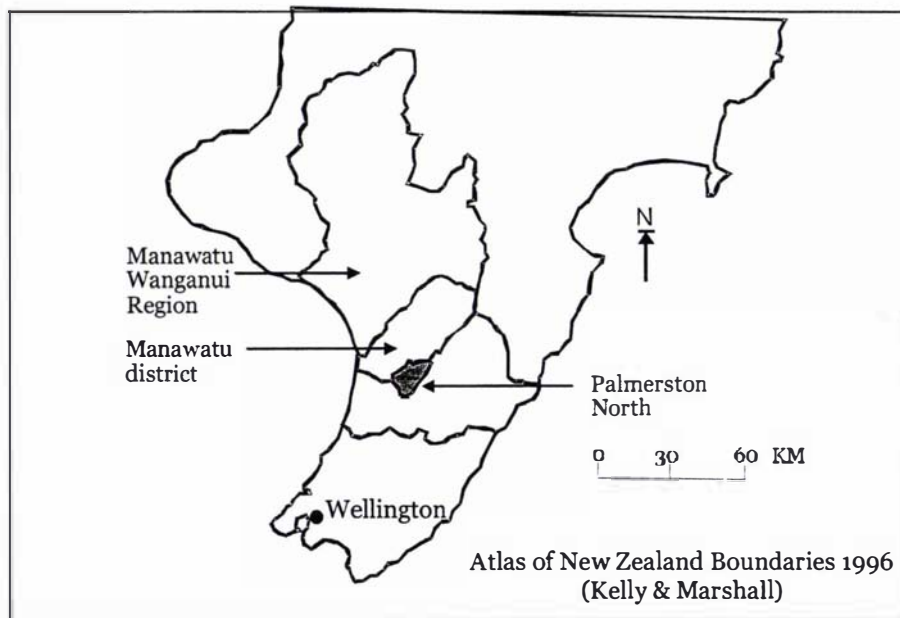


Figure 2.5 Present Manawatu district and the Manawatu-Wanganui Region.

The rest of the information on soil survey reports and maps and other miscellaneous soil-related studies are published mostly on a county basis. However, no detailed soil surveys have been published in the northern Manawatu Region, including KIWITEA County. The information available for other counties is given below. The source of soil information and a brief description of the type of information available in the report are given for each county.

### **2.3.1. Rangitikei County**

The Soil Bureau report "Soils and agriculture of Flock House, Bulls, Manawatu" (Cowie *et al.* 1965), describes the soils of Flock House Farm situated nearly 14 km south west of Bulls on the northern bank of the Rangitikei River. This survey covers an area of about 1000 ha. The farm lies within the area covered by the Manawatu-Rangitikei Sand Country soil survey (Cowie *et al.* 1967). Soils are mapped at a detailed scale of 1:15,840 (20 chains to one-inch) and the map units shown are soil types and their phases. The report includes the soil map and an extended legend for the soil map.

The publication "Soils of the Manawatu-Rangitikei Sand Country" (Cowie *et al.* 1967) covers the soils of coastal areas of Rangitikei and Manawatu Counties and part of Horowhenua County. The soil survey covers some 80,000 ha extending from Hokio Beach in the south to Whangaehu River in the north. Soils were grouped into three physiographic units; sand country, river flats and terraces. Soils of the sand country were mapped as soil associations. These are groups of soil types and phases, which are geographically associated in a regular predictable pattern, with the individual soils restricted to one segment of the landscape. Soils on river flats and terraces were mapped as soil series. This bulletin describes the soil associations of a major part of the sand country and gives brief notes on the soils, their utilization and their management. Also it describes the soils of the river flats and terraces, which are within the survey boundary. Chemical analyses of representative soils are also given in the report. The soil distribution pattern of the area is shown at 1:63,360 scale on two accompanying map sheets.

The National Resources Survey Part VII (1971) prepared an inventory of natural resources in the Wanganui region. This report covers Rangitikei County and the soil resources are shown at 1:500,000 scale. In this report soils of Rangitikei, their limitations to pastoral farming, cropping and forestry have been discussed. A land suitability classification and soil conservation measures and problems are discussed.

New Zealand Soil Survey Report No. 4 "Map and Section of River Terraces in the Rangitikei Basin"(Milne 1973b) provides a detailed description of river terraces formed along the Rangitikei River during different time periods. The report includes three 1:50,000 scale map sheets and one 1:250,000 scale map sheet.

The soil survey report "Soils of Rangitikei County"(Campbell, 1979) was compiled at 1:63,360 scale. Existing soil data by Cowie *et al.* (1967) for the coastal sand country was incorporated in soil maps without re-mapping but with minor updating. The survey covers approximately 448,600 ha. The soil map units used to show the distribution pattern of principal soil units are associations, steep land associations, hill soils, series, types and phases. Soils of the area have been grouped under four different physiographic units. They are the coastal sand country, the terrace lands, the central steep land and related flat, rolling and moderately steep land and the northern upland and dissected mountain lands. The extended legend provided with the report briefly discusses some of the properties of soils and the limitations of soils for cropping, forestry and pastoral use. In the map legend of this survey, the soils are grouped into limitation classes for cropping, forestry and pastoral use.

### **2.3.2. Manawatu County**

A detailed soil survey conducted in Manawatu County covering a wide range of sand country soils has been published in "Soils and Agriculture of Oroua Downs, Taikorea and Glen Oroua Districts, Manawatu County"(Cowie *et al.*, 1958). This survey covers a rectangular strip of the former Manawatu County, 10 km in width and extending 18 km in from the coast. The total area covered was 18,000 ha. The soil distribution pattern is shown on 1:15,840 (20 chains to 1 inch) scale soil maps. The principal factors of soil formation are discussed. The bulletin also includes the soils, their chemical properties,

and agriculture of the district and a short account of soil erosion. Some parts of Manawatu County have been covered in publications by Cowie *et al.* (1967) and Milne *et al.* (1973b).

The soil survey report “Soils of Manawatu County, North Island” (Cowie *et al.*, 1977) gives a good account of soils of Manawatu County. The soil survey covers about 69,000 ha. Soils have been grouped under three physiographic units, river flats, terrace lands and coastal sand country. The soils of the sand country are mapped in associations because of their complex nature, which cannot be shown on 1:63,360 scale soil maps.

Detailed information is given on the soil map and extended legend about the soils and drainage, which is a major limitation to agricultural uses on these soils. Classification of soils according to their potential for pastoral, cropping and forestry uses is listed.

### **2.3.3. Kairanga County**

Soil Bureau Bulletin 33 “Soils and Agriculture of Kairanga County” (Cowie, 1978), deals mainly with soils and agriculture, but it also describes the early history, geology, relief, climate and vegetation of the county and their effects on the soil pattern and present land use.

Accompanying the bulletin is a soil map (Cowie *et al.*, 1972), which shows the soil distribution pattern at 1:63,360 scale. The soils have been grouped under three main physiographic units. The map units shown are soil types and phases of soil types except for the hill country where the soil distribution pattern is very complex. Physiographic and pedological legends for the soil map units are given on the soil map.

The extended legend (Cowie *et al.*, 1972) accompanying the bulletin describes the physical environment, morphological features, natural fertility, present and potential land use, limitations for intensive land use, response of pastures to top dressing and erosion status of soils.

The soil survey report “Soils of Palmerston North City and Environs” (Cowie, 1974) includes a soil map of Palmerston North City and a series of interpretative maps

(N.Z. Soil Bureau maps 148/1-6) and an extended legend (Cowie, 1974). The soils are mapped at 1:15,840 scale and the map units used are soil types and their phases. A series of single factor land use maps have been produced interpreting the soil map. Soil limitations for urban, horticultural, pastoral, cropping uses and classification of soils for food production are the interpretative maps. The extended legend provides a summary of some soil, agricultural, horticultural and urban properties of soil map units.

A soil report compiled by Cowie *et al.*, (1977), also discuss the soil resources, agricultural and horticultural resources of Palmerston North and their production capacity.

#### **2.3.4. Oroua County**

There is no detailed soil information available in literature except for the soil survey report "Soils and Agriculture of Oroua Downs, Taikorea and Glen Oroua Districts, Manawatu County" (Cowie *et al.*, 1958). An unpublished 1:63,360 scale soil map is held by Landcare Research in Palmerston North. This unpublished information has been used on Land Use Capability maps of the area.

#### **2.3.5. Pohangina County**

The bulletin "Soils of Pohangina County" (Rijske, 1977) describes and classifies the soils of Pohangina County. The survey covers 77,500 ha of hill country, terraces and river flats of the Pohangina and Oroua Rivers. The soil survey was undertaken primarily to provide information for possible improvement in soil utilization and control of erosion.

The soils are grouped in five major physiographic units. The soils of each unit are described to give a general outline of their soil properties and agricultural uses. Detailed soil profile descriptions for representative soil types, their chemical and physical properties and agricultural limitations are discussed. General and technical classifications of soil types are given.

The soil distribution pattern is shown on the soil map of Pohangina County at 1:63,360 scale. Soil properties and some agricultural properties are summarized in the extended legend.

In the land use section, soils are classified according to their limitations, for pastoral, cropping, and forestry uses. Six classes of pastoral land uses have been determined and shown on a "Potential Land Use" map of Pohangina County.

## **2.4. Physical Environment**

### **2.4.1. Climate**

The daily weather and overall climatic conditions of New Zealand are very much a result of the geographic position and physiographic features of the country. New Zealand is located in the westerly wind belt of middle latitude and is characterized by high mountain ranges and young physiographic landforms.

The country is very often affected by the anticyclones and troughs or depressions, which move eastward over the Tasman Sea and New Zealand. The frontal system and the associated weather conditions of the country are a result of these moving anticyclones. Another important factor affecting the weather conditions of the country is the air masses originating in the tropics and /or the Antarctic regions.

The combined effect of all these factors determines the climatic conditions in New Zealand. Manawatu is located in the "Middle New Zealand Climatic Region" according to the classification of climatic regions by Garnier (1958). The characteristic features of the region can be summarized as follows. Westerly air streams are the main influence on the climatic conditions of the Manawatu region. The rainfall is relatively high and reliable and the annual range of temperatures is relatively small. Although the weather conditions are occasionally affected by external sub tropical or Antarctic influences they are not prominent. The diversity of climate is moderate.

The climatic conditions prevailing in the study area are typical of climatic conditions of the Manawatu region. The Manawatu region is characterized by a windy climate. The prevailing winds in the region are mainly westerly to north westerly, and occur 30 to 50 percent of the time. Rainfall is reliable and varies from 900 mm to 1200 mm annually. Summers are warm and dry. Winters are usually wet and frosts frequent in sheltered areas. The area does not experience any extremes of temperatures. Mean annual temperature ranges from 12° C to 13.5° C. Most of the time the sky is cloudy about the hills, but hours of sunshine increase toward the coast (Burgess, 1988).

There are no meteorological stations located in the study area. The nearest stations around the area are Palmerston North, Kairanga, Ohakea and Marton. Private owners maintain rainfall stations at Kiwitea, Feilding and Kimbolton.

#### 2.4.1.1. Rainfall

Mean monthly rainfall figures for the Kiwitea study area, Feilding and Kimbolton are presented in Table 2.1.

Table 2.1 Mean monthly rainfall (1985-1999) for Feilding, Kiwitea and Kimbolton.

Location	Elevation m.	Mean monthly rainfall mm												
		Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total
Feilding 1	76	71	72	74	82	73	89	88	75	73	88	92	79	955
Kiwitea 2	300	78	80	95	91	91	102	111	91	98	116	105	95	1152
Kimbolton3	540	74	76	95	88	87	97	111	88	87	106	102	90	1104

Sources of rainfall data:

1. Alan & Mary Mason, Sandon Road, P.O.Box 155, Feilding
2. Triss White, Reid Line West, R.D.7, Feilding & Richard Heerdegen, Geography Dept., Massey University
3. Rodney Wilson & Margaret Sargent, Cross Hills Gardens, P.O.Box 20, Kimbolton

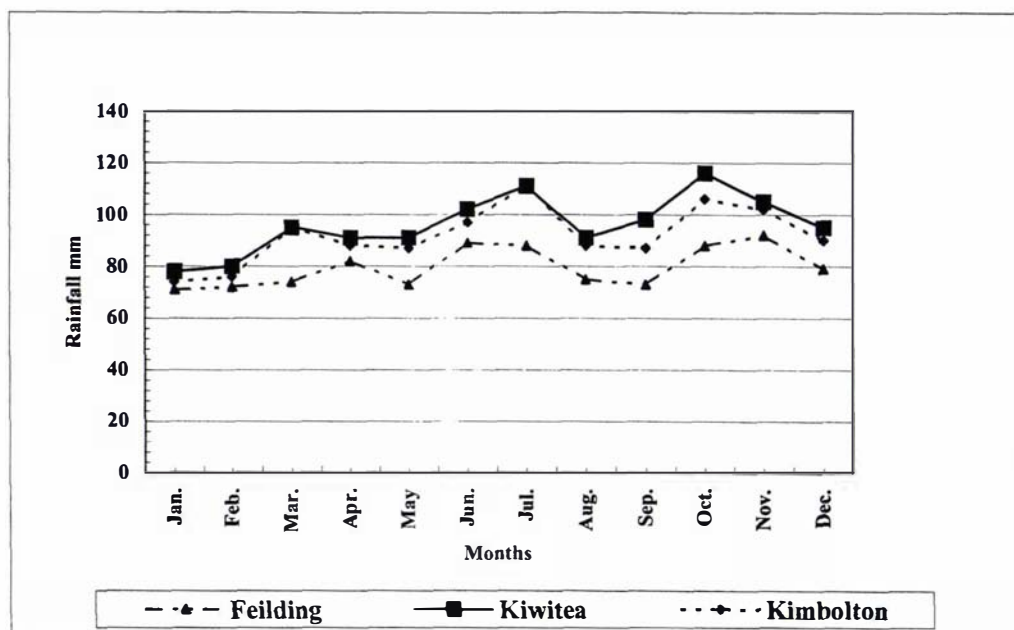


Figure 2.6 Mean monthly rainfall distribution pattern for Feilding, Kiwitea and Kimbolton.

Annual rainfall is evenly distributed in the Kiwitea and adjoining areas. The amounts range from about 950 mm to 1150 mm. Although Kimbolton is situated at higher elevation the total annual rainfall is lower than that of Kiwitea (Table 2.1). The rainfall distribution pattern in these three locations is very similar (Figure 2.6).

The seasonal rainfall distribution pattern shows that the region receives slightly more rain in winter and spring than in summer and autumn (Table 2.2 and Figure 2.7). The results indicate that evapotranspiration rates in the study area are higher than that of rainfall during summer months from December to March (Table 2.3 and Figure 2.8). However, during other seasons there is no soil moisture deficit in the area.

The evapotranspiration figures used in this comparison were taken from meteorological stations close to the area, as no figures are available for Kiwitea.

Table 2.2 Seasonal distribution of rainfall (mm) in Feilding, Kiwitea and Kimbolton.

Location	Elevation m	Summer	Autumn	Winter	Spring	Total
Feilding	76	222	229	252	253	956
Kiwitea	300	253	277	304	319	1153
Kimbolton	540	240	270	296	295	1101

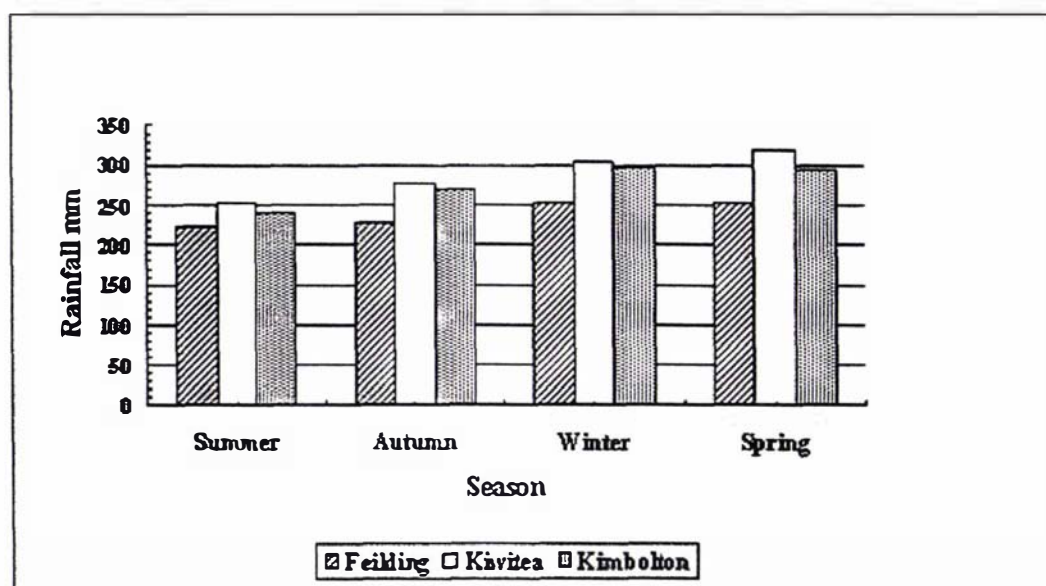


Figure 2.7 Seasonal distribution of rainfall in Feilding, Kiwitea and Kimbolton.

Table 2.3 Rainfall (RF) for Kiwitea and evapo-transpiration (ET) for Ohakea, Kairanga and Palmerston North (DSIR).

RF/ET mm	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	year
RF - Kiwitea	78	80	95	91	91	102	111	91	98	116	105	95	1152
ET - Ohakea	156	121	97	59	36	25	26	42	65	97	126	149	999
ET -Kairanga	141	115	88	50	29	19	23	37	58	89	115	136	900
ET -PN (DSIR)	134	109	86	50	27	17	20	34	55	83	108	128	851

PN (DSIR) = Palmerston North (Department of Scientific and Industrial Research).

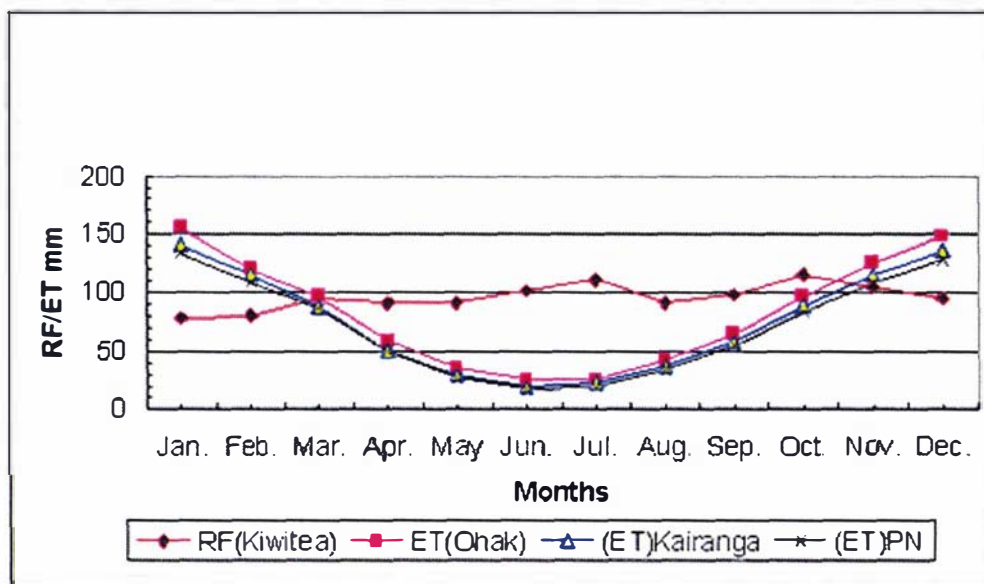


Figure 2.8 Rainfall (RF) at the Kiwitea study area and evapotranspiration (ET) rates for Ohakea, Kairanga and Palmerston North.

#### 2.4.1.2. Temperature

Temperature figures given here (Table 2.4) are for the climatological stations located within Manawatu district close to the study area and maintained by the New Zealand Meteorological Service (1983). It is evident that the area experiences very mild temperatures without any extremes. Mean air temperatures decrease with altitude. On the assumption that the mean air temperature decreases at a rate of approximately  $0.6^{\circ}\text{C}$  for every 100 m in altitude, we can expect about  $1^{\circ}\text{C}$  to  $1.5^{\circ}\text{C}$  lower mean air temperatures in Kiwitea compared to Palmerston North mean air temperatures.

Table 2.4 Mean monthly/annual air temperatures for Kairanga, Palmerston North (DSIR), Ohakea and Marton.

Station	Elev.	Period	Mean Monthly/Annual Temperature° C												
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Kairanga	15	1970-1980	17.5	17.6	16.5	13.9	10.6	8.4	8.1	9.1	11	12.4	14	15.8	12.9
PN (DSIR) <sup>1</sup>	34	1928-1980	17.3	17.6	16.4	13.9	10.9	8.6	8	9	10.6	12.4	14.2	16.1	12.9
Ohakea	48	1940-1980	17.5	17.8	16.6	14	11.3	9	8.4	9.3	11	12.6	14.3	16.2	13.2
Marton	141	1947-1966	16.3	16.9	15.3	12.7	10.4	8.3	7.4	8.3	9.8	11.6	13.2	15.1	12.1

1. PN (DSIR) = Palmerston North (Department of Scientific and Industrial Research).

Mean monthly soil temperatures are slightly higher than that of air temperatures from November to February in Kairanga, from October to February in Palmerston North and from October to March in Marton (Table 2.5) The higher the elevation the higher the numbers of months during which soil temperatures are higher than that of air temperatures. For many plants, the optimum soil temperature for seed germination is 12° C. Therefore, optimum soil temperature conditions for seed germination prevail in Manawatu from October to April.

Table 2.5 Mean monthly/annual soil temperature (at 10 cm depth) for Kairanga, Palmerston North (DSIR), Ohakea and Marton.

Station	Elev.	Period	Mean Monthly/Annual Soil Temperature C												
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Kairanga	15	1970-1980	18.4	17.7	16.1	12.8	9.1	6.7	6.2	7.2	9.6	12.3	14.5	16.9	12.3
PN (DSIR)	34	1939-1980	18.5	18.1	16.3	13.2	10.1	7.7	6.7	7.6	9.9	12.5	15.1	17.3	12.8
Ohakea	48	1940-1980	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Marton	141	1947-1966	17.9	17.7	15.5	12.4	9.4	7.5	6.2	6.8	9.1	11.9	14.4	16.8	12.1

PN (DSIR) = Palmerston North (Department of Scientific and Industrial Research).

The annual range in mean air temperature for summer to winter is about 8°-9° C and the mean soil temperature range is 10°-11° C (Table 2.6). Mean daily temperature range in the region is 8°-11° C. (Table 2.7) which is more than that of seasonal mean temperature variation.

Table 2.6 Seasonal mean air and soil temperature variations for Kairanga, Palmerston North (DSIR), Ohakea and Marton.

Station	Elevation m.	Mean air temperature° C			Mean soil temperature° C		
		Summer	Winter	Range	Summer	Winter	Range
Kairanga	15	16.9	8.5	8.4	17.6	6.7	10.9
PN (DSIR)	34	17	8.5	8.5	17.9	7.3	10.6
Ohakea	48	17.1	8.9	8.2	NA	NA	NA
Marton	141	16.1	8	8.1	17.4	6.8	10.6

PN (DSIR) = Palmerston North (Department of Scientific and Industrial Research).

Table 2.7 Mean Daily Temperature Ranges for Kairanga, Palmerston North, Ohakea and Marton.

Station	Elevation m.	Period	Mean daily range° C											
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Kairanga	15	1970-1980	10.1	10.9	10.7	10	9.5	9.3	8.9	8.9	8.5	8.8	9.6	9.8
PN (DSIR)	34	1928-1980	9.1	9.5	9.2	8.6	8.2	7.9	7.9	8.1	8.1	8.3	8.7	9
Ohakea	48	1954-1980	9.1	9.5	9.2	8.7	8.1	7.7	8	8	8	8.2	8.5	8.8
Marton	141	1947-1966	9.9	10	9.6	9.2	8.5	7.6	7.8	7.9	8.3	8.5	8.8	9.4

PN (DSIR) = Palmerston North (Department of Scientific and Industrial Research).

The highest temperature recorded in the Manawatu region was 30.4° C at Levin. Daily maximum temperatures have been recorded at Palmerston North DSIR since 1928, and the temperatures seldom exceed 30° C. Temperatures over 25° C are quite frequent in January and February in Manawatu and occur on 15-20 days each year (Burgess, 1988).

### 2.4.1.3. Sunshine Hours

The total number of sunshine hours ranges from around 1800 to 2100 hours per year (Table 2.8). The cloud cover increases close to the mountain ranges, and decreases towards the coast. Inland areas at higher elevations receive substantially less sunshine owing to exposure to rising moist airflows, which lead to cloudier conditions. Seasonal variation of sunshine is pronounced. In winter average total cloud cover is greatest, and in most places 10 to 15 per cent of days are overcast. In summer 5 to 10 percent of days have no sunshine.

The amount of solar radiation received depends upon the length of day, azimuth of the sun, cloud cover and aerosols in the atmosphere.

Table 2.8 Total numbers of sunshine hours for Kairanga, Palmerston North (DSIR), and Ohakea.

Station *	Elevation m.	Period	Mean sunshine hours												
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Kairanga	15	1970-1980	232	205	179	153	122	108	123	126	136	179	207	219	1989
PN (DSIR)	34	1935-1980	209	186	170	136	112	94	104	122	133	158	177	193	1794
Ohakea	48	1954-1980	242	213	185	159	128	111	119	137	157	191	211	227	2080

\* No data was available for Marton.

PN (DSIR) = Palmerston North (Department of Scientific and Industrial Research).

#### 2.4.1.4. Wind

The predominant wind flow over New Zealand is westerly, as the country is located in the westerly wind belt of middle latitude. The majority of anticyclones that pass over New Zealand have their centres just to the north of the North Island. Therefore, the predominant wind flow over the Manawatu region is between northwest and southwest. Prevailing surface winds in Manawatu, west of the ranges, are westerly to north-westerly, and occur 30 to 50 percent of the time.

At the surface wind direction and speed is strongly modified by the hills, the Ruahine and Tararua Ranges and the Manawatu Gorge. Wind speed has a large local variation in the hills and ranges because of the complex terrain. At less exposed sites, sheltering from trees and buildings reduce surface wind speed. On well-exposed coastal and lowland areas, wind speeds average 15 to 18 km/hr (Burgess, 1988).

Seasonal variation in wind speed is not great, but winds are generally a little lighter in strength from March through to August (Table 2.9.). Windy conditions (mean speeds of at least 30 km/hr) occur least during winter in Manawatu (Table 2.10). In summer, anticyclonic conditions with light winds are more prevalent. In most lowland and coastal areas, gales (a mean speed over a ten minutes period of at least 63 km/hr) occur on average 3 to 7 days and high wind gusts occur less than 10 days a year.

Table 2.9 Mean daily wind speed (km/hr) for Kairanga, Palmerston North (DSIR) and Ohakea. (Source: Burgess, 1988).

Station	Elevation m.	Period	Mean daily wind speed km/hr												
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	year
Kairanga 1	15	1970-1984	18	17	15	15	15	13	13	15	17	18	18	17	15
PN (DSIR) 2	34	1928-1984	13	13	11	11	9	9	9	11	13	13	13	13	11
Ohakea	48	1940-1984	18	18	17	17	17	17	15	17	18	18	20	18	17

1 Mean wind speeds obtained by cup-counters at a height of 6 m.

2 PN (DSIR) = Palmerston North (Department of Scientific and Industrial Research).

Table 2.10 Seasonal frequency (percentage) of fresh (30-39 km/hr) and strong winds (at least 40 km/hr) at Kairanga, Palmerston North Airport and Ohakea. (Source: Burgess, 1988).

Station	Period	Fresh					Strong				
		Spr.	Sum.	Aut.	Win.	Year	Spr.	Sum.	Aut.	Win.	Year
Kairanga **	1972-1978	17	17	14	11	15	15	11	9	9	11
PN (Air) **	1972-1978	12	6	6	5	7	3	4	3	2	3
Ohakea *	1960-1978	11	10	8	7	9	7	7	4	3	5

\* = hourly observations

\*\* = 9.00 a.m. observations

PN (Air) = Palmerston North (Airport)

#### 2.4.1.5. Frost and Hail

Air frost is quite common a few days a month except in summer. Ground frosts usually occur between March and November, but are most likely on clear, calm nights in winter. Slight ground frosts have occasionally been recorded in summer. The frequency of frost varies from place to place (Table 2.11), depending on the exposure of the site to wind and drainage of cold air from the hills. Severe frost is not common in this region, but is likely to occur in sheltered inland areas. Hailstorms are infrequent, occurring on average less than five times annually (Table 2.12). Most occur in winter and spring, and are associated with cold unstable air streams.

Table 2.11 Average days of air frost and ground frost at Kairanga, Palmerston North, Ohakea and Marton.

Station	Period		Average days of air frost and ground frost												
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Kairanga	1970-1980	Air	0.2	0.2	0.7	1.6	7.7	11.8	10.3	8.7	4.7	3.1	1.5	0.2	50.7
		Ground	0	0	0.1	0.3	3	6.3	6	2.8	1.3	0.2	0	0	20
PN (DISR)	1928-1980	Air	0.2	0.3	0.8	2.4	6.5	10.6	13.1	10.4	6	3	1	0.1	54.4
		Ground	0	0	0	0	0.2	3.8	4.8	2.6	0.9	0.2	0	0	13.5
Ohakea	1940-1980	Air	0	0	0	0.4	1.6	5.9	7	4.8	2	0.6	0.3	0	22.6
		Ground	0	0	0	0	0.2	1.3	1.8	0.6	0.2	0	0	0	4.1
Marton	1947-1966	Air	0.3	0.2	0.9	3.9	7.7	10.2	12.7	10.7	7.4	2.4	1.5	0.3	58.2
		Ground	0	0	0.1	0.3	2.2	4.8	6.2	3.4	1.6	0.3	0.1	0	19

PN (DSIR) = Palmerston North (Department of Scientific and Industrial Research).

Table 2.12 Mean annual hail frequencies in Kairanga, Palmerston North and Ohakea. (Source: Burgess, 1988).

Station	Period	Days per year	Maximum recorded in any year
Kairanga	1970 - 1984	4.9	13
PN (DSIR)	1928 - 1984	2.4	11
Ohakea	1940 - 1984	5.8	13

PN (DSIR) = Palmerston North (Department of Scientific and Industrial Research).

## 2.4.2. Landforms

The landform of the study area is characterized by suites of river terraces at different elevations. Three major terraces can be identified within the study area; lower terrace, an intermediate terrace and an upper terrace (Figure 2.9). They are situated at 180 m, 200 - 240 m and 240 - 300m above mean sea level respectively. The study area is located on the western limb of the Pohangina Anticline and the range in height of the intermediate and upper terrace is caused by a perceptible dip of both the terrace surface and the underlying Early Pleistocene sands toward the southwest, particularly noticeable (2-3 degrees) for the upper terrace. This terrace landform system is common in the Manawatu region that comprises catchments of the Rangitikei, Oroua, Pohangina and Manawatu rivers. (Cowie *et al.* 1967; Milne 1973a; Campbell 1977 & 1979). The suites

of terraces formed as a result of climatic fluctuations during the Quaternary period coupled with uplift of the area.

Wanganui Basin contains up to 4000 m of Pliocene/Pleistocene sediments (Pillans, 1991). These sediments were derived from the rising arc of land extending from Taranaki, across to Tongariro Volcanic Centre to the Ruahine and Tararua Ranges. Sediments eroded from northwest Nelson far to the south were also deposited here. During the late Tertiary to mid-Quaternary period most of the Manawatu-Wanganui region was submerged under the sea. Gradually, as uplift of this northern arc of land occurred, a large coastal plain formed. During this time of coastal plain emergence, many worldwide climatic oscillations took place (Molloy 1993).

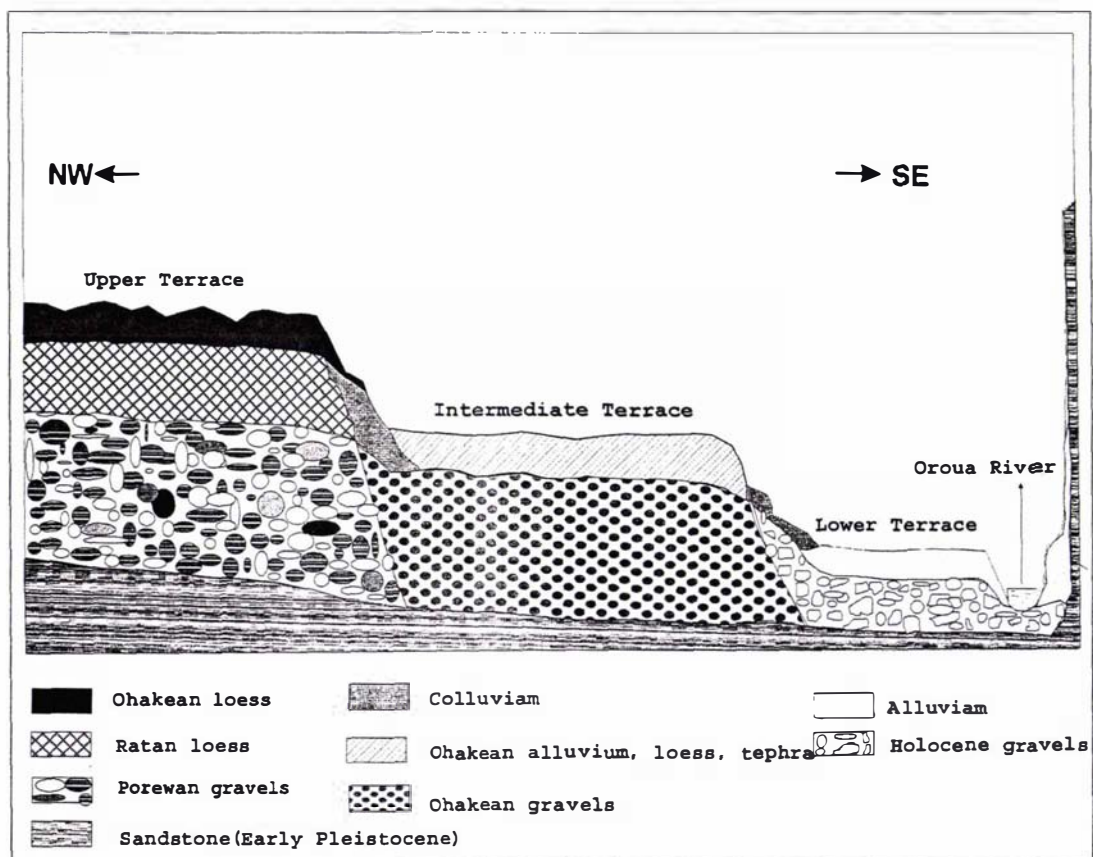


Figure 2.9 The typical terrace landform system in northern Manawatu. (Figure is not to scale).

Climatic conditions prevailing on Earth during the last 150,000 years have been inferred from an ice core taken from the Russian Vostok station on the Antarctic icecap. New

Zealand temperature change over the past 150,000 years, appears to resemble the Vostok results. According to these studies the world has experienced long periods of warm (interglacial periods) and cold climates (glacial periods). The Last Interglacial period began 125,000 years BP and ended 80,000 years B.P. The temperatures were 1°C to 2°C below present day values at the end of the interglacial (<http://Katipo.niwa.cri.nz>).

The glacial period began 80,000 years B.P and ended 10,000 years B.P. The last glacial was punctuated by three particularly cold periods: the Porewan from 80,000 years to 60,000 years B.P., Ratan 50,000 years to 30,000 years B.P., and Ohakean 26,000 years to 10,000 years B.P. The last glacial maximum was between 26,000 years and 18,000 years ago. The New Zealand annual average temperature is estimated to have been 4.5° to 5° C below present day values during the glacial maximum (Pillans *et al.*, 1993). Warming to the current interglacial period began about 14,000 years ago. The warmest conditions of the present cycle occurred between 10,000 and 8,000 B.P. with temperatures about 1°C above modern values. (<http://Katipo.niwa.cri.nz>).

During ice ages the sea level was much lower than it is today. It was about 130 m lower at the last glacial maximum and the shoreline would have been located more than 50 km seaward of the succeeding interglacial shoreline, 18,000 years ago (Pillans, 1994). In the colder conditions that prevailed during the ice ages, the tree line was at a much lower altitude, probably below current sea level in the Manawatu region, and consequently erosion in the mountains was much more vigorous. The Rangitikei, Oroua, Pohangina and Manawatu rivers have carried vast amount of rock debris to the down stream low lands. Burdened by this load, the rivers built-up (aggraded) their beds by depositing the rock debris to form wide, bare, flood plains.

During times of warm climates forest cover returned, erosion rates decreased and the rivers cut down (degraded) through the aggradation terrace. This aggradation and degradation process has taken place alternately. The glacial stage has been subdivided into sub-stages of relative cold and warmth. The Otiran, last glaciation period, has been sub-divided into the Ohakean, Apitian, Ratan, Orouan and Porewan substages (Milne, 1973a). It is generally believed that climatic fluctuations during the late Pleistocene were of sufficient magnitude to induce changes in the regime of the rivers that would

allow for periodic aggradation and degradation on a large scale. The terraces are preserved by uplift. Uplift rates are greater in the north and east in the district and decrease to the southwest.

According to Milne (1973a) terraces with greater than 3 m of alluvial gravels were termed aggradational, while those with less than 3 m of gravel were termed degradational. The choice of 3m as the critical thickness was guided by the maximum thickness of alluvium on clearly degradational terraces younger than the Ohakea terrace. Further, aggradational terraces are characterized by thick accumulations of spheroidal water-worn gravels in a sandy matrix, while degradation terraces feature a complex array of sands, silt and gravels (Palmer *et al.*, 1988).

River terraces developed during the last 400,000 years and the cover deposits that mantle them in the Rangitikei drainage basin were studied in detail by Milne (1973a). Ages of river terraces and the cover beds have been estimated. The terrace ages were later revised by Pillans (1994). River terraces present in the Oroua catchments have not previously been correlated with them. The major river terraces in Manawatu are less than 120,000 years old as they lie below the Tokomaru Marine Terrace formed during the last interglacial period (Heerdegen *et.al.* 1992).

An estimate of ages of river terraces in the study area can be made from the previous studies carried out in the Manawatu region for the Manawatu and Rangitikei Rivers. Cowie (1964a) pointed out that the Aokautere ash (correlated with Kawakawa Tephra) is interbedded on the Milson and older terraces of the Manawatu district but absent from the thin loess of the Ohakea Terrace. The Kawakawa rhyolitic tephra layer interbedded in loess deposits on river terraces is an important marker bed for correlation and dating the other cover beds in the area. The Kawakawa Tephra layer is dated at 24,000 calendar years old (Wilson *et al.*, 1988; Shepherd and Price, 1990; Pillans *et al.*, 1993). Soil profile studies on the upper terrace of the study area shows that the Kawakawa Tephra is interbedded in loess about 0.7 – 0.8 m below the surface. On the upper terrace there are at least two loess units separated by a paleosol, the upper one containing Kawakawa Tephra. On Milne's criteria the upper terrace is of at least Porewan age. The Porewan terrace surfaces have been estimated to be 70,000 to 80,000 years B.P (Pillans, 1994). However, on what is thought to be the same surface at a site a few km away,

Palmer (pers comm.. 2002) has found much thicker loess, with a rhyolitic tephra considered to be 280-300,000 years old near the base overlying gravels. The Porewan age attributed to the upper terrace in this study must therefore be considered to be a minimum age

The Kawakawa Tephra is not present on the intermediate terrace; therefore the intermediate terrace can be correlated with the Ohakean terraces. A number of sub-terraces (Milne 1973a), at different elevations, can be identified within the Ohakean terrace present in the study area; younger terraces with stony surfaces and older terraces with up to 1.5 m of loamy alluvium, colluvium, loess and tephra cover. The ages of the sub-terraces estimated by Milne (1973a) are 15,000 years B.P (Ohakea III), 15,000 – 13,000 years B.P. (Ohakea II) and 13,000 – 12,000 years B.P. (Ohakea I). This has been revised by Pillans (1994) to 18,000, 12,000 and 10,000 years B.P. respectively.

### **2.4.3. Parent Materials**

The parent materials of soils formed on terrace lands of the Manawatu region were once considered to be old alluvial or marine deposits (N.Z. Soil Bureau, 1954; Oliver, 1948; Fife, 1945; Te Punga, 1953a, 1957). Fleming (1953) considered that the thick cover on the higher and the older marine terraces in the adjoining Wanganui district was loess derived from the dune sands bordering the coast to the west. He was the first to describe the North Island loess deposits. However, Cowie (1964b) was the first to study loess in detail in the area and has shown that parent materials of soils of the upper terrace are wind blown material known as Ohakean loess.

This loess material is thought to have been blown from the alluvial deposits of the aggradational Ohakean terrace by the prevailing north-westerly winds. According to Vella (1963) and Milne (1973b), major phases of aggradation resulted from increased sediment production in headwater regions accompanying glacial and stadial changes to vegetation patterns. Aggrading river flood plains were major sources of loess during these times. The source of these fluvial sediments was the quartzo-feldspathic greywacke-argillite derived from adjacent mountain ranges (Palmer, 1988). The greywacke –argillite loess parent material is low in calcium, and in the present humid

temperate climate the loess contains no free carbonate. Therefore, New Zealand loess contrasts strongly with European, North American and Chinese loess materials (Palmer, 1987). During periods of river down cutting little or no loess appears to have been produced on a regional scale, and soil development occurred on previously deposited loess. Milne (1973a, 1973b) estimated that the Ohakean loess was deposited 12,000 to 24,000 years B.P. He estimated that accumulation of Ohakean loess started 26,000 years B.P and ceased about 10,000 years B.P. This indicates that parent materials of the upper terrace have undergone weathering at least for 10,000 to 15,000 years.

Soils of the intermediate terrace have been formed from the alluvial deposits laid down by the Oroua River during final stages of aggradation of the Ohakean terrace, and are thus 10,000 to 24,000 years old (Milne, 1973a; Pillans, 1994). The river abandoned this surface some time between 15,000 and 10,000 years ago; therefore soils of the intermediate terrace are also at least 10,000 years old.

Added to the alluvium is probably loess and tephra deposited in the last 15,000 years, locally derived alluvium and colluvium. Mineralogical analyses (Chapter 4, Tables 4.66) show the sand fraction of both parent materials from the upper terrace and the intermediate terrace are similar. They have originated from a quartzo-feldspathic parent material. The glass present in the sand fraction indicates that there has been some influence of tephra in the formation of soils on these terrace lands. A considerable amount of pumice is also present in the Early Pleistocene sediments that underlie all the terrace gravels (see Figure 2.9) and may be the source of some of the glass. Symes and Wells (1973) have also reported the contamination of loess with glass in the Manawatu district. They have reported that Marton soils are mixed with about 50% volcanic glass in addition to loess in the topsoil. Because pumice is a common component of the river alluvium, some of the glass may have been deposited as loess.

Soils of the lower terrace are formed from alluvium laid down by the Oroua River derived mainly from Mesozoic greywacke-argillite of the Ruahine Ranges, Tertiary and Quaternary sandstones, mudstones and limestone. They contain appreciable amounts of micaceous minerals. These minerals weather rapidly and ensure an adequate supply of K in most of the soils (Cowie *et al.*, 1967, Cowie, 1978; Rijkse, 1977). They are very young deposits having been deposited over the last 2000 years.

#### 2.4.4. Vegetation and Land Use

Natural vegetation and land use in the northern Manawatu region was quite different in the past compared to that of today. Although there are no systematic records available on the past vegetation cover, it is possible to obtain a picture of the early vegetation from the remaining forest reserves, from early maps and from the accounts of some early visitors to the Manawatu region.

Most of the information on historical events, native vegetation and botany of the Manawatu have been compiled by Buick (1903), Greenwood (1949), Elder (1958, 1965) and Esler (1978).

According to the information gathered from survey plans drawn between 1859 and 1881, about half of the Manawatu region was covered by forest around the 1860's (Esler, 1978). As intensive farming had not then started, the distribution of native forest cover fairly accurately portrays the situation before modification by settlers. Stewart (1859) who surveyed the Manawatu block of lands in 1858 noted that the block was mainly bush land. The impact of Maori over the previous several hundred years is unknown, except for burning and disturbances of dunes near the coast.

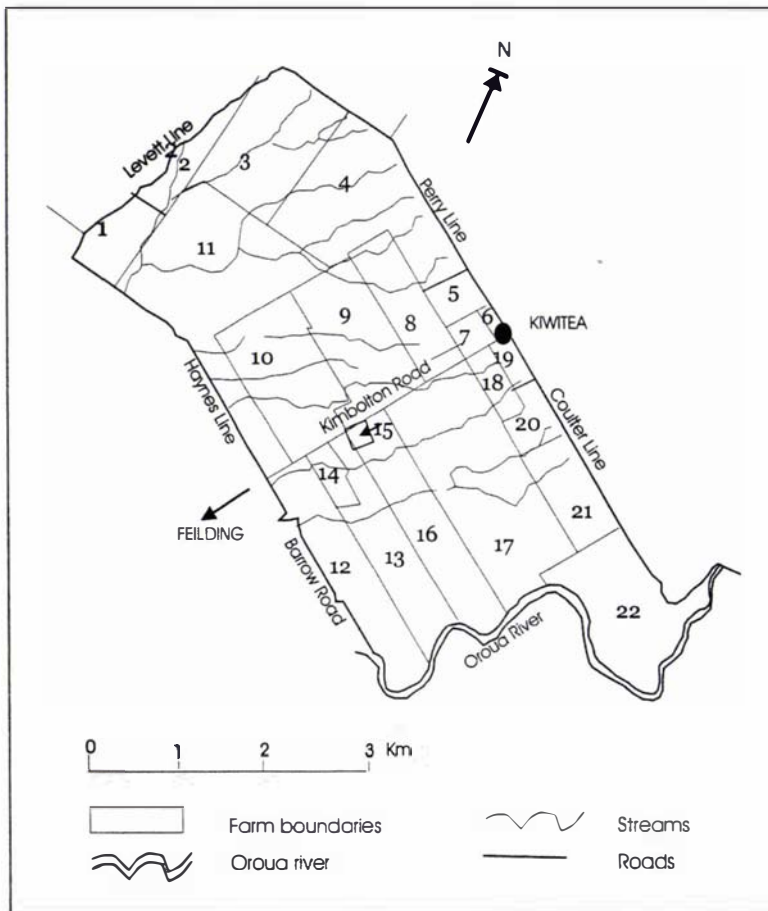
The early European settlers cleared native forests and the region was gradually converted to an agricultural area. New varieties of grasses and clover were introduced to the area in the 1900s with the introduction of super phosphate. The economy was then mainly concentrated on the rearing of fat lambs and cattle and on dairying. Establishment of the first dried milk factory followed by a butter factory in 1904 near Bunnythorpe, proves that the Manawatu region was already an important dairying area.

The area is well known for top Romney stud farms. The stretch from Cheltenham to Kiwitea on Kimbolton Road was known as "Ram Alley" or the "Golden Mile". The premier Romney event in the New Zealand calendar until well after the Second World War was the annual Feilding ram sale (N.Z.Rural press, 1990).

The traditional land use pattern in this area has been gradually diversified into other agricultural uses such as cut flowers and bulbs, maize, barley, contract vegetables, dairy

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conversion, etc. Deer farming has also become popular. There are two deer farms within the survey area. The present land use pattern in the survey area is shown in Figure 2.10.



- |                                    |                                    |
|------------------------------------|------------------------------------|
| 1. Sheep and beef                  | 2. Beef                            |
| 3. Sheep and beef                  | 4. Sheep, beef, barley and parsnip |
| 5. Beef                            | 6. Kiwitea school                  |
| 7. Sheep and beef                  | 8. Deer                            |
| 9. Sheep, beef, barley and parsnip | 10. Sheep and beef                 |
| 11. Sheep and beef                 | 12. Dairy                          |
| 13. Sheep and beef                 | 14. Sheep                          |
| 15. Homestead                      | 16. Sheep, deer, beef and maize    |
| 17. Dairy                          | 18. Sheep and parsnip              |
| 19. Homestead gardens              | 20. Sheep and beef                 |
| 21. Cut flowers, bulbs and sheep   | 22. Sheep, beef and dairy.         |

Figure 2.10 Present land holdings and land use in the study area.

## **Soil Mapping and Characterization: Methods**

### **3.1. Introduction**

The intention of this chapter is to discuss the methods used in:

- Soil mapping of the Kiwitea study area.
- Soil sampling and preparation for laboratory analysis.
- Physical, chemical and mineralogical characterization of soil types, and
- Preparation of the soil map of Kiwitea at 1:25,000 scale.

Out of thirteen soil types identified and mapped in this survey, four soils were considered to be potential new soil series. Characterization of all thirteen soil units is beyond the scope of this study. Therefore, priority was given for the characterization of new soil types. Landcare Research's National Soil Data Base provides information about most of the other soil types identified and mapped in the study area. This information was used where possible in this study to supplement the new soil data.

Soil morphological properties were studied for Coulter, Horoeke and Barrow silt loams from the intermediate terrace and Kiwitea, Cheltenham and Feilding silt loams from the Upper Terrace. Physical, chemical and mineralogical characteristics were determined only for Coulter, Barrow, Kiwitea and Feilding silt loams. Although Horoeke and Cheltenham silt loams are also potential new soil series, their distribution is limited to a small area. Laboratory analyses were not carried out for these soils. Their properties can, to a certain extent, be inferred because of their position in a drainage sequence.

## **3.2. Soil Survey Methodology**

### **3.2.1. Preliminary Study**

Previous soil maps, soil reports and climatological reports for the Manawatu district were studied to become familiarized with the climate, landforms, parent materials, vegetation, land use and the soils and their distribution pattern in the northern Manawatu. The study area near Kiwitea village was visited and local residents and farmers were informed of the impending study. Information about land use and management practices was collected. A traverse was made through the area on all available roads and farm tracks to become familiarized with the landforms and physiography.

### **3.2.2. Base Maps**

Black and white aerial photographs (NZ Aerial Mapping, 1983, SN 8158) at 1:25,000 scale were used in combination with the 1:50,000 topographical map of Kimbolton (NZMS 260 T23), to locate and to mark field observation points.

### **3.2.3. Aerial Photo Interpretation**

The black and white aerial photographs were examined using a stereoscope. Major physiographic units were identified using elevation differences between terraces and demarcated on aerial photographs. The separation of physiographic units is based on parent materials and their age. Landscape units were identified and separated within major physiographic units using slopes and minor elevation differences. Roads, farm tracks, streams and other important physical features were also identified and marked on aerial photos.

### **3.2.4. Field Observations**

Soils on different landscape units separated on aerial photographs were studied making mini soil profiles. Soil horizons, their morphological and physical properties were examined to a depth of 110 cm in deep soils and to within the gravel layer in shallow soils. Soils were mapped taking auger observations in a grid pattern at 250 m intervals on each physiographic unit. The observation points were marked on aerial photographs

### **3.2.5. Separation of Soil Series and Types**

In soil mapping, identification of different soils in the field is based on morphological and physical properties of soil horizons (Soil Survey Staff, 1993). Soil morphological properties such as soil colour, presence or absence of low chroma mottles, texture, structure and consistency are easy to recognize in the field. These properties were studied in subsoil horizons. The parent materials of the soils were also taken into account. Altogether eleven soil series were separated in the study area.

A group of soils that have horizons similar in arrangement and differentiating characteristics except for the texture of the A horizon were considered as a soil series (Soil Survey Staff, 1993). Soil series were further subdivided into soil types based on the texture of the A-horizon. (e.g. Coulter silt loam). Most of the topsoil in the area is silt loam in texture, except for Manawatu fine sandy loam. Thirteen soil types were mapped in the study area.

### **3.2.6. Separation of Soil Drainage Classes**

Separation of soil drainage classes in the study area is based on the presence of reductimorphic features in soil horizons at certain depths in the soil profile. Soil auger observations and the profile observations made on the upper (soils developed in loess) and the intermediate terraces (soils developed in a mixture of loess, alluvium, colluvium and tephra), in the survey area were used to observe the reductimorphic features, as they are not so clear in the sandy soils of the river flats. The frequency distribution pattern

(Figure 3.1) clearly indicates that there are 4 distinct peaks at depth class intervals 21-30, 61-70, 81-90 and 101-110 cm.

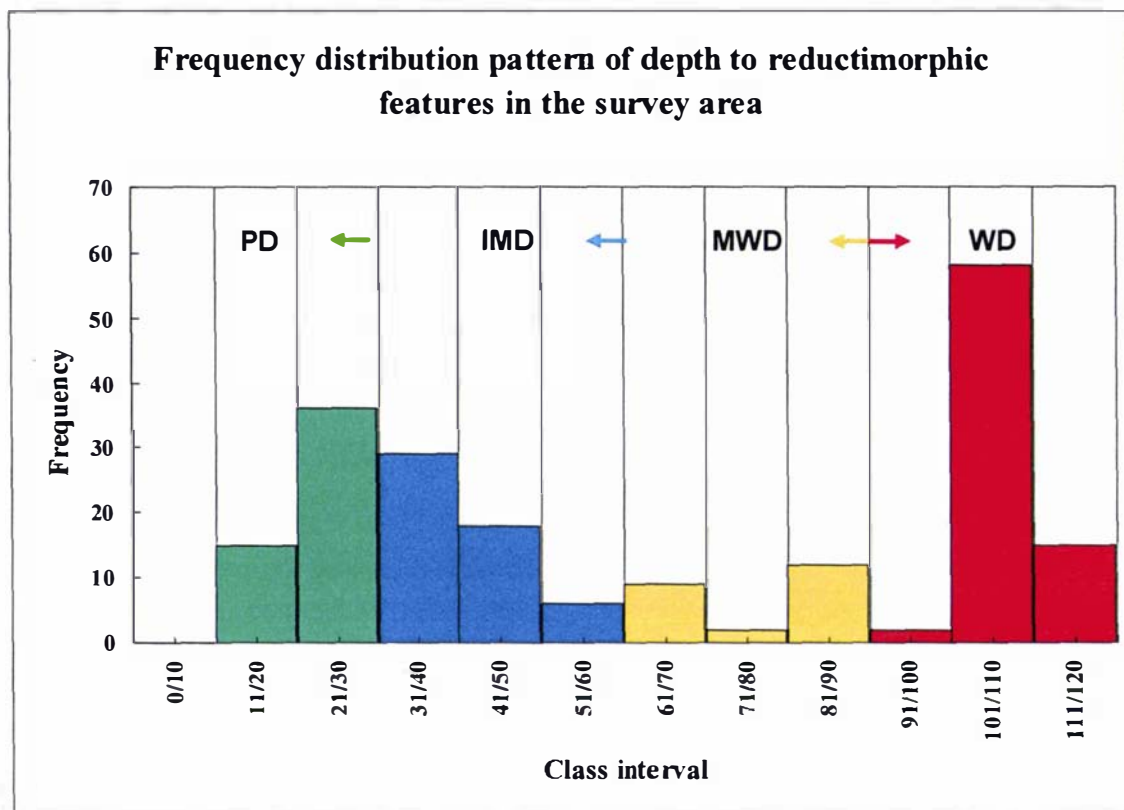


Figure 3.1 Frequency distribution pattern of depth to reductimorphic features in the survey area (PD = poorly drained; IMD = imperfectly drained; MWD = moderately well drained; WD = well drained).

This pattern provides a strong base for selecting different soil depths to reductimorphic features (Hewitt, 1992) in deciding soil drainage classes in the study area and also the criteria used is in conformity with the drainage class separation criteria used in New Zealand soil surveys (Milne *et al*, 1995). The 30 cm depth criteria used in the New Zealand Soil Classification (Hewitt, 1992) for the separation of Gley Soils conforms to this distribution pattern. Based on these observations, four different soil drainage classes were identified in the study area (Table 3.1).

Table 3.1 Soil drainage classes and depths to reductimorphic features.

Depth to reductimorphic features	Drainage class
< 30 cm.	Poorly drained
30 – 60 cm.	Imperfectly drained
60 – 90 cm.	Moderately well drained
> 90 cm.	Well drained

Identification of reductimorphic features is based on the criteria described in the New Zealand Soil Classification (Hewitt, 1992). Diagnostic horizons and profile forms used in separating drainage classes and the criteria for recognizing them are defined below.

### ***Reductimorphic horizon***

Reductimorphic horizons have low chroma colours (moist chroma 2 or less, or moist chroma 3 with value 6 or more) that occupying 50% or more of the matrix exposed in a cut face of the horizon or are dominant on ped faces.

### ***Redox mottled horizon***

Chroma 3 with value 6 or more that occupy less than 50% of the matrix exposed in a cut face of the horizon and are not dominant on ped faces.

### ***Gley profile form***

A gley profile form is defined by the presence of a reductimorphic horizon within 30 cm of the mineral soil surface (Figure 3.2).

### ***Mottled profile form***

A mottled profile form is defined by either:

A redox mottled horizon with an upper boundary within 30 cm of the mineral soil surface or

A reductimorphic horizon with an upper boundary between 30 and 60 cm of the mineral soil surface (Figure 3.2).

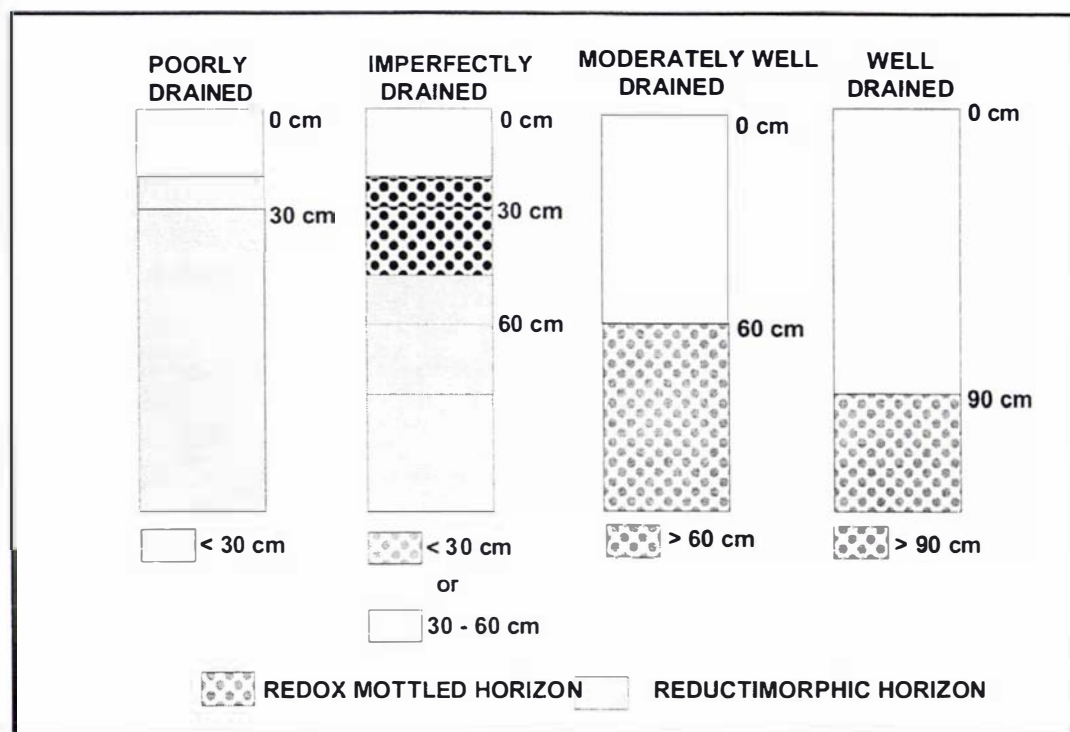


Figure 3.2 Schematic representation of soil drainage classes.

### ***Poorly drained soils***

Soils with a gley profile form are recognized as poorly drained soils (Figure 3.2). A similar criterion was used in the soil drainage classification of Taylor and Pohlen (1968).

### ***Imperfectly drained soils***

Soils with a mottled profile form are recognized as imperfectly drained soils (Figure 3.2).

### ***Moderately well drained soils***

Soils with a reductimorphic horizon below 60 cm from the mineral soil surface were recognized as moderately well drained soils (Figure 3.2).

### ***Well drained soils***

Soils with no reductimorphic horizon or redox mottled horizon within 90 cm of the mineral soil surface were recognized as well drained soils. The soil drainage classes are presented schematically in Figure 3.2.

### **3.2.7. Soil Map Units**

Soil map units are the segments shown on soil maps. They are represented by different colours or symbols. Soil types, phases of soil types and complexes of soil types are the soil map units separated and shown in the soil maps of the study area. Soil map units are not pure soil units. Other soil types are also included in soil map units as inclusions. The name of the map unit carries the name of the dominant soil type included in that particular map unit (Table 3.2).

#### ***Soil depth phases***

Soil depth phases are shown on the soil map where soil mapping scale does not impose any limitations. The shallow soils occurring along margins of streams and the terrace edges are not shown on the soil map due to scale limitations. All other soil types are mapped as deep soils where the gravel layer is below 90 cm from the soil surface. The terms used to describe soil depth phases in the soil mapping legend are as follows, according to depth to terrace gravels:

- < 30 cm    shallow soils
- 30-60 cm    moderately shallow soils
- 60-90 cm    moderately deep soils
- > 90 cm    deep soils.

#### ***Soil slope phase***

Soils on the upper terrace having slopes ranging from 8% (4.5 °) to 16% (9 °) are mapped as rolling phase (FAO, 1977). These usually occur on gently dissected loess covered areas.

## ***Soil complex***

Complex soil patterns, which have no relationship to landscape features and cannot be separated at the mapping scale, are shown as soil complexes.

Table 3.2 Soil map units and their inclusions.

Map Unit	Inclusions
1. Manawatu fine sandy loam	Manawatu sandy loam and Manawatu fine sandy loam (moderately shallow) soils.
2. Manawatu fine sandy loam (moderately shallow)	Manawatu fine sandy loam shallow soils.
3. Manawatu silt loam	Manawatu fine sandy loam and Manawatu sandy loam soils.
4. Kawhatau silt loam	Coulter silt loam, Horoeke silt loam and Barrow silt loam soils.
5. Coulter silt loam	Horoeke silt loam and Barrow silt loam soils.
6. Horoeke silt loam	Coulter silt loam, Barrow silt loam and Ohakea silt loam soils.
7. Barrow silt loam	Horoeke silt loam and Ohakea silt loam soils.
8. Ohakea silt loam	Barrow silt loam soil.
9. Dannevirke silt loam	Kiwitea silt loam soil.
10. Kiwitea silt loam	Dannevirke silt loam, Cheltenham silt loam and Feilding silt loam soils.
11. Cheltenham silt loam	Kiwitea silt loam and Feilding silt loam soils.
12. Feilding silt loam	Marton silt loam, Kiwitea silt loam and Cheltenham silt loam soils.
13. Marton silt loam	Feilding silt loam soil.
14. Steep slope soil complex	A number of soil types having various textures, drainage properties and soil depths.

### **3.2.8. Soil Profile Descriptions**

Out of thirteen soil types mapped in the study area, six soil profiles were sampled in the field for analysis. They are:

1. Coulter silt loam
2. Horoeke silt loam
3. Barrow silt loam
4. Kiwitea silt loam
5. Cheltenham silt loam and

## 6. Feilding silt loam

Soil profile descriptions for the other seven soils were taken from the Landcare Research National Soil Data Base (LCRNSDB). There are some dissimilarities among soil descriptions extracted from LCRNSDB and the ones made in the field as to soil horizon designations and soil horizon descriptions. Therefore, some LCRNSDB soil horizon designations were adapted to the USDA system in order to be consistent between soil descriptions.

### *Soil horizon designations*

Soil horizon designations used for mineral soil horizons were in accordance with the Keys to Soil Taxonomy (Soil Survey Staff, 1994), FAO horizon designation system (FAO-UNESCO, 1974) and Horizon Notations for New Zealand soils (Clayden & Hewitt, 1994).

The capital letters A, E, B, C and R represent the master horizons and layers of soils.

Two capital letter symbols are used to designate horizons dominated by properties of one master horizon, but having subordinate properties of another.

Lower-case letters are used as suffixes to designate specific kinds of master horizons:

b	buried genetic horizon
c	concretions or nodules
e	unripe horizon
f	redox segregations without low chroma colors as specified for g.
g	strong gleying
p	tillage or other disturbance
t	accumulation of silicate clay
w	development of colour or structure

Arabic numerals are used as suffixes to the letters of the horizon designation to indicate vertical subdivisions of the soil horizons.

Arabic numerals are used as prefixes to horizon designations to indicate lithological discontinuities.

### ***Soil horizon descriptions***

Soil horizon descriptions were made according to the criteria described in the Guidelines For Soil Profile Descriptions (FAO, 1977).

### ***Soil colour***

Soil colours were measured by comparison with the Munsell Soil Colour Charts (1994). In the Munsell system soil colours are described in three parts, hue, value and chroma. The hue notation indicates its relation to red, yellow, green, blue and purple; the value notation indicates its lightness; and the chroma notation indicates its strength of colour. In writing the Munsell notation, the order is hue, value, chroma with a space between the hue letter and the succeeding value number, and a diagonal between the two numbers for value and chroma.

## **3.2.9. Soil Mapping Legend**

A soil mapping legend defines the important field criteria used in differentiating soil map units and serves as a guide to the field surveyor. The mapping legend is updated while the soil survey is in progress. When a new soil is encountered it is added into the legend. The updated mapping legend is described below. Soil units described in the mapping legend will later be correlated to soil types in existing surveys. Detailed soil profile descriptions are given in Chapter 4.

### ***A. Soils of the Lower Terrace***

Soils of the river flats are derived from the recent alluvial deposits brought down by the Oroua River and deposited during flooding. Their profile development has been interrupted by occasional flooding so that development of soil horizons and soil structure is weak and soils are relatively young. More details on landforms and parent materials are discussed in chapter 2 (see Sections 2.4.2 and 2.4.3).

**a. Slowly Accumulating**

The alluvial deposits can be further sub-divided on the basis of rate of accumulation. Flooding is occasional in slowly accumulating alluvial deposits and the rate of accumulation is very slow (Cowie 1978). The deposits of each flood are thin, over time deepening the A horizon producing aggrading or up-building soil profiles. There is sufficient time for the formation of soils between floods, probably 10 to 20 years. B horizons produced in this manner might be a few hundred years old.

***Manawatu fine sandy loam (Mfsl)***

Deep, well drained soils derived from fine sandy alluvium having very dark greyish brown, dark greyish brown, dark brown or brown fine sandy loam surface horizons over dark greyish brown, brown, olive brown or light olive brown fine sand to loamy sand subsurface horizons. Fine specks of mica can be seen throughout the soil profile. The genetic soil horizon sequence is A/Bw/C.

***Manawatu fine sandy loam - moderately shallow (Mfsl.ms)***

Similar to mfsL, but the soil depths range from about 45 –60 cm from the surface to the terrace gravel layer. The genetic soil horizon sequence is A/Bw/C/2C.

***Manawatu silt loam (Mzl)***

Moderately deep to deep, well drained, soils derived from silty over sandy alluvium having brown to dark greyish brown, silt loam surface horizons underlain by olive brown to light olive brown, loamy sand to sand subsurface horizons occasionally containing fine specks of mica. The genetic soil horizon sequence is A/Bw/C.

**B. Soils of the Intermediate Terrace**

Soils of the middle terrace are derived from a mixture of loamy alluvium, colluvium and some air fall volcanic ash deposited on the Ohakean aggradational terrace. More details are given in chapter 2 (see Sections 2.4.2 and 2.4.3).

***Kawhatau silt loam (Kzl)***

Well drained soils derived from gravely alluvium having dark brown or dark yellowish brown silt loam to silty clay loam surface horizons underlain by brown, yellowish brown or dark yellowish brown silt loam, silty clay loam subsurface horizons. Rounded gravels and pebbles are common to abundant throughout the soil profile. They occur mainly at the edge of the Ohakean aggradation terrace and on several degradation terraces. The genetic soil horizon sequence is A/Bw1/Bw2/C.

***Coulter silt loam (Czl)(new series)***

Deep, well drained, soils derived from loamy alluvium with some loess, colluvium and tephra. They have brown, dark brown or dark yellowish brown silt loam to silty clay loam surface horizons underlain by brown, yellowish brown or dark yellowish brown silt loam or silty clay loam subsurface horizons, occasionally having grey mottles below 90 cm. The genetic soil horizon sequence is A/Bw1/Bw2/2C.

***Horoeka silt loam (Hzl)(new series)***

Deep, moderately well drained soils derived from loamy alluvium with some loess, colluvium and tephra. They have dark brown to dark yellowish brown silt loam to silty clay loam surface horizons underlain by dark yellowish brown to yellowish brown, silty clay loam to silty clay subsurface horizons, with medium common faint grey mottling below 60 cm. depth. The genetic soil horizon sequence is A/Bw1/Bw2g/2C.

***Barrow silt loam (Bzl)(new series)***

Moderately deep to deep, imperfectly drained, soils derived from loamy alluvium with some colluvium, loess and tephra. They have brown, dark brown or dark yellowish brown, silt loam, silty clay loam or silty clay surface horizons underlain by brown, yellowish brown or dark yellowish brown silty clay to clay subsurface horizons with more than 50% low chroma mottles and occasional strong brown mottles below 30 cm. from the soil surface. The genetic soil horizon sequence is A/Bw/Bg/2C.

### ***Ohakea silt loam (Ozl)***

Moderately deep to deep, poorly drained, soils derived from alluvium with some colluvium, loess and tephra. They have brown, dark grayish brown or grayish brown silty clay loam to silty clay surface soils underlain by greenish gray clay to silty clay subsoils occasionally with common strong brown mottles. Gleying and more than 50% low chroma mottles occur depths below the topsoil, only 20 cm from the soil surface. The genetic soil horizon sequence is A/Bg1/Bg2/2Cg.

## **C. *Soils of the Upper Terrace***

Soils of the Upper terrace are derived from wind blown Ohakean loess material. The loess is intermixed and overlain by tephra. Details are discussed in Chapter 2 (see Sections 2.4.2 and 2.4.3)

### ***Dannevirke silt loam (Dzl)***

Deep, well drained soils derived from loess and tephra. They have dark brown to dark greyish brown silty clay to silty clay loam surface horizons and brown, dark yellowish brown or yellowish brown, silty clay, silty clay loam, clay loam or clayey subsoils with low bulk density. Occasional light olive brown to strong brown mottles are present below 80 cm. The Kawakawa Tephra is present as a 5 to 10 cm layer below 80 cm from the soil surface. The genetic soil horizon sequence is A/Bw1/Bw2/2C.

### ***Kiwitea silt loam (Kizl)***

Deep, well drained soils derived from loess and tephra. They have brown to dark brown silt loam surface soils underlain by dark yellowish brown, yellowish brown silty clay loam to clay loam subsoil. Occasionally thin, patchy clay skins can be observed on ped faces. A yellowish brown, 5 to 10 cm thick coarse sandy loam tephra layer (Kawakawa Tephra) occur at about 70 to 80 cm depth. The genetic soil horizon sequence is A/Bw/Bt/2C.

***Cheltenham silt loam (Chzl)(new series)***

Deep, moderately well drained soils derived from loess and tephra. They have dark brown silt loam to silty clay loam surface horizons underlain by dark yellowish brown to yellowish brown, silty clay loam to clay loam subsurface horizons. Faint and low chroma mottles occur below 60 cm from the soil surface. Kawakawa Tephra is present 70 to 80 cm below the soil surface. The genetic soil horizon sequence is A/Bw/Bg/2C.

***Feilding silt loam (Fzl)(new series)***

Deep, imperfectly drained soils derived from loess and tephra. They have brown, dark brown or very dark brown silt loam to silty clay loam surface horizons underlain by yellowish brown, dark yellowish brown to strong brown silty clay loam, silty clay to clay subsurface horizons with about 30% low chroma mottles within 60 cm depth from the surface and are sometimes gleyed below 50 cm. The genetic soil horizon sequence is A/Bw/Bg1/Bg2/Bg3.

***Marton silt loam (Mzl)***

Deep, poorly drained soils derived from loess and tephra. They have brown, dark brown or dark yellowish brown silty clay loam, silty clay or clay loam, surface horizons with low chroma mottles underlain by gleyed, silty clay loam, silty clay and clayey subsurface horizons with strong brown mottles. Gleying occurs within 30 cm from the surface. Subsoils are very difficult to dig or auger. The Kawakawa Tephra occurs as a 5 to 10 cm layer 50 to 80 cm below the surface. The genetic soil horizon sequence is A/Bg/2Bg//3Bg.

***Marton + Feilding complex (Mzl+Fzl)***

Fielding silt loam and Marton silt loam soils occur in the landscape in a complex manner that can not be separated at 1: 25,000 scale.

## ***D. Soils of Terrace Risers***

### ***Steepland soil complex***

Soils mostly developed from colluvium having various textures and drainage properties occur on the steep slopes of river terraces. These soils are extremely variable, on hilly or steep slopes, and of little agronomic versatility.

## **3.3. Soil Correlation and New Soil Series**

Individual soil types were identified as soil units on the soil mapping legend in the soil mapping process (previous section). The morphological and physical properties of soils were compared with the properties of the existing soil series. Environmental factors such as total annual rainfall mean annual temperature that influence the soil formation were also taken into account. Soil units that were comparable to the existing soil series were correlated with those series. Other soil units were identified as potential new soil series (Table 3.3).

Soils within a series are considered to be essentially homogeneous in all soil properties except for the texture of the topsoil (Soil Survey Staff, 1993). Soils having different drainage properties were identified as a separate soil series according to this criterion. However in New Zealand the soil series is defined as a grouping of soil types with similar modal profiles, similar temperature and moisture regimes, and the same or very similar parent materials (Taylor and Pohlen, 1962). In New Zealand it is used with a somewhat wider meaning than in the United States. In Manawatu regional soil surveys, soils having different drainage properties ranging from imperfect to poor have been grouped together as one soil series. e.g Marton and Ohakea (Campbell 1979). In some other surveys Marton series have been separated as poorly drained soils (Rijske 1977, Campbell 1977, Cowie 1978) and Ohakea series as imperfectly drained soils (Campbell 1977).

In this detailed soil survey soils having gley profile form were separated as Marton and Ohakea series whereas soils having mottled profile form were separated as Feilding and Barrow series. The parent material of Marton and Feilding soils is loess and tephra

whereas that of Ohakea and Barrow soils is mostly loamy alluvium, colluvium, with minor loess and tephra.

Out of 110 auger observations (poor + imperfect drainage classes) made on the upper terrace, only 32% showed the gley profile form. The other 68% showed the mottled profile form. Out of 18 auger observations (poor + imperfect drainage classes) made on the middle terrace, only 22% showed the gley profile form. The other 78% showed the mottled profile form. The impact of the different drainage status on present and potential land use and management will be discussed later. Therefore, separation of imperfectly to poorly drained Marton and Ohakea series into imperfectly drained Feilding and Barrow series and poorly drained Marton and Ohakea series respectively is recommended.

A well drained, deep, allophane rich soil present on the middle terrace and developed primarily on alluvium, has not been recorded in previous soil surveys. The physical properties of this soil are very much similar to the Dannevirke soils present on the upper terrace. But soil horizon thickness and soil depth vary and heavy textured soil layers are sometimes present in the subsoil indicating the alluvial origin of Coulter soils. In Dannevirke soils textural properties in soil horizons and soil profile thickness are more constant. The properties of Dannevirke soils indicate that it is developed from loess and tephra. Also Dannevirke soil and all other soils on upper terrace contain Kawakawa Tephra, whereas Coulter soils and all others on the intermediate terrace do not. Therefore, this new soil unit was separated from Dannevirke soils and named as Coulter series after a local road. The moderately well drained equivalent of Coulter series was named as Horoeke series after a local farm.

Forty five per cent of the middle terrace is covered by the Coulter series. The moderately well drained Horoeke series covers only 15% of the landscape at 1:25,000 scale soil mapping, but at 1:5000 scale soil mapping (see Section 5.2) Coulter silt loam and Horoeke silt loam cover 47% and 53% of the landscape respectively. Therefore, the introduction of a new soil series for the moderately well drained soils is also recommended.

Table 3.3 Correlation of soil units and new soil series.

Soil Units	Existing soil series	New soil series	Soil Type
Lower Terrace			
Well drained			
Slowly accumulating			
Msf1	Manawatu	No	Manawatu fine sandy loam
Mfsl.ms	Manawatu	No	Manawatu fine sandy loam (moderately shallow)
Mzl	Manawatu	No	Manawatu silt loam
Intermediate Terrace			
Well drained			
Kzl	Kawhatau	No	Kawhatau silt loam
Czl	Kawhatau	Coulter	Coulter silt loam
Mod. Well drained			
Hzl	Kawhatau	Horoeka	Horoeka silt loam
Imperfectly drained			
Bzl	Ohakea	Barrow	Barrow silt loam
Poorly drained			
Ozl	Ohakea	No	Ohakea silt loam
Upper Terrace			
Well drained			
Dzl	Dannevirke	No	Dannevirke silt loam
Kzl	Kiwitea	No	Kiwitea silt loam
Mod. well drained			
Chzl	Kiwitea mottled	Cheltenham	Cheltenham silt loam
Imperfectly drained			
Fsl	Marton	Feilding	Feilding silt loam
Poorly drained			
Mzl	Marton	No	Marton silt loam

### 3.4. Soil Sampling and Preparation

Soil samples were collected from representative profile pits excavated in modal areas, selected following the soil mapping. About two kg of bulk samples were collected from each soil horizon. Undisturbed soil samples were taken vertically by pushing the soil cores into the soil horizon, for bulk density, hydraulic conductivity and water retention measurements. Once a topsoil horizon was sampled, it was removed using a spade in order to sample the next horizon. All samples were collected within hours of the profile pit being excavated.

Bulk soil samples were air dried at temperatures of 30° C. Samples were lightly crushed using mortar and pestle and were sieved through 2 mm sieve. These soil samples were stored in polythene bags for analysis.

## 3.5. Methods of Soil Characterization

### 3.5.1. Physical Characterization

#### *Bulk density (BD)*

Bulk density measurements were made on core samples taken from each soil horizon. Six core samples were taken from each horizon using thin walled metallic rings having a known volume (91 cm<sup>3</sup>). Soil samples were oven dried at 105° C until the weight became constant.

Bulk density is defined as the weight of a unit volume of dry soil. The mean value of six samples (bulk soil) was taken as the bulk density of the soil horizon. In a few cases extreme values were omitted from the calculation of the average.

#### *Particle density (PD)*

Particle density is usually defined as the weight of a unit volume of soil solids. Soil particle density measurements were made using a water displacement method (Gradwell, 1972).

#### *Total porosity (TP)*

Total porosity refers to the percentage of the total volume of a soil sample that is occupied by air or water and was calculated using the following formula:

$$\% \text{ Porosity} = 1 - \frac{BD}{PD} * 100$$

### ***Macro porosity***

Macro porosity represents the pores that drain free water at a tension of -5 kPa (kilo pascal) of water. Large pores > 60 micrometres in diameter are usually considered as macro pores. From the calculated total porosity, macro porosity was calculated by subtracting the volumetric water content at a matric potential of -5 kPa (Gradwell and Birrell, 1979).

### ***Water retention***

The water content of the soil at matric potentials of -5 kPa, -10 kPa, -33 kPa and -1500 kPa were measured for each soil horizon. A pressure membrane apparatus was used to measure -5 kPa and -10 kPa matric potentials whereas a pressure plate apparatus was used to measure -33 kPa, 100 kPa and -1500 kPa matric potentials. The laboratory equivalents of field capacity and wilting point are the soil water contents at the matric potentials of -10 kPa and -1500 kPa respectively. The soil water content held between -10 kPa and -1500 kPa is considered as total available water.

The water content held between -10 kPa and -100 kPa is considered as readily available water (RAWC). The volumetric water content obtained from the -100 kPa was obviously erroneous, for an unknown reason. Therefore, the -100 kPa water content was interpolated from a graph using -5 kPa, -10 kPa, -33 kPa and -1500 kPa water contents.

For each soil horizon, total available water capacity and readily available water capacity was calculated as a percentage of soil volume and converted to mm of water using horizon thickness. Profile total available water capacity and readily available water capacity was calculated by summing capacities for individual horizons within the soil profile. Total and readily available water capacities were calculated for 50 cm and 100 cm depths as there were no rooting barriers observed in soils.

The volume of water drained between saturation and a matric potential of -5 kPa was considered to be equivalent to the volume of macro pores. Methods used were similar to those specified by Gradwell and Birrell (1979).

### ***Saturated hydraulic conductivity ( $K_{sat}$ )***

Saturated hydraulic conductivity measurements were made for undisturbed soil samples taken from each soil horizon using intact cores (150 mm height and 74 mm diameter). The corer was filled to about 100 mm by driving carefully, with a wooden block between hammer and corer. The corer was carefully excavated to minimize damage from below. Back in the laboratory cores were clamped on a retort stand above beakers. The core bottom was supported by a fine nylon net. Water was ponded on the soil surface to a standard depth and maintained by regular additions. The water volume that was collected in the beaker was measured. Measurements continued until conductivity reached an approximately constant. The amount of water collected in the beaker for a unit time was measured and converted to mm per hour. Six samples were taken from each horizon for comparison and extreme values were discarded (Klute, 1986).

### ***Infiltration***

Infiltration rates were measured in paddocks within 10 m of the soil profile pits using ring infiltrometers. Five infiltration tests were done in situ for each site, for 4 to 5 hours until the infiltration rate became constant. Extreme values were discarded and the mean of the remaining values was taken as the infiltration rate (mm/hr) of that particular soil type.

## **3.5.2. Chemical Characterization**

Soil chemical analyses were carried out according to methods described by Blakemore *et al.*, (1987).

### ***Soil pH***

Soil pH was measured on soil water suspension at 1:2.5 ratio using a glass electrode pH meter.

### ***Exchangeable cations***

Exchangeable  $\text{Ca}^{++}$ ,  $\text{Mg}^{++}$ ,  $\text{K}^+$  and  $\text{Na}^+$  in soils were extracted using 1M ammonium acetate at pH 7. A semi-micro leaching method was used to saturate exchange sites with cations. The  $\text{Ca}^{++}$  and  $\text{Mg}^{++}$  concentration in extracts were determined by atomic absorption spectroscopy and the  $\text{K}^+$  and  $\text{Na}^+$  concentrations were determined by flame emission spectroscopy.

### ***Total exchangeable bases (TEB)***

TEB values were calculated by summing up individual basic cations and expressed in cmol/kg soil.

$$\text{TEB}_{\text{sum}} = \text{Ca}^{++} + \text{Mg}^{++} + \text{K}^+ + \text{Na}^+.$$

### ***Cation exchange capacity (CEC)***

Exchange sites of the soil were saturated with  $\text{NH}_4^+$  ions using 1M ammonium acetate at pH 7 and then  $\text{NH}_4^+$  ions held on exchange site were displaced by  $\text{Na}^+$  using a 1M sodium chloride solution. The concentration of  $\text{NH}_4^+$  ions displaced by sodium ions was determined by a colorimetric method using an auto analyzer. A semi-micro leaching method was used to saturate exchange sites with cations.

### ***Base saturation (BS)***

Base saturation at pH 7 was calculated as a percentage by dividing  $\text{TEB}_{\text{sum}}$  by the CEC.

### ***Available phosphorus (Olsen P)***

Available forms of phosphorus in soils were measured according to the method given by Olsen *et al.*, (1954).

### ***Phosphate retention (P-retention)***

Phosphate retention of soils was determined according to the method by Saunders (1965) with some slight modifications to avoid practical difficulties. This is an empirical measure of the ability of a soil to remove phosphorus rapidly from phosphate

solution. This is a more rapid process than the process of phosphorus fixation, which renders phosphorus unavailable to plants, and is probably a precursor to it.

Five grams of air dry soil (< 2 mm) were shaken with 25 ml of P-retention solution<sup>1</sup> (pH 4.6) in a polypropylene centrifuge tube for 16 hours at about 20°C, in an automatic shaker (about 50 rpm) and centrifuged at 8000 rpm for 5 minutes.

Two ml of supernatant was diluted with 12.5 ml of nitric vanado-molybdate and distilled water to 50 ml in a volumetric flask, shaken well and left for 30 minutes. The absorbance was read on an atomic absorption spectrophotometer at 420 nm.

### ***Total carbon and nitrogen***

Total carbon and nitrogen were measured using the LECO FP 2000 automated analyzer. This measures carbon and nitrogen content by combustion in a resistance furnace. Gasses are passed through an infrared cell to determine carbon and a thermal conductivity cell to determine nitrogen.

### **3.5.3. Mineralogical Characterization**

Mineralogical properties of soil samples were determined according to methods described by Whitton and Churchman (1987). Numbers in parentheses refer to sections of Whitton and Churchman (1987). These methods have been used by NZ Soil Bureau since 1986 for routine mineralogical analysis of soil survey samples, and by Landcare from its inception to the present day.

Primary and secondary crystalline minerals present in clay, silt, sand and heavy mineral fractions of soil samples were identified by X ray diffraction and differential thermal analysis. In order to determine the minerals present in clay, silt and sand fractions, it is

---

<sup>1</sup> P-retention solution (1mg P/ml) Dissolve 8.80 g potassium dihydrogen phosphate (KH<sub>2</sub>PO<sub>4</sub>), and 32.8 g anhydrous sodium acetate (CH<sub>3</sub>COONa) in water, add 23 ml glacial acetic acid, and dilute to 2 litres in a volumetric flask. The pH of this solution should be 4.6 ± 0.05.

necessary to first remove cementing agents such as calcium carbonate, organic matter, iron and aluminium oxides and oxyhydroxides that may hold the soil particles together, and fill the interlayer spaces of some clay minerals.

The procedure employed in this mineralogical analysis is briefly described step by step as follows:

### ***Step 1. Removal of cementing agents:***

#### ***Removal of calcium (2.2.1)***

Approximately 10 g of air dried (< 2 mm) soil is placed in a 90 ml centrifuge tube with 50 ml of distilled water and a few drops of 1:1 HCl. The pH of the solution should be around 3.5. When the reaction was completed samples were centrifuged for 10 minutes at 1500 rpm and the supernatant was siphoned off. The treated soil was then ready for organic matter removal.

#### ***Removal of organic matter (2.2.2)***

Approximately 10 ml of hydrogen peroxide was added to the soil together with 10 ml of distilled water, stirred, and the samples left to stand overnight. The following day the tubes were transferred into a water bath and heated gradually until the water was boiling. They were kept at this temperature, stirring occasionally with teflon stirring rods, until all frothing cease. The tubes were centrifuged for 15 minutes at 1500 rpm and the supernatant liquid was discarded.

#### ***Removal of iron and aluminium oxides and oxyhydroxides (2.2.3)***

Organic matter free soils were treated with 30 ml of citrate reagent and 5 ml of 1M sodium bicarbonate and placed in a water bath at 90 to 100° C. When solutions in the tubes were hot they were stirred again and about 1g solid sodium dithionite was added with gentle stirring. Tubes were left in the water bath for another 15 minutes with stirring at intervals. Then tubes were centrifuged for 15 minutes at 1500 rpm and the supernatant solution was discarded. This procedure was repeated twice for all samples, and was repeated up to a further two times for samples with brownish supernatant solutions.

### ***Step 2. Separation of the clay fraction (2.2.4)***

Soil samples free of cementing material were used in step 2 for separation of the clay fraction. Distilled water was added to the tubes to the 10 cm mark and the suspensions were stirred thoroughly with a motorized stirrer. Tubes were centrifuged for 5 minutes at 800 rpm and the supernatant clay suspension was collected into 1 litre beakers. The separation was repeated until the supernatant became clear. The time for the second run was 4 minutes and third and subsequent runs were 3 minutes. The residue, sand plus silt, was kept in the tubes for separation of sand and silt fractions in step 6.

### ***Step 3. Saturation of clay with cations (2.2.5)***

#### ***K<sup>+</sup> saturation***

About 10 ml aliquots of clay suspension (from step 2) were transferred to 15 ml centrifuge tubes and saturated with K<sup>+</sup> using 1M KCl by adding about 3 ml to the clay suspension in the 15 ml tubes, and allowed to flocculate overnight. The clear supernatant solution was sucked off, a further 10 ml of KCl added, the tubes shaken and clay again allowed to flocculate overnight. The clear supernatant was sucked off and the K<sup>+</sup> saturated clay suspension was washed with distilled water and centrifuged at 1500 rpm for 5 minutes. The clear supernatant was discarded. Washing and centrifuging was repeated until the clay just began to disperse. X-ray slides were prepared from the K<sup>+</sup> saturated clay.

#### ***Mg<sup>++</sup> saturation***

To the remaining bulk clay suspension (from step 2), 10 ml of saturated MgCl<sub>2</sub> was added, followed by 1 drop of bromophenol blue indicator. The beaker was filled with distilled water and then the suspension was allowed to flocculate overnight. The clear supernatant liquid was sucked off; the beaker refilled with distilled water and again allowed to flocculate overnight. The clear supernatant liquid was again sucked off and the washed Mg<sup>++</sup> saturated clay retained for x-ray slide preparation.

#### ***Step 4. Preparation of x-ray slides (2.2.6)***

Clean dry glass slides (25 mm by 25 mm) were covered with clay suspensions saturated with  $K^+$  and  $Mg^{++}$  separately and allowed to dry in air. An eye dropper was used to spread the clay suspension over the glass slides.

#### ***Step 5. Glycerol and heat treatment (2.2.6)***

X-ray diffractograms were obtained using the air-dry slides as prepared above and then further treatments were carried out on these slides.

$Mg^{++}$  saturated slides were sprayed with 10% glycerol in water solution and allowed to dry overnight and examined by x-ray diffraction.

After the diffractogram for the  $K^+$  sample was obtained, the slide was heated to  $550^\circ C$  for 2 hours, cooled and another diffractogram was obtained.

#### ***Step 6. Silt and sand separation (2.2.7)***

The residue remaining in the centrifuge tubes after step 2 was used to separate silt and sand fractions. The tubes were filled with distilled water up to the 10 cm mark, stirred and allowed to stand for 5 minutes. The supernatant containing the silt fraction was poured into a 600 ml beaker. This procedure was repeated 4 to 5 times until the supernatant solution became clear. The silt in suspension in the 600 ml beakers was first saturated with  $Mg^{++}$  (as for clays), then allowed to settle overnight and the supernatant sucked off next morning. The silt was washed with distilled water, air-dried and stored in vials for x-ray diffraction.

#### ***Step 7: Sand separation (2.2.7)***

The sand fraction remaining after step 6 was dried in an oven at  $110^\circ C$  overnight and stored in vials for x-ray diffraction and density separation.

#### ***Step 8: Density separation (2.2.8)***

The sand fraction was separated into heavy minerals and volcanic glasses using sodium polytungstate (SPT) of density  $2.80 g cm^{-1}$  and SPT of density  $2.45 g cm^{-1}$  respectively.

0.5 g of sand was used in the density separations. Once the heavy and light fractions were separated, they were dried in a fume cupboard at 110 °C overnight, weighed and stored in vials for x-ray diffraction.

### ***Step 9: Preparation of dry clay (2.2.9)***

The remaining clay suspension from step 3 was air dried in petri dishes, ground and stored in vials for differential thermal analysis (DTA).

### ***Step 10: X-ray diffraction (XRD) (3.1)***

Crystalline minerals present in clay, silt, sand and heavy mineral fractions of soils were determined by x-ray diffraction. The principle of XRD is that each crystalline substance has a characteristic arrangement of atoms, which diffracts x-rays in a unique pattern. X-ray diffraction takes place from lattice planes according to Bragg's Law

$$n\lambda = 2d \sin \theta,$$

where  $d$  = lattice spacing

$\lambda$  = wave length of the x-rays

$\theta$  = glancing angle of reflection

$n$  = order of the reflection.

Experimentally  $\lambda$  is determined by the type of x-ray tube and therefore known and constant. Scanning a range of angles of reflection with a detector therefore gives a pattern of peaks at certain spacings and intensities that are characteristic of the minerals present. As  $d \propto 1/\sin\theta$  the diffraction angle ( $2\theta$ ) can be converted to  $d$  spacing by means of standard tables.

### ***Oriented clay samples***

X-ray slides prepared at step 4 were placed in sample holders, stacked in the sample magazine, loaded into the sample changer and an x-ray diffractogram obtained using appropriate programs for the PW 1710 instrument. They were  $Mg^{++}$ -saturated clay in air, program 222;  $Mg^{++}$ -saturated and glycerated,  $K^+$ -saturated, and 550 °C heated, program 223 (Percival, 1984).

### ***Non oriented powder samples***

For sand (step 7) and heavy mineral (step 8) samples, a few milligrams of samples were finely ground and mixed to a slurry on a glass slide with acetone, evenly distributed over the whole slide, and the acetone allowed to evaporate. X-ray diffractograms were obtained using programs 211 (Percival, 1984) for heavy minerals and 210 (Percival, 1984) for sand.

X-ray diffraction patterns were interpreted qualitatively using the above information and the constituents present in the soil sample. Assuming that the heights of the peaks are proportional to the amount of each constituent present, the percentage of minerals present in soils were calculated using the procedure outlined in NZ Soil Bureau Scientific Report 79 (Whitton and Churchman, 1987).

### ***Step 11: Differential thermal analysis (DTA) (3.2)***

The amount of kandite (kaolinite + halloysite) and gibbsite present in the clay fraction of soil samples were determined by DTA. The principle used in DTA is that endothermic and exothermic reactions occur when a sample is heated. The sample material is placed in a suitable holder alongside a holder containing a thermally inert reference material. The temperature difference between the two materials is continuously recorded on a graph paper automatically as they are heated. Exothermic and endothermic reactions, which occur in clay samples, are recorded as peaks on the graph paper. The amount of kandite can be estimated by comparing peak heights with standard graphs of peak height (or peak area) versus concentration.

Clay samples from step 9 were finely ground and 50 mg of clay was used in the DTA. Once the thermogram was obtained it was compared with thermograms obtained from pure mineral specimens and a qualitative analysis of the minerals present was established. Measuring peak heights under characteristic endothermic peaks at temperatures of 520-560 ° C and obtaining the concentration of minerals present from standard graphs enabled a quantitative estimate of kandite to be made.

### ***Step 12: Determination of allophane***

Allophane present in soils was determined according to the method of Parfitt (1986) and Parfitt and Wilson (1985). This method is based on solubility of  $Al_o$ ,  $Al_p$  and  $Si_o$ , where 'o' refers to solubility in acid-oxalate reagent and 'p' refers to solubility in pyrophosphate reagent. The method requires first the determination of  $(Al_o - Al_p) / Si_o$  to estimate the Al:Si ratio of the allophane and, second, the multiplication of  $Si_o$  by a factor which is dependent on the Al:Si ratio. Most allophane in New Zealand soils have Al:Si values lying close to and just greater than 2.0, so therefore the factor 8 has been selected (Parfitt, 1986).

Acid-oxalate extractable Si in soils was determined according to the method of Blakemore *et al.*, (1987). One g of soil (air dry, < 2mm) was placed into a 250 ml centrifuge bottle and 100 ml acid oxalate reagent added. The bottle was shaken for 4 hours at 50 rpm and filtered through no. 42 filter paper and about 50 ml filtrate collected. The filtrate was diluted 10 times. Silicon concentration was read by Atomic Absorption Spectro Photometer and multiplied by a factor of 8 to obtain the allophane percentage.

## **3.6. Method of Soil Map Production**

Soil boundaries were plotted on 1:25,000 scale black and white aerial photographs. Soil map units were separated in the field, on the basis of auger observations and the topographic variations. In most cases it was observed that there was little topographic variation between soil map units. In such cases arbitrary soil boundaries were constructed between auger observations. Soil boundaries drawn in the field were further rectified using a mirror stereoscope.

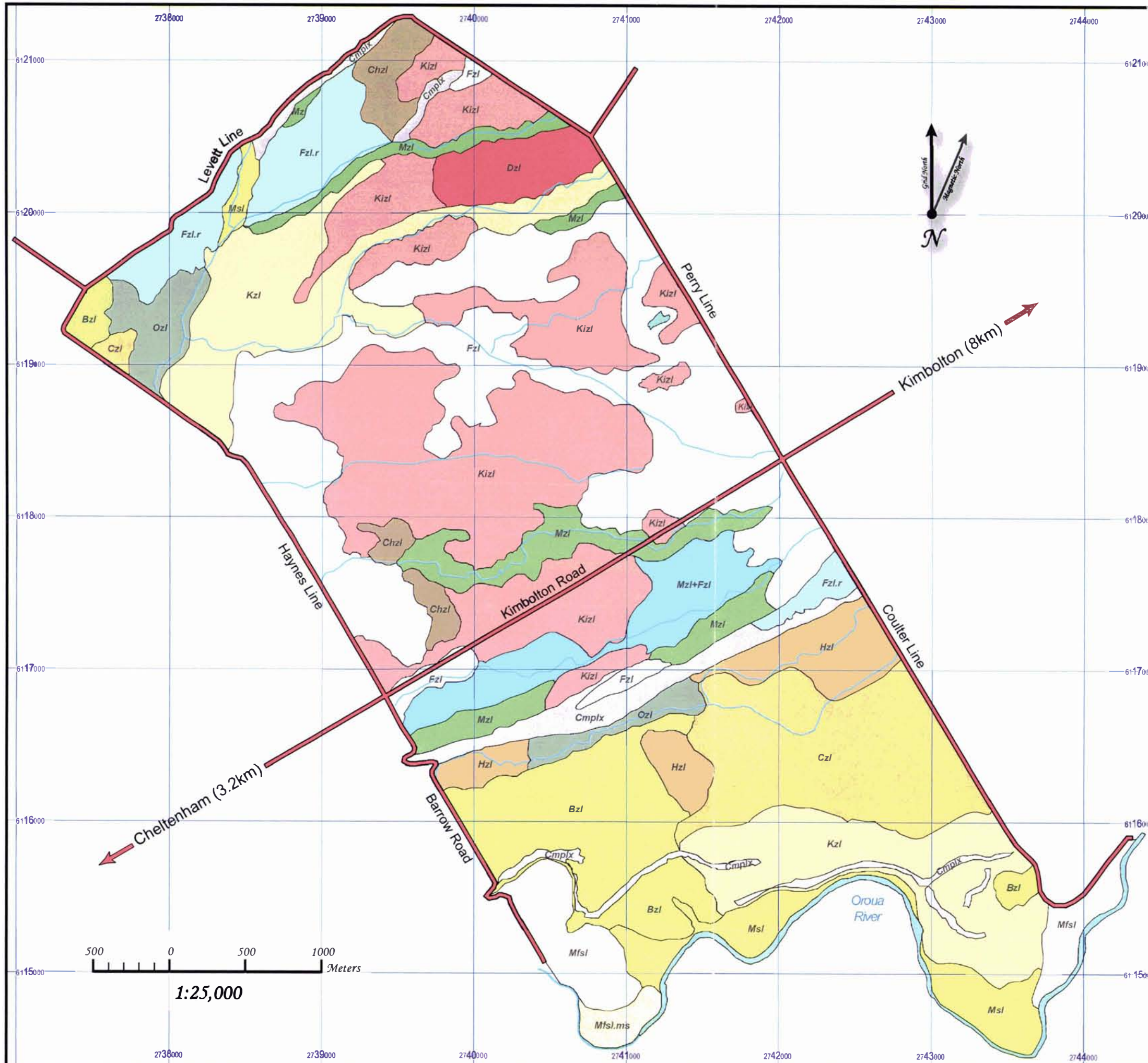
Soil boundaries on aerial photographs were transferred on to 1:25,000 scale topographic sheets. Tilt distortions in aerial photographs were rectified using a zoom transfer scope.

Creating the soil map involved two steps; digital capture of soil boundaries and a spatial database, and the cartographic generation of the final map.

The map was originally digitally captured using the Geographical Information System (GIS) Pc Arc Info (version 3.4D) (ESRI) and a conventional digitizing tablet. This was later converted for use in Arc View (version 3.4) (ESRI) to prepare a provisional map used for presentations and posters. However, through a series of university computer upgrades, the original GIS file was misplaced. This necessitated a novel regeneration of the file. An enhanced windows metafile (.emf) was created from a picture used in an earlier power point presentation, and subsequently reformatted into a coordinated Arc View shapefile (.shp) using Map Maker Pro (version 3) GIS software. The resulting database was upgraded to include each of the soil classifications.

Cartographic preparation of the map was through the graphics application Adobe Illustrator (version 9.0) using the Avenza Map Publisher (version 4.0) (Avenza Systems Inc.) plug-in to interpret the GIS data file. This combination allows for cartographic precision with flexible map manipulation. The GIS data was imported as a shapefile and coordinated to the New Zealand Map Grid. Soil polygons were assigned colours by filtering the soil classes from the shape file database. Streams and roads were imported as separate files because they contained lines rather than polygons. The final map was postscripted and printed through a high definition laser printer.

# SOIL MAP 1 Of Kiwitea Study Area



### Soils of the Lower Terrace

- Mfs1 Manawatu fine sandy loam
- Mfs1.ms Manawatu fine sandy loam - moderately shallow
- Msl Manawatu silt loam

### Soils of the Intermediate Terrace

- Kz1 Kawhatau stony silt loam
- Cz1 Coulter silt loam
- Hz1 Horoeaka silt loam
- Bz1 Barrow silt loam
- Oz1 Ohakea silt loam

### Soils of the Upper Terrace

- Dz1 Dannevirke silt loam
- Kiz1 Kiwitea silt loam
- Chz1 Cheltenham silt loam
- Fz1 Feilding silt loam
- Fz1.r Feilding silt loam - rolling phase
- Mz1 Marton silt loam
- Mz1+Fz1 Marton and Feilding complex

### Soils of the Terrace Risers

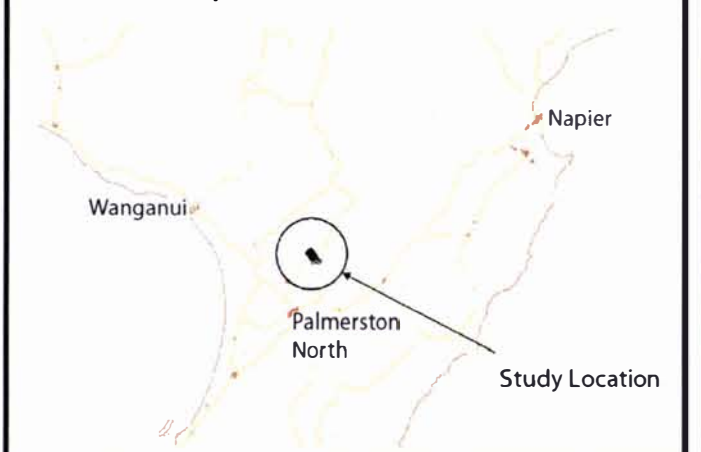
- Cmplx Steep slope complex

### Miscellaneous features

- Water bodies
- Streams
- Roads

Asoka Senarath 2002

### Location Map



# **Characteristics of Soils of the Study Area:**

## **Results and Discussion**

### **4.1. Introduction**

The objective of this chapter is two fold.

- The first is to provide an account of the morphological, physical, chemical and mineralogical characteristics of thirteen soil types mapped in the study area which will be used later in Chapter 8 for the land suitability evaluation study and in writing a user friendly format of soil report for the study area (Appendix 14).
- The second is to highlight the important soil properties, which are variable over the landscape, but have a significant effect on soil management practices in the area, so that the intended soil spatial variability study can be designed in order to investigate these properties in detail.

Soil types were arranged, according to their position in the natural landscape, under three physiographic units: lower terrace, intermediate Terrace and upper terrace. Soil morphology, genesis, physical, chemical and mineralogical characteristics and their interpretation are discussed under each soil type.

Not all soils could be analysed in detail in this study because of resource constraints. Therefore, where appropriate, soil profile descriptions and laboratory analytical data for some soils are extracted from the Landcare Research National Soil Data Base (LCRNSDB). These soil profiles are situated in the same region as the study area and formed on similar parent materials and landforms under similar environmental conditions.

New soil series were studied in the field and characterized in the laboratory. Some field tests like infiltration measurements were also carried out for new soil units. Particle size

analyses were not carried out; field soil textures have to be relied upon. Although particle size analytical data are available for some soil types extracted from LCRNSDB, they are not given in tables in order to maintain consistency among data tables. Coulter, Horoeoka and Barrow silt loams are three new soil types mapped on the intermediate terrace. Feilding and Cheltenham silt loams are another two new soil types mapped on the Upper Terrace.

Genetic soil horizon designations used in some Landcare National Soil Data Base soil descriptions were adapted to the USDA soil horizon designations in order to maintain consistence among all soil descriptions.

Soil profile available water was summed to 50 cm and 100 cm depths where possible. This makes it easy to compare available water in different soils for shallow-rooted (50 cm depth) and deep-rooted (100 cm depth) crops.

## 4.2. List of Abbreviations

The following abbreviations are used regularly in this chapter and throughout the rest of the thesis:

A/C	young stage of weathering
A/Bw/C	intermediate stage of weathering
A/Bw/Bw (no C horizon)	more advanced stage of weathering
cm	centimetres
cmol <sub>c</sub> kg <sup>-1</sup>	centimoles per kilogram
g kg <sup>-1</sup>	grams per kilogram
kpa	kilopascal
mg kg <sup>-1</sup>	milligrams per kilogram
Mg m <sup>-3</sup>	megagrams per cubic metre
mm hr <sup>-1</sup>	millimetres per hour
mm y <sup>-1</sup>	millimetres per year
mm	millimetres
Mpa	magapascal
v/v %	percentage by volume
Av. water	available water

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BD	bulk density
Ksat	saturated hydraulic conductivity
PD	particle density
BS	base saturation
CEC	cation exchange capacity
P-ret	phosphate retention
TEB	total exchangeable bases
Aggre	aggregates
Allo	allophane
Chl	chlorite
Crist	crystalobolite
DTA	differential thermal analysis
Epi	epidote
Feld	feldspar
HB	hornblende
HIV	hydroxy interlayered vermiculite
HM	heavy minerals
Ilm	illmenite
Kand	kandite
Mag	magnetite
M-Chl	mica-Chlorite
M-HIV	mica-Hydroxy interlayered vermiculite
M-Smec	mica-smectite
M-Ver	mica-vermiculite
Pyrox	pyroxene
Qu	quartz
Tr	trace
Ver	vermiculite
VG	volcanic glass
XRD	X-ray diffraction
Zir	zircon
NA	not available
ND	not determined

### 4.3. Physiographic Legend of Soil Types

The soils present on the terraces can be arranged according to their position in the landscape. This arrangement is called a physiographic legend (Table 4.1).

Table 4.1 Physiographic legend for the soils of the study area.

#### A. Soils of the Lower Terrace

##### *Slowly Accumulating*

Well drained-deep\*

Manawatu fine sandy loam

Manawatu silt loam

Well drained-Moderately shallow

Manawatu fine sandy loam-moderately shallow

#### B. Soils of the Intermediate Terrace

Well drained-moderately deep to deep

Coulter silt loam

Well drained-stony

Kawhatau stony silt loam

Moderately well drained-moderately deep to deep

Horoeka silt loam

Imperfectly drained-moderately deep to deep

Barrow silt loam

Poorly drained-moderately deep to deep

Ohakea silt loam

#### C. Soils of the Upper Terrace

Well drained-deep

Dannevirke silt loam

Kiwitea silt loam

Moderately well drained-deep

Cheltenham silt loam

Imperfectly drained-deep

Feilding silt loam

Poorly drained-deep

Marion silt loam

#### D. Soils of the Terrace Risers

Steep slope soil complex

\* See page 39 for soil depth phases

## **4.4. Soil Characteristics**

### **4.4.1. Soils of the Lower Terrace**

The soils of the lower terrace are derived from recent alluvial sediments laid down by the Oroua River. The source of the alluvium is Mesozoic greywacke and argillite, Tertiary and Quaternary sandstone, mudstone and limestone (Cowie, 1978) and is thus quartzo-feldspathic in mineralogy, also with appreciable amounts of mica (5-10%) and pumice. The alluvial sediments are mainly sand to fine sand in texture.

#### **Soils on slowly accumulating alluvial deposits**

These alluvial sediments can be grouped on the basis of rate of accumulation. Deposits that occur on slightly higher elevations than that of present flood level are grouped as slowly accumulating. Flooding is infrequent (10-20 years) and new alluvial material is usually assimilated into the topsoil, which slowly builds up with time.

#### **4.4.1.1. Manawatu fine sandy loam**

##### ***Morphology and genesis***

Manawatu fine sandy loams are deep, well drained soils developed from slowly accumulating alluvial deposits. These soils occur on an almost flat landscape on slightly higher and broader levees bordering the Oroua River. Frequent floods do not affect the soils. Therefore, the accumulation rate of new material to older deposits is very slow. There is sufficient time between floods for the accumulation of organic matter to darken each flood layer and for the worms to incorporate organic matter into the soil. Therefore, flood layering is not evident except in the subsoil of Manawatu soils.

Genetic soil horizons are not clearly expressed in the soil profile. Topsoil horizons can be distinguished separately from the subsoil because of the accumulation of organic matter, but subsoil boundaries are not well marked.

The parent material has not been altered much since its deposition except for the formation of a surface A horizon. The soils exhibit mostly the properties of the parent material.

Topsoil is dark brown to dark greyish brown, fine to very fine sandy loam in texture with moderately developed coarse-nut and strongly developed fine-nut structure.

Subsoil colours are very similar to topsoil colours. Textural properties are sometimes uniform throughout the soil profile, but in some cases different horizons show layering of textures. Soil textural properties are mostly dependent on the nature of the parent material from which soils are developed as little weathering has taken place. Moderately developed or single grain soil structure in the subsoil indicates that these soils are still young. Very fine specks of mica are present throughout the soil profile, again indicating that the parent material is still in the early stages of weathering. Accumulations of clay in the lower part of the soil profile or any other forms of soil forming processes, apart from development of weak structure and slight browning of the alluvium, have not been observed in the soil profile.

Distribution of live roots throughout the soil profile down to about 100 cm indicates that there are no physical barriers like hardpans or compact layers within the soil profile. Soil aeration conditions are favourable for root development.

The genetic soil horizon sequence of Manawatu fine sandy loams can be expressed as A/Bw/C. These soils are classed as Weathered Fluvial Recent Soils according to the New Zealand Soil Classification System (Hewitt, 1992).

## ***Soil description***

(Source: Landcare Research National Soil Data Base. Lab No.SB 10034)

Location: Otaki, Horowhenua Region

Annual rainfall: 1000 mm

Mean annual temperature: 13 ° C.

Landform: Terrace

Parent material: quartzo-feldspatic alluvium

The soil forming factors of the Otaki area are similar to those of the study area. The soils are formed under similar environmental conditions and typical of the Manawatu sandy loams in the study area.

Ap            0-10 cm

Dark greyish brown (10YR 4/2), very fine sandy loam; non sticky, non plastic; very weak soil strength; very weak ped strength; brittle uncemented firm penetration resistance; moderately developed coarse nut breaking to strongly developed fine nut structure; no mottles; no stones; many fine live roots; moist; indistinct irregular boundary.

Bw1           10-33 cm

Dark brown (10YR 3/3), silt loam; non sticky, slightly plastic; very weak soil strength; very weak ped strength; brittle uncemented firm penetration resistance; moderately developed medium nut breaking to weakly developed very fine nut structure; few fine faint dark greyish brown (10YR 4/2) mottles; common unweathered sub rounded coarse greywacke gravels; common very fine live roots; moist; Note: Gravels (about 15%) within horizon (25-32cm depth) up to 20 mm diameter; distinct wavy boundary.

Bw2           33-49 cm

Dark greyish brown (2.5Y 4/2), loamy fine sand; non sticky, non plastic; loose soil strength; brittle uncemented soft penetration resistance; single grain structure; no mottles; no stones; few very fine live roots; moist; distinct wavy boundary.

2C 49-102 cm

Dark greyish brown (2.5Y 4/2), sand; non sticky, non plastic; loose soil strength; brittle uncemented soft penetration resistance; single grain structure; no mottles; no stones; few very fine live roots; moist; bands of fine sand occur throughout horizon; distinct irregular boundary.

3C 102<sup>+</sup> cm

Gravelly sand; non sticky, non plastic; loose soil strength; brittle uncemented single grain structure; no mottles; profuse unweathered sub rounded greywacke stones; no live roots; moist.

### ***Physical properties***

The Manawatu fine sandy loam soils have fine sandy loam textures throughout the soil profile, but in some instances fine sand layers can be observed in the subsoil. Medium bulk densities (can be high in sandy horizons), moderate total porosities and moderate to high macro porosities (Table 4.2) are associated with free root development and exploration throughout the profile. There are no compacted soil layers present in soils that inhibit root penetration. High macroporosity in subsoils associated with sandy textural properties help maintains free drainage and aeration. The total and readily available water within 50 cm and 100 cm depths (Table 4.3) indicate that the moisture storage capacity in the soil is low. The above physical properties indicate that these soils have no physical fertility limitations for plant growth except for the possibility of drying out in dry summer periods, especially where the loamy alluvium is thinner over gravel.

Wet soil consistence is non-sticky and non-plastic where the texture is sand or fine sand and slightly plastic when soils contain some silt. Soil consistence properties indicate that these soils are workable within a wide range of moisture contents.

Table 4.2 The physical properties of Manawatu fine sandy loam: density and porosity.

(Source: Landcare Research National Soil Data Base. Lab No.SB 10034)

Horizon	Depth (cm)	Sample Depth (cm)	B.D (Mg m <sup>-3</sup> )	P.D (Mg m <sup>-3</sup> )	Porosity (%)	
					Total	Macro
Ap	0-10	1-4	1.16	2.59	55.2	9.9
		5-8	1.28	2.63	51.4	11.4
Bw1	10-33	18-21	1.35	2.65	49.5	10.9
		22-25	1.42	2.66	48.3	10.6
Bw2	33-49	37-40	1.28	2.70	52.7	20.6
		41-44	1.27	2.70	53.0	20.9
2C	49-102	71-74	1.36	2.71	49.6	25.2
		75-78	1.39	2.71	48.8	22.4

Table 4.3 The physical properties of Manawatu fine sandy loam: water relationships.

(Source: Landcare Research National Soil Data Base. Lab No.SB 10034)

Horizon	Horizon Thickness (cm)	Sample Depth (cm)	Water retention (% v/v) at				Total water		Readily av. water	
			5 (kpa)	10 (kpa)	100 (kpa)	1500 (kpa)	Sample (% v/v)	Horizon (mm)	Sample (% v/v)	Horizon (mm)
Ap	10	1-4	45.3	42.9	34.8	18.9	24.0		8.1	
		5-8	40.0	37.9	31.3	21.9	16.0	20	6.6	7.4
Bw1	23	18-21	38.6	36.6	29.3	16.9	19.7		7.3	
		22-25	37.7	35.7	28.2	17.9	17.8	43.1	7.5	17.0
Bw2	16	37-40	32.1	25.5	15.5	8.0	17.5		10.0	
		41-44	32.1	25.4	12.9	7.9	17.5	28.0	12.5	18.0
2C	53	71-74	24.4	19.7	11.8	7.2	12.5		7.9	
		75-78	26.4	21.4	11.7	7.1	14.3	71.0	9.7	46.6
Profile available water mm : 50 cm depth								92.4		43.2
: 100 cm depth								159.3		87.1

### *Chemical properties*

Moderate to strong acid reaction (Table 4.4) in Manawatu fine sandy loam soils indicate that these soils are developed from a non-calcareous parent material and inherently poor in basic cations.

The exchange complex contains low to very low amounts of exchangeable cations. High amounts of Ca<sup>++</sup> in the topsoil may be due to application of lime. CEC values are medium in the topsoil, but low in the subsoil. This is because Manawatu fine sandy loam soils contain low to very low amounts of organic carbon (Table 4.5). Also these soils inherently lack a colloidal clay fraction, which can retain exchangeable cations on their exchange sites. Although mica contains high amounts of K, it is not in

exchangeable form. Base saturation is very high in the topsoil, possibly due to application of lime, and medium to high in the subsoil.

Low to very low levels of total nitrogen can be attributed to the low levels of organic matter in the soils. Low C/N ratio indicates that the organic matter present in soils is highly decomposed. Application of raw organic residues into the soil may create a nitrogen imbalance, therefore addition of mineral nitrogen fertilizer is recommended when applying organic residues into the soil.

P-retention values of Manawatu fine sandy loam soils are low (Table 4.5) indicating that small amounts of P fertilizer can increase the available P in soils. Therefore, split applications of P fertilizer are recommended.

Table 4.4 The chemical properties of Manawatu fine sandy loam: cation exchange Properties.

(Source: Landcare Research National Soil Data Base. Lab No. SB10034)

Horizon	Depth (cm)	pH (H <sub>2</sub> O) 1:2.5	Exchangeable cations (cmol <sub>c</sub> kg <sup>-1</sup> )				TEB (cmol <sub>c</sub> kg <sup>-1</sup> )	CEC (cmol <sub>c</sub> kg <sup>-1</sup> )	B.S (%)
			Ca <sup>++</sup>	Mg <sup>++</sup>	K <sup>+</sup>	Na <sup>+</sup>			
Ap	0-10	5.4	10.8	1.28	0.22	0.30	12.6	15.5	81
Bw1	10-33	5.1	4.79	0.36	0.11	0.22	5.48	10.0	55
Bw2	33-49	5.5	3.74	0.38	0.08	0.13	4.33	7.0	62
2C	49-102	5.8	3.30	0.48	0.11	0.06	3.95	5.1	77

Table 4.5 The chemical properties of Manawatu fine sandy loam: phosphorus, carbon and nitrogen.

(Source: Landcare Research National Soil Data Base. Lab No. SB10034)

Horizon	Depth (cm)	P- 0.5 M H <sub>2</sub> SO <sub>4</sub> (mg kg <sup>-1</sup> )	P-ret. (%)	Total C (g kg <sup>-1</sup> )	Total N (g kg <sup>-1</sup> )	C/N
Ap	0-10	760	21	3.50	0.33	11
Bw1	10-33	440	22	1.80	0.16	11
Bw2	33-49	330	15	0.89	0.08	11
2C	49-102	440	8	0.49	0.04	12

### ***Mineralogical properties***

Sand mineralogy (Table 4.6) indicates that the parent material is mainly composed of quartz and feldspars. Small amounts of mica and chlorite are also present at 4 - 6 percent. The sand mineralogy indicates that source of the parent material is mainly

greywacke. The soils are inherently acidic because they are derived from an acidic parent material. The quantity of heavy minerals present in the soils is low. The minerals present in the heavy mineral fraction is very common in greywacke except for pyroxene (Table 4.7), which can be a result of mixing rhyolitic or andesitic material to the river alluvium.

There is no allophane (at this particular site) present in the clay fraction (Table 4.8), reflected by low P-retention values. The clay fraction consists mainly of mica, some chlorite and some vermiculite (Table 4.8). Therefore, the medium to low CEC values in the soil can be attributed to the clay mineralogy present in the clay fraction.

There are enough K reserves in these soils (Table 4.6 and 4.8) stored in unweathered mica, therefore, the soils are naturally rich in plant available K. The high levels of reserve K indicate that these soils may not be response to fertilizer K applications.

Table 4.6 . Mineralogy of the sand fraction of the Manawatu fine sandy loam.

(Source: Landcare Research National Soil Data Base. Lab No.SB 10034).

Horizon	Depth (cm)	Mineral %						
		Qu	Feld	HM	VG	Mica	Chl	Crist
Ap	0-10	40	20	2	0	4	4	0
Bw1	10-33	40	25	2	0	5	5	0
Bw2	33-49	40	25	2	0	6	5	0
2C	49-102	35	20	1.3	0	6	5	0

Table 4.7 Mineralogy of the heavy mineral fraction of the Manawatu fine sandy Loam.

(Source: Landcare Research National Soil Data Base. Lab No. SB10034)

Horizon	Depth (cm)	Minerals (%)							
		HB	Chl	Pyrox	Zir	Ilm	Mag	Epi	Mica
Ap	0-10	6	35	25	10	0	0	10	15
Bw1	10-33	0	35	25	10	0	3	15	15
Bw2	33-49	0	40	25	10	0	0	12	15
2C	49-102	0	35	26	6	0	0	15	15

Table 4.8 Mineralogy of the clay fraction of the Manawatu fine sandy loam.

(Source: Landcare Research National Soil Data Base. Lab No.SB 10034)

Horizon	Depth (cm)	Mineral (%)										
		Qu	Feld.	Kand	Mica	Chl	Allo	M-Chl	M-HIV	HIV	M-Smec	Ver
Ap	0-10	2	2	0	65	12	0	0	0	0	0	15
Bw1	10-33	2	2	0	70	12	0	0	0	0	0	12
Bw2	33-49	2	2	0	75	12	0	0	0	0	0	10
2C	49-102	2	3	0	75	15	0	0	0	0	0	5

#### 4.4.1.2. Manawatu fine sandy loam (moderately shallow)

Manawatu fine sandy loam (moderately shallow) soils are also developed from the same parent material as Manawatu fine sandy loam and occur on an almost flat landscape. They are well drained. Morphological properties are similar to that of Manawatu fine sandy loam except for soil depth. The river terrace gravel is present within 60 cm of the soil surface. The shallow soil depth is one of the limiting factors of this soil, limiting moisture storage, rooting depth and plant nutrient storage.

The soil horizon sequence is A/Bw/C/2C. Physical, chemical and mineralogical properties were not studied in detail, as the soil is very similar to Manawatu fine sandy loam.

#### 4.4.1.3. Manawatu silt loam

##### *Morphology and genesis*

Manawatu silt loams are deep, well drained soils developed from similar parent material to Manawatu fine sandy loam soils. These soils occur on an almost flat landscape, alongside Manawatu fine sandy loams. The soils are again categorised as slowly accumulating Recent Soils. Floods bringing new alluvial material to old deposits are infrequent and there is ample time between floods for the formation of soil.

Manawatu silt loam soils are separated from Manawatu fine sandy loam soils on the basis of the noticeable textural difference of the topsoil. Topsoil horizons can be separated from subsoil horizons easily because of the textural differences.

Other soil horizons and boundaries between them are not well developed.

The silt loam topsoil horizon is 15 to 20 cm thick. Topsoil colours range from dark brown to very dark greyish brown. Strongly developed fine nut structure in topsoils and moderately developed fine nut structure in the Bw1 horizon immediately below the topsoils indicate that weak soil formation has taken place.

Subsoils vary in colour and texture. Soil colours range from dark brown to olive grey. Soil textures are mostly silt loam, very fine sandy loam, sandy loam, loamy sand, or fine sand. There is no soil structural development below the Bw2 horizon. It is massive when moist and breaks into single grains under gentle pressure when dry. Subsoil properties resemble the properties of the parent material. Absence of any low chroma mottles in soil horizons indicates that the soil is well drained. No clay migration or clay bridges between sand particles can be observed in subsoils. This also indicates that soil formation is still at initial stages.

The soil horizon sequence in soil profiles is A/Bw/C. These soils are also classified as Weathered Fluvial Recent Soils according to the New Zealand Soil Classification system (Hewitt, 1992) in common with Manawatu fine sandy loam soils.

### ***Soil description***

(Source: Landcare Research National Soil Data Base. Lab No. SB10036)

Location: Otaki, Horowhenua Region

Annual rainfall: 1100 mm

Mean annual temperature: 13 ° C.

Land form: Terrace

Parent material: quartzo-feldspathic alluvium

The soil forming factors operating in this area is similar to that of the study area. The soils are formed under similar environmental conditions and typical of the Manawatu silt loams in the study area.

Ap            0-15 cm.

Very dark greyish brown (10YR 3/2), silt loam; non sticky, slightly plastic; moderately weak soil strength; moderately weak ped strength; semi-deformable uncemented firm penetration resistance; moderately

developed coarse nut breaking to strongly developed fine nut structure; no mottles; no coatings; few unweathered subrounded greywacke gravels; abundant fine live roots; very moist; wetness 200-300 cm suction; diffuse boundary.

Bw1 15-32 cm

Dark brown (10YR 3/3), silt loam; non sticky, slightly plastic; moderately weak soil strength; very weak ped strength; brittle uncemented firm penetration resistance; moderately developed fine nut structure; no mottles; no coatings; no stones; many very fine live roots; very moist; wetness 50 cm suction; diffuse boundary.

Bw2 32-52 cm

Dark greyish brown (2.5Y 4/2), very fine sandy loam; slightly sticky, moderately plastic; moderately weak soil strength; very weak ped strength; brittle uncemented firm penetration resistance; moderately developed fine nut breaking to moderately developed fine granular structure; no mottles; no coatings; no stones; common very fine live roots; very moist; wetness <50 cm suction; distinct wavy boundary.

2C1 52-68 cm

Olive grey (5Y 5/2), fine sand; non sticky, non plastic; loose soil strength; brittle uncemented soft penetration resistance; single grain ; no mottles; no coatings; no stones; few very fine live roots; very moist; wetness 100-200 cm suction; diffuse boundary.

2C2 68-97+ cm

Olive grey (5Y 4/2), fine sand; non sticky, non plastic; loose soil strength; brittle uncemented soft penetration resistance; single grain ; no mottles; no coatings; no stones; no live roots; very moist; wetness 50-100 cm suction.

### *Physical properties*

The physical properties of Manawatu silt loams are very similar to that of Manawatu fine sandy loams except for the topsoil texture. Both topsoil and subsoil consistence show that these soils have workability properties within a wide range of moisture. Low to medium bulk densities, not surprising for such a sandy soil, (Table 4.9) are very favourable for root development. Soil profile description shows that there are live roots throughout the soil profile. There are no compacted layers that restrict root penetration. Particle densities between 2.6 and 2.7 Mg m<sup>-3</sup> indicate that solid particles are mainly made up of quartz and feldspars. Moderate total porosity values and moderate to high macroporosity values are associated with good soil drainage and low soil compaction. Macroporosity values in subsoils are high due to the sandy textural properties of these soil horizons.

Total and readily available water within 50 cm depth is 94 mm and 37 mm respectively (Table 4.10). This is comparable to the soil moisture storage capacity of Manawatu fine sandy loams. The low water storage capacity is also associated with sandy textural properties, medium bulk densities and moderate to high porosity of the soil. Physical parameters show no soil limitations to plant growth except that it is possible that there may be some moisture limitations during dry seasons.

Table 4.9 The physical properties of Manawatu silt loam: density and porosity.

(Source: Landcare Research National Soil Data Base. Lab No. SB10036)

Horizon	Depth (cm)	Sample Depth (cm)	B.D (Mg m <sup>-3</sup> )	P.D (Mg m <sup>-3</sup> )	Porosity (%)	
					Total	Macro
Ap	0-15	4-7	1.14	2.61	56.4	11.7
		8-11	1.24	2.64	52.9	9.6
Bw1	15-32	20-23	1.36	2.69	49.5	10.6
		24-27	1.34	2.69	50.3	11.4
Bw2	32-52	38-41	1.34	2.70	50.5	14.9
		42-45	1.39	2.70	48.7	14.6
2C1	52-68	56-59	1.33	2.73	51.3	34.9
		60-63	1.32	2.72	51.6	34.0
2C2	68-97 <sup>+</sup>	79-83	1.27	2.73	53.6	32.5
		83-86	1.36	2.73	50.2	25.1

Table 4.10 The physical properties of Manawatu silt loam: water relationships.

(Source: Landcare Research National Soil Data Base. Lab No. SBI0036)

Horizon	Depth (cm)	Sample Depth (cm)	Water retention % (v/v) at				Total water		Readily av. water	
			5 (kpa)	10 (kpa)	100 (kpa)	1500 (kpa)	Sample (% v/v)	Horizon (mm)	Sample (% v/v)	Horizon (mm)
Ap	0-15	4-7	44.7	42.7	36.4	19.0	23.7		6.3	
		8-11	43.3	41.4	35.1	20.2	21.2	33.7	6.3	9.5
Bw1	15-32	20-23	38.9	37.3	28.5	17.3	20.0		8.8	
		24-27	38.9	37.2	26.0	15.4	21.8	35.5	11.2	17.0
Bw2	32-52	38-41	35.6	33.7	27.7	19.0	14.7		6.0	
		42-45	34.1	32.2	26.2	19.1	13.1	27.8	6.0	12.0
2C1	52-68	56-59	16.4	11.6	8.6	8.6	3.0		3.0	
		60-63	17.6	13.0	9.7	8.0	5.0	6.4	3.3	5.0
2C2	68-100 <sup>+</sup>	79-83	21.1	13.8	8.8	7.1	6.7		5.0	
		83-86	25.1	16.4	10.2	6.7	9.7	26.5	6.2	18.0
Profile available water mm: for 50 cm depth								94.2		37.3
: for 100 cm depth								129.7		61.5

### *Chemical properties*

Moderately acid soil reaction indicates that the soils are poor in exchangeable basic cations such as  $\text{Ca}^{++}$ ,  $\text{Mg}^{++}$ ,  $\text{K}^+$ ,  $\text{Na}^+$ . Low to very low  $\text{K}^+$  and  $\text{Na}^+$  status and medium to low  $\text{Ca}^{++}$  and  $\text{Mg}^{++}$  status shows this clearly (Table 4.11). High  $\text{Ca}^{++}$  only slightly acid reaction and very high base saturation in topsoils is an indication of the application of lime. High to very high  $\text{H}_2\text{SO}_4$  soluble inorganic phosphorus levels (Table 4.12) proves that the soils are still in the initial stage of weathering.

Medium to low CEC values can be attributed to low to very low organic carbon levels (Table 4.12), the texture and the clay mineralogy. High base saturation in the topsoil again is an indication of the application of lime. Base saturation in the subsoils is also more than 50 percent.

Manawatu fine sandy loam soils have low phosphate retention. Wind erosion losses of topsoil from exposed areas can be expected in dry seasons, because of the silty texture of the topsoils.

Manawatu soils are low to very low in total nitrogen, because the soils are low to very low in organic carbon. C/N ratio is low to medium, indicating that the organic matter present in the soil is well decomposed. Addition of organic residues into the soil may cause a temporary nitrogen deficiency.

Table 4.11 The chemical properties of Manawatu silt loam: cation exchange properties.

(Source: Landcare Research National Soil Data Base. Lab No. SB10036)

Horizon	Depth (cm)	pH (H <sub>2</sub> O) 1:2.5	Exchangeable cations (cmol <sub>c</sub> kg <sup>-1</sup> )				TEB (cmol <sub>c</sub> kg <sup>-1</sup> )	CEC (cmol <sub>c</sub> kg <sup>-1</sup> ) <sup>1</sup>	B.S (%)
			Ca <sup>++</sup>	Mg <sup>++</sup>	K <sup>+</sup>	Na <sup>+</sup>			
Ap	0-7.5	6.2	16.7	1.42	0.34	0.20	18.7	15.5	100
	7.5-15	5.1	7.52	0.85	0.31	0.09	8.77	13.2	66
Bw1	15-32	5.4	5.29	0.50	0.26	0.08	6.13	10.0	61
Bw2	32-52	5.7	6.45	0.72	0.18	0.12	7.47	10.8	69
2C1	52-68	5.8	3.57	0.55	0.10	0.14	4.36	6.0	73
2C2	68-97 <sup>+</sup>	5.9	3.39	0.67	0.07	0.10	4.23	6.3	67

Table 4.12 The chemical properties of Manawatu silt loam: phosphorus, sulphate, carbon and nitrogen.

(Source: Landcare Research National Soil Data Base. Lab No. SB10036)

Horizon	Depth (cm)	P- 0.5 M H <sub>2</sub> SO <sub>4</sub> (mg kg <sup>-1</sup> )	P-ret. (%)	Total C (g kg <sup>-1</sup> )	Total N (g kg <sup>-1</sup> )	C/N
Ap	0-7.5	720	22	3.30	0.33	10
	7.5-15	580	23	2.10	0.22	10
Bw1	15-32	490	22	1.30	0.13	10
Bw2	32-52	300	22	1.20	0.11	11
2C1	52-68	430	12	0.54	0.04	14
2C2	68-97 <sup>+</sup>	380	13	0.55	0.04	14

### *Mineralogical properties*

Sand mineralogy (Table 4.13) suggests that the soil parent material is mainly composed of quartz, feldspars, mica and chlorite, which are common minerals in the greywacke. The sand fraction consists of about 2 percent heavy minerals (Table 4.13). The minerals present in the heavy mineral fraction (Table 4.14) are very common in greywacke except for pyroxenes that are common in basic or volcanic rocks. Sand mineralogy suggests that the parent material is mostly derived from greywacke. Moderate amounts of chlorite, pyroxene, mica, epidote and zircon are also present in the heavy mineral fraction.

The clay fraction (Table 4.15) mainly consists of mica and chlorite, which both have very low CEC values. Although vermiculite has a high CEC, this mineral is present in very small amounts. The micas are largely primary in origin and inherited by the soil from parent materials such as shale, slates, phyllite, schist, gneisses and granites and

sediments derived from these rocks; in this case greywacke, argillite, sandstones and mudstone. They are 2:1 non-expanding type phyllosilicate minerals. Potassium ions are strongly attracted between the crystal units preventing much of the expansion of the crystal. Potassium trapped between crystal layers can be released to the soil solution upon weathering. The chlorite minerals present in sand, silt and clay fractions may also be inherited by the sedimentary parent material. These minerals are also non-expanding and low in CEC values. However, micas present in the clay fractions (Table 4.15) of Manawatu silt loam soils are an important source of potassium.

Table 4.13 Mineralogy of the sand fraction of the Manawatu silt loam.

(Source: Landcare Research National Soil Data Base. Lab No.SB 10036)

Horizon	Depth (cm)	Mineral (%)						
		Qu	Feld	HM	VG	Mica	Chl	Crist
Ap	0-7.5	40	25	2	NA	4	4	0
	7.5-15	40	25	2	NA	5	5	0
Bw1	15-32	35	25	2.2	NA	6	5	0
Bw2	32-52	40	22	1.5	NA	5	4	0
2C1	52-68	35	15	1.5	NA	6	5	0
2C2	68-97 <sup>+</sup>	35	20	1.5	NA	6	7	0

Table 4.14 Mineralogy of the heavy mineral fraction of the Manawatu silt loam.

(Source: Landcare Rereach National Soil Data Base. Lab No. SB10036)

Horizon	Depth (cm)	Minerals (%)							
		HB	Chl	Pyrox	Zir	Ilm	Mag	Epi	Mica
Ap	0-7.5	7	30	30	3	0	0	12	18
	7.5-15	5	30	24	5	0	5	18	12
Bw1	15-32	4	30	24	4	0	0	15	20
Bw2	32-52	0	30	25	4	0	5	18	16
2C1	52-68	5	30	35	6	0	0	7	18
2C2	68-97 <sup>+</sup>	4	35	30	3	0	0	15	12

Table 4.15 Mineralogy of the clay fraction of the Manawatu silt loam.

(Source: Landcare Research National Soil Data Base. Lab No.SB 10036)

Horizon	Depth (cm)	Mineral (%)										
		Qu	Feld.	Kand	Mica	Chl	Allo	M-Chl	M-HIV	HIV	M-Smec	Ver
Ap	0-7.5	2	5	0	65	10	NA	0	0	0	0	15
	7.5-15	2	3	0	65	15	NA	0	0	0	0	12
Bw1	15-32	3	3	0	70	15	NA	0	0	0	0	8
Bw2	32-52	2	4	0	70	12	NA	0	0	0	0	12
2C1	52-68	2	2	0	75	12	NA	0	0	0	0	8
2C2	68-97*	2	4	0	75	12	NA	0	0	0	0	8

#### 4.4.1.4. Discussion

Flat terrain, sand, fine sand, fine sandy loam, loamy fine sand and silt loam textures, and presence of soil horizons with different textural properties indicate that soils of the lower terrace are derived from alluvial deposits as pointed out in Section 2.4.3.

The sand mineralogy suggests that the parent material is quartzo-feldspathic (see Table 4.6 and 4.13). The minerals present in the sand fraction and the heavy mineral fraction (see Table 4.6, 4.7, 4.13 and 4.14) are quite common in greywacke (N.Z. Soil Bureau, 1968) and hence the major source of the alluvium is greywacke and other younger rocks derived from it, as suggested by Cowie (1978).

Weak to moderately developed soil structure in the subsoil, presence of un weathered specks of mica in the soil profile and high H<sub>2</sub>SO<sub>4</sub> soluble phosphate (see Table 4.5 and 4.12) in the soils indicate that the parent material is weakly weathered and therefore the soils are still young. The alluvial sediments are probably less than 2000 years old (see Section 2.4.3). The soil profiles exhibit A/Bw/C soil horizon sequence.

Most of the physical and chemical properties of these soils are dependent on the nature of the parent material. Better soil drainage conditions, medium bulk density, high macro porosity (see Table 4.2 and 4.9), and non sticky and non plastic soil consistency are associated with sandy textural properties. Low amounts of total and readily available water (see Table 4.3 and 4.10) present in soils are also associated with sandy textural properties.

Medium to acid soil reaction, low to very low exchangeable cations in soils (see Table 4.4 and 4.11) are inherited from quartz rich acidic parent materials.

Low to medium CEC values are associated with sandy soil texture, low organic matter and the type of clay minerals. The clay minerals present in the soil are mica, chlorite and vermiculite (see Table 4.8 and 4.15). The CEC of these clay minerals are low except for vermiculite, but its presence in the clay fraction is low. Phosphate retention is also dependent on the type of clay minerals present in the soil. Low P-retention properties are associated with absence of allophane in these soils.

The parent materials, physical, chemical and mineralogical properties of the three soils occurring on lower terrace are similar. The variability of soil properties within soil types and between soil types would not have a significant effect on soil management practices except for the Manawatu fine sandy loam moderately shallow phase.

#### **4.4.2. Soils of the Intermediate Terrace**

The intermediate terrace is composed of a number of sub terraces situated at different elevations ranging from 200 m to 260 m above mean sea level. Formation of fluvial aggradation terraces and the parent materials were discussed in Sections 2.4.2 and 2.4.3 respectively.

Five soil types were identified and mapped on the intermediate terrace. Separation of soil types is based on both nature of the parent material and the drainage status of the soils.

##### **4.4.2.1. Kawhatau stony silt loam**

###### ***Morphology and genesis***

Kawhatau stony silt loam soils mostly occur along the edges of younger intermediate terraces that are situated well above flood level, at elevations ranging from about 200 m to 240 m. They are well drained soils consisting of coarse greywacke gravel throughout the soil profile, and occur on flat to gently sloping terrain. These soils are derived from alluvium consisting of greywacke gravel intermixed with subsequent air fall volcanic ash (see Section 2.4.3).

Morphological and physical properties of the soil profile shows that the parent material has been considerably altered by soil forming processes.

The parent material is a light olive brown colour, which has been weathered to a yellowish brown, strong brown and very dark greyish brown in the subsoil. The stony silt loam texture of the soils is inherited from the parent material. The soil structure is moderately developed nut and granular. Presence of a few clay coatings in the Bw1 horizon is due to local accumulation of clay in the soil profile. The topsoil and subsoil are clearly separated by a distinct soil horizon boundary. Genetic soil horizons in subsoils also can be identified clearly, although they are separated by indistinct or diffuse boundaries. Absence of low chroma mottles and gleying in the profile shows that drainage is not impeded.

Although consistency properties are favorable for tillage within a wide range of moisture conditions, greywacke gravels present in soils may have unfavorable influence. Presence of live roots throughout the soil profile indicates that there are no obstructions to plant root development and good soil aeration conditions.

The genetic soil horizon sequence identified in soil profiles is A/Bw1/Bw2/C. These soils are classified as Acidic Allophanic Brown Soils according to the New Zealand Soil Classification system (Hewitt, 1992).

### ***Soil description***

(Source: Landcare Research National Soil Data Base. Lab No. SB09943)

Location: Otaki, Horowhenua Region

Annual rainfall: 1200 mm

Mean annual temperature: 12 °C.

Land form: Ohakean Terrace

Parent material: weakly weathered, alluvial, greywacke, greywacke alluvium.

The soil forming factors operating at Otaki is similar to that of the study area. The soils are formed under similar environmental conditions and typical of the Kawhatau stony silt loams in the study area.

- Ap 0-17 cm.
- Very dark greyish brown (10YR 3/2), stony silt loam; slightly plastic; very weak soil strength; soft penetration resistance; moderately developed fine nut plus granular structure; abundant weakly weathered sub rounded greywacke stones; abundant very fine live roots; moist; no NaF reaction; distinct irregular boundary.
- AB 17-28 cm
- Very dark greyish brown (10YR 3/2), stony silt loam; very weak soil strength; firm penetration resistance; moderately developed fine nut plus granular structure; abundant weakly weathered sub rounded greywacke stones; common very fine live roots; moist; Common distinct organo/Fe-Mn coatings (5YR 3/4); indistinct wavy boundary.
- Bw1 28-52 cm
- Strong brown (7.5YR 5/8), stony silt loam; slightly plastic; very weak soil strength; firm penetration resistance; moderately developed medium nut breaking to moderately developed fine nut structure; few faint clay coatings; abundant weakly weathered sub rounded greywacke stones; few very fine live roots; moist; diffuse boundary.
- Bw2 52-75 cm
- Yellowish brown (10YR 5/8), stony silt loam; slightly plastic; very weak soil strength; firm penetration resistance; moderately developed medium nut breaking to moderately developed fine nut structure; few prominent dark reddish brown (5YR 3/2) coatings; abundant weakly weathered sub rounded greywacke stones; few very fine live roots; moist; indistinct irregular boundary.
- C 75+ cm
- Light olive brown (2.5Y 5/6), stony silt loam; slightly sticky; very weak soil strength; firm penetration resistance; massive structure; common

prominent dark reddish brown (5YR 3/3) coatings; abundant weakly weathered subrounded greywacke stones; few very fine live roots; moist; 5YR 3/3 coatings around stones.

### *Physical properties*

Accurate measurements of most of the physical properties are rather difficult in Kawhatau soils due to its stony nature. The measurements such as bulk density and macroporosity therefore are not so reliable (Table 4.16). Water retention properties were calculated only for 50 cm depth. Total available water is about 130 mm and readily available water is 35 mm. Readily available water is comparable to Manawatu soils (Table 4.17). Water storage capacity is low due to the presence of inert gravels in these soils, therefore the soils dry out easily. Physical soil properties are thus not so suitable for plant growth.

Table 4.16 The physical properties of Kawhatau stony silt loam: density and porosity.

(Source: Landcare Research National Soil Data Base. Lab No. SB09943)

Horizon	Depth (cm)	Sample Depth (cm)	B.D (Mg m <sup>-3</sup> )	P.D (Mg m <sup>-3</sup> )	Porosity (%)	
					Total	Macro
Ap	0-17	0-17	1.60	2.29	60.3	0
AB	17-28	17-28	1.60	2.51	60.6	13.1
Bw1	28-52	28-52	1.52	2.55	59.2	4.8
Bw2	52-75	NA	NA	NA	NA	NA
C	75 <sup>+</sup>	NA	NA	NA	NA	NA

Table 4.17 The physical properties of Kawhatau stony silt loam: water relationships.

(Source: Landcare Research National Soil Data Base. Lab No. SB09943)

Horizon	Depth (cm)	Sample Depth (cm)	Water retention % (v/v) at				Total water		Readily av. water	
			5 (kpa)	10 (kpa)	100 (kpa)	1500 (kpa)	Sample (% v/v)	Horizon (mm)	Sample (% v/v)	Horizon (mm)
Ap	0-17	0-17	65.0	61.0	53.3	27.1	33.9	57.6	7.7	13.1
AB	17-28	17-28	47.5	44.5	38.5	26.0	18.5	20.4	6.0	6.6
Bw1	28-52	28-52	54.4	52.4	45.5	29.0	23.4	56.2	6.9	16.6
Bw2	52-75	NA	NA	NA	NA	NA	NA	NA	NA	NA
C	75 <sup>+</sup>	NA	NA	NA	NA	NA	NA	NA	NA	NA
Profile available water mm: for 50 cm depth								129.5		34.9

## *Chemical properties*

Chemical properties show that the soil reaction changes from medium acid in the topsoil to slightly to strongly acid in the subsoil. Exchangeable basic cations in the subsoil are low to very low (Table 4.18). High to very high amounts of  $\text{Ca}^{++}$  and  $\text{K}^+$  in the topsoil are due to application of lime and potassium bearing fertilizers.

High CEC values in the topsoil and medium to low CEC values in the subsoil (Table 4.19) can be attributed to medium and medium to low levels of organic carbon present in the topsoil and subsoil respectively. Base saturation in the topsoil is medium to high, possibly due to application of lime. Subsoil base status is low to very low.

Very high to high levels of sulphuric acid soluble phosphorus (Table 4.19) indicate that the soils are not highly weathered. High phosphorus retention values in the subsoil can be attributed to the presence of allophane. Although the topsoil shows good response to applied phosphorus fertilizers, the allophane adsorbs most of it in forms unavailable to plants.

High to medium nitrogen levels in topsoils may be attributed to application of fertilizers and medium organic matter levels. Low to very low levels of nitrogen in subsoils are due to low to very low levels of organic carbon. Low to very low C/N ratio indicates that the organic matter in the soils is highly decomposed and is in equilibrium with the soil environment.

Table 4.18 The chemical properties of Kawhatau stony silt loam: cation exchange.Properties.

(Source: Landcare Research National Soil Data Base. Lab No. SB09943)

Horizon	Depth (cm)	pH (H <sub>2</sub> O) 1:2.5	Exchangeable cations (cmol <sub>c</sub> kg <sup>-1</sup> )				TEB (cmol <sub>c</sub> kg <sup>-1</sup> )	CEC (cmol <sub>c</sub> kg <sup>-1</sup> )	B.S (%)
			Ca <sup>++</sup>	Mg <sup>++</sup>	K <sup>+</sup>	Na <sup>+</sup>			
Ap	0-7.5	6.0	28.20	2.26	1.14	0.41	32.0	41.3	77
	7.5-17	5.2	13.20	0.80	0.39	0.34	14.7	28.6	51
AB	17-28	5.4	3.20	0.28	0.17	0.10	3.75	17.7	21
Bw1	28-52	5.3	0.80	0.09	0.15	0.09	1.13	12.0	9
Bw2	52-75	5.1	0.30	0.04	0.16	0.08	0.58	11.1	5
C	75 <sup>+</sup>	5.2	0.70	0.08	0.09	0.05	0.92	7.9	12

Table 4.19 The chemical properties of Kawhatau stony silt loam: phosphorus, sulphate, carbon and nitrogen.

(Source: Landcare Research National Soil Data Base. Lab No. SB09943)

Horizon	Depth (cm)	P- 0.5 M H <sub>2</sub> SO <sub>4</sub> (mg kg <sup>-1</sup> )	P-ret. (%)	Total C (g kg <sup>-1</sup> )	Total N (g kg <sup>-1</sup> )	C/N
	0-7.5	2140	54	9.50	1.08	9
Ap	7.5-17	850	55	7.00	0.57	12
AB	17-28	240	80	3.70	0.29	13
Bw1	28-52	210	90	2.10	0.17	12
Bw2	52-75	170	85	1.00	0.09	11
C	75 <sup>+</sup>	160	62	0.90	0.06	15

### *Mineralogical properties*

Sand mineralogy (Table 4.20) indicates that the parent material is mainly composed of quartz and feldspars. It also contains aggregates, minor amounts of heavy minerals, volcanic glass, mica and chlorite. Presence of volcanic glass in the sand fraction (Table 4.20) and higher percentages of hornblende, pyroxene and magnetite in the heavy mineral fraction (Table 4.21) indicate that the parent material has a component of tephra or reworked glass. Medium to strong soil reaction and low amounts of basic cations in subsoil are also attributed to the properties of soils developed from quartzo-feldspathic acidic parent material.

Clay minerals present in the soil do not contribute much to the CEC of the soils. Kandite, mica and chlorite minerals (Table 4.22) have low CEC values. Other mixed layer minerals, mica-HIV and HIV have medium CEC values. Allophane minerals again bear low negative charges on their surfaces when soils are acidic. Therefore, medium to low CEC values in soils are partly associated with the clay mineralogy. High P-retention in the subsoil (see Table 4.19) is also attributed to the presence of allophane.

Table 4.20 Mineralogy of the sand fraction of the Kawhatau stony silt loam.

(Source: Landcare Research National Soil Data Base. Lab No.SB 09943)

Horizon	Depth (cm)	Mineral (%)						
		Qu	Feld	Aggre	HM	VG	Mica	Chl
Ap	0-7.5	60	25	5	5	3	2	2
	7.5-17	50	25	15	2	2	3	2
AB	17-28	50	25	15	2	2	2	2
Bw1	28-52	55	20	15	3	2	1	3
Bw2	52-75	55	25	10	2	1	2	3
C	75 <sup>+</sup>	45	25	20	1	1	3	4

Table 4.21 Mineralogy of the heavy mineral fraction of the Kawhatau stony silt loam.

(Source: Landcare Research National Soil Data Base. Lab No. SB09943)

Horizon	Depth (cm)	Minerals (%)							
		HB	Chl	Pyrox	Zir	Ilm	Mag	Epi	Mica
Ap	0-7.5	20	0	25	0	0	35	20	0
	7.5-17	15	5	27	0	0	35	20	0
AB	17-28	25	4	30	0	0	20	20	0
Bw1	28-52	20	4	27	0	0	30	20	0
Bw2	52-75	12	6	30	0	0	30	20	0
C	75 <sup>+</sup>	10	15	30	0	0	25	20	0

Table 4.22 Mineralogy of the clay fraction of the Kawhatau stony silt loam.

(Source: Landcare Research National Soil Data Base. Lab No.SB 09943)

Horizon	Depth (cm)	Mineral (%)										
		Qu	Feld.	Kand	Mica	Chl	Allo	M-Chl	M-HIV	HIV	M-Ver	Ver
Ap	0-7.5	0	0	15	4	15	0	0	0	50	15	0
	7.5-17	0	0	12	3	15	0	0	0	55	15	0
AB	17-28	0	0	10	2	15	1	0	0	50	20	0
Bw1	28-52	0	0	10	3	20	5	0	0	40	20	0
Bw2	52-75	0	0	10	5	20	4	0	0	35	25	0
C	75 <sup>+</sup>	0	0	12	9	25	2	0	0	25	25	0

#### 4.4.2.2. Coulter silt loam (new series)

##### *Morphology and genesis*

Coulter silt loams are moderately deep to deep, well drained soils occurring on the flat to gently sloping terrain, about 240 m to 260m elevation, of the intermediate terrace. This portion of the terrace is slightly higher in elevation compared to the remainder of the terrace. The soil has not been reported in previous soil surveys. They were mapped as Kawhatau stony silt loam under the General Soil Survey of the soils of North Island (NZ Soil Bureau, 1954) and as Kiwitea loam under New Zealand land resource inventory (1979).

The soils are derived from a mixture of a fine textured alluvium, colluvium and perhaps loess intermixed with subsequent air fall tephra (see Section 2.4.3). River terrace gravels are present at 125 to 150 cm depths.

The soil profile shows clear genetic soil horizon differentiation. The processes of soil formation have been active on the parent material for a considerable time, at least 10,000 years, in order to alter the parent material into soil. A and B soil horizons can be clearly distinguished from each other, with an abrupt boundary, indicating regular ploughing.

The topsoils are dark brown, silt loam with moderately developed fine to medium nutty structure. The subsoils are dark yellowish brown, silt loam with moderately developed fine to medium nuts and medium to coarse blocks. Soil structural development in the soil is not strong. Soil aggregates can be easily damaged during tillage operations and the topsoil is prone to wind erosion. The boundaries of sub horizons within the B-horizon are clear.

There is no gleying or mottling to 90 cm from the soil surface. Therefore, they are well drained soils, but mottles occurring below 90 cm show some impeded drainage conditions deeper down the profile. This is due to the perching of the water table during rainy seasons on the underlying fluvial gravels.

The soils are biologically active. Earthworms are very common in the topsoil and plant roots are well distributed throughout the soil profile.

The soil horizon sequence in the profile is A/Bw1/Bw2/2C. They are classified as Typic Orthic Allophanic Soils according to the New Zealand Soil Classification system (Hewitt, 1992). In the survey area, the Coulter Soils are intensively used for flower production, limiting the available sites to excavate a soil pit for sampling and detailed description. The sampled site has a well developed buried A horizon with vermiform fabric, overlying gravels. This was not seen in all other augered sites. At the profile pit site there was evidently a hiatus in the deposition of alluvium, loess and tephra, enabling the buried topsoil to be well expressed. Such features are not unexpected in up-building soil profiles.

### ***Soil description***

(source: Survey of Kiwitea area by author)

Ap            0 – 20 cm.

Dark brown (10YR 3/3) moist, silt loam; smeary feeling when moist; moderate fine to medium nutty structure; non sticky and non plastic, friable moist; common earthworms; very frequent very fine and fine roots; abrupt smooth boundary.

Bw1           20 – 65 cm

Dark yellowish brown (10YR 4/4) moist, silt loam; moderate fine to medium nutty structure; non sticky and non plastic, friable moist; frequent very fine and fine roots; clear smooth boundary.

Bw2           65 – 95 cm

Dark yellowish brown (10YR 4/6) moist, silt loam; moderate fine to medium nutty and moderate medium blocky structure; non sticky and non plastic, friable moist; frequent fine roots; clear smooth boundary.

2Ab 95 – 125 cm

Dark yellowish brown (10YR 4/4) moist, common medium distinct light olive brown (2.5Y 5/4) mottles; clay loam; moderate medium to coarse blocky structure; sticky and plastic, slightly hard moist; common very fine and fine roots; abrupt smooth boundary.

125<sup>+</sup> cm

Rounded fluvial gravels and pebbles

### ***Physical properties***

Medium bulk density (Table 4.23) indicates that these soils are porous, and not compacted. Moderately high porosity is attributed to the presence of allophane. Bulk density values show that there are no compacted horizons or hard pans within 90 cm of the surface. Porous soils with low bulk density assist free root distribution and exploration throughout the soil.

The physical properties of the soil sampled below 95 cm have high bulk density, moderate total porosity, moderately low macroporosity and slow hydraulic conductivity indicating that this is a rather compacted layer. It contains no allophane. Soil texture is clay loam, the horizon has vermiform fabric, indicating that it might once have been a topsoil horizon.

The infiltration rate is about 77 mm hr<sup>-1</sup>. This indicates that rain water enters into soils rapidly without surface ponding and run off. The flat soil surface together with high infiltration rate minimizes water erosion.

Profile total available water and readily available water in Coulter silt loam is moderate (Table 4.24).

Table 4.23 The physical properties of Coulter silt loam: density, porosity, hydraulic conductivity and infiltration.

Horizon	Sample Depth (cm)	B.D (Mg m <sup>-3</sup> )	P.D (Mg m <sup>-3</sup> )	Porosity (%)		k Sat. (mm hr <sup>-1</sup> )	Infiltration (mm hr <sup>-1</sup> )
				Total	Macro		
Ap	0-7.5	0.89	2.44	64	7	8	77
	10-20	0.9	2.48	64	6	NA	
Bw1	30-40	0.9	2.6	65	11	8	
Bw2	70-80	0.97	2.53	62	8	4.3	
2Ab	100-110	1.31	2.58	49	5	4.6	

Table 4.24 The physical properties of Coulter silt loam: water relationships.

Horizon	Horizon thickness (cm)	Water retention % (v/v) at				Total av. water		Readily av. water	
		5 (kpa)	10 (kpa)	100 (kpa)	1500 (kpa)	Sample (% v/v)	Horizon (mm)	Sample (% v/v)	Horizon (mm)
Ap	7.5	56.6	52.3	41	29.8	22.5	22.5	11.3	8.4
	12.5	57.6	52.5	39	28.0	24.5	24.5	13.5	16.8
Bw1	35	54.1	47.8	36	28.9	18.9	18.9	11.8	41.3
Bw2	30	53.2	49.6	38	29.2	20.4	20.4	11.6	34.8
2Ab	30	43.8	40.8	33	24.2	16.6	16.6	7.8	23.4
Profile available water mm: for 50 cm depth							104		60.6
: for 100 cm depth							199		113

### *Chemical properties*

Coulter silt loam soils are slightly to moderately acid (Table 4.25), mainly because the parent material from which the soil developed is medium to low in basic cations. High levels of calcium in the topsoil are probably due to application of lime. Magnesium, potassium and sodium levels are low to very low in these soils.

Medium CEC values in the topsoil are due to medium organic carbon levels. CEC levels in subsoils are medium to low, which may be attributed to low to very low amounts of organic carbon and the clay mineralogy (see mineralogical properties below).

High phosphate retention values (Table 4.26) are again attributed to presence of allophane.

Total nitrogen level in the topsoil is medium due to medium amounts of organic carbon, and C/N ratio is low, indicating a highly decomposed nature of organic matter in the

soils. However, low C/N ratios would indicate nitrogen saturation of the soil organic matter with increased risk of N leaching (Schipper and Percival, 2002).

The bulk soil is made up of a number of soil samples (0-7.5 cm depth) collected from the paddock where the soil profile is located. The chemical properties show little variability except for Olsen P between the topsoil of the bulk soil and the topsoil of the soil profile.

Table 4.25 The chemical properties of Coulter silt loam: cation exchange properties.

Horizon	Sample Depth (cm)	pH (H <sub>2</sub> O) 1:2.5	Exchangeable cations (cmol <sub>c</sub> kg <sup>-1</sup> )				TEB (cmol <sub>c</sub> kg <sup>-1</sup> )	CEC (cmol <sub>c</sub> kg <sup>-1</sup> )	B.S (%)
			Ca <sup>++</sup>	Mg <sup>++</sup>	K <sup>+</sup>	Na <sup>+</sup>			
Bulk soil	0-7.5	5.8	10.6	1.1	1.55	0.17	13.4	26	52
Ap	0-7.5	6	11.30	0.96	0.40	0.17	12.8	25	51
	10-20	6.1	9.00	0.45	0.16	0.18	9.8	21	46
Bw1	30-40	6.5	5.40	0.35	0.04	0.11	5.9	13	45
Bw2	70-80	6	2.70	0.66	0.05	0.08	3.5	10	35
2Ab	100-110	5.3	1.70	2.45	0.09	0.23	4.5	12	37

Table 4.26 The chemical properties of Coulter silt loam: phosphorus, sulphate, carbon and nitrogen.

Horizon	Sample Depth (cm)	Olsen P (mg kg <sup>-1</sup> )	P-ret. (%)	Total C (g kg <sup>-1</sup> )	Total N (g kg <sup>-1</sup> )	C/N
Bulk soil	0-7.5	24.4	79	7.55	0.73	10
Ap	0-7.5	18	86	6.64	0.68	10
	10-20	16	87	5.55	0.56	10
Bw1	30-40	8	90	1.49	0.14	11
Bw2	70-80	5	87	0.96	0.08	12
2Ab	100-110	3	33	0.3	0.02	15

### ***Mineralogical properties***

The sand mineralogy proves that the parent material mainly consists of quartz, feldspars and volcanic glass (Table 4.27). Presence of high percentages of hornblende, magnetite and augite in the heavy mineral fraction (Table 4.28) also proves the influence of volcanic material. Volcanic glass present in the sand fraction weathers into allophane under well-drained conditions (Parfitt *et al.*, 1983, Singleton *et al.*, 1989). Most of the

physical and chemical properties of Coulter soils discussed above are attributed to the presence of allophane in the clay fraction (Table 4.29).

Clay minerals present in Coulter soils are low to medium in CEC except for allophane (Table 4.29). Allophane is a group name for clay minerals with short-range order consisting of silica, alumina and water in chemical combination (Farmer, 1985). The surface of the allophane spherule is porous and reactive AlOH groups are present at the edges of these pores. These reactive groups are available for the many chemical reactions that occur in allophanic soils (Parfitt and Henmi, 1980). They develop variable charge on their surfaces, influenced by soil pH, by the nature and concentration of surrounding cations and anions, potential determining ions, and by temperature (Wada, 1977, 1989). CEC values of allophane are low when soils are acidic whereas CEC values are higher when soils become less acidic due to the pH dependent surface characteristics of allophane.

Table 4.27 Mineralogy of the sand fraction of the Coulter silt loam.

Horizon	Sample Depth (cm)	Mineral (%)						
		Qu	Feld	HM	VG	Mica	Chl	Crist
Ap	0-10	41	32	14	13	0	0	0
	10-20	51	23	16	10	0	0	0
Bw1	30-40	56	30	10	4	0	0	0
Bw2	70-80	55	23	7	15	0	0	0
2Ab	100-110	52	30	5	13	0	0	0

Table 4.28 Mineralogy of the heavy mineral fraction of the Coulter silt loam.

Horizon	Sample Depth (cm)	Minerals (%)							
		HB	Chl	Hyp	Aug	Ilm	Mag	Epi	Mica
Ap	0-10	11	1	9	21	0	48	10	Tr
	10-20	11	2	9	13	0	24	41	0
Bw1	30-40	13	4	33	9	2	17	22	0
Bw2	70-80	9	16	20	9	4	19	23	0
2Ab	100-110	11	7	12	6	4	31	28	1

Table 4.29 Mineralogy of the clay fraction of the Coulter silt loam.

Horizon	Sample Depth (cm)	Mineral (%)										
		Qu	Feld.	Kand	Mica	Chl	Allo	M-Chl	M-HIV	HIV	M-Smec	M-Ver
Ap	0-10	7	8	16	11	18	10	0	15	15	0	0
	10-20	6	7	16	10	17	13	0	16	15	0	0
Bw1	30-40	4	6	16	11	19	12	0	14	18	0	0
Bw2	70-80	9	12	13	10	13	22	0	10	11	0	0
2Ab	100-110	7	3	52	10	1	0	0	2	8	17	0

#### 4.4.2.3. Horoeka silt loam (new series)

##### *Morphology and genesis*

This is a moderately well drained soil, on the same terrace and landscape position as the Coulter silt loam. The soils occur as a mosaic on the same flat terrain at elevations ranging from about 240 to 260 m. Soil drainage conditions are difficult to correlate with landscape features. The soil is developed in the same parent material as Coulter silt loam, being moderately deep to deep loamy alluvium, loess and tephra over gravels. This soil also has not been reported in previous soil surveys. They were mapped as Kawhatau stony silt loam under the general soil survey of the soils of North Island (NZ Soil Bureau, 1954) and as Kiwitea loam under New Zealand land resource inventory (1979).

Horoeka silt loams are characterized by dark brown, silt loam top soils with moderately developed nutty structures underlain by dark yellowish brown and olive, silt loam to heavy silt loam subsoils with moderately developed nutty structure and having low chroma mottles below 60 cm from the soil surface.

There is an abrupt boundary between the topsoil and the subsoil due to tillage. Soil structures are moderately developed and no evidence of clay migration or accumulation can be seen in the subsoil. These pedological parameters indicate that the Horoeka soils are also in the intermediate stage of soil development.

The horizon sequence of Horoeka soils is A/Bw1/Bw2/Bg/2Cg

The soils are biologically active, with large numbers of earthworms and other mesofauna even in the subsoil. Organic carbon content determined for a composite topsoil (0-7.5 cm) sample under pasture is 5.2. g kg<sup>-1</sup>. Moist and wet soil consistency properties are very favourable for tillage to be performed over a wide range of soil moisture conditions. Physical soil properties for the upper 60 cm of the profile are very similar to that of Coulter silt loam.

No laboratory analysis was carried out to determine physical, chemical and mineralogical properties of this soil. Phosphate retention values determined for five topsoil (0-7.5 cm) samples show that P-retention in the topsoil is high, but lower than that of Coulter soils (Table 4.30). The results indicate that Horoeke soils may have better response to applied phosphate fertilizer than that of Coulter silt loam.

Table 4.30 The phosphate retention values for topsoil samples of Horoeke silt loam and Coulter silt loam.

Soil	Phosphate Retention % in topsoil				
	Sample no.1	Sample no. 2	Sample no.3	Sample no.4	Sample no. 5
Horoeke silt loam	61	69	59	69	65
Coulter silt loam	Sample no.6	Sample no.7	Sample no.8	Sample no.9	Sample no.10
	82	84	80	82	79

### ***Soil description***

(Source: Survey of Kiwitea area by author)

Ap        0 – 20 cm.

Dark brown (10YR 3/3) moist, silt loam; moderate medium nutty, easily break into fine nutty; slightly sticky and slightly plastic, friable moist; many earthworms and other mesofauna; very frequent very fine and fine roots; abrupt smooth boundary.

Bw1 20 – 60 cm

Dark yellowish brown (10YR 4/6) moist, silt loam; moderate fine to medium nutty; non sticky and non plastic, friable moist; frequent very fine and fine roots; common mesofauna; gradual boundary.

Bgw 60 – 80 cm

Olive (5Y 5/3) moist, strong brown (7.5YR 4/6) common medium distinct mottles; silt loam (heavy); moderate medium nutty and moderate medium blocky; slightly sticky and slightly plastic; firm moist; few fine roots. Clear smooth boundary.

2C 80<sup>+</sup> cm

Rounded pebble and cobble size greywackey gravels in a sandy matrix.

#### 4.4.2.4. Barrow silt loam (new series)

##### *Morphology and genesis*

Barrow silt loams are moderately deep to deep, imperfectly drained soils occurring on flat to gently sloping terrain of the intermediate terrace at elevations ranging from about 200 m to 220 m. above mean sea level. These soils occur at slightly lower elevations of the intermediate terrace compared to Coulter and Horoeoka silt loams. Barrow soil also has not been reported in previous soil surveys. They were also mapped as Kawhatau stony silt loam under the general soil survey of the soils of North Island (NZ Soil Bureau, 1954) and as Kiwitea loam under New Zealand land resource inventory (1979).

Barrow soils are also developed from a mixture of alluvium, colluvium and tephra. Soil profiles are approximately 80 cm deep, and below 80 cm are gravelly coarse sand containing about 50 per cent rounded gravel.

Soil horizons are well developed and the boundaries between soil horizons are also well marked. Soil texture is silt loam in the topsoil and silty clay loam, fine sandy loam or clay loam in the subsoil. Texture and occasional clay skins on ped faces in the subsoil

indicate some migration of clay down the profile, but not enough to warrant designation of a Bt horizon.

Low chroma mottles and gleying in the subsoil is an indication of alternate oxidation and reduction taking place. This is the result of the fluctuating water table within the soil. The water table perches on the compact, river gravels mostly during winter and spring. Barrow silt loam soils have a mottled profile form; therefore the soil is categorized as imperfectly drained (Taylor and Pohlen, 1968; Hewitt, 1992).

The soil horizons present in the profile are A/Bg/2Bg/3C. Barrow silt loam soils are classified as Mottled Immature Pallic Soils according to the New Zealand Soil Classification system (Hewitt, 1992).

### ***Soil description***

(source: survey of Kiwitea area by author)

Ap            0 – 21 cm.

Very dark greyish brown (10YR 3/2) moist, silt loam; strong fine to medium nutty structure; slightly sticky and slightly plastic wet, friable moist; abundant very fine and fine roots; abrupt smooth boundary.

Bg1           21 – 34 cm

Olive (5Y 4/3) moist, 30% strong brown (7.5YR 4/6) medium distinct mottles; silty clay loam; 5% rounded gravel size iron stones; strong very fine, fine and medium nutty and moderate medium blocky structure; sticky and plastic wet, firm moist; many very fine and fine roots; clear smooth boundary.

Bg2           34 – 65 cm

Light olive grey(5Y 6/2) moist, 25% strong brown (7.5YR 4/6) coarse prominent mottles; fine sandy clay loam; strong medium to coarse nutty structure; sticky and plastic wet, friable moist; many very fine and fine

roots; common very fine specks of quartz; common macro pores; gradual smooth boundary.

Bg3 65 – 82 cm

Olive grey (5Y 5/2) moist, 25% dark yellowish brown (10YR 4/4) coarse prominent mottles; clay loam; moderate medium to coarse blocky structure; sticky and plastic wet, friable moist; common very fine and fine roots; gradual smooth boundary.

2Bg4 82 – 95 cm

Olive grey (5Y 5/2) moist, 25% yellowish brown (7.5 YR 4/4) prominent distinct mottles; clay loam; moderate fine to medium blocky structure; about 50% rounded greywacke gravels; sticky and plastic wet, friable moist; gradual smooth boundary.

3C 95+ cm

Dark yellowish brown (10YR 3 / 4) moist, coarse loamy sand and rounded fluvial gravels; massive structure; non sticky and non plastic wet, loose moist.

### ***Physical properties***

Medium bulk density (Table 4.31) throughout the soil profile indicates that the soils are porous and that there are no hard pans or compacted layers within the profile. These properties facilitate good root penetration and distribution of live plant roots throughout the soil profile. Macroporosity is moderately low to low, indicating slow internal drainage. Low macroporosity in the top 7.5 cm may be due to pugging, compaction and the break down of soil aggregates. Soil consistency properties are not so favorable when soils are wet. Sticky and plastic conditions in soils may require more power to operate agricultural implements, and more passes to create a seedbed.

Saturated hydraulic conductivity (Ksat) is also moderately slow to very slow, indicating slow water movement within the soil. Very slow Ksat figures in Bg1 and Bg3 horizons

are associated with silty clay loam and clay loam textures respectively, and blocky structures.

The infiltration rate is  $60 \text{ mm hr}^{-1}$ . This is less than that of Coulter soils, however, infiltration rates are high enough to absorb rainwater into soils without runoff.

Total and readily available water present in the profile is moderate (Table 4.32).

Table 4.31 The physical properties of Barrow silt loam: density, porosity, hydraulic conductivity and infiltration.

Horizon	Sample	B.D ( $\text{Mg m}^{-3}$ )	P.D ( $\text{Mg m}^{-3}$ )	Porosity (%)		k Sat. (mm/hr)	Infiltration (mm/hr)
	Depth (cm)			Total	Macro		
Ap	0-7.5	1.12	2.51	55	4	6.4	60
	12.5-20	1.04	2.5	58	8	13.9	
Bg1	25-30	1.12	2.61	57	12	0.9	
Bg2	45-55	1.08	2.61	59	9	7.6	
Bg3	70-80	1.35	2.61	48	3	0.8	

Table 4.32 The physical properties of Barrow silt loam: water relationships.

Horizon	Horizon thickness (cm)	Water retention % (v/v) at				Total water		Readily av. water	
		5 (kpa)	10 (kpa)	100 (kpa)	1500 (kpa)	Sample (% v/v)	Horizon (mm)	Sample (% v/v)	Horizon (mm)
Ap	7.5	50.8	49.1	37	24.5	24.6	18.4	12.1	9.0
	13.5	50.4	46.3	39	29.4	16.9	22.8	7.3	9.8
Bg1	13	44.8	42.6	35	30.5	12.1	15.7	7.6	9.8
Bg2	31	50.2	48.6	39	30.7	17.9	55.4	9.6	29.7
Bg3	17	44.6	43.7	33	28.6	15.1	25.6	10.7	18.1
Profile available water mm: for 50 cm depth							85		43.9

### ***Chemical properties***

Topsoils of Barrow soils are moderately acid whereas subsoils are slightly acid. These soils contain medium levels of exchangeable bases and base saturation is also medium to high. Although the parent material is quartzo-feldspathic, Barrow soils are developed under imperfectly drained conditions. Therefore, leaching of the soil profile is minimal and most of the basic cations remain in the soil. Barrow soils contain medium to low amounts of exchangeable calcium, low to medium amounts of magnesium and very low amounts of potassium (Table 4.33).

Phosphate retention is medium to low (Table 4.34) except for the Bg1 horizon, which shows a high value. This indicates fairly good response to applied phosphate fertilizer. Olsen P values in the topsoil range from 8-13 mg kg<sup>-1</sup> and in the subsoil 5-21 mg kg<sup>-1</sup>.

Low to very low nitrogen levels are attributed to low to very low levels of organic carbon. Low to very low C/N ratio indicates that the soil organic matter is completely mineralized.

Analytical results for the bulk soil show little difference to the topsoil of the profile except for exchangeable Ca and K. The profile site is apparently limed and fertilized.

Table 4.33 The chemical properties of Barrow silt loam: cation exchange properties.

Horizon	Depth (cm)	pH (H <sub>2</sub> O) 1:2.5	Exchangeable cations (cmol <sub>c</sub> kg <sup>-1</sup> )				TEB (cmol <sub>c</sub> kg <sup>-1</sup> )	CEC (cmol <sub>c</sub> kg <sup>-1</sup> )	B.S (%)
			Ca <sup>++</sup>	Mg <sup>++</sup>	K <sup>+</sup>	Na <sup>+</sup>			
Bulk soil	0-7.5	5.7	2.30	0.79	0.09	0.11	3.29	11	30
Ap	0-7.5	5.7	6.60	0.76	0.34	0.10	7.8	15	52
	12.5-20	5.6	7.50	0.79	0.26	0.18	8.7	16	54
Bg1	25-30	6.0	6.30	1.66	0.20	0.42	8.6	15	57
Bg2	45-55	6.3	5.00	2.89	0.20	0.70	8.8	15	59
Bg3	70-80	6.2	4.50	3.69	0.22	0.40	8.8	14	63
2Bg4	85-90	6.2	4.30	3.68	0.18	0.27	8.4	13	65
3C	95	6.0	2.80	2.42	0.21	0.20	5.6	12	47

Table 4.34 The chemical properties of Barrow silt loam: phosphorus, sulphate, carbon and nitrogen.

Horizon	Depth (cm)	Olsen P (mg kg <sup>-1</sup> )	P-ret. (%)	Total C (g kg <sup>-1</sup> )	Total N (g kg <sup>-1</sup> )	C/N
Bulk soil	0-7.5	10	39.5	3.54	0.31	11
Ap	0-7.5	13	50	4.05	0.33	12
	12.5-20	8	NA	3.56	0.31	11
Bg1	25-30	5	79	1.08	0.11	10
Bg2	45-55	7	41	0.50	0.05	10
Bg3	70-80	9	30	0.27	0.03	9
2Bg4	85-90	11	27	0.24	0.03	8
3C	95	21	25	0.30	0.03	10

### *Mineralogical properties*

The sand mineralogy of Barrow silt loam is similar to that of Coulter silt loam, mainly composed of quartz, feldspar and volcanic glass (Table 4.35). Presence of volcanic glass in the sand fraction and a high percentage of hornblende, magnetite and augite in the heavy mineral fraction (Table 4.36) confirm the influence of tephra or reworked pumice. It indicates that Barrow soils are also developed from similar parent material to both Coulter and Horoecka soils.

Medium CEC values can be attributed to clay mineralogy. Barrow soils contain a mixed assemblage of clays; mostly kandite with low charge, mica with moderate charge and vermiculite and interlayered clays with higher charge (Table 2.37). Although volcanic glass is present in the sand fraction, the clay fraction contains no allophane. This indicates that volcanic glass has been transformed into kandite under the imperfectly drained conditions. Low P-retention except in the Bg1 horizon of Barrow soils can be attributed to absence of allophane in the clay fraction.

Table 4.35 Mineralogy of the sand fraction of the Barrow silt loam.

Horizon	Depth (cm)	Mineral (%)						
		Qu	Feld	HM	VG	Mica	Chl	Crist
Ap	0-7.5	54	29	9	8	0	0	0
	12.5-20	55	26	10	9	0	0	0
Bg1	25-30	54	29	7	10	0	0	0
Bg2	45-55	50	24	5	21	0	0	0
Bg3	70-80	61	32	4	3	0	0	0

Table 4.36 Mineralogy of the heavy mineral fraction of the Barrow silt loam.

Horizon	Depth (cm)	Minerals (%)							
		HB	Chl	Hyp	Aug	Ilm	Mag	Epi	Mica
Ap	0-7.5	17	2	48	20	4	0	9	0
	12.5-20	13	2	16	30	4	5	30	0
Bg1	25-30	21	8	26	18	6	0	21	0
Bg2	45-55	21	8	41	14	5	0	11	0
Bg3	70-80	45	5	8	5	3	13	21	0

Table 4.37 Mineralogy of the clay fraction of the Barrow silt loam.

Horizon	Depth (cm)	Mineral (%)										
		Qu	Feld.	Kand	Mica	Chl	Allo	M-Chl	M-HIV	HIV	M-Smec	M-Ver
Ap	0-7.5	12	11	31	7	13	0	0	9	17	0	0
	12.5-20	8	8	24	6	16	0	0	15	23	0	0
Bg1	25-30	6	7	35	12	11	0	0	0	18	0	11
Bg2	45-55	6	5	38	17	7	0	0	0	8	19	0
Bg3	70-80	9	11	47	14	2	0	0	5	7	5	0

#### 4.4.2.5. Ohakea silt loam

##### *Morphology and genesis*

Ohakea silt loams are poorly drained, moderately deep, soils occurring on the flat terrain of the intermediate terrace. They occur side by side with Barrow silt loams, but usually in slightly lower positions or depressions in the landscape, however, their position in the landscape is not always predictable. The soils have been derived from loamy-clayey textured alluvium, colluvium, and perhaps some loess and tephra similar to the parent materials of the other soils present on the intermediate terrace.

Subsoils are gleyed, mottled and heavy textured, and soil horizon boundaries are indistinct. Topsoil structures are strongly developed whereas subsoil structures are weakly to moderately developed.

The clayey textures of the subsoils may be inherited from the parent material. Gleying and mottling occur from a depth of 25 cm onwards, often directly below the topsoil. Ohakea soils are more gleyed than the Barrow soils. The fluctuating water table remains for a considerable time close to the soil surface, therefore the subsoil remains reduced for a long period. Ohakea silt loam profiles exhibit a gley profile form, therefore these soils are categorized as poorly drained soils (Taylor and Pohlen, 1968; Hewitt, 1992).

Genetic soil horizons present in the profile are A/Bg1/Bg2/Cg. The soils are classified as Typic Orthic Gley Soils according to the New Zealand Soil Classification system (Hewitt, 1992).

Presence of few live roots in the subsoil and the poor drainage indicates that the soil conditions are not favourable for plant growth.

Bulk density, particle density and water retention properties are not available for Ohakea soils. Generally physical properties of Ohakea soils are not favourable for plant growth because of the poor drainage conditions.

### ***Soil description***

(Source: Landcare Research National Soil Data Base. Lab No. SB08683)

Soil horizons are renamed according to Hewitt (1992)

Location: Shannon, Wanganui Region

Annual rain fall: 965 mm

Mean annual temperature: NA

Land form: NA

Parent material: quartzo-feldspatic colluvium

The soil forming factors operating in this area is similar to that of the study area. The soils are formed under the similar environmental conditions and typical of the Ohakea silt loams in the study area.

Ap            0-15 cm.

Very dark brown (10YR 2/2), silt loam; slightly sticky, moderately plastic; moderately weak soil strength; strongly developed fine nut plus blocky structure; abundant live roots; indistinct boundary.

AB            18-25 cm

Moderately weak soil strength; mixed zone, 50% A in B.

Bgl           25-33 cm

Pale olive (5Y 6/3) and pale yellow (5Y 7/3), clay loam; slightly sticky, moderately plastic; moderately weak soil strength; weakly developed coarse nut structure; few fine faint mottles and yellowish brown mottles; few live roots; indistinct boundary.

Bg2 36-48 cm

Pale yellow (5Y 7/3) and yellowish brown (10YR 5/8), clay; moderately sticky, moderately plastic; moderately weak soil strength; moderately developed medium blocky plus moderately developed fine blocky structure; few live roots; no readily discernable clay coatings; indistinct boundary.

Bg3 51-66 cm

light olive grey (5Y 6/2), clay; moderately sticky, moderately plastic; moderately weak soil strength; moderately developed medium blocky structure.

### ***Chemical properties***

Soil reaction is moderately acid to slightly acid (Table 4.38). The slightly acid subsoils show high base saturation values. Basic cations have accumulated in subsoils due to slow leaching in the soil profile because of poor drainage.

Ohakea soils are poor in plant nutrients. Low exchangeable calcium, medium magnesium levels and very low potassium levels reveal this situation. High calcium in the topsoil is common due to application of lime.

Phosphate retention is medium to low (Table 4.39), indicating absence of allophane in the clay fraction.

Organic carbon in the topsoil is medium whereas in the subsoil it is low to very low. This reflects medium total nitrogen in topsoils and low to very low total nitrogen levels in subsoils. Medium C/N ratios indicate that the organic matter present in the soil is mineralised and is in equilibrium with the soil environment.

Table 4.38 The chemical properties of Ohakea silt loam: cation exchange properties.

(Source: Landcare Research National Soil Data Base. Lab No. SB08683)

Horizon	Depth (cm)	pH (H <sub>2</sub> O) moist	Exchangeable cations (cmol <sub>c</sub> kg <sup>-1</sup> )				TEB (cmol <sub>c</sub> kg <sup>-1</sup> )	CEC (cmol <sub>c</sub> kg <sup>-1</sup> )	B.S (%)
			Ca <sup>++</sup>	Mg <sup>++</sup>	K <sup>+</sup>	Na <sup>+</sup>			
Ap	0-15	5.2	11.7	1.62	0.34	0.35	14.01	22.8	61
AB	18-25	5.6	3.5	0.66	0.08	0.18	4.42	14.1	31
Bg1	25-33	5.7	2.1	0.80	0.04	0.13	3.07	9.7	32
Bg2	36-48	6.1	3.8	2.87	0.03	0.22	6.92	10.9	63
Bg3	51-66	6.3	4.3	3.70	0.06	0.27	8.33	11.4	73

Table 4.39 The chemical properties of Ohakea silt loam: phosphorus, carbon and nitrogen.

(Source: Landcare Research National Soil Data Base. Lab No. SB08683)

Horizon	Depth (cm)	P- 0.5 M H <sub>2</sub> SO <sub>4</sub> (mg kg <sup>-1</sup> )	P-ret. (%)	Total C (g kg <sup>-1</sup> )	Total N (g kg <sup>-1</sup> )	C/N
Ap	0-15	240	34	5.60	0.46	12
AB	18-25	90	54	2.90	0.19	15
Bg1	25-33	90	29	0.90	0.07	13
Bg2	36-48	50	17	0.30	0.04	7.5
Bg3	51-66	140	21	0.20	0.04	5

#### 4.4.2.6. Discussion

Soils of the intermediate terrace are developed on old alluvium laid down by the Oroua River at least 10,000 years ago (see Section 2.4.3). The alluvial material has been intermixed with loess, colluvium and tephra (see Section 2.4.3). The minerals present in the sand fraction are high in quartz and feldspars (Tables 4.20, 4.27, and 4.35), indicating that the parent material is quartzo-feldspathic. Presence of volcanic glass in the sand fraction and the presence of hypersthene and augite (pyroxenes) in the heavy mineral fraction (Tables 4.21, 4.28 and 4.36) is an indication of influence of tephra or reworked pumice. These heavy minerals are common in rhyolitic and andesitic tephra (Fieldes, 1968). The sand mineralogy suggests that the parent materials for the soils on the intermediate terrace also have been derived from the same sources as that of soils of the lower terrace except that more tephra is present on the intermediate.

The soils of the intermediate are moderately deep to deep (60-90 cm) and rest on the Ohakean river gravels except for Kawhatau soils, which are developed directly from

Ohakean greywacke gravels. Soils are medium textured, and soil structures are moderately developed. Strongly developed B-horizons are not observed, however soil morphology indicates that soil formation is in a more advanced stage compared to the soils of the lower terrace.

Water retention properties of soils are important in the area because of the likelihood of a dry spell during summer. The total and readily available water content in Coulter and Barrow soils is moderate.

Allophane consists of hollow, irregularly spherical particles with diameters of 3.5 to 5.0 nm. These unit particles of allophane can interact with each other and with other soil constituents resulting in the formation of stable and porous aggregates (Wada, 1977, 1989). Therefore, soils rich in allophane are characterized by high porosity and low bulk density (e.g. Coulter silt loam, Table 4.23).

Quartz rich parent materials inherit acidic soil reaction and small quantities of exchangeable basic cations in soils. Therefore, regular application of liming material is essential to raise the soil pH. Small amounts of organic matter and the clay minerals with low to medium surface charges are the reason for the low to medium CEC in soils. Moreover, low levels of nitrogen in the soils are attributed to low organic matter levels. Low to medium C/N ratio indicates that the organic matter in soils is completely mineralized.

The drainage properties of soils range from well drained through moderately well drained, imperfectly drained to poorly drained. Other soil forming factors operating on the parent material are almost similar over a short distance except for the drainage which is not related to the topography of the soil surface. The drainage properties influence the weathering of volcanic glass in the sand fraction (discussed in detailed in Chapter 7). At well drained sites volcanic glass weathers into allophane and at imperfectly and poorly drained sites it forms kaolinite and halloysite (kandite). The clay mineralogy is responsible for phosphate retention of soils. Coulter and Kawhatau soils (well drained) have high P-retention values because the clay fraction contains allophane. Barrow (imperfectly drained) and Ohakea (poorly drained) soils have low P-retention values because the clay fraction of these soils contains no allophane. High phosphate

retention values indicate that more phosphate fertilizer should be applied to soil for better plant response.

It is evident from the discussion that soil drainage influences the weathering of volcanic glass present in the parent material and in turn the types of clay minerals present in the clay fraction affects the phosphate retention of soils. As far as the soils of the intermediate terrace are concerned soil drainage and phosphate retention can be considered as two important soil properties influencing soil management in terrace lands of northern Manawatu.

### **4.4.3. Soils of the Upper Terrace**

The upper terrace is situated above the intermediate terrace at elevations ranging from about 240 m to 300 m above mean sea level. The soils are derived mainly from Ohakean loess intermixed with tephra (see Section 2.4.3).

Five soil types are identified and mapped on the upper terrace in this soil survey. All these soils were mapped as one soil type, Kiwitea loam, under both General Soil Survey of the soils of North Island (NZ Soil Bureau, 1954) and New Zealand Land Resource Inventory (1979). Soil types are separated on the basis of the nature of the parent material and drainage properties.

#### **4.4.3.1. Dannevirke silt loam**

##### ***Morphology and genesis***

Dannevirke silt loams are deep, well drained soils which occur on flat to gently sloping terrain of the upper terrace at elevations of about 300 m above mean sea level. The soils are derived from loess intermixed with appreciable amounts of air fall tephra.

These soils are characterized by dark brown, silt loam to fine sandy loam top soils with moderately developed fine to medium nut structures and dark yellowish brown, fine sandy loam subsoils with weakly developed coarse nuts and coarse to medium blocky structures. Horizon boundaries between soil horizons are indistinct. There is no

evidence of clay migration down the profile. These properties show that the genetic soil horizons are not strongly developed and soil formation is still at an intermediate stage. Sulphuric acid soluble phosphate levels are very high to high in Dannevirke soils (see Table 4.43), which also indicates that these soils are still not mature.

The genetic soil horizon sequence in soil profiles can be given as A/Bw/2Bw/3C. Dannevirke soils are classified as Typic Orthic Allophanic Soils according to the New Zealand Soil Classification system (Hewitt, 1992).

The fine sandy loam horizons of the upper 50-70 cm are most likely Holocene tephra. Silt loam horizons are Ohakean loess with interbedded Kawakawa Tephra.

Fe/Mn concretions present in the Ohakean loess (2Bw3) horizons suggest that there is perching of some water in deeper horizons. However, dark brown, dark yellowish brown and yellowish brown colours and absence of mottling or gleying in subsoils indicate that the soils are well drained.

### ***Soil description***

(Source: Landcare Research National Soil Data Base. Lab No. SB 09846)

Location: Manawatu Region

Annual rainfall: 1800 mm

Mean annual temperature: NA

Land form: Terrace

Parent material: moderately weathered tephra interbedded with loess.

The annual rainfall appears to be higher than that of the survey area. However, parent material plays a dominant roll in the development of Dannevirke soils. Therefore, this profile is typical of Dannevirke soils in the survey area.

Ap            0-23 cm

Dark brown (10YR 3/3), fine sandy loam; moderately weak soil strength; moderately developed medium nut plus fine nut structure; abundant live roots; (fine loamy texture); worm mixed boundary; many worms and grass grubs; indistinct smooth boundary.

Bw1 23-43 cm.

Dark yellowish brown (10YR 4/4), fine sandy loam; moderately weak soil strength; weakly developed coarse nut structure; many live roots; (medial); clay or silt cutans not diagnostic for argillic horizon; indistinct smooth boundary.

Bw2 43-62 cm.

Yellowish brown (10YR 5/6), fine sandy loam; moderately firm soil strength; weakly developed coarse blocky structure; few fine live roots; (medial); diffuse boundary.

2Bw3 62-97 cm.

Yellowish brown (10YR 5/6), silt loam; moderately firm soil strength; weakly developed coarse nut structure; few live roots; (medial); few fine prominent Fe/Mn concretions; distinct wavy boundary.

3C 97-123 cm.

Yellowish brown (10YR 5/8) and strong brown (7.5YR 5/8), fine sandy loam; moderately firm soil strength; weakly developed medium blocky structure; many medium distinct strong brown (7.5YR 5/8) mottles and light yellowish brown (2.5Y 6/4) mottles; red (2.5YR 5/8) coatings, also thin discontinuous (2.5Y 6/4) (medial) coatings; few live roots;; Kawakawa Tephra layer; distinct wavy boundary.

4C 123-150 cm.

Light yellowish brown (2.5Y 6/4), silt loam; moderately firm soil strength; weakly developed medium blocky structure; yellowish brown (10YR 5/8) coatings; few live roots; fine silty texture; coatings on root channels; few fine black Mn concretions; thin discontinuous cutans (2.5Y 6/4).

### ***Physical properties***

Low to moderate bulk density (Table 4.40) is associated with high to moderately high total porosity. Soils rich in allophane are characterized by high porosity (see Section 3.4.2.2). High porosity is in turn associated with low amounts of total available water and readily available water (Table 4.41). Profile available water content in Dannevirke soils is lower than in Coulter soils even though Dannevirke soils contain more allophane. In this particular profile soil texture is mostly fine sandy loam, therefore low water retention is attributed to the textural properties of the soil.

Macroporosity is high to moderately high down to about 75 cm from the soil surface. This helps maintain free drainage in the soil profile. Below 75 cm it is moderate and moderately low.

Table 4.40 The physical properties of Dannevirke silt loam: density and porosity.

(Source: Landcare Research National Soil Data Base. Lab No. SB 09846)

Horizon	Depth (cm)	Sample Depth (cm)	B.D (Mg m <sup>-3</sup> )	P.D (Mg m <sup>-3</sup> )	Porosity (%)	
					Total	Macro
A	0-23	5-8	0.67	2.23	69.9	18.1
		9-12	0.71	2.28	68.8	18.6
Bw1	23-43	28-31	0.67	2.37	71.7	18.0
		32-35	0.69	2.45	71.8	19.7
Bw2	43-62	48-51	0.86	2.58	66.6	14.0
		52-55	0.86	2.57	66.5	14.9
2Bw3	62-97	72-75	1.00	2.59	61.4	10.5
		76-79	1.02	2.60	60.7	8.4
3C	97-123	107-110	0.82	2.36	65.3	15.3
		111-114	0.90	2.44	63.1	13.3
4C	123-150	132-135	1.08	2.63	58.9	4.6
		136-139	1.04	2.64	60.6	5.4

Table 4.41 The physical properties of Dannevirke silt loam: water relationships.

(Source: Landcare Research National Soil Data Base. Lab No. SB 09846)

Horizon	Depth (cm)	Sample Depth (cm)	Water retention (% v/v) at				Total water		Readily av. water	
			5 (kpa)	10 (kpa)	100 (kpa)	1500 (kpa)	Sample (% v/v)	Horizon (mm)	Sample (% v/v)	Horizon (mm)
A	0-23	5-8	51.8	46.8	39.9	28.6	18.2		6.9	
		9-12	50.2	47.1	40.4	30.3	16.8	40.3	6.7	15.6
Bw1	23-43	28-31	53.7	48.6	40.5	30.8	17.8		8.1	
		32-35	52.1	47.2	40.0	32.0	15.2	33.0	7.2	15.3
Bw2	43-62	48-51	52.6	49.1	42.9	32.8	16.3		6.2	
		52-55	51.6	47.6	41.3	32.7	14.9	29.6	6.3	11.9
2Bw3	62-97	72-75	50.9	48.2	42.4	34.1	14.1		5.8	
		76-79	52.3	49.7	43.9	34.8	14.9	50.8	5.8	20.3
3C	97-123	107-110	50.0	47.3	42.2	33.2	14.1		5.1	
		111-114	49.8	48.0	43.8	36.8	11.2	32.9	4.2	12.1
4C	123-150	132-135	54.3	52.8	48.2	37.4	15.4		4.6	
		136-139	55.2	53.8	49.9	35.8	18.0	45.1	3.9	11.5
Profile available water mm: for 50 cm depth							84.2		35.2	
: for 100 cm depth							157.4		64.4	

### *Chemical properties*

Soil reaction in Dannevirke soils range from strongly acid in the topsoil through slightly acid and neutral to slightly alkaline in the subsoil (Table 4.42). Although the parent material is derived from non-calcareous Mesozoic greywacke-argillite, the topsoil contains appreciable amounts of exchangeable  $\text{Ca}^{++}$ , indicating application of lime material. Even then the topsoil acidity has not been neutralised, because the topsoil also contains high amounts of organic matter (Table 4 43). Medium base saturation in the topsoil shows that part of the exchange complex is saturated with  $\text{H}^+$  and  $\text{Al}^{+++}$  ions. Slightly acid to slightly alkaline reaction in the subsoil can be attributed to high to medium base saturation. Organic matter content decreases from medium through low to very low in subsoil.

Exchangeable  $\text{Mg}^{++}$ ,  $\text{K}^+$ , and  $\text{Na}^+$  are also low to very low. High  $\text{K}^+$  levels in the topsoil are due to application of potassic fertilizer. High to medium base saturation levels may be due to high to medium levels of  $\text{Ca}^{++}$  present in the subsoil.

High CEC in the topsoil is attributed to large amounts of organic matter. CEC in the subsoil is medium to low, due to low to very low organic matter content and the type of clay minerals present.

Dannevirke soils have very high P-retention values (Table 4.43), which is mainly due to presence of allophane in the clay fraction ( see Section 3.4.2.2).

High nitrogen levels in the topsoils are attributed to the high organic matter content. Nitrogen content in the subsoil is medium to low. C/N ratios also range from medium to high (13-17), indicating that the soil organic matter is still mineralizing and releasing nitrogen into soil.

Table 4.42 The chemical properties of Dannevirke silt loam: cation exchange properties.

(Source:Landcare Research National Soil Data Base. Lab No. SB09846)

Horizon	Depth (cm)	pH (H <sub>2</sub> O) 1:2.5	Exchangeable cations (cmol <sub>c</sub> kg <sup>-1</sup> )				TEB (cmol <sub>c</sub> kg <sup>-1</sup> )	CEC (cmol <sub>c</sub> kg <sup>-1</sup> )	B.S (%)
			Ca <sup>++</sup>	Mg <sup>++</sup>	K <sup>+</sup>	Na <sup>+</sup>			
A	0-23	5.2	17.00	1.16	0.97	0.19	19.3	38.7	50
Bw1	23-43	6.5	16.3	0.50	0.39	0.09	17.3	24.4	71
Bw2	43-62	7.0	11.0	0.29	0.36	0.10	11.8	15.6	76
2Bw3	62-97	7.1	7.3	0.15	0.21	0.07	7.73	11.2	69
3C	97-123	7.2	6.0	0.11	0.09	0.06	6.26	9.6	65
4C	123-150	7.1	5.9	0.12	0.15	0.06	6.23	10.5	59

Table 4.43 The chemical properties of Dannevirke silt loam: phosphorus, carbon and nitrogen.

(Source:Landcare Research National Soil Data Base. Lab No. SB09846)

Horizon	Depth (cm)	P- 0.5 M H <sub>2</sub> SO <sub>4</sub> (mg kg <sup>-1</sup> )	P-ret. (%)	Total C (g kg <sup>-1</sup> )	Total N (g kg <sup>-1</sup> )	C/N
A	0-23	810	94	10.40	0.83	13
Bw1	23-43	380	97	5.00	0.31	16
Bw2	43-62	310	95	2.40	0.14	17
2Bw3	62-97	220	94	1.20	0.09	13
3C	97-123	220	99	1.40	0.09	16
4C	123-150	250	96	1.20	0.08	15

### ***Mineralogical properties***

Sand mineralogy (Table 4.44) suggests that the parent material is quartzo-feldspathic. Volcanic glass in the sand fraction and high amounts of hornblende, magnetite and pyroxene in the heavy mineral fraction (Table 4.45) proves the volcanic influence as well. The clay minerals present (Table 4.46) are, kandite, mica, chlorite, M-HIV and HIV, which have low to medium CEC values. CEC values in allophane are pH dependent. In an acidic environment allophane surfaces are positively charged whereas in an alkaline environment there are more positively charged surfaces.

The 3C horizon contains high amounts of volcanic glass (Table 4.44) and allophane (Table 4.46) indicating that this layer is most probably Kawakawa Taphra.

Table 4.44 Mineralogy of the sand fraction of the Dannevirke silt loam.

(Source:Landcare Research National Soil Data Base. Lab No. SB09846)

Horizon	Depth (cm)	Mineral (%)						
		Qu	Feld	HM	VG	Mica	Chl	Crist
A	0-23	43	30	13	12	0	0	0
Bw1	23-43	45	28	13	10	0	0	0
Bw2	43-62	52	30	9	6	0	0	0
2Bw3	62-97	50	30	5	7	0	5	0
3C	97-123	30	20	5	38	0	3	0
4C	123-150	55	25	7	6	0	5	0

Table 4.45 Mineralogy of the heavy mineral fraction of the Dannevirke silt loam.

(Source:Landcare Research National Soil Data Base. Lab No. SB09846)

Horizon	Depth (cm)	Minerals (%)							
		HB	Chl	Pyrox	Zir	Ilm	Mag	Epi	Mica
A	0-23	10	1	47	0	6	30	5	0
Bw1	23-43	10	2	43	0	5	35	5	0
Bw2	43-62	5	3	50	0	2	32	8	0
2Bw3	62-97	17	10	29	5	2	20	17	0
3C	97-123	12	7	52	2	5	17	5	0
4C	123-150	18	15	30	0	3	22	12	0

Table 4.46 Mineralogy of the clay fraction of the Dannevirke silt loam.

(Source: Landcare Research National Soil Data Base. Lab No. SB09846)

Horizon	Depth (cm)	Mineral (%)										
		Qu	Feld.	Kand	Mica	Chl	Allo	M-Chl	M-HIV	HIV	M-Smec	Ver
A	0-23	6	3	22	2	15	15	0	7	30	0	0
Bw1	23-43	5	3	10	5	17	18	0	10	32	0	0
Bw2	43-62	6	4	18	6	15	12	0	16	23	0	0
2Bw3	62-97	6	4	20	8	12	10	0	18	22	0	0
3C	97-123	3	3	10	7	12	38	0	12	15	0	0
4C	123-150	6	4	15	12	15	17	0	15	17	0	0

#### 4.4.3.2. Kiwitea silt loam

##### *Morphology and genesis*

Kiwitea silt loams are well drained, deep soils occurring on the flat to undulating terrain of the upper terrace at elevations ranging from 260 to 300 m. The parent materials of the soils are Ohakea loess intermixed with tephra (see Section 2.4.3).

These soils are characterized by dark brown, silt loam top soils with strongly developed fine to medium nutty structures and yellowish brown to dark yellowish brown, silty clay loam subsoils with strong to moderately developed medium to coarse nutty structure. The Kawakawa Tephra is a 5-10 cm sandier layer interbedded in the soil below about 80 cm from the soil surface. The paleosol beneath also has free drainage properties and poses little restriction for water movement down through the profile. In other soils (e.g. Cheltenham, Feilding and Marton) this paleosol can be mottled, argillic and blocky structured, causing water to perch in the overlying horizons.

Genetic soil horizons in the Kiwitea silt loam are well developed and the soil horizon boundaries are well marked. Subsoils are more clay rich than the topsoil. Patchy clay skins are present on ped faces, which indicates that clay migration and accumulation in subsoils is taking place.

The soil profile morphology indicates that, compared to other soils in the study area, Kiwitea soils are at a more advanced stage of soil formation. The genetic horizon sequence is A/Bt/2C. The Kiwitea soils are classified as Typic Orthic Melanic Soils

according to the New Zealand Soil Classification system (Hewitt, 1992). This soil is classified as Typic Orthic Melanic Soil by Landcare Research (NSDB Lab No. SB 08471).

Earthworm activity in the topsoil and plant root distribution throughout the soil profile shows that the soil is biologically active and there are no barriers in soils to root penetration. No mottling or gleying is observed in the subsoil, indicating that the soils are well drained.

### ***Soil description***

(source: survey of Kiwitea area by author)

Ap            0 – 25 cm.

Dark brown (10YR 3/3) moist, silt loam; strong fine to medium nutty structure; slightly sticky and slightly plastic wet; friable moist, hard dry; many very fine and fine roots; few earthworms; few verticals cracks (about 3 mm width) abrupt smooth boundary.

BA            25 – 40 cm

Dark yellowish brown (10YR3/4) moist, silty clay loam; strong fine to medium nutty structure; sticky and plastic wet, friable moist, hard dry; common very fine and fine roots; few vertical cracks (1-2 mm width), gradual smooth boundary.

Bt            40 –69/74 cm.

Dark yellowish brown (10YR3/6), yellowish brown (10YR5/8 and 5/6) moist, silty clay loam; strong medium to coarse nutty structure; sticky and plastic wet, friable moist, hard dry; common very fine and fine roots, few vertical cracks; very thin clay skins on ped faces, abrupt wavy boundary.

2C 69/74 – 77/85 cm

Yellowish brown (10YR5/8) dry, yellowish brown (10YR 5/6 to 5/8) moist, coarse sandy loam; single grain structure; non sticky and non plastic wet, very friable moist, loose dry; Few very fine roots; abrupt wavy boundary (Kawakawa Tephra).

3Bb1 77/85 – 90 cm

Dark yellowish brown (10YR 4/4) moist, silty clay loam; moderate fine to medium nutty structure; sticky and plastic wet, friable moist, hard dry; few very fine and fine roots; gradual smooth change.

3Bb2 90 – 120+ cm

Yellowish brown (10YR4/4) moist; silty clay loam; sticky and plastic wet, friable moist, hard dry; moderate fine to medium nutty; few very fine and fine roots.

### ***Physical properties***

Medium bulk density (Table 4.47) in the soils is very favourable and associated with free root penetration throughout the soil profile, moderate total porosity and absence of compacted layers. Profile total available and readily available water content is high in Kiwitea soils (Table 4.48), significantly higher than for Dannevirke soils. Macro porosity values are low to moderately low. Dry, moist and wet soil consistency properties indicate that the soils have a reasonable moisture range for favourable tillage operations.

In some instances macro porosity values are shown as 0 (Table 4.47) because water held at  $-5$  kpa is higher than the total porosity (Table 4.48). This indicates that at suction  $-5$  kpa and  $-10$  kpa, water has not been removed from soil samples completely.

Infiltration rate is  $166 \text{ mm hr}^{-1}$ , which is very high compared with the infiltration rates of Coulter and Barrow soils.

Low bulk density value in the 2Cb horizon (Table 4.47) represents Kawakawa Tephra layer interbedded within the loess deposit.

Table 4.47 The physical properties of Kiwitea silt loam: density, porosity, hydraulic conductivity and infiltration.

Horizon	Sample Depth (cm)	B.D (Mg m <sup>-3</sup> )	P.D (Mg m <sup>-3</sup> )	Porosity (%)		k Sat. (mm/hr)	Infiltration (mm/hr)
				Total	Macro		
Ap	0-7.5	1.12	2.48	55	0	92	166
BA	30-40	1.23	2.61	53	9	32	
Bt	50-60	1.18	2.57	54	0	17	
2C	70-75-	0.83	2.49	67	14	13	
3Bb1	80-85	1.33	2.69	51	0	0.7	
3Bb2	100-110 <sup>+</sup>	1.29	NA	NA	NA	1	

Table 4.48 The physical properties of Kiwitea silt loam: water relationships.

Horizon	Horizon Thickness (cm)	Sample Depth (cm)	Water retention % (v/v) at				Total water		Readily av. water	
			5 (kpa)	10 (kpa)	100 (kpa)	1500 (kpa)	Sample (% v/v)	Horizon (mm)	Sample (% v/v)	Horizon (mm)
Ap	25	0-7.5	56.3	48.6	34	23.7	24.9	62.2	14.6	36.5
BA	15	30-40	43.6	39.3	33	30.1	9.2	13.8	6.3	9.4
Bt	32	50-60	55.2	50.1	37	31.0	19.1	60.1	13.1	41.9
2C	10	70-75-	52.2	45.6	30	20.5	25.1	23.8	15.6	15.6
3Bb1	8	80-85	53.8	46.6	31	23.6	23.0	20.7	15.6	12.4
3Bb2	30	100-110	51.2	45.4	35	30.7	14.7	44.1	10.4	31.2
Profile available water mm: for 50 cm depth								95		58.9
: for 100 cm depth								196		126.2

### ***Chemical properties***

Soil reaction ranges from slightly acid in the topsoil to slightly acid and near neutral in the subsoil (Table 4.49). The topsoil has been treated with lime, therefore soil calcium levels are high to medium and base saturation is also high to very high. Magnesium levels are low to medium. Potassium and sodium levels are low to very low. These chemical properties are associated with acidic parent materials rich in quartz. P-retention is medium in Kiwitea soils (Table 4.50), in contrast with high values in Dannevirke soils.

There is hardly any difference in chemical properties of the bulk soil and the topsoil of the soil profile.

Table 4.49 The chemical properties of Kiwitea silt loam: cation exchange properties.

Horizon	Sample Depth (cm)	pH (H <sub>2</sub> O) 1:2.5	Exchangeable cations (cmol <sub>c</sub> kg <sup>-1</sup> )				TEB (cmol <sub>c</sub> kg <sup>-1</sup> )	CEC (cmol <sub>c</sub> kg <sup>-1</sup> )	B.S (%)
			Ca <sup>++</sup>	Mg <sup>++</sup>	K <sup>+</sup>	Na <sup>+</sup>			
Bulk soil	0-7.5	5.7	11.2	0.84	0.48	0.20	12.7	20	64
Ap	0-7.5	5.6	11.50	0.72	0.32	0.30	12.8	20	64
BA	30-40	6.1	10.60	0.83	0.22	0.23	11.9	16	74
Bt	50-60	6.4	11.30	2.21	0.27	0.28	14.1	18	78
2C	70-75	6.6	6.40	1.62	0.09	0.25	8.4	12	70
3Bb1	80-85	6.6	7.40	2.97	0.09	0.20	10.7	13	82
3Bb2	100-110	6.6	6.10	3.57	0.09	0.20	10.0	12	83

Table 4.50 The chemical properties of Kiwitea silt loam: phosphorus, sulphate, carbon and nitrogen.

Horizon	Sample Depth (cm)	Olsen P (mg kg <sup>-1</sup> )	P-ret. (%)	Total C (g kg <sup>-1</sup> )	Total N (g kg <sup>-1</sup> )	C/N
Bulk soil	0-7.5	16	44	NA	NA	NA
Ap	0-7.5	15	41	NA	NA	NA
BA	30-40	5	49	NA	NA	NA
Bt	50-60	6	55	NA	NA	NA
2C	70-75	11	59	NA	NA	NA
3Bb1	80-85	3	26	NA	NA	NA
3Bb2	100-110	5	39	NA	NA	NA

### *Mineralogical properties*

High percentages of quartz and feldspars in the sand fraction indicate that the parent material of Kiwitea soils is dominantly quartzo-feldspathic. Presence of volcanic glass in the sand fraction (Table 4.51) and relatively high amounts of hornblende, magnetite and augite in the heavy mineral fraction (Table 4.52) indicate the contribution of tephra to the parent material.

Clay minerals present in the soil (Table 4.53) are dominated by low activity kandite and do not contribute much to the CEC, which is medium. Kiwitea silt loam soil shows medium phosphate retention. This can be attributed to very low amounts of allophane present in the clay fraction. High amounts of volcanic glass in the sand fraction of the

2C horizon (Table 4.51) and some allophane in the clay fraction (Table 4.53) indicate that this is Kawakawa Tephra.

Table 4.51 Mineralogy of the sand fraction of the Kiwitea silt loam.

Horizon	Sample Depth (cm)	Minerals (%)						
		Qu	Feld	HM	VG	Mica	Chl	Crist
Ap	0-7.5	53	29	10	8	0	0	0
BA	30-40	53	33	9	4	0	1	0
Bt	50-60	57	20	5	11	1	2	4
2C	70-75	19	10	8	63	0	0	0
3Bb1	80-85	57	33	5	5	0	0	0
3Bb2	100-110	63	29	6	2	0	0	0

Table 4.52 Mineralogy of the heavy mineral fraction of the Kiwitea silt loam.

Horizon	Sample Depth (cm)	Minerals (%)							
		HB	Chl	Hyp	Aug	Ilm	Mag	Epi	Mica
Ap	0-7.5	5	2	14	11	2	30	36	0
BA	30-40	8	5	14	8	4	8	53	Tr
Bt	50-60	14	13	17	3	4	20	28	1
2C	70-75	24	1	35	9	7	13	11	0
3Bb1	80-85	13	8	28	11	6	20	13	1
3Bb2	100-110	16	5	11	13	4	36	15	0

Table 4.53 Mineralogy of the clay fraction of the Kiwitea silt loam.

Horizon	Sample Depth (cm)	Mineral (%)										
		Qu	Feld	Kand	Mica	Chl	Allo	M-Chl	M-HIV	HIV	M-Smec	M-Ver
Ap	0-7.5	12	10	35	5	12	0.5	0	17	8	0	0
BA	30-40	13	9	30	11	9	0	0	0	10	0	18
Bt	50-60	7	8	33	11	5	0	4	0	18	0	14
2C	70-75	5	4	50	9	7	2.7	4	0	7	0	11
3Bb1	80-85	9	6	48	11	3	0	0	0	7	16	0
3Bb2	100-110	9	6	56	10	1	0	0	0	7	11	0

### 4.4.3.3. Cheltenham silt loam (new series)

#### *Morphology and genesis*

Cheltenham soils were formerly included with Kiwitea soils as the Kiwitea mottled silt loam. The soils are limited to a very small area in the survey area, but are thought to be widespread in the region. Cheltenham soils occur on slightly lower positions of the landscape compared to Kiwitea silt loams. They are deep soils occurring at elevations ranging from about 260 to 280 m.

Morphologically Cheltenham soils differ from Kiwitea soils by being mottled below 60 cm from the soil surface and are moderately well drained. They are developed from the same loess parent material as Kiwitea soils.

The topsoils are dark brown or dark greyish brown; the texture is silt loam and the structure is well developed nutty. Subsoils are brown, yellowish brown or olive and mottled below 60 cm from the soil surface. Soil texture becomes clay rich down the profile, which may be due to clay migration although clay skins were not observed. Soil structure is moderate to strongly developed. Soil boundaries are also well marked.

The soil unit was not analysed in this survey, nor is it available on the Landcare Research National Soil Data base. The soil horizon sequence can be expressed as A/Bw/Bg/2C.

#### *Soil description*

(source: survey of Kiwitea area by author)

Ap            0 – 20 cm.

Very dark greyish brown (10YR 3/2) moist, silt loam; strong fine nutty structure; slightly sticky and slightly plastic wet, friable moist; many very fine and fine roots; few earthworms; clear smooth boundary.

BA 20 – 30 cm

Brown (10YR 4/3) moist, silt loam; moderate fine to medium nutty structure; slightly sticky and slightly plastic wet, friable moist; many very fine and fine roots; clear smooth boundary.

Bw 30 –60 cm.

Dark yellowish brown (10YR4/4) moist, silty clay loam; strong fine to medium nutty structure; sticky and plastic wet, friable moist; many fine roots; clear smooth boundary.

Bg 60 – 90 cm.

Dark olive (5Y 3/3) moist, strong brown ( 7.5 YR 4/6) common medium distinct mottles; clay loam; moderate coarse to medium blocks break into medium to fine nuts; sticky and plastic wet, firm moist; few fine roots; clear smooth boundary.

Bw 90 - 110 cm.

Yellowish brown (10YR 5/6) moist, silt loam; weak fine nutty; slightly sticky and slightly plastic wet, friable moist; few very fine and fine roots; abrupt smooth change.

2B 110 – 130 cm

Brown (10YR5/3) moist, clay; sticky and plastic wet, firm moist; moderate coarse blocky. Abrupt smooth boundary.

130<sup>+</sup> cm

Rounded cobble and pebble size gravels.

#### 4.4.3.4. Feilding silt loam (new series)

##### *Morphology and genesis*

Feilding silt loams are deep, imperfectly drained soils occurring on flat to undulating terrain of the upper terrace. The soils occur at the same elevation as Kiwitea silt loams, ranging from 240 m to 300 m above mean sea level, in the study area. Soil drainage properties show no relationship with the topographic features. Well-drained Kiwitea soils, moderately well drained Cheltenham soils, imperfectly drained Feilding soils and poorly drained Marton soils occur in the same soil-landscape. Therefore, soil boundaries between mapping units are arbitrary. Feilding soils were formerly included with Marton soils, however in this survey the imperfectly drained Feilding soils are separated from the poorly drained Marton soils.

Feilding soils are also developed from loess deposits intermixed with air fall tephra. The Kawakawa Tephra layer within the soil is found about 65 cm to 75 cm below the surface, but it is not as prominent as in Dannevirke or Kiwitea soils.

The soils have very dark greyish brown to greyish brown topsoils with strong crumb to fine nutty structures and greyish brown, olive brown or grey, silt loam subsoils with strongly developed sub angular blocks. Genetic soil horizons are well marked and horizon boundaries are clear. No clay accumulation was observed in the subsoil.

The genetic soil horizon sequence can be expressed as A/Bw/Bg/2Bg/3Bbg. Feilding soils are classified as Mottled Immature Pallic Soils according to the New Zealand Soil Classification system.

Sandy loam texture, non-sticky and non-plastic wet consistency and the thickness of the 2Cbg horizon (about 10 cm) suggest that this layer is the Kawakawa Tephra. This layer is separated from the surrounding soil horizons by clear smooth boundaries.

The soil profile contains a mottled profile form within 45 cm to 60 cm from the soil surface suggesting fluctuating water table within the profile. Therefore, soils are imperfectly drained. Soil consistency properties at moist and wet conditions are

favourable for tillage operations. Earthworms in the topsoil and the distribution of live roots in the soil profile indicate that the soil is biologically very active.

### ***Soil description***

(source: survey of Kiwitea area by author)

Ap1        0 - 8 cm

Very dark greyish brown (10 YR 3/4) moist, silt loam; strong fine crumb structure; non sticky and non plastic wet, friable moist; abundant very fine and fine grass roots; common earthworms; clear smooth boundary.

Ap2        8 – 23 cm

Dark greyish brown (10 YR 4/2) moist, silt loam; strong fine crumb and strong fine nutty structure; slightly sticky and slightly plastic, friable moist; many very fine and fine grass roots; some earthworms; clear smooth boundary.

ABw        23 - 35 cm

Dark greyish brown (10YR4/2) moist, few fine faint mottles; silt loam; strong fine to medium nutty structure; slightly sticky and slightly plastic wet, friable moist; many fine grass roots; clear smooth boundary.

Bwg        35 -47 cm

Light olive brown (2.5Y 5/3) moist, strong brown (7.5YR 4/6) many fine distinct mottles; silt loam; strong fine to medium nutty structure; sticky and plastic wet; friable moist; common very fine and fine grass roots; gradual smooth boundary.

Bg1        47 - 65 cm

Grey (5Y 5/1) moist, strong brown (7.5 YR 4/6) common medium distinct mottles; silt loam; strong medium to coarse nutty structure; non

sticky and non plastic wet, friable moist; common medium pores; common very fine grass roots; clear smooth boundary.

2Cg 65 - 75 cm (Kawakawa Tephra)

Grey (5Y 5/1) moist, strong brown (7.5 YR 4/6) common medium distinct mottles; sandy loam; moderate fine to medium nutty structure; non sticky and non plastic wet, friable moist; very few very fine grass roots; clear smooth boundary.

3Bg2 75 - 100+ cm

Grey (5Y6/1) moist, strong brown (7.5 YR 4/6) common coarse distinct mottles; silt loam; strong very coarse to coarse blocky structure; slightly sticky and slightly plastic wet, very firm moist; very few very fine grass roots.

### ***Physical properties***

Feilding silt loam is characterized by medium bulk density, moderate to moderately high total porosity (Table 4.54). These properties are associated with free root distribution and good water relations in soils. Total and readily available water (Table 4.55) within 50 cm of the soil profile is 93 and 55 mm respectively. Impeded drainage conditions in Feilding soils are associated with moderately low to low subsoil macroporosity.

Table 4.54 The physical properties of Feilding silt loam: density, porosity, hydraulic conductivity and infiltration.

Horizon	Sample Depth (cm)	B.D	P.D	Porosity (%)		k Sat. (mm/hr)	Infiltration (mm/hr)
		(Mg m <sup>-3</sup> )	(Mg m <sup>-3</sup> )	Total	Macro		
Ap1	0-7.5	0.92	2.46	63	0	71	162
Ap2	7.5-20	1.05	2.49	58	14	74	
ABw	22-30	1.12	2.55	56	12	19.5	
Bwg	35-45	1.33	2.62	49	7	5.2	
Bg1	50-60	1.12	2.61	57	9	3.8	
2Cg	65-75	1.26	ND	ND	ND	ND	
3Bg2	80-100	1.46	ND	ND	ND	2.2	

Table 4.55 The physical properties of Feilding silt loam: water relationships.

Horizon	Horizon Thickness (cm)	Sample Depth (cm)	Water retention % (v/v) at				Total water		Readily av. water	
			5 (kpa)	10 (kpa)	100 (kpa)	1500 (kpa)	Sample (% v/v)	Horizon (mm)	Sample (% v/v)	Horizon (mm)
Ap1	8	0-7.5	70.3	61.4	37	22.5	38.9	31.1	24.4	19.5
Ap2	15	7.5-20	43.8	39.3	30	22.9	16.4	24.6	9.3	13.9
ABw	12	22-30	43.6	38.5	29	21.9	16.6	19.2	9.5	11.4
Bwg	12	35-45	41.7	38.5	32	27.3	11.2	13.4	6.5	7.8
Bg1	18	50-60	47.9	45	38	32.9	12.1	21.7	7.0	12.6
2Cg	10	65-75	ND	ND	ND	ND	ND	ND	ND	ND
3Bg2	25	80-100	40.8	39.4	35	32.4	7.0	17.5	4.4	11.0
Profile available water mm: for 50 cm depth'								93		54.7

### *Chemical properties*

Soil reaction is moderately acid to slightly acid (Table 4.56), because base saturation is also medium to high. The exchange complex appears to be semi-saturated with Ca<sup>++</sup> and Mg<sup>++</sup> ions, indicating that the soil is treated with lime. Potassium levels are low to very low and the sodium levels are low to medium. CEC values are also medium. Base saturation is medium to high. P retention is low in Feilding soils (Table 4.57). There is little difference in chemical properties between the bulk soil and the topsoil of the profile. The Ca<sup>++</sup> and Mg<sup>++</sup> levels in the 3Bg2 horizon are similar indicating that the subsoil is a Pallic Soil.

Table 4.56 The chemical properties of Feilding silt loam: cation exchange properties.

Horizon	Sample Depth (cm)	pH (H <sub>2</sub> O) 1:2.5	Exchangeable cations (cmol <sub>c</sub> kg <sup>-1</sup> )				TEB (cmol <sub>c</sub> kg <sup>-1</sup> )	CEC (cmol <sub>c</sub> kg <sup>-1</sup> )	B.S (%)
			Ca <sup>++</sup>	Mg <sup>++</sup>	K <sup>+</sup>	Na <sup>+</sup>			
Bulk soil	0-7.5	5.6	7.60	1.44	0.51	0.20	8.2	18	45
Ap1	0-7.5	5.6	7.90	0.97	0.33	0.25	9.5	18	53
Ap2	7.5-20	5.7	7.30	0.98	0.13	0.19	8.6	17	51
ABw	22-30	6.0	6.40	1.17	0.09	0.21	7.9	15	53
Bwg	35-45	6.2	6.70	2.22	0.07	0.26	9.3	14	66
Bg1	50-60	6.4	8.10	4.78	0.26	0.59	13.7	17	81
3Bg2	80-100	6.3	4.00	4.79	0.13	0.34	9.3	13	71

Table 4.57 The chemical properties of Feilding silt loam: phosphate, sulphate, and carbon and nitrogen.

Horizon	Sample Depth (cm)	Olsen P (mg kg <sup>-1</sup> )	P-ret. (%)	Total C (g kg <sup>-1</sup> )	Total N (g kg <sup>-1</sup> )	C/N
Bulk soil	0-7.5	14	36	NA	NA	NA
Ap1	0-7.5	12	38	NA	NA	NA
Ap2	7.5-20	7	38	NA	NA	NA
ABw	22-30	3	36	NA	NA	NA
Bwg	35-45	2	34	NA	NA	NA
Bg1	50-60	3	44	NA	NA	NA
3Bg2	80-100	1	23	NA	NA	NA

### *Mineralogical properties*

Volcanic glass in the sand fraction (Table 4.58) and relatively high amounts of hornblende, magnetite and augite in the heavy mineral fraction (Table 4.59) indicate that the quartzo-feldspathic loess parent material is intermixed with tephra.

The clay mineralogy (Table 4.60) shows that kandite, mica, chlorite and interlayer clays dominate, all of which have low exchange capacity.

Table 4.58 Mineralogy of the sand fraction of the Feilding silt loam.

Horizon	Sample Depth (cm)	Minerals (%)						
		Qu	Feld	HM	VG	Mica	Chl	Crist
Ap1	0-7.5	49	32	10	9	0	0	0
Ap2	7.5-20	48	33	10	9	0	0	0
Abw	22-30	49	33	10	8	0	0	0
Bwg	35-45	59	22	6	8	0	0	5
Bg1	50-60	38	41	5	16	0	0	0
2Cg	65-75	NA	NA	NA	NA	NA	NA	NA
3Bg2	80-100	59	34	4	3	0	0	0

Table 4.59 Mineralogy of the heavy mineral fraction of the Feilding silt loam.

Horizon	Sample Depth (cm)	Minerals (%)							
		HB	Chl	Hyp	Aug	Ilm	Mag	Epi	Mica
Ap1	0-7.5	23	2	40	32	3	0	0	0
Ap2	7.5-20	26	1	29	33	6	2	3	0
ABw	22-30	46	1	15	9	4	6	19	0
Bwg	35-45	29	4	16	5	3	7	36	0
Bg1	50-60	13	8	33	2	8	3	33	Tr
2Cg	65-75	NA	NA	NA	NA	NA	NA	NA	NA
3Bg2	80-100	30	8	7	3	17	4	31	0

Table 4.60 Mineralogy of the clay fraction of the Feilding silt loam.

Horizon	Sample Depth (cm)	Mineral (%)										
		Qu	Feld.	Kand	Mica	Chl	Allo	M-Chl	M-HIV	HIV	M-Smec	M-Ver
Ap1	0-7.5	14	12	41	2	7	0	0	8	6	10	0
Ap2	7.5-20	13	11	36	5	9	0	0	12	14	0	0
ABw	22-30	12	12	37	5	9	0	0	9	16	0	0
Bwg	35-45	12	12	43	3	6	0	0	0	7	13	4
Bg1	50-60	7	9	53	6	3	0	1	0	8	9	4
2Cg	65-75	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
3Bg2	80-100	9	13	43	9	0	0	3	0	9	13	1

#### 4.4.3.5. Marton silt loam

##### *Morphology and genesis*

Marton silt loams are poorly drained, deep soils occurring on flat to gently sloping terrain on the upper terrace at elevations ranging from about 240 m to 260 m. These soils are also developed from Ohakean loess intermixed with tephra. The textural properties of the soils show that they are developed from rather fine textured loess material compared to the other soils present on the same landscape, or have weathered to contain more clay.

The soils are characterized by brown, dark brown, dark yellowish brown or very dark greyish brown, gleyed and mottled silt loam top soils and gleyed and mottled, heavy textured subsoil with massive and weakly developed fine blocky structures. The Kawakawa Tephra layer is present about 50 cm below the soil surface. The amount of volcanic glass present in this tephra layer is high (see Table 4.63) compared to the other soil horizons.

Mottling and gleying in the upper part of the soil profile indicates that the water table remains close to the soil surface for a considerable time and hence the soils become reduced. Heavy textured blocky and massive soil horizons in the subsoil are probably impervious and prevent water moving down the profile; therefore a temporary perched water table develops. Most of the Marton soils display a gley profile form and hence are classed as poorly drained soils.

Strong mottling, gleying and sometimes iron stone concretions in the soil profile reflect that the soils are developed under impeded drainage conditions. Clay rich soil textures in subsoils may be inherited from the parent material. Clay skins on ped faces have been reported in the Marton soils (Rijkse, 1977, Pollock, 1975), and also well developed clay skins were observed on ped faces, indicating clay migration down the profile. Sulphuric acid soluble phosphorus levels are also very low, except for the top soil, indicating a weathered soil.

The soil horizon sequence in Marton soils is A/Bg/2Bg/3Bg. The soils are classified as Argillic Perched-Gley Pallic soils according to the New Zealand Soil Classification system (Hewitt, 1992).

### ***Profile description***

(Source: Landcare Research National Soil Data Base)

Location: Wanganui Region

Annual rain fall: 1050 mm

Mean annual temperature: 12.8 ° C.

Land form: NA

Parent material: moderately weathered, quartzo-feldspathic loess derived from Tertiary and Mesozoic sedimentary rocks and andesitic and rhyolitic tephra.

The soil forming factors operating in this area are similar to that of the study area. The soils are formed under similar environmental conditions and typical of the Marton silt loams in the study area.

Ap            0-20 cm

Very dark greyish brown (10YR 3/2) silt loam, slightly sticky; slightly plastic; weakly developed fine nut plus granular structure; abundant fine live roots; indistinct irregular boundary.

Bg1           20-30 cm

Greyish brown to light olive brown (2.5Y 5/3), silty clay loam; moderately sticky, moderately plastic; moderately developed fine blocky structure; many fine distinct strong brown (7.5YR 5/8) mottles; many prominent black to very dark brown (7.5YR 2/1) coatings; few fine live roots; indistinct irregular boundary.

Bg2           30-51 cm

Light brownish grey to light yellowish brown (2.5Y 6/3), clay loam; moderately sticky, moderately plastic; massive breaking to weakly

developed fine blocky structure; many fine distinct strong brown (7.5YR 4/6) mottles; few distinct black to very dark brown (7.5YR 2/1) coatings; few fine live roots; diffuse boundary.

2C 51-63 cm

Light brownish grey to light yellowish brown (2.5Y 6/3), sandy clay loam; moderately sticky, moderately plastic; massive structure; common fine distinct yellowish red (5YR 4/8) mottles; many prominent black (5YR2/1) coatings; few fine live roots; indistinct boundary.

3Bg 63-73 cm

Light brownish grey to light yellowish brown (2.5Y 6/3), clay loam; moderately sticky, moderately plastic; massive breaking to weakly developed fine blocky structure; common fine distinct strong brown (7.5YR 4/6) mottles; few distinct black (5YR 2/1) coatings; indistinct boundary.

3C 73-96 cm

Light olive brown (2.5Y 5/4), silt loam; moderately sticky, slightly plastic; moderately developed coarse prismatic breaking to weakly developed very fine blocky structure; many medium distinct light olive grey (5Y 6/2) mottles; many prominent dark brown (7.5YR 3/3) coatings; distinct irregular boundary.

4ABb 96-124 cm

Light olive brown (2.5Y 5/4), sandy clay; moderately sticky, moderately plastic; massive breaking to weakly developed very fine blocky structure; many fine distinct strong brown (7.5YR 5/8) mottles; distinct black (5YR 2/1) coatings; few subrounded greywacke stones; indistinct boundary.

4Bgb 124-149 cm

Light olive grey (5Y 6/2), clay; slightly sticky, slightly plastic; massive breaking to weakly developed very fine blocky structure; many medium distinct strong brown (7.5YR 5/8) mottles; few prominent black (5Y 2/1) coatings; indistinct boundary.

4Bgb2 149-164 cm

Strong brown (7.5YR 5/8), clay; moderately sticky, moderately plastic; weakly developed medium platy breaking to weakly developed very fine blocky structure; many faint light olive brown (2.5Y 5/4) mottles.

### ***Physical properties***

Soil physical conditions are not favourable due to poor drainage conditions. Poor live root distribution in the subsoil indicates poor aeration conditions. Dry and wet soil consistence properties are also not so favourable for tillage operations. The NZSDB contains no physical data for Marton soils.

### ***Chemical properties***

The pH values range from strongly acid in the topsoil through slightly acid, medium acid, near neutral to slightly alkaline in subsoils (Table 4.61). This can be attributed to the fact that the base saturation is high to very high. Exchangeable  $\text{Ca}^{++}$  is medium to low.  $\text{Mg}^{++}$  is medium through high to very high and exceeds  $\text{Ca}^{++}$  in the subsoil.  $\text{K}^+$  is low to very low. Medium CEC values can probably attribute to low to very low organic carbon levels (Table 4.62) and the clay mineralogy. The high B.S % in the subsoil is attributed to the high levels of  $\text{Ca}^{++}$ ,  $\text{Mg}^{++}$  and  $\text{Na}^+$  in the subsoil. Clay minerals present in the soil have low CEC except for vermiculite (Table 4.65).

Table 4.61 The chemical properties of Marton silt loam: cation exchange properties.

(Source: Landcare Research National Soil Data Base. Lab No. SB09369)

Horizon	Depth (cm)	Sample Depth (cm)	pH (H <sub>2</sub> O) 1:2.5	Exchangeable cations cmol <sub>c</sub> kg <sup>-1</sup>				TEB (cmol <sub>c</sub> kg <sup>-1</sup> )	CEC (cmol <sub>c</sub> kg <sup>-1</sup> )	B.S (%)
				Ca <sup>++</sup>	Mg <sup>++</sup>	K <sup>+</sup>	Na <sup>+</sup>			
Ap	0-20	0-18	5.0	9.00	1.30	0.58	0.19	11.1	14.0	79
Bg1	20-30	23-28	6.0	7.30	1.87	0.33	0.33	9.83	11.7	84
Bgt	30-51	33-48	5.8	5.70	5.00	0.18	0.70	11.6	13.8	84
2C	51-63	53-63	5.9	4.40	6.50	0.19	1.35	12.4	15.5	80
3Bg	63-73	63-73	6.1	4.10	6.20	0.18	1.12	11.6	13.0	89
3C	73-96	73-94	6.6	4.20	5.80	0.16	1.18	11.3	12.1	93
4ABb	96-124	99-124	7.0	5.50	7.80	0.23	1.62	15.2	15.7	97
4Bgb	124-149	124-149	7.1	6.50	8.90	0.25	1.93	17.6	18.6	95
4Bgb2	149-164	149-164	7.1	5.70	7.10	0.14	1.95	14.9	16.1	93

Table 4.62 The chemical properties of Marton silt loam: phosphorus, sulphate, carbon and nitrogen.

(Source: Landcare Research National Soil Data Base. Lab No. SB09369)

Horizon	Depth (cm)	Sample Depth (cm)	P- 0.5 M H <sub>2</sub> SO <sub>4</sub> (mg/100g)	P-ret. (%)	Total C (g kg <sup>-1</sup> )	Total N (g kg <sup>-1</sup> )	C/N
Ap	0-20	0-18	27	27	2.8	0.26	11
Bg1	20-30	23-28	4	32	0.80	0.09	9
Bgt	30-51	33-48	2	31	0.40	0.05	8
2C	51-63	53-63	1	34	0.30	0.04	
3Bg	63-73	63-73	1	15	0.20	0.02	
3C	73-96	73-94	1	14	0.20	0.02	
4ABb	96-124	99-124	0	15	0.10	0.02	
4Bgb	124-149	124-149	2	18	0.10	0.02	
4Bgb2	149-164	149-164	2	23	0.10	0.02	

Low phosphate retention values (Table 4.44b) show that the soils are highly responsive to applied phosphate fertilizers. Low to very low organic carbon, total nitrogen and C/N ratios indicate low biological activity. Both chemical and biological properties indicate that Marton soils have poor natural fertility.

### *Mineralogical properties*

Presence of volcanic glass in the sand fraction (Table 4.63) and relatively high percentages of hornblende, pyroxene and magnetite in the heavy mineral fraction (Table 4.64) confirms the influence of tephra, in the dominantly quartzo-feldspathic parent material. Clay minerals are dominated by kandite, mica-vermiculite, vermiculite and halloysite (Table 4.65)

Table 4.63 Mineralogy of the sand fraction of the Marton silt loam.

(Source: Landcare Research National Soil Data Base. Lab No.SB 09369)

Horizon	depth (cm)	Sample Depth (cm)	Mineral (%)							
			Qu	Feld	HM	Pl. opal	VG	Mica	Chl	Crist
AP	0-20	0-18	55	30	9	1	5	0	0	0
Bg1	20-30	23-28	55	32	8	1	5	0	0	0
Bgt	30-51	33-48	65	22	6	2	5	0	0	0
2C	51-63	53-63	32	20	4	0	40	3	0	0
3Bg	63-73	63-73	55	30	5	1	4	5	0	0
3C	73-96	73-94	60	28	5	2	2	4	0	0
4ABb	96-124	99-124	62	30	5	2	1	0	0	0
4Bgb	124-149	124-149	68	27	5	2	0	0	0	0
4Bgb2	149-164	149-164	65	30	6	2	0	0	0	0

Table 4.64 Mineralogy of the heavy mineral fraction of the Marton silt loam.

(Source: Landcare Research National Soil Data Base. Lab No. SB09369)

Horizon	Depth (cm)	Sample Depth (cm)	Minerals (%)							
			HB	Chl	Pyrox	Zir	Ilm	Mag	Epi	Mica
AP	0-20	0-8	15	0	40	10	6	10	18	0
Bg1	20-30	23-28	18	0	43	3	5	10	20	0
Bgt	30-51	33-48	20	0	40	6	7	8	18	0
2C	51-63	53-63	15	0	66	4	5	3	5	0
3Bg	63-73	63-73	25	2	19	4	6	10	35	0
3C	73-96	73-94	32	0	19	4	7	7	30	0
4ABb	96-124	99-124	40	0	9	4	10	7	30	0
4Bgb	124-149	124-149	35	0	8	8	6	12	30	0
4Bgb2	149-164	149-164	37	0	5	5	8	10	35	0

Table 4.65 Mineralogy of the clay fraction of the Marton silt loam.

(Source: Landcare Research National Soil Data Base. Lab No.SB 09369)

Horizon	Depth (cm)	Mineral (%)										
		Qu	Feld.	Kaoli	Mica	Chl	Allo	Hallo	M-Ver	HIV	M-Smec	Ver
AP	0-8	0	0	30	8	5	NA	5	20	5	0	22
Bg1	23-28	0	0	20	6	5	NA	15	23	3	0	14
Bgt	33-48	0	0	22	7	0	NA	20	28	0	0	13
2C	53-63	0	0	30	10	0	NA	30	22	0	0	0
3Bg	63-73	0	0	15	9	0	NA	25	30	0	0	12
3C	73-94	0	0	13	6	0	NA	22	30	0	0	18
4ABb	99-124	0	0	15	8	0	NA	35	20	0	0	12
4Bgb	124-149	0	0	15	0	0	NA	33	25	0	0	17
4Bgb2	149-164	0	0	15	0	0	NA	35	17	0	0	25

#### 4.4.3.6. Discussion

It is clear from the observations made in soil profiles of Dannevirke and Kiwitea soils that Kawakawa Tephra layer is present about 80 cm below the soil surface. Therefore, the soils of the upper terrace are developed from wind blown material; loess deposits (see Section 2.4.3). The sand mineralogy of parent materials show that they all are quartzo-feldspathic (see Tables 4.44, 4.51, 4.58 and 4.63), indicating the source of the parent material, greywacke-argillite is the same for all the soils present in this area. The loess material was probably blown from alluvial material on the intermediate terrace.

The heavy mineral fraction indicates that minerals like pyroxenes (augite, hypersthene) (see Tables 4.45, 4.52, 4.59 and 4.64) which are only minor components of the original source of parent material are present in the soils. Volcanic glass present in the sand fraction and pyroxene minerals are components of rhyolitic and andesitic tephra. Therefore, the influence of tephra on parent materials is very clear on the upper terrace.

The physical, chemical and mineralogical properties of soils of the area are dependant mostly on the parent materials from which the soils are developed. Acid soil reaction, low amounts of exchangeable cations in the exchangeable complex are associated with soils developed from acidic quartz rich parent materials.

The CEC of soils are mostly dependent on the organic matter present. Most of the clay minerals present in the colloidal complex such as mica, chlorite and kandite have low

CEC values. Although vermiculite and some interlayer clays have high CEC values, they are present in low amounts in most of the soils. The CEC of allophane present in the clay fraction is pH dependent. Under acidic soil conditions the CEC of allophane is very low, because the surface charges become positive when the soils are acidic. Phosphate retention is high in soils when allophane is present and pH is low.

Low bulk density and high porosity are associated with presence of allophane in soils (see Section 3.4.2.6).

As explained in Section 4.4.2.6, the soil forming factors operating on the parent material of the upper terrace are similar except for drainage. The drainage influences the weathering of volcanic glass and in turn the types of clay minerals present in the clay fraction, and P-retention.

#### **4.4.4. Soils of the Terrace Risers**

These soils are present on the steep slopes of the terrace rises having slopes ranging from about  $16^{\circ}$  to  $35^{\circ}$ . Soil properties are extremely variable and the soils were mapped as a soil complex in this survey.

##### **4.4.4.1. Steepland soil complex**

###### ***Morphology and genesis***

Soils on slopes between the upper terrace and the intermediate terrace and the steep slopes of the upper terrace are mostly developed on colluvium derived from loess. The other steepland soils are developed on colluvium derived from alluvium. Soil properties such as drainage, colour, texture, structure, depth etc. are highly variable within a short distance.

Genetic soil horizons except for A and Bw are not so clear in soil profiles. The subsoil is strongly gleyed in some places. Rounded river gravels are present within the subsoil of most of the soils.

Soils of the steepland were identified as Pohangina steepland soils in the soil survey of the neighboring Pohangina County (Rijkse, 1977). However, Pohangina steepland soils are mostly sandy loam developed from sandstones. The steepland soils of the study area are mostly silty clay loam, clay and silty clay in texture and developed from loess or silty alluvium. Therefore, these soils can not be correlated with Pohangina steepland soils or any other named soil series and remain un-named as a steep slope soil complex.

### *Soil descriptions*

#### **Discription 1**

Ap            0-20 cm

Brown (10YR 4/3), silty clay; sticky and plastic wet; weakly developed fine nut plus granular structure; abundant fine live roots; gradual smooth boundary.

Bgl           20-30 cm

Yellowish brown (10YR 5/4), sandy clay; moderately sticky, moderately plastic wet; moderately developed fine blocky structure; common medium distinct strong brown (10YR 5/8) and grey (10Y 6/1) mottles; abut 2% iron stone gravels; irregular indistinct boundary.

2C            30<sup>+</sup> cm

Rounded river gravels.

#### **Discription 2**

Ap            0-10 cm

Brown (10YR 4/3), silty clay loam; slightly sticky and slightly plastic wet; friable moist; weakly developed fine nut plus granular structure; abundant fine live roots; gradual smooth boundary.

Bwg1 10-30 cm

Greenish grey (5GY 5/1), silty clay; sticky and plastic wet, friable moist; moderately developed fine blocky structure; common medium distinct yellowish brown (10YR 4/4) mottles; about 2% iron stone gravels; indistinct irregular boundary.

2Bwg2 30-70 cm

Greenish grey (5GY 6/1), silty clay; sticky and plastic wet, friable moist; weak to moderate medium nutty structure; strong brown (7.5YR 5/8) common coarse distinct mottles; indistinct irregular boundary.

3C 70<sup>+</sup> cm

Rounded river gravels.

### **Discription 3**

Ap 0-25 cm

Dark brown (10YR 3/3), silty clay loam; sticky and plastic wet, friable moist; weakly developed fine nut plus granular structure; abundant fine live roots; gradual smooth boundary.

Bw1 25-40 cm

Dark yellowish brown (10YR 4/4), clay; sticky and plastic, friable moist; moderately developed fine blocky structure; common live roots; indistinct irregular boundary.

Bw2 40-50 cm

Dark yellowish brown (10YR 4/4), clay; sticky and plastic wet, friable moist; weak to moderate medium to coarse nutty structure; few fine faint mottles; indistinct irregular boundary.

Bw3g 50-110 cm

Greenish grey (10Y 6/1), clay; sticky and plastic wet, friable moist; strong brown (10YR 5/8) common medium distinct mottles; moderate medium blocky structure; water table at 70 cm depth.

2C 110<sup>+</sup> cm

Rounded river gravels.

## 4.5. Summary and Conclusions

The soils of the lower terrace are developed from recent alluvial deposits derived from Mesozoic greywacke-argillite and Quaternary sandstone, mudstone and limestone. Absence of volcanic glass in the sand fraction (Table 4.66) indicates that the influence of tephra on these soils is minimal.

The soils of the intermediate terrace are developed from a mixture of late Pleistocene alluvium, colluvium, loess and tephra. Presence of volcanic glass in the sand fraction (Table 4.66) and pyroxene minerals in the heavy mineral fraction indicates the influence of tephra (Table 4.67). The age of the soils may range from 10,000 to 15,000 years.

The soils of the upper terrace are developed from a mixture of loess and tephra. Sand mineralogy suggests that both the alluvium and loess are quartzo-feldspathic (Table 4.66) hence the source of loess is local alluvium. This suggests that the soils of the upper terrace are also similar in age to the soils of the intermediate terrace.

Table 4.66 Percentage minerals present in the sand fraction of analysed soil types occurring on the lower terrace, intermediate terrace and upper terrace. Percentage volcanic glass present in the Kawakawa Tephra layer present within Dannevirke, Kiwitea and Marton soils is shown in brackets.

W.D = well drained; Im.D = imperfectly drained; P.D = poorly drained.

Soil Type	Drainage	Qu	Feld	HM	VG	Mica	Aggre	Crist	
Lower Terrace									
Manawatu fine sandy loam	W.D	35-40	20-25	1-2	0	4 - 6	4 - 5	0	0
Manawatu silt loam	W.D	35-40	15-25	1-2	NA	4 - 6	4 - 7	0	0
Intermediate Terrace									
kawhatau stony silt loam	W.D	45-60	20-25	1-5	1-3	1-3	2-4	0	5-20
Coulter silt loam	W.D	41-56	23-32	5-16	4 -15	0	0	0	0
Barrow silt loam	Im.D	50-61	24-32	4 -10	3-21	0	0	0	0
Upper Terrace									
Dannevirke silt loam	W.D	30-55	25-30	5-13	6-12(38)	0	3-5	0	0
Kiwitea silt loam	W.D	19-63	10-33	5-10	2-11(63)	0-1	1-2	0-4	0
Feilding silt loam	Im.D	38-59	22-41	4 -10	3-16	0	0	0-5	0
Marton silt loam	P.D	32-65	20-32	4-9	0-5(40)	0-5	0	0	0

Presence of volcanic glass is common in the sand fraction of the soils of both the intermediate terrace and the upper terrace. However, Kawakawa Tephra is present only on the upper terrace.

Mica is common in soils of the lower terrace and poorly drained soils of the upper terrace indicating that these soils are still at initial stage of weathering. Chlorite is common in the soils of the lower terrace because, chlorite is very common in greywacke and schist (Fieldes, 1968). The well drained soils of the intermediate and upper terrace are also high in chlorite (Table 4.66). This is due to the advanced weathering of rhyolitic parent material of these soils (Fieldes, 1968).

There is a clear relationship between the presence of volcanic glass in the sand fraction, soil drainage and presence of allophane in the clay fraction (Table 4.67 and 4.68). Allophane is present only in the clay fraction of well-drained soils, developed from parent materials rich in volcanic glass. The clay fraction of the imperfectly and poorly drained soils does not contain allophane, although their sand fraction has volcanic glass. Under well drained conditions volcanic glass weathers into allophane and kandite

(kaolinite and halloysite). Under imperfectly and poorly drained conditions volcanic glass weathers into halloysite, (Parfitt *et al.*, 1984) instead of allophane (Table 4.68).

Table 4.67 Percentage of heavy minerals present in the heavy mineral fraction of different soil types occurring on lower terrace, intermediate terrace and upper terrace.

Soil Type	HB	Pyrox	Aug	Hyp	Chl	Mag	Ilm	Epi
Lower Terrace								
Manawatu fine sandy loam	0-6	25-26	ND	ND	35-40	0-3	0	10-15
Manawatu silt loam	0-7	24-30	ND	ND	30-35	0-5	0	7-18
Intermediate Terrace								
kawhatau stony silt loam	10-20	25-30	ND	ND	0-15	20-35	0	20
Coulter silt loam	9-13	ND	6-21	9-33	1-16	17-48	0-4	10-41
Barrow silt loam	13-45	ND	5-30	8-48	2-8	0-13	3-6	9-30
Upper Terrace								
Dannevirke silt loam	5-18	29-50	ND	ND	1-15	17-35	2-6	5-17
Kiwitea silt loam	5-24	ND	3-13	11-35	1-13	8-36	2-7	11-53
Feilding silt loam	13-46	ND	2-33	7-40	1-8	0-7	3-17	0-36
Marton silt loam	15-40	5-66	ND	ND	0-2	3-12	5-10	5.35

Table 4.68 The relationship between drainage, clay minerals and phosphate retention of some soil types on different terraces

Soil Type	Drainage	Kandite %	Allophane %	P-ret %
Lower terrace				
Manawatu fine sandy loam	W.D	0	0	8-21
Manawatu silt loam	W.D	0	NA	12-22
Intermediate Terrace				
Kawhatau stony silt loam	W.D	10-15	0-5	54-90
Coulter silt loam	W.D	13-52	0-22	86-90
Barrow silt loam	Im.D	24-47	0	25-79
Upper Terrace				
Dannevirke silt loam	W.D	10-22	10-18	94-99
Kiwitea silt loam	W.D	30-56	0-3	26-59
Feilding silt loam	Im.D	41-53	0	23-44
Marton silt loam	P.D	40-60	NA	14-34

There is a strong relationship between the presence of allophane in the clay fraction and the P-retention of soils (Table 4.68). P-retention is high in soils when allophane is present.

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It is clear from this chapter that the properties of soils of the study area are dependent on the properties of the parent material and the drainage conditions under which soils are developed. These soil properties are very important in soil management practices in the area and will be examined in more detail in following chapters.

# **Spatial Variability of Three Soil Properties on Terrace Lands: Drainage, P-retention and Penetration Resistance**

## **5.1. Introduction**

It became apparent, during the course of the soil survey (Chapter 3) that the soils of the study area are quite variable in their drainage status. They range from poor through imperfect, moderately well to well drained and mostly unrelated to the local topographic variations. Another observation made is that during rainy seasons, winter and spring (Chapter 2), some soils become too wet. The wet soils are vulnerable to pugging and treading hazards caused by grazing animals. Subsequent characterization of representative soil profiles (Chapter 4), revealed that there was a huge range in the P-retention of topsoil in the study area and that there was a close relationship between the soil drainage and P-retention.

Variable soil drainage conditions, P-retention and susceptibility to pugging are three important properties of soils in the study area in relation to agricultural management practices. Poor soil drainage conditions in farmlands cause a number of problems during rainy seasons such as pugging, soil compaction and poor trafficability. Pugging affects farm productivity by damaging pasture, decreasing pasture growth, decreasing soil productivity by way of compaction and reducing macro porosity. Furthermore highly variable P-retention properties in soils within a paddock, management unit, pose difficulties for phosphate fertilizer management practices. Therefore, the distribution pattern of these properties over the landscape is important in formulating management plans. Soil maps are the most commonly used tools in making land use and management

plans. The segments shown on soil maps are map units and are identified in the field using morphological, physical and in some instances physiographic features of the landscape. Soil map units may or may not have a direct relationship to parameters that are directly related to land management such as soil drainage, P-retention and soil pugging problems.

The objective of this chapter is to investigate the relationship between soil map units mapped at different intensities and soil drainage, P-retention and pugging hazards represented by penetration resistance of the topsoil. If there is a positive relationship, then farmers can use soil maps to identify areas having different drainage status in their farms, different soils in the farm requiring low, medium and high doses of phosphate fertilizers and the areas susceptible to pugging hazards and adopt management practices accordingly.

The relationships are investigated separately in Sections 5.4, 5.5 and 5.6. Section 5.2, "Field observations and soil sampling methodology" is common to all the three sections.

## **5.2. Soil Sampling Methodology**

A representative area (2000 m by 300 m) was selected from the intermediate terrace of the study area. When mapped at a scale of 1:25,000 the area appeared to encompass three different soil map units, Coulter silt loam (Czl), Horoeke silt loam (Hzl) and Barrow silt loam (Bzl) (Figure 5.1).

The map units are defined as being well drained, moderately well drained and imperfectly drained respectively and are developed from a mixture of loamy alluvium, colluvium, loess and tephra. No artificial drainage has been installed by the farmers. An array of observation points, 100m apart, was set up to cover the 3 map units on a 2000 m by 300 m grid (Figure 5.1 and 5.2).

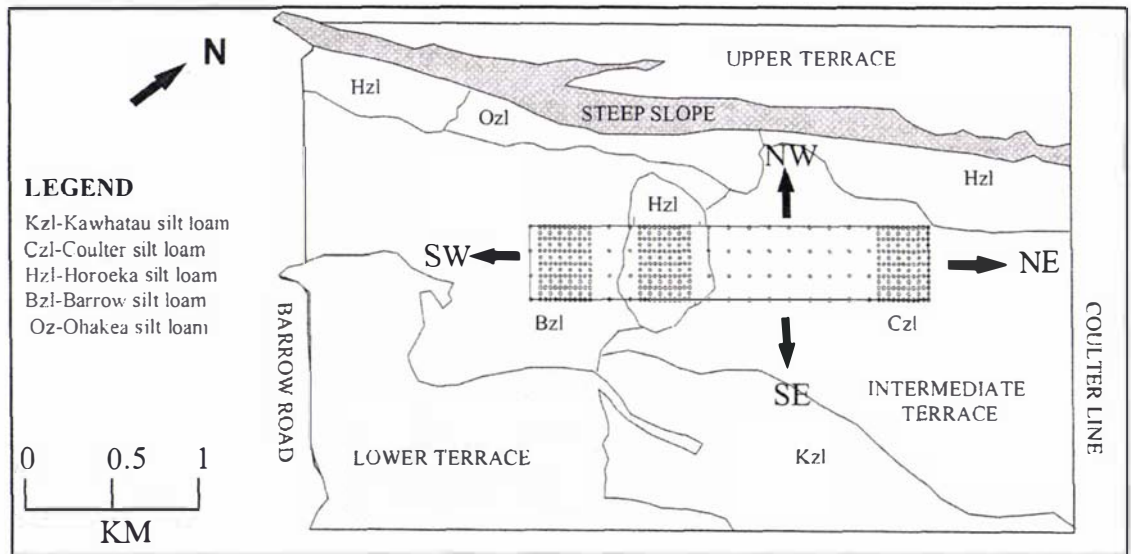


Figure 5.1 Part of the soil map at 1:25,000 scale showing the soil distribution in the 2000 m by 300 m window area of the intermediate terrace.

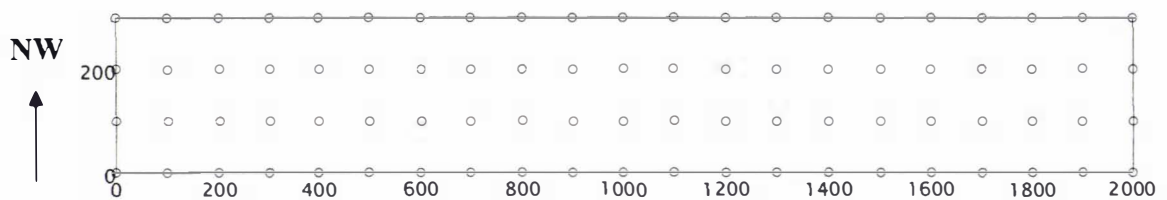


Figure 5.2 A detailed plan of the 100 m by 100 m soil sampling grid for the 2000 m by 300 m window area.

On each map unit a 300 m by 250 m window area was established (Figure 5.1 and 5.3) and sampling points were selected at 50 m intervals on a grid as shown in Figure 5.3.

A dumpy level and ranging poles were used to establish straight grid lines in the field. All the sampling points were demarcated in the field with wooden pegs painted with fluorescent paint so that it was easy to locate them,

For more intensive field observations and sampling, additional 25 m interval grids were introduced at alternative rows and columns as shown in Figure 5.1 and 5.4. The intensive sampling grid was used only for P-retention and penetration resistance variability studies. This sampling grid was not used for the drainage variability study

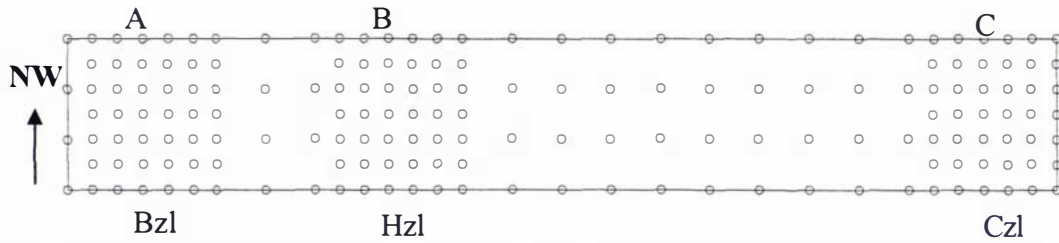


Figure 5.3 The 250 m by 300 m windows (A, B and C) within soil map units showing the 50 m interval grid sampling design.

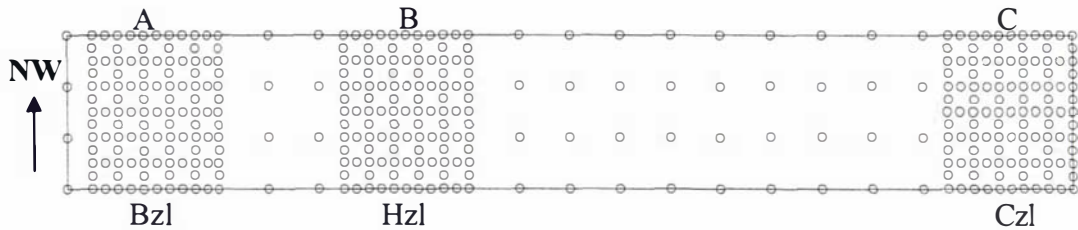


Figure 5.4 The 250 m by 300 m windows (A, B and C) within soil map units showing the intensive grid sampling design

## 5.3. Spatial Variability of Drainage Properties

### 5.3.1. Introduction

Soil drainage properties within the study area vary from well drained through moderately well drained, imperfectly drained to poorly drained. The variations are associated with the behaviour of the ground water table and/or perched water table. The water table remains very close to the soil surface (within 30 cm from the surface) a considerable period of time during a year in poorly drained soils. In imperfect, moderately well and well drained soils the water table depths remain below 30 cm, 60 cm and 80 cm from the soil surface respectively, most of the time during a year.

The ground water table of an area is closely related to the geomorphology and the genesis of landforms. The presence or absence of layers with good permeability properties, of barriers to ground water flow, of springs or waterways and the relation between ground water and surface water directly or indirectly influence the ground water conditions of an area (de Ridder, 1968). In some instances a compacted layer such

as a hard pan or a plough pan within a soil may prevent deep percolation and may develop a perched water table, which leads to poor drainage conditions.

Many unfavourable physical soil conditions on farmland are moisture related, seasonal, and are associated with poor soil drainage conditions. The main problems associated with high soil moisture status are pugging, compaction and low poor trafficability. In the study area these problems arise mostly in winter and spring (see Section 2.4.1). Mapping the spatial distribution of soil drainage conditions on a property would help suitable soil management practices to be adopted.

A ground water table or a perched water table is not static. It remains close to the soil surface in poorly drained soils during the rainy seasons and moves downwards during dry seasons. The most appropriate way of detecting the spatial distribution pattern of poorly drained soils in a particular region is to monitor the behaviour of the water table depths of the area at regular intervals by using established auger holes. Although it permits collecting accurate and up to date information about drainage conditions, this type of study cannot be justified in large or distant areas. Therefore, soil profile morphological features, which are related to the behaviour of the water table, are used to identify different drainage properties of soils in the field.

Soil morphological features associated with poor soil drainage conditions are commonly known as redoximorphic features (Soil Survey Staff, 1994) and form as a result of alternate oxidation and reduction processes taking place in soil due to fluctuating water table. Fluctuation of water table is a continuous process and creates oxidized and reduced environmental conditions within the soil, which influences solubility of iron and manganese compounds. Under reduced conditions iron and manganese compounds become soluble, and can then move from one place to another with moving water in the soil and become concentrated or depleted. Under oxidized conditions the places where iron and manganese compounds concentrate become red, brown or yellow mottles or concretions. The places from which these compounds are removed will remain bleached with low chroma or gley colours. The features, gleying and mottling, formed in the soil by movement of reduced iron and manganese, are known as reductimorphic features and are used in soil drainage class identification.

Small scale soil maps (e.g.1: 50,000) cannot delineate soil drainage variability in the landscape accurately due to limitations of soil map scale. For farm scale applications emphasis should be given to farm and paddock scale soil variability studies. However, there are some practical problems due to the high cost involved in detailed soil mapping. The objective of this chapter is:

- To investigate variability of drainage properties within map units mapped at varying intensities.
- To find the most suitable soil mapping scale for the area that delineates drainage classes reliably.
- To investigate the possibility of using the Geonics 'EM38' sensor for soil mapping.
- To find the most suitable method of soil survey which gathers the most reliable information.

### **5.3.2. Methodology**

#### **5.3.2.1. Mapping of Drainage Classes**

Soil drainage properties were examined by making auger observations to a depth of 110 cm where possible. Observations were made on a 100 m interval grid (Figure 5.2), giving 84 observation points and on a 50 m grid (Figure 5.3) giving 42 observation points from each window. The drainage classes were determined on the basis of depth to a redox mottled horizon and /or reductimorphic horizon (Hewitt, 1992, Taylor and Pohlen, 1968). Details of drainage class separation were discussed in Chapter 3, Section 3.2.6.

A series of soil drainage class maps were produced at 1:25,000 (observations on a 250 m grid), 1:10,000 (observations on a 100 m grid) and 1:5000 (observations on a 50 m grid) scales to investigate the variability pattern of soil drainage classes within map units at different mapping intensities.

### **5.3.2.2. Use of the EM38 Sensor for Soil Mapping**

A 300 m by 250 m window area (block B) was mapped with a Geonics 'EM38' sensor (Geonics Ltd., 1999) and RTK Differentiated Global Positional technology. The EM-38 measures soil electrical conductivity (EC) via electromagnetic induction. Soil EC measurements are averaged over a depth of up to 1.2 m. The EC map was compared with the soil drainage class map produced for the block B, at 1:5,000 scale. The possibility of using EM38 for alternative method of soil mapping was investigated.

### **5.3.2.3. Topographic Survey**

A topographic survey was conducted in the 250 m by 300 m window area established in the Horoeoka silt loam block (block B). Spot heights were taken on the same 50 m interval grid established for soil sampling (see Figure.5.3) by using a dumpy level and staff. These spot heights were used to construct the topography of the soil surface in this block.

Depth to the underlying river terrace gravels was also measured on the same 50 m interval grid by using a soil auger. These depths were used to construct the topography of the surface of the river gravels underlying the cover of fine textured alluvium.

Drainage class maps and topographic maps of window areas were generated using the "Microsoft Surfer" (version 5) software program.

### **5.3.2.4. Water Table Measurements**

Ground water table measurements were taken in spring (October, 2000). Deep auger holes were dug to the underlying river terrace gravels using a soil auger on the same 50 m by 50 m grid in the 250 m by 300 m Horoeoka silt loam mapping unit (Block B). When ground water level came to a constant level, its depth was measured by using a metal tape.

### 5.3.3. Results and Discussion

#### 5.3.3.1. Drainage Variability within Map Units

When mapped at 1:10,000 scale it becomes apparent that the relatively simple soil pattern represented in the 1:25,000 scale map (Figure 5.6) is in fact much more complex (Figure 5.7 and 5.8 A, B, and C). Instead of a gradation of drainage status from well drained Coulter silt loam soil at the NE end of the transect, to the imperfectly drained Barrow silt loam at the SW end of the transect (Figure 5.6), there is a mixture of well, moderately well and imperfectly or poorly drained soils in close proximity right throughout the transect (Figure 5.7). At least three different soil series are identified in each of the 250 m by 300 m blocks (Figure 5.8 A, B and C) at 1:10,000 scale. Each of these blocks comprised only one soil series when mapped at 1:25,000 scale.

When mapped at 1:10,000 scale, it appeared that all the different drainage classes in the 250 m by 300 m area were represented on the map. When mapped at 1:5000 scale, no new drainage classes were found in any areas except for block B (Figure 5.9 B), but the drainage class boundaries could be shown more accurately and it was apparent that the distribution of drainage classes was more complex even than that revealed at 1:10,000 scale (Figure 5.9, A, B and C). It is evident that when ground observation intensity is increased a more and more variable soil drainage pattern can be observed.

The problem associated with mapping of drainage classes (soil mapping) in this area is that it is difficult to establish an obvious relationship between soil drainage and the topography of the land. There are some instances where soils in local depressions, areas close to water bodies or streams are imperfectly or poorly drained (Figure 5.10 and 5.11), but that cannot be accepted as a general rule for the entire area. Figure 5.10 and 5.11 shows the topography of the land surface of the block B and the relationship between the topography and the soil (drainage) distribution pattern respectively. Although the poorly drained Ohakea silt loam is located in the lowest position of the landscape, the other soils show no relationship to landscape.

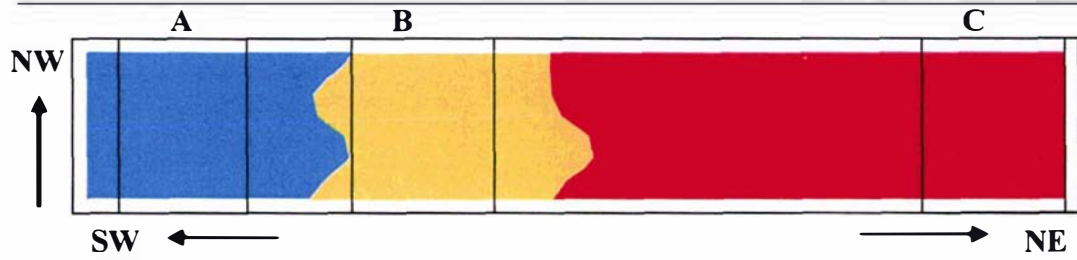


Figure 5.5 Soil drainage class map for the 2000 m by 300 m block (1:25,000 scale) showing the A, B and C sampling blocks. The legend appears below.

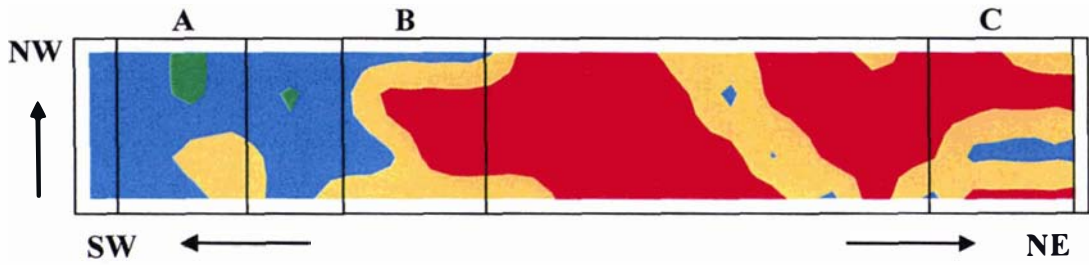


Figure 5.6 Soil drainage class map for the 2000 m by 300 m block (1:10,000 scale). The legend appears below.

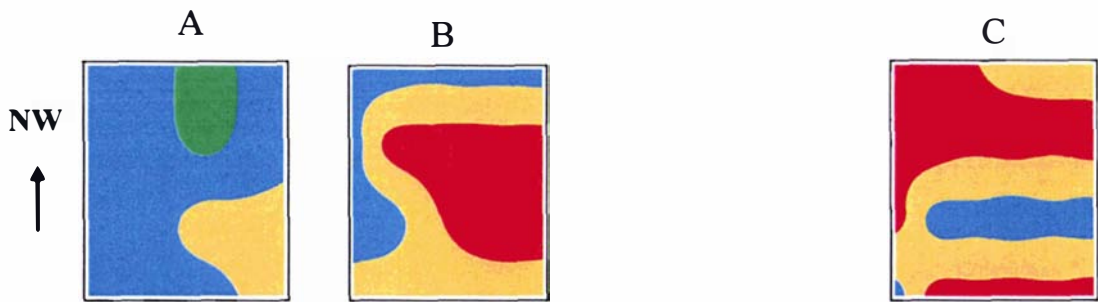


Figure 5.7 Soil drainage class maps for the 250 m by 300 m blocks (1:10,000 scale). The legend appears below.

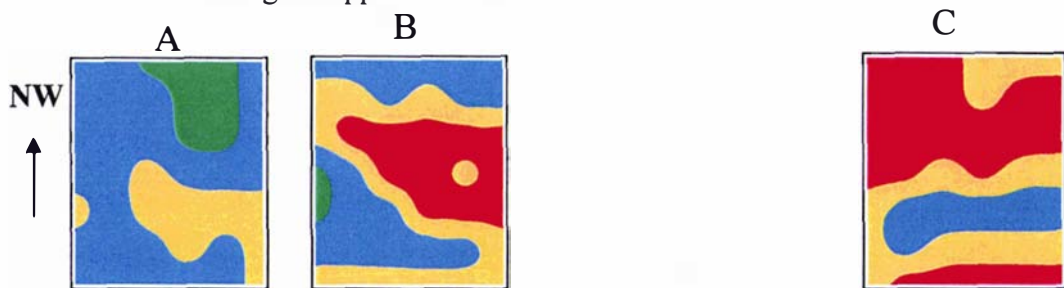


Figure 5.8 Soil drainage class maps for the 250 m by 300 m blocks (1:5,000 scale).

**Legend**

- Coulter silt loam (well drained)
- Horoeke silt loam (moderately well drained)
- Barrow silt loam (imperfectly drained)
- Ohakea silt loam (poorly drained)

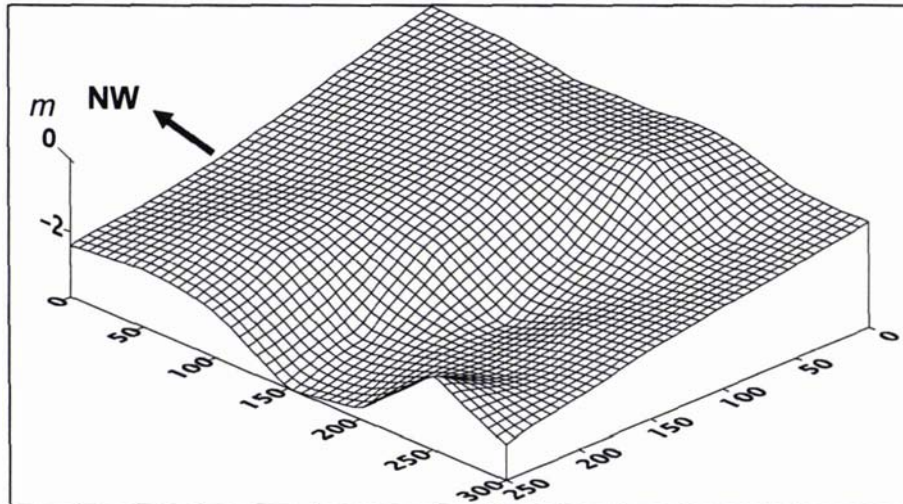


Figure 5.9 Topography of the land surface of the 250 m by 300 m Block (B) on a 50 m grid (1:5,000 scale).

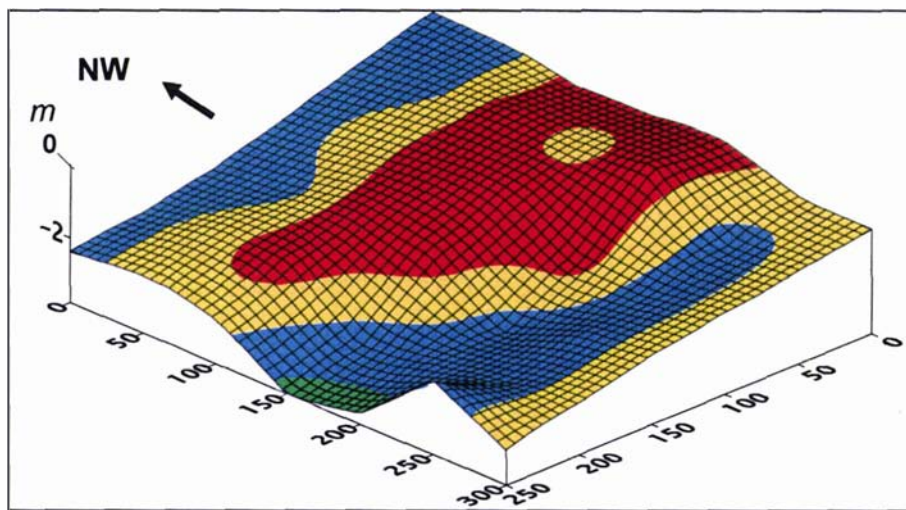


Figure 5.10 The relationship between the topography of the land surface and the drainage classes of the 250 m by 300 m Block (B) on a 50 m grid (1:5,000 scale).

#### Legend

- Well drained soils (Coulter silt loam).
- Moderately well drained soils (Horoeka silt loam).
- Imperfectly drained soils (Barrow silt loam).
- Poorly drained soils (Ohakea silt loam).

A linear regression between land surface elevation and the soil drainage classes (Figure 5.11) calculated for Block B, suggest that there is little relationship ( $R^2 = 0.37$ ).

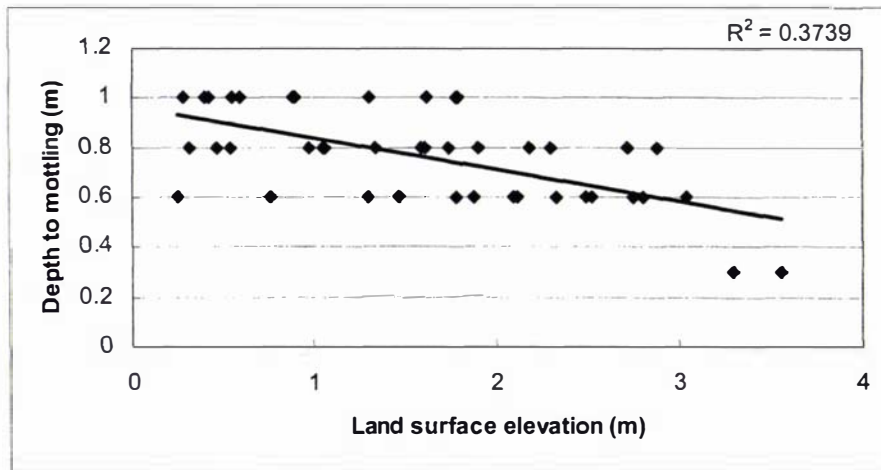


Figure 5.11 The relationship between land surface elevation and the soil drainage class for Block B.

The soil drainage distribution pattern shows no relationship to the topography of the underlying river gravels either. The linear regression between depth to gravels and the drainage classes (Figure 5.12) indicates that the relationship is very poor ( $R^2 = 0.04$ ) Figure 5.13 and 5.14 reveal the same.

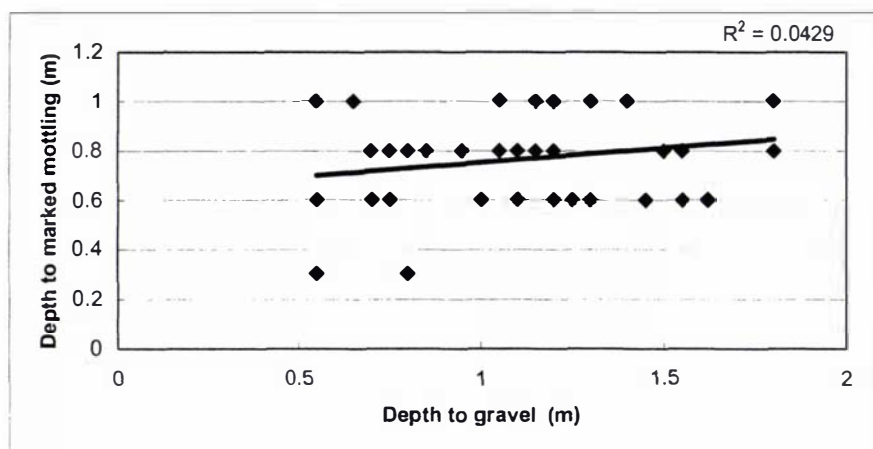


Figure 5.12 The relationship between depth to gravel layer and the soil drainage class for Block B.

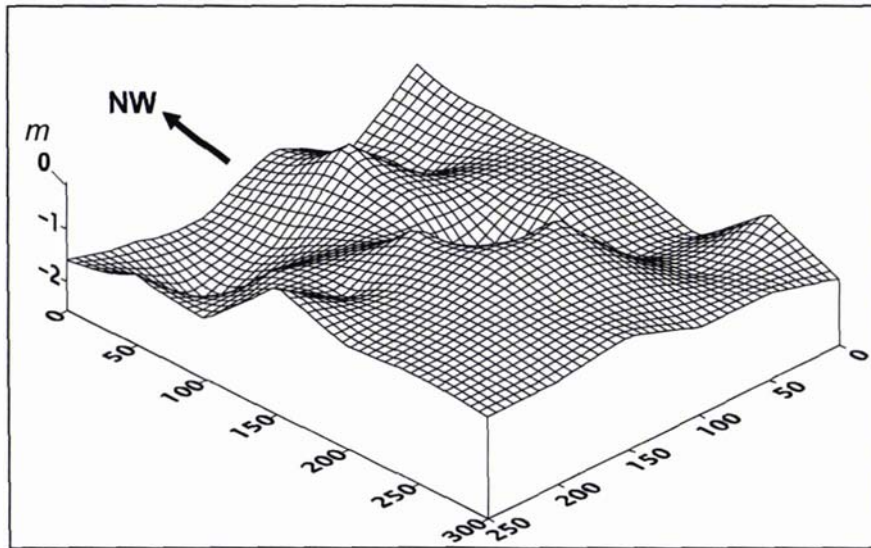


Figure 5.13 The topography of the underlying river gravels of the 250 m by 300 m block B on a 50 m grid (1:5,000 scale).

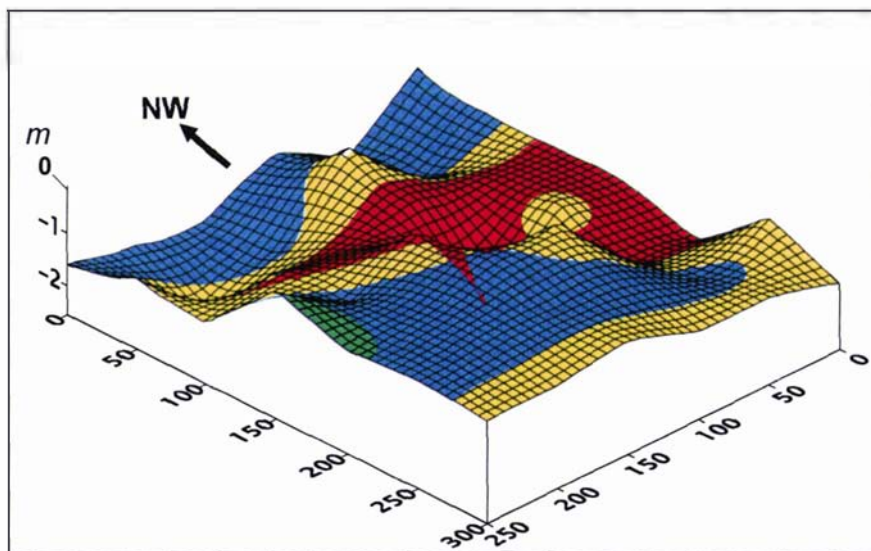


Figure 5.14 The relationship between the topography of underlying river gravels and three drainage classes of the 250 m by 300 m Block B on a 50 m grid (1:5,000 scale).

**Legend**

- Well drained soils (Coulter silt loam).
- Moderately well drained soils (Horoeka silt loam).
- Imperfectly drained soils (Barrow silt loam).
- Poorly drained soils (Ohakea silt loam).

Drainage observations made in the 250 m by 300 m Horoeoka silt loam map unit (block B), reveals that the local drainage distribution pattern is more complex than first appears. Deep auger holes made down to the river gravels (50 m by 50 m grid) in spring (October 2000) showed that the ground water table was developed in some places on the surface of the river gravels (Figure 5.15). Fine soil material (clay) eluviated into the upper part of the gravels has apparently sealed macro pores preventing drainage. Therefore, rainwater and seepage water percolating down from the upper terrace accumulates and builds up a temporary perched water table on the river gravels.

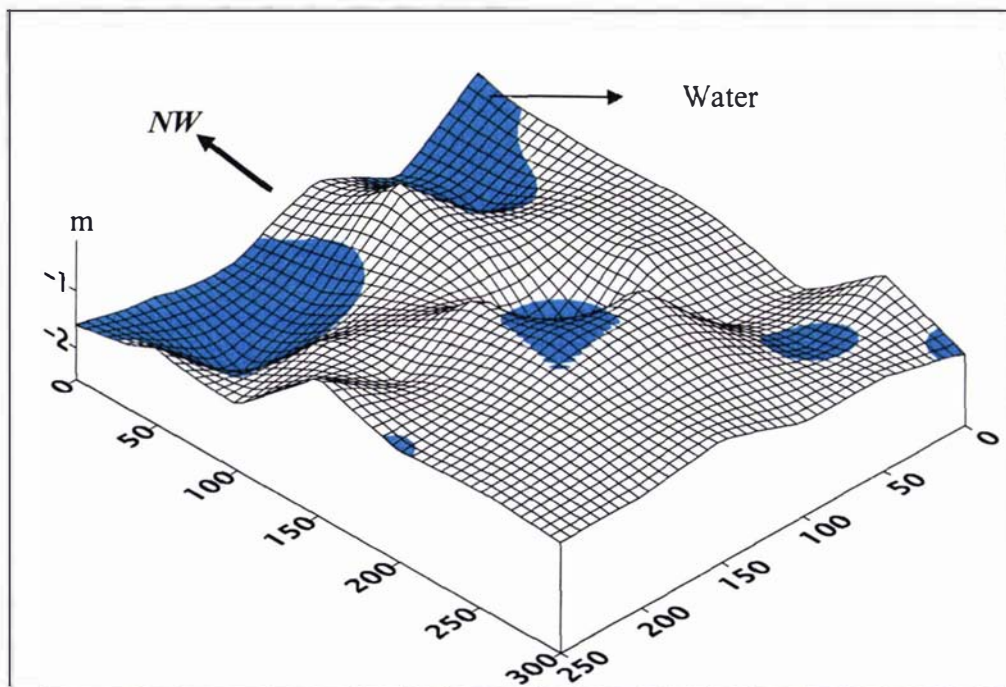


Figure 5.15 Areas of the river terrace gravel surface in Block B where ground water was encountered in October 2000.

### 5.3.3.2. A Brief Explanation of the Drainage Class Maps

The drainage class maps (Figure 5.5, 5.6, 5.7 and 5.8) are contour maps generated by the “Surfer” programme based on the point drainage data. The values between the points are generated automatically by kriging. The numerical values assigned for well drained, moderately well drained, imperfectly drained and poorly drained drainage classes are 100, 80, 60 and 30 respectively. When generating the contour pattern the programme always generates a sequential drainage pattern according to this order. It never jumps from 100 to 60 or 100 to 30. Instead the programme interpolates the contour pattern.

This phenomenon is evident in the soil drainage class maps generated both at 1:10,000 and 1:5000 scales for the 250 m by 300 m blocks (Figures 5.17 and 5.18). In Figure 5.17 C, auger observation points show that the block has a row of 3 Barrow silt loam observations between two rows of Coulter silt loam observations (shown by arrows). The contour map generated has interpolated a strip of moderately well drained Horoeka soil unit between the well drained, Coulter soils and the imperfectly drained, Barrow soils. Similarly Figure 5.17 B and 5.18 B also show that interpolation by the programme has introduced Horoeka soil unit (shown by arrows).

This phenomenon was further tested by introducing a poorly drained Ohakea soil (observation, X ) in the place of a moderately well drained Horoeka soil in the middle of well drained Coulter soil units in the block B (Figure 5.19). As explained above, the numerical values assigned for poorly drained and well-drained soils are 30 and 100 respectively. The “Surfer” Programme has generated numbers 60 and 80, between 30 and 100, representing imperfectly and moderately well drained soils and appears on the drainage class map (Figure 5.19 shown by an arrow).

This situation is acceptable in the real soil landscape situation. Soils normally do not change abruptly from poorly drained to well drained unless there is an abrupt textural or topographic change. This is a very rare field situation and not found within the study area. Therefore, it appears that the interpolated drainage class maps generated by the “Surfer” programme are plausible. It is clear that the interpolated soil pattern (Figure 5.17 C) is comparable with the real field situation (Figure 5.18 C, auger observations

shown by arrows). However, it is difficult to assess whether this “new” information generated by the “Surfer” programme can be relied upon.

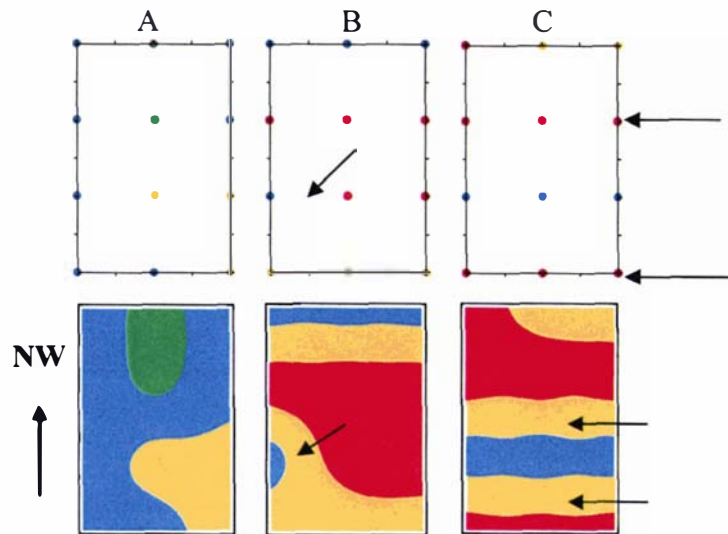


Figure 5.16 100 m by 100 m grid information and 1:10,000 scale soil maps for blocks A, B and C. Arrows show ground observation points and the extrapolated information.

### Legend

- Well drained soils (Coulter silt loam).
- Moderately well drained soils (Horoecka silt loam).
- Imperfectly drained soils (Barrow silt loam).
- Poorly drained soils (Ohakea silt loam).

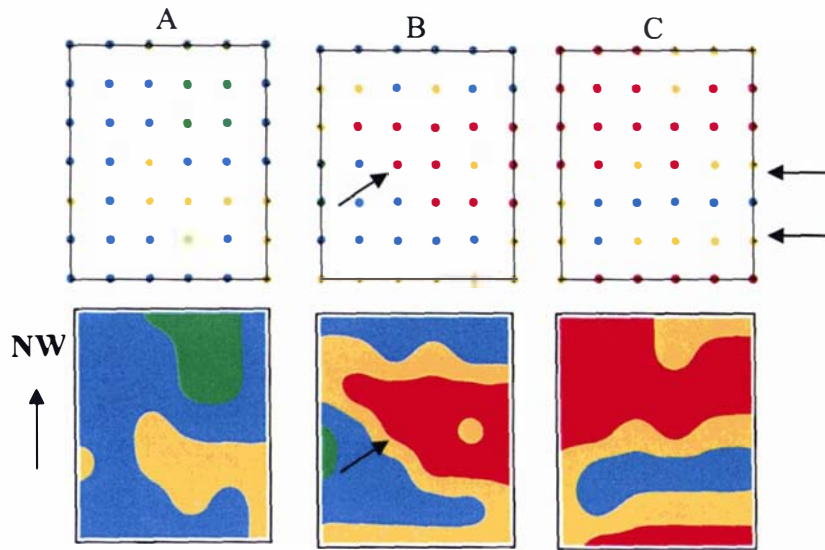


Figure 5.17 50 m by 50 m grid information and 1:5,000 scale soil maps for blocks A, B and C. Arrows show ground observation points and the extrapolated information. The legend is same as for Figure 5.16.

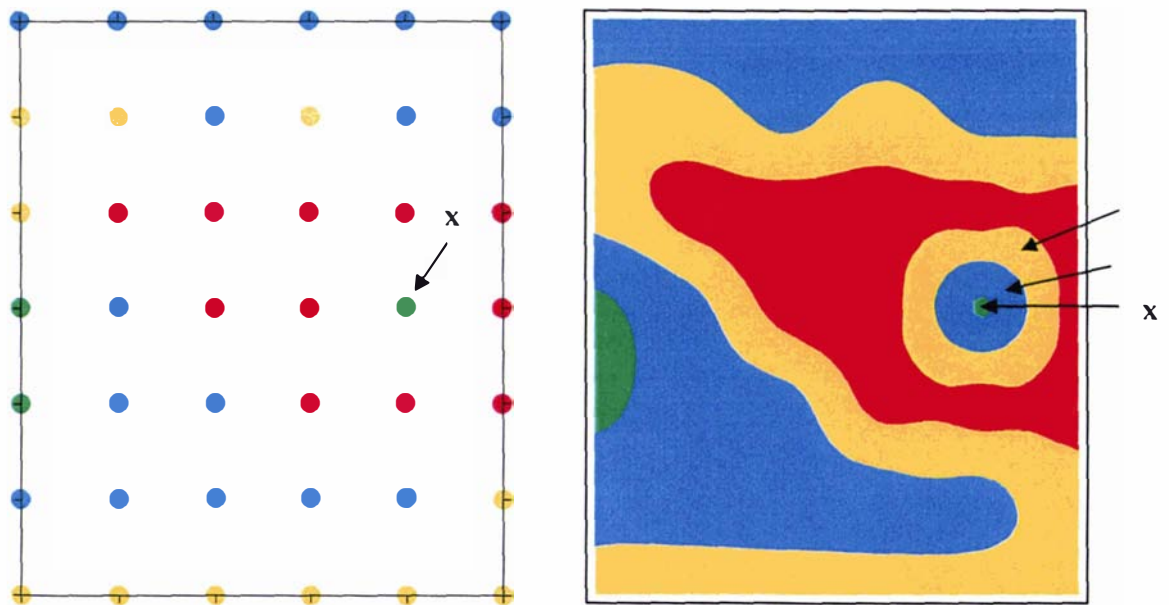


Figure 5.18 New information being added to the soil map by the Surfer mapping programme (X= Ohakea soil observation introduced in the place of a Horokea soil observation). Arrows show imperfectly drained Barrow soils and moderately well drained Horokea soils interpolated between poorly drained Ohakea and well drained Coulter soils. The legend is same as for Figure 5.16.

### 5.3.3.3. Drainage Class Maps and Electrical Conductivity (EC) Maps

When soils of the window area are mapped at 1:25,000 scale, block B comprises of moderately well drained Horoeka soils (see Figure 5.5B). When it is mapped again at 1:10,000 and 1:5,000 scales all four-drainage classes are present on the soil map (see Figure 5.8B). As discussed earlier, since there is little relationship between topographic features and soil drainage, a grid survey is the only reliable conventional soil survey method, which can be employed to map such a complex soil pattern. However, conventional soil surveys have some disadvantages considering the precision of soil maps and the time and cost involved.

Recently Geonics Limited of Mississauga, Ontario, Canada (Geonics Ltd., 1999) manufactured an EM38 sensor which can measure soil electrical conductivity (EC) indirectly. It is a rapid, non-invasive technique for measuring soil EC (Waine *et al.*, 2000). The EM38 instrument works on the principle of electro-magnetic induction. The conduction of electricity in soils takes place through the moisture filled pores that occur between individual soil particles. Soil EC is therefore a measurement that correlates to soil properties such as texture, water content, salinity, CEC, temperature etc.

The EC map produced for block B reveals that EC values of the soil range from 9.8–37.3 mS/m (Figure 5.19 A, B). Most of the soils (78%) mapped as well drained and moderately well drained at 1:5,000 scale correspond to an EC between 9.8 and 15.3 mS/m whereas 89% of imperfectly drained and poorly drained soils correspond to EC values between 15.4 and 26.3 mS/m (Figure 5.19 A, B). Waine *et al.* (2000) pointed out that in arable soils where salinity is not a significant factor, measurements of EC are primarily a function of soil moisture and soil texture. Textural variability is minimal in this area and textures are predominantly silty. Silty soils have a medium EC (Lund *et al.*, 1999). EC values in block B, 9.8-37.3, fall within the medium range. Therefore, EC values in the area directly correlate with soil drainage conditions. The lowest EC range 9.8-15.3 mS/m represents well-drained and moderately well drained soils; and EC values more than 15.3 mS/m represents imperfectly and poorly drained soils. Separation of moderately well drained soils from well drained soils and separation of poorly drained soils from imperfectly drained soils are rather difficult using EM38 data.

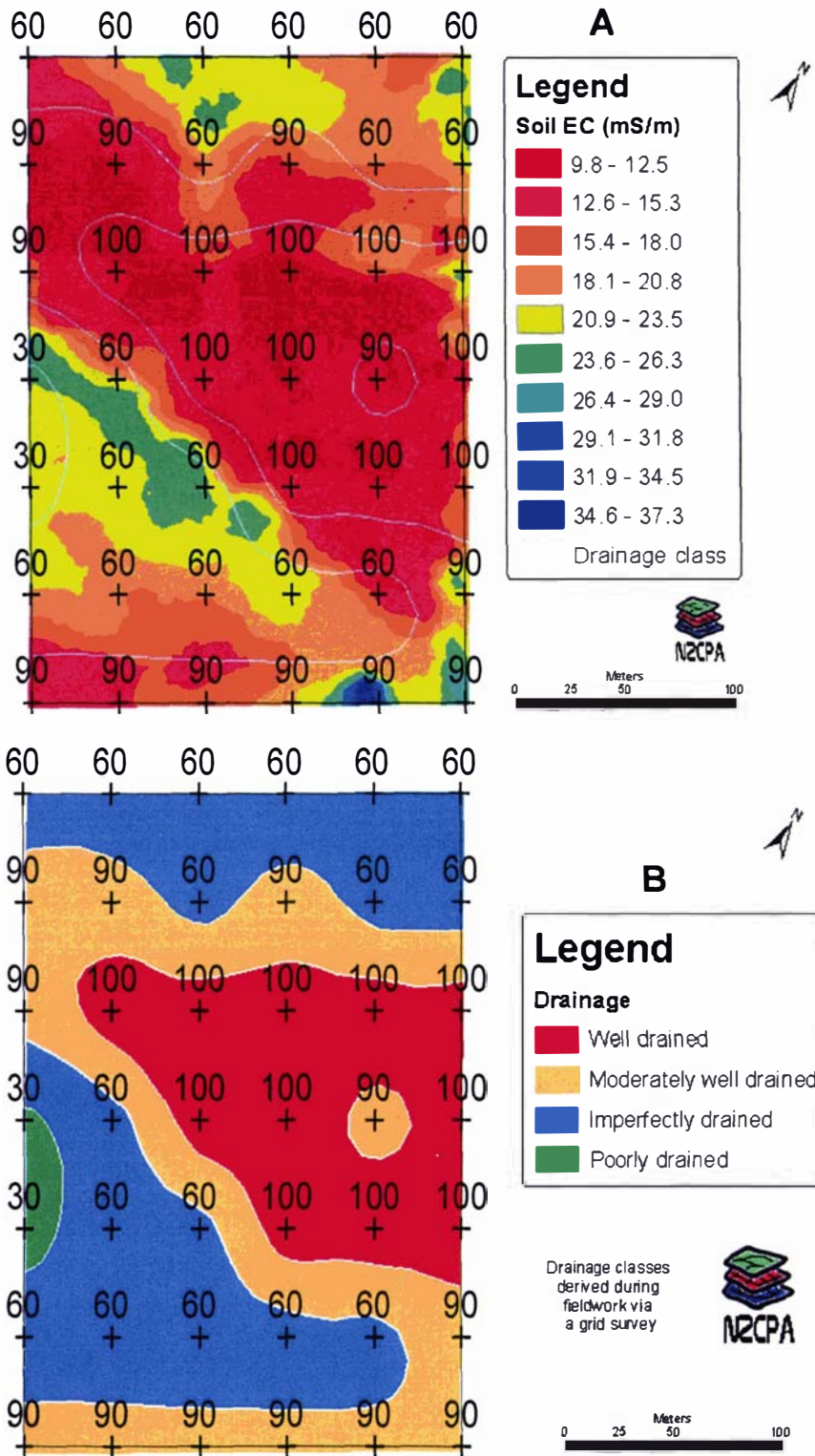


Figure 5.19 Comparison of soil drainage class maps and soil EC maps. A Soil EC map. B Soil drainage class map. Plus sign (+) represents the auger observation points. Numerical figures represent the different drainage classes obtain from depth to gleying or low chroma mottles. 30 = poorly drained, 60 = imperfectly drained, 90 = moderately well drained, 100 = well drained.

However, the results show that there is a great potential for using EM38 for field soil mapping. Further research needs to be carried out to test the potential of the equipment.

The results demonstrate that the EM38 sensor can assess drainage variability in the landscape and also there is a good correlation between EC and the soil drainage. The average cost of production of an EC map is NZ \$ 40 per ha (includes an A2 size laminated map). The minimum charge is NZ \$ 800 per day (calibration costs are not included) and 80 ha can be mapped per day (personal communication with Eastwood, NZCPA). Therefore, this equipment is suitable for rapid acquisition of soil drainage data and for conducting precise and less costly soil surveys in this particular area.

### **5.3.4. Conclusions**

- 1:25,000 and smaller scale soil maps are not capable of reliably delineating drainage status in the study area.
- A 1:10,000 scale soil map is the smallest scale that portrays reliable information that would be useful for farm scale planning.
- A simple relationship cannot be established between soil drainage status and landscape features or depth to the underlying river gravels. Therefore, a grid method is recommended for conducting conventional soil surveys in this area.
- The EM38 sensor can successfully be used in soil drainage class mapping. It is fast, accurate and less costly.

## 5.4. Spatial Variability of Phosphate Retention

### 5.4.1. Introduction

The phosphate retention (P-retention) values of topsoil samples, collected from the Kiwitea study area, reveal that there is an enormous variability of P-retention values within the study area. It ranges from low through medium to high even within the smallest management unit of a farm, a paddock. Most New Zealand soils are deficient in phosphorus for pasture or crop growth in their natural state. This fact, together with the dominant role of legume-based grassland farming and the fact that the legumes have a high P requirement, explain the prime importance that P has in New Zealand's agricultural industry.

Soil scientists have long been concerned with advising farmers how much fertilizer it is economically justifiable to apply to grow a crop on a particular soil and have devoted a considerable time devising simple and reliable methods to help them. After a considerable time of gathering experience, they are now clear that there cannot be a universal simple and reliable method of soil analysis that will allow an accurate forecast of the amount of phosphate to be added to a soil to maintain the optimum P-level (Russel, 1973). It is now a well-known fact that a large proportion of phosphate added to soil as water-soluble and plant available forms react with the soil in ways, which make the phosphate less soluble and less available to plants. This phenomenon has been known traditionally as phosphate fixation, but in recent years the term soil loss of phosphate has been used (McLaren and Cameron, 1996). In New Zealand, an estimate of soil's capacity to fix phosphate is determined by a "P-retention test".

In normal practice, the Olsen P-test values are used to indicate the plant available phosphorus status of soils. (Kamprath and Watson, 1980; Hedley *et al.*, 1995). However, these values have no reference to P-retention properties of soils (Kamprath and Watson, 1980). A soil's capacity to fix phosphate or P-retention properties of soils is one of the factors taken into account in developing fertilizer models to decide phosphate fertilizer requirements for grazed pastures (Metherell *et al.*, 1995). This is an important soil management practice for both the fertilizer economy and environmental

protection. Further, this soil property play an important roll in adopting precision agricultural management practices. Modern farm machinery is capable of applying required amounts of fertilizer to the soil using soils data coupled with the GPS technology.

No previous work has been done on P-retention of the soils in the study area. Therefore, the objectives of this part of the study are to investigate:

- The magnitude of variability of P-retention in topsoil samples from the study area.
- The variability of P-retention within map units mapped at different mapping scales.
- The relationship between P-retention and soil drainage in individual soil types.
- The usefulness of soil maps to identify different soil phosphate retention classes in the field.

## **5.4.2. Methodology**

### **5.4.2.1. Soil Sampling**

Soil samples were collected from 0-7.5 cm surface soils, on the grid patterns shown in Figure 5.2 and 5.4. Three soil samples were taken within 30 cm diameter of each observation point using a core sampler and a composite sample was taken from each point. The number of soil samples collected from the 2000 m by 300 m window area at 100 m intervals is 48 (Figure 5.2). Also 113 samples were collected from each of the 250 m by 300 m blocks on the grid design shown in Figure. 5.4 giving a total of 339 samples on three blocks (blocks A, B and C). The total number of soil samples collected from the whole area for analysis is 387 samples.

### **5.4.2.2. Soil Chemical Analysis**

P-retention of soils was determined according to the method given by Saunders (1965) and the results are expressed as percentage values. Details of the method are discussed in Section 3.5.2.

The 387 soil samples were analysed in five batches, 100 samples at a time. Eight quality control samples with known P-retention values were incorporated within each 100-sample batch at numbers 1, 25, 40, 50, 60, 75, 90 and 100 to monitor the possible variations that might arise among different batches. The quality control samples incorporated were QC-A (2 samples), QC-B (2 samples), Egmont Soil (2 samples) and Tokomaru Soil (2 samples).

The same P-retention solution and vanado-molybdate solutions were used throughout the analysis of the 387 samples for a fair comparison of results.

### **5.4.2.3. Preparation of Phosphorus Retention Class Maps**

P-retention class maps were generated by the “Microsoft Surfer” programme (version 5.0) based on the point P-retention data, as explained for the drainage class maps. The numerical values assigned for the low, medium and high P-retention classes are 10-30%, 31-60% and 61-90% respectively (Saunders, 1968). The colour scheme (green, blue and red) used to separate different P-retention classes is the same as the one used in the separation of the drainage classes. This makes for easy comparison of the relationship between P-retention and soil drainage.

## **5.4.3. Results and Discussion**

### **5.4.3.1. Reliability of Laboratory Data**

The total number of soil samples analyzed for P-retention was 427, including 40 quality control samples (387+40). The co-efficient of variation (CV) between P-retention values of quality control samples range from 0.85% to 3.8% (Table 5.1). In the high P-

retention soil samples (QC-B and Egmont), CV ranges only between 0.85% and 1.5%, but in the low P-retention soils (QC-A and Tokomaru), CV ranges between 2.3% and 3.8%. However, these CV values are very low, indicating that the variability of P-retention results among 387 soil samples imposed by laboratory analytical errors are minimal and the laboratory results obtained for the soil samples are reliable.

Table 5.1 The range of P-retention values among and between quality control samples in each run and co-efficient of variation of P-retention among quality control samples.

Statistics	Sample Nos.	P-retention %							
		QC - A		QC - B		Egmont		Tokomaru	
	1 - 100	35	36	74	74	81	82	19	18
	101 - 200	36	36	76	76	82	82	18	18
	201 - 300	36	37	75	75	81	81	18	18
	301 - 400	35	38	75	75	83	82	18	17
	401 - 427	37	38	77	77	82	83	18	19
Mean		35.8	37	75.4	75.4	81.8	82	18.2	18
Stdv.		0.83	1.0	1.14	1.14	0.83	0.7	0.44	0.7
CV %		2.3	2.7	1.5	1.5	1.0	0.85	2.4	3.8

#### 5.4.3.2. Variability of P-retention in the Study Area

The P-retention values of the 387 topsoil samples (Section 5.4.3.1) collected from the study area range from 15% to 86%. These values indicate that there is a huge variability in P-retention within the soils. According to Saunders (1968) these values range from low through medium to high (Figure 5.20). The frequency distribution pattern of P-retention values indicates that there is no marked difference between frequencies around boundaries of low to medium (30-31%) and medium to high (60-61%) P-retention classes (Figure. 5.20). However, some arbitrary values are needed to group the entire population into classes.

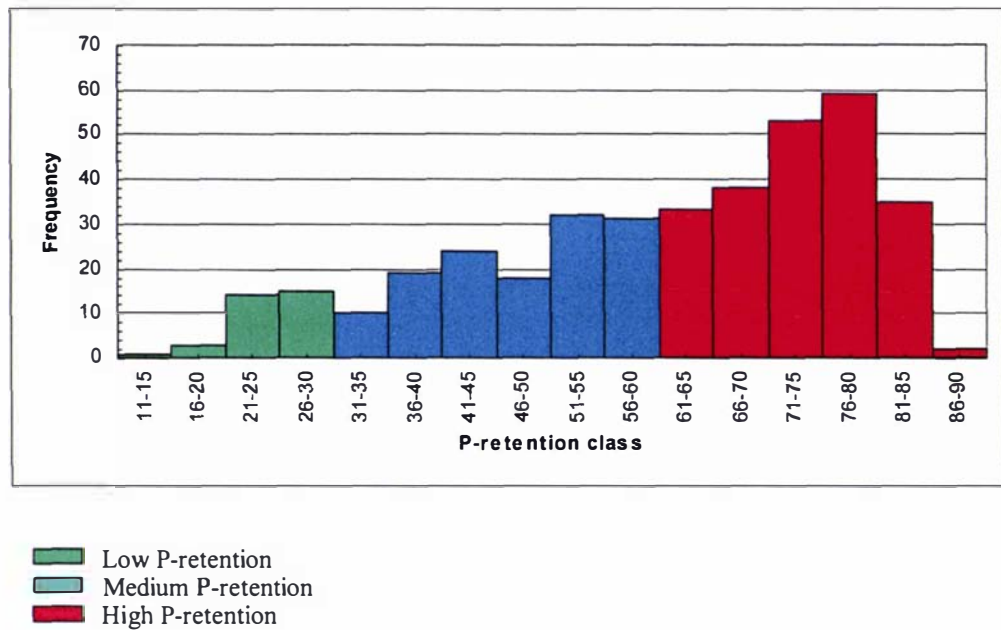


Figure 5.20 The frequency distribution of P-retention of topsoil in the study area. Green, blue and red colours represent low, medium and high P-retention classes respectively.

The variability in P-retention should have a significant influence on the phosphate fertilizer management practices in the area. Nevertheless soils with low P-retention cannot withhold excess phosphate, when high rates of phosphate fertilizer are applied. The excess phosphate easily gets into the local waterways through erosion and runoff and then creates environmental problems such as eutrophication (<http://www.msu.edu>). So it is clear from both an economic and an environmental point of view, that soils within different P-retention groups should be treated differently. Therefore, identification of low, medium and high P-retention areas in the landscape and managing them accordingly is important.

### 5.4.3.3. The Variability of P-retention within Map Units

The variability of P-retention within soil map units mapped at different scales is investigated in this section. The range of P-retention values, co-efficient of variation (CV) and frequency distribution patterns of P-retention values are used as measures of variability within map units mapped at 1:25,000, 1:10,000 and 1:5,000 for comparison.

When the area is mapped at 1:25,000 scale, the range of P-retention values within the three map units, blocks A, B and C, (Figure 5.21) are 15 – 72%, 23 – 86% and 34 – 86% respectively (Table 5.2). These Figures show that the variability within each map unit has not reduced considerably compared with the initial range of P-retention (15 – 86%).

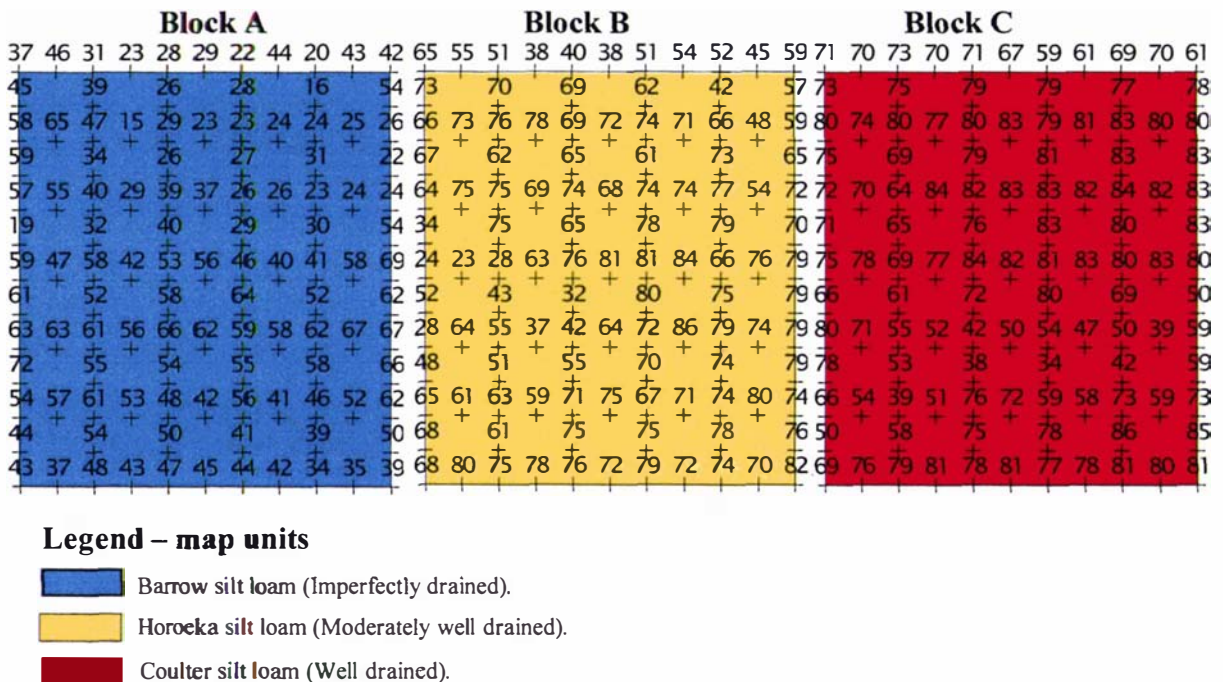
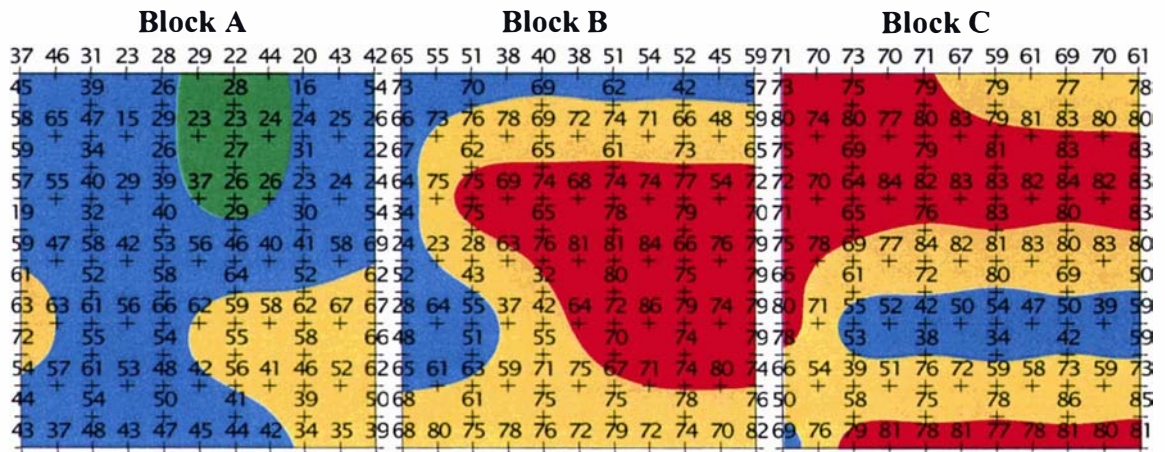


Figure 5.21 The variability of P-retention within Barrow, Horoeka and Coulter silt loam map units at 1:25,000 scale. Numerical values represent the P-retention values for the sampling points.

When the mapping scale is increased from 1:25,000 to 1:10,000 (Figure 5.22), a new map unit (Ohakea silt loam) with less variable P-retention values (22 – 44%) has been added to the soil map (Table 5.2). The range of P-retention values in the Barrow (15 – 73%) and Horoeka (23 – 86%) map unit changed only slightly. However, there

is a considerable change of range in P-retention within the Coulter map unit (from 34 – 86% to 54 – 86%). The co-efficient of variation (CV) indicates that Barrow and Horoeoka map units mapped at 1:10,000 scale are slightly less variable compared to that of 1:25,000 scale. CV of P-retention slightly reduced in Barrow (from 32.6 to 29.2%) and Horoeoka (from 21.8 to 21.2%) silt loams whereas CV considerably reduced in Coulter silt loams (from 17.4% to 8%) (Table 5.2).



**Legend – map units**

- Ohakea silt loam (Poorly drained).
- Barrow silt loam (Imperfectly drained).
- Horoeoka silt loam (Moderately well drained).
- Coulter silt loam (Well drained).

Figure 5.22 The variability of P-retention within Ohakea, Barrow, Horoeoka and Coulter silt loam map units at 1:10,000 scale. Numerical values represent the P-retention values for the sampling points of the particular map unit

Table 5.2 The variability of P-retention within the soil map units in the study area when mapped at three different scales.

Map unit	Range	Mean	STD	CV%
	P-retention %			
Mapping scale 1:25,000				
Ohakea silt loam	No mapping unit at 1:25,000 scale			
Barrow silt loam (Block A)	15 - 72	44.1	14.4	32.6
Horoeka silt loam (Block B)	23 - 86	65.1	14.2	21.8
Coulter silt loam (Block C)	34 - 86	71	12.4	17.4
Mapping scale 1:10,000				
Ohakea silt loam	22 - 44	28	6.7	23.9
Barrow silt loam	15 - 73	46.2	13.5	29.2
Horoeka silt loam	23 - 86	64.8	13.8	21.2
Coulter silt loam	54 - 86	75.9	6.1	8
Mapping scale 1:5,000				
Ohakea silt loam	16 - 52	27.5	8.3	30.1
Barrow silt loam	15 - 78	48.5	14	28.8
Horoeka silt loam	32 - 85	67.9	10.4	15.3
Coulter silt loam	54 - 86	76.7	5.9	7.6

When the mapping scale increased from 1:10,000 to 1:5,000 (Figure 5.23), the variability of P-retention increased in Ohakea silt loam (from 23.9% to 30.1%) (Table 5.2). The frequency distribution of P-retention in the Ohakea soils reveals that there is one observation having a P-retention class value of 51-55% (Appendix 1). This can be regarded as an outlier (Figure 5.24). The high CV in the Ohakea silt loam map unit at 1:5,000 scale compared to the 1:25,000 scale can be attributed to the medium P-retention value of this particular observation. The CV at 1:5,000 scale would be 22.3% (instead of 30.1%) if this observation had not been taken into account. Then the Ohakea silt loam map unit would also become slightly less variable with regard to P-retention when mapped at 1:5,000 scale. The variability also very slightly decreased in Barrow (from 29.2% to 28.8%), Horoeka (from 21.2% to 15.3%) and Coulter (from 8% to 7.6%) silt loam map units at 1:5,000 scale (Table 5.2).

The frequency distribution of P-retention within the Ohakea silt loam map unit reveals that 9 observations fall within 21% to 30% P-retention classes at 1:10,000 scale and 15 observations fall within 16-30% p-retention classes at 1:5,000 scale (Appendix 1), indicating that more observations cluster around a low P-retention class when the mapping scale is increased (Figure 5.24).

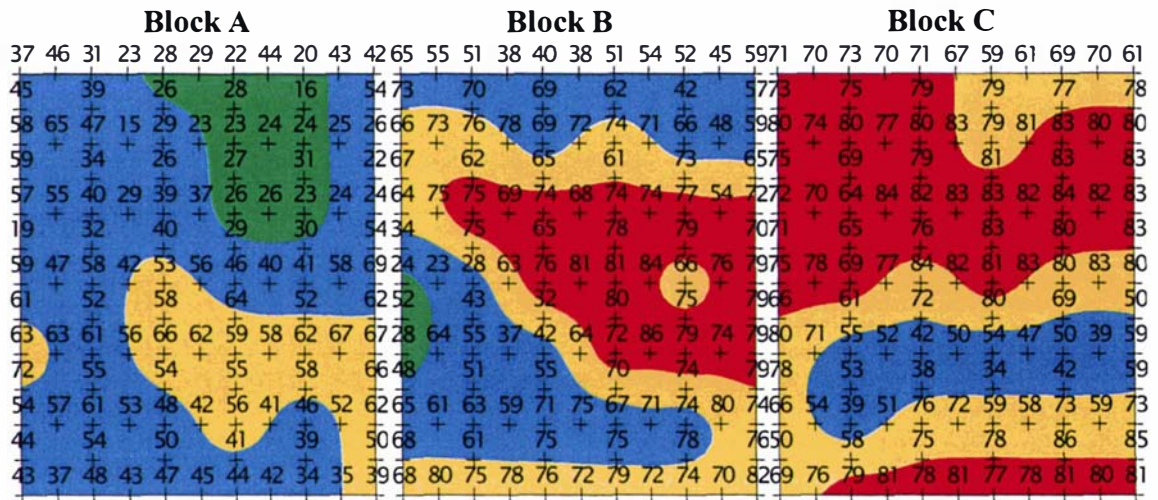


Figure 5.23 The variability of P-retention within Ohakea, Barrow, Horoeoka and Coulter silt loam map units at 1:5,000 scale. Numerical values represent the P-retention values for the sampling points of the particular map unit. The legend is the same as for Figure 5.22.

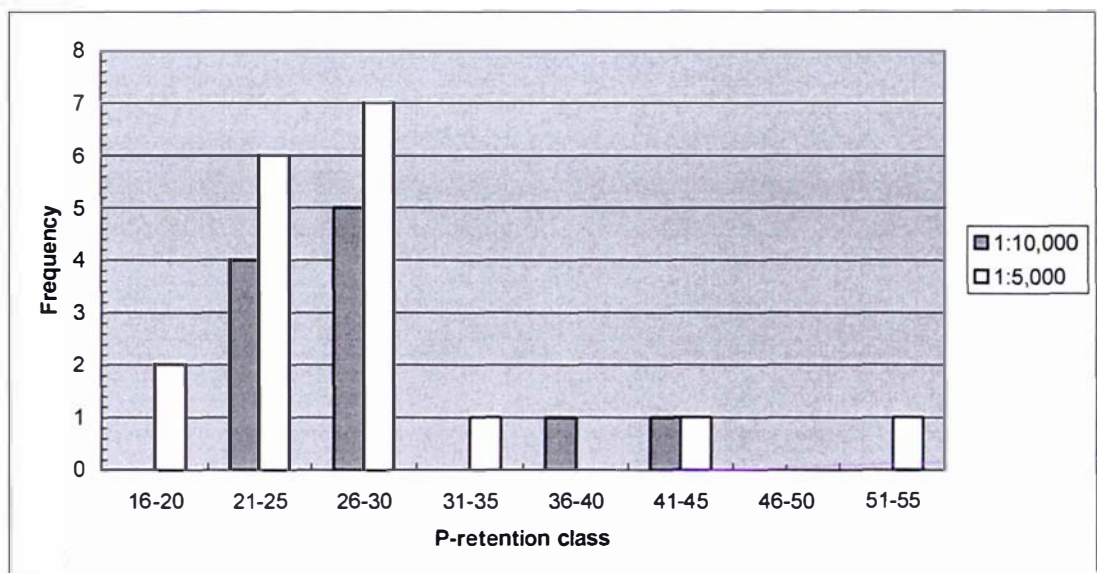


Figure 5.24 The frequency distribution of P-retention within the Ohakea silt loam map unit at 1:10,000 and 1:5,000 scales.

The frequency distribution pattern of P-retention in the imperfectly drained Barrow silt loams remains almost the same at all the three mapping scales (Figure 5.25).The

frequencies within classes change with the change of mapping scale, but the distribution of observations within different P-retention classes remains almost the same (Appendix 2). The number of observations clustering around medium P-retention class (31- 60%), increased from 68 through 84 to 92 when the mapping scale increased from 1:25,000 through 1:10,000 to 1:5,000 respectively.

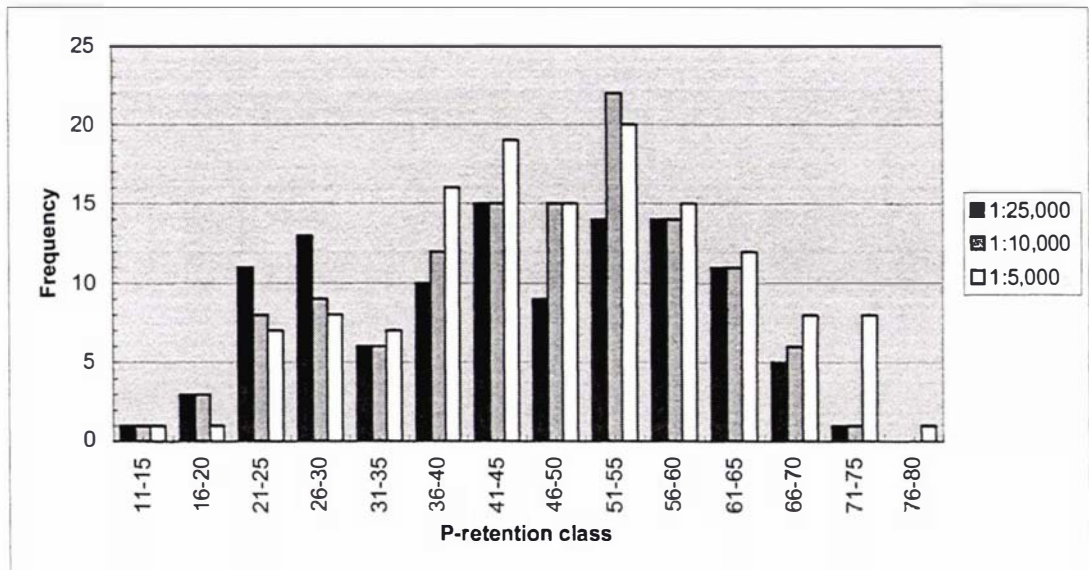


Figure 5.25 The frequency distribution of P-retention within the Barrow silt loam map unit at 1:25,000, 1:10,000 and 1:5,000 mapping scales.

The P-retention frequency distribution patterns in the moderately well drained Horoeka map unit indicate that the frequencies of low P-retention classes are less at all the mapping scales. A majority of the observations fall within the medium to high P-retention classes. The highest frequencies occur at 71-75 P-retention class in the Horoeka map unit both at 1:25,000 and 1:10,000 mapping scales and 76-80% P-retention class at 1:5,000 mapping scale (Appendix 3). The distribution of frequency classes at 1:25,000 and 1:10,000 scales are similar, but at 1:5,000 scale the classes cluster towards the medium to high P-retention class (Figure 5.26).

The highest frequencies occur at 76-80% P-retention class in the well-drained Coulter silt loam at all the three mapping scales (Appendix 4). The frequency distribution patterns reveal that all the observations fall within medium and high P-retention classes. As the mapping scale increased from 1:25,000 to 1:10,000 and 1:5,000 scales all the

observations cluster around the high P-retention class, except for only one value (Figure 5.27).

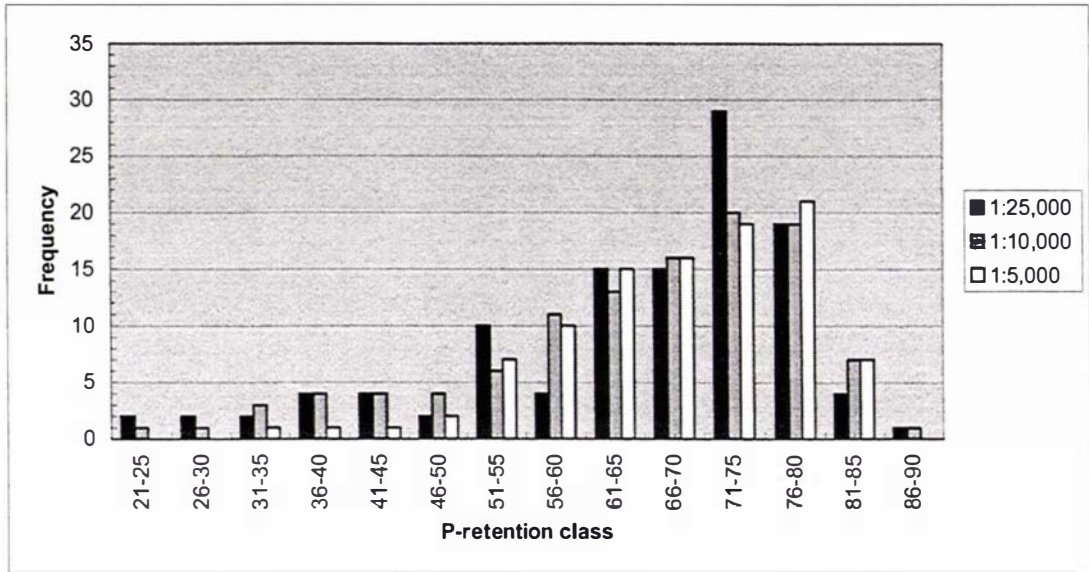


Figure 5.26 The frequency distribution of P-retention classes within the Horoeoka silt loam map unit at 1:25,000, 1:10,000 and 1:5,000 mapping scales.

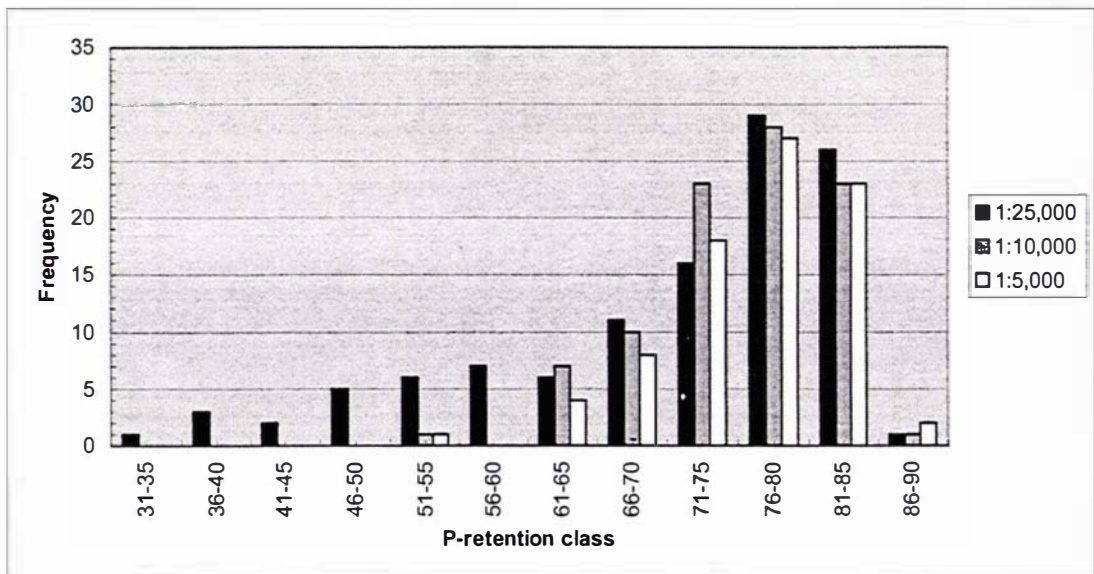


Figure 5.27 The frequency distribution of P-retention within the Coulter silt loam map unit at 1:25,000, 1:10,000 and 1:5,000 mapping scales.

#### 5.4.3.4. P-retention and Soil Drainage

It is clear from the previous section that there is a relationship between soil drainage and P-retention of the topsoil. This relationship was investigated in detail using soil drainage information collected from blocks A, B and C on a 50 m interval grid (Figure 5.28).

The comparison between soil drainage and the P-retention at each observation point indicates that the poorly drained soils have a low P-retention, the majority of the imperfectly drained soils have medium P-retention but some have low and high P-retention values; the majority of the moderately well drained soils have a high P-retention but some have medium P-retention values whereas well drained soils have high P-retention values (Figure.5.29). This relationship is displayed in quantitative figures in Appendix 5. It indicates that 100% of the poorly drained soils in the study area have low P-retention, whereas 100% of the well drained soils have high P-retention. P-retention in imperfectly drained soils ranges from low through medium to high, but 69% of the observations have medium P-retention. Twenty two percent show high values and only 8% show low values. A majority of the moderately well drained soils have high P-retention (85%), whereas only 15% of the observations have medium P-retention values.

Figure 5.28, and 5.29 display the same information graphically. From these observations it is evident that poorly drained soils have low P-retention, imperfectly drained soils have medium P-retention and moderately well drained and well drained soils have high P-retention. Therefore, the variability in P-retention within mapping units can be attributed to the variability of soil drainage. The relationship has been suspected but never before demonstrated for the New Zealand soils. The frequency distribution pattern of P-retention within individual profile classes shows that there is variability of P-retention within profile classes (Figure 5.30 and Appendix 6).

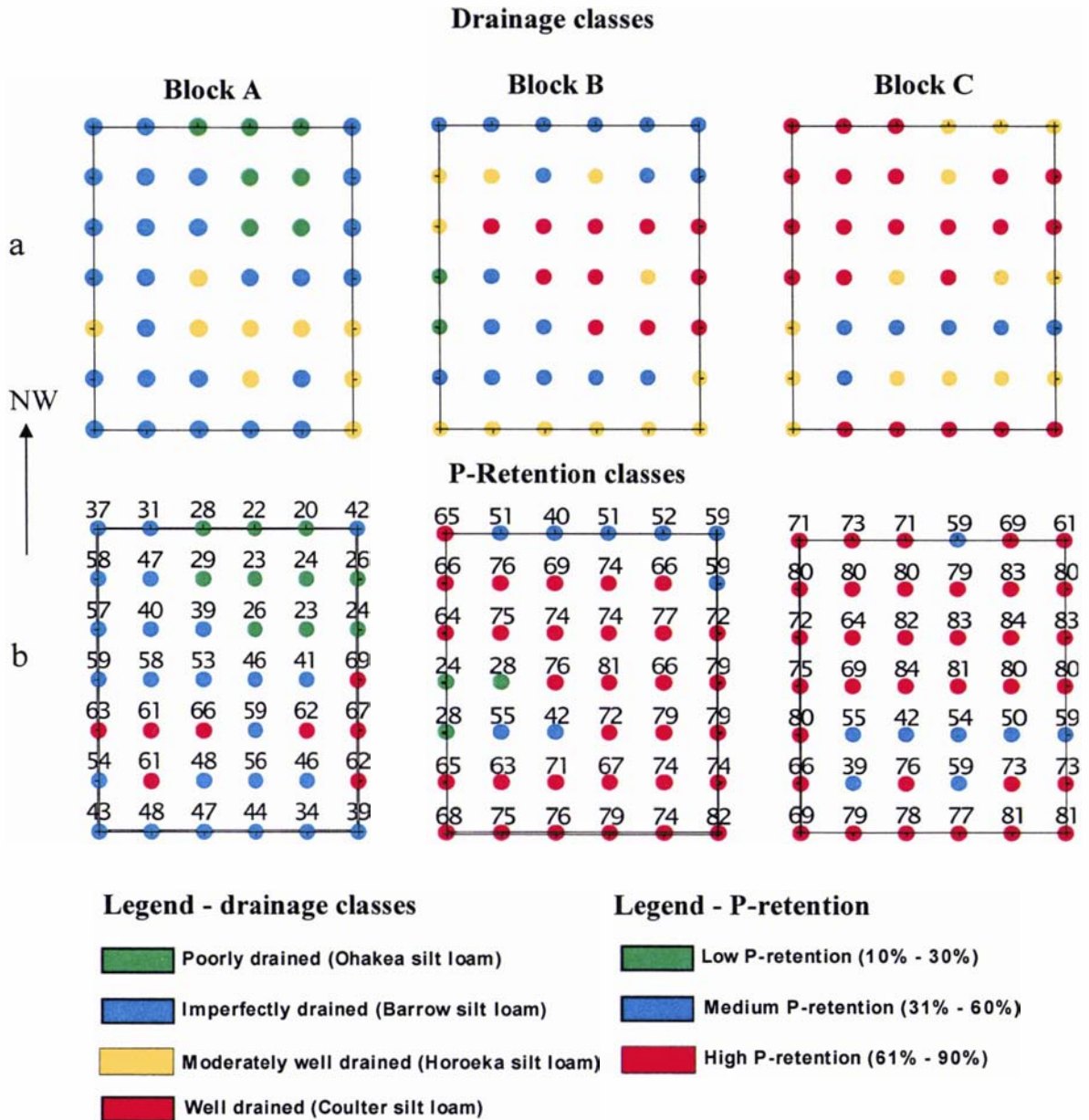


Figure 5.28 Soil drainage class (a) and P-retention class (b) on blocks A, B and C, at a 50 m interval grid. Numerical values represent the P-retention of topsoils at the observation point.

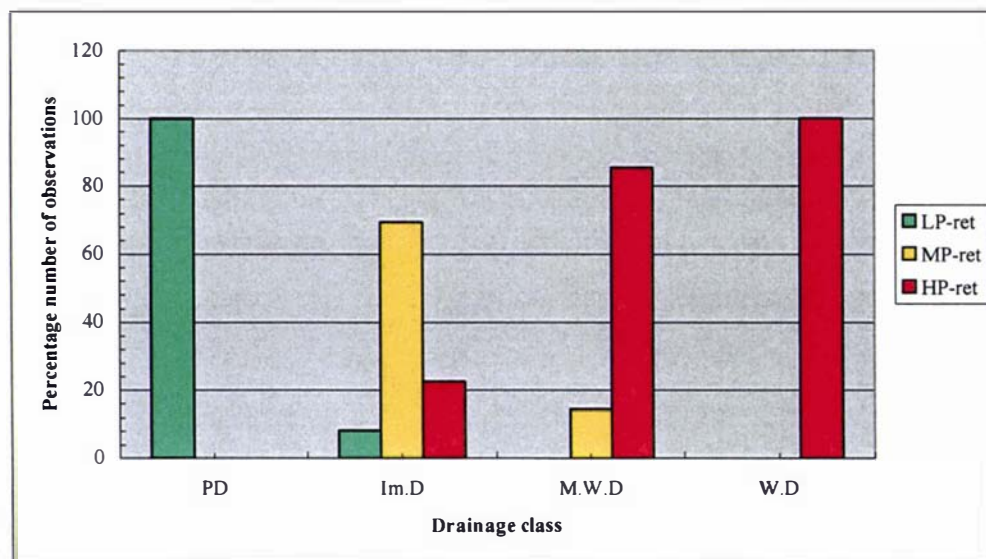


Figure 5.29 The percentage number of different P-retention class observations made within each drainage class. All the 126 (42 from each block) observations made in blocks A, B and C on a 50 m by 50 m grid were used. LP-ret = low P-retention; MP-ret = medium P-retention; HP-ret = high P-retention.

According to the criteria used in the separation of drainage classes (Section 3.26), poorly drained soils (depth to reductimorphic features < 30 cm) and well drained soils (depth to reductimorphic features > 80 cm) can be mapped reliably. Within imperfectly drained soils, there can be a range of soils having different depths to reductimorphic features (eg. 30-40 cm, 40-50 cm, 50-60 cm, 60-80 cm). Some of these depths are close to the poorly drained limit whereas some other depths are close to the well drained depths. Therefore, the range of P-retention values from low through medium to high in the Barrow silt loam profile classes is attributed to the variability of range of depths to reductimorphic features. The same hypothesis applies to the variability of P-retention in Horoeke silt loam soils. The depth criteria used is 60-80 cm. Soils having reductimorphic features close to 60 cm depth have medium P-retention whereas soils having reductimorphic features close to 80 cm depth have high P-retention.

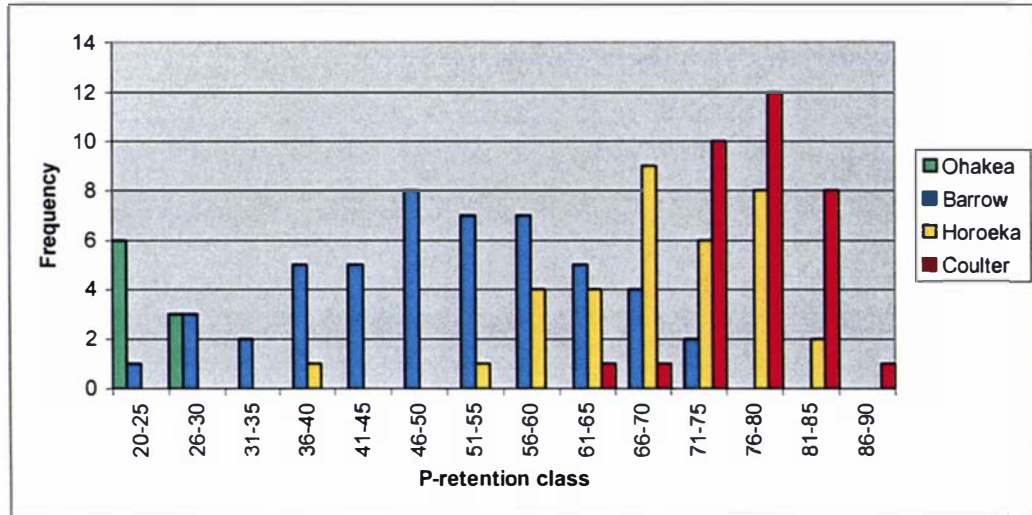


Figure 5.30 The frequency distribution of P-retention within Ohakea, Barrow, Horoeke and Coulter silt loam profile classes.

#### 5.4.4. Conclusions

Drainage and P-retention are two of the most determining factors of production and management of northern Manawatu Soils.

The soils of the study area have highly variable P-retention. The values range from 15 – 86 percent and belong to low, medium and high P-retention classes.

P-retention within map units mapped at 1:25,000 scale is highly variable. Variability within imperfectly drained Barrow silt loam did not change considerably with increasing mapping intensity. Variability within poorly drained Ohakea silt loam and well drained Coulter silt loam map units considerably decreased at 1:10,000 scale. Variability within moderately well drained Horoeke silt loam map unit considerably decreased at 1:5,000 scale.

There is a relationship between P-retention and the soil drainage in the study area. Low P-retention values are associated with poorly drained soils and high P-retention values are associated with well-drained soils. The relationship is not so strong with moderately well drained and imperfectly drained soils. It ranges from low through medium to high

in imperfectly drained soils, but a majority of the observations have medium values. The values range from medium to high in moderately well drained soils.

Soil maps at 1:25,000 scale are of little use in identifying different areas of P-retention in the field. Drainage class maps at 1:10,000 scale can be used to identify low and high P-retention areas successfully, but always some uncertainty exists within moderately well and imperfectly drained areas. Although 1:5000 scale maps are more precise and less variable, there is no advantage in using them instead of 1:10,000 maps when the cost of producing the maps and results are taken into account.

## **5.5. Spatial Variability of Penetration Resistance**

### **5.5.1. Introduction**

Penetration resistance (PR) measurements made on the topsoil in the study area reveal that there is a huge variability of this property over the landscape. Resistance to penetration is known to be closely associated with a number of soil properties, particularly the moisture status, compaction, tillage operations, soil texture, structure and organic matter content of soils (Eijkelkamp, 1999).

It was considered that the spatial variability of soil drainage discussed in the previous section in relation to P-retention may have an influence on the spatial variability of penetration resistance. Moreover, although the predominant land use in the area is improved pastures, the farm paddocks were put into different uses such as sheep, dairy cattle, deer and flowerbeds. Because of the body weight of animals, they impose pressure on the soil surface. The total hoof area of a cow or a bullock is estimated at about 320 cm<sup>2</sup> (Frame, 1975). Static load exerted by a cow with all feet has been estimated at a range of 200 to 350 kpa (Climo, 1985; Thomas *et al.*, 1990) while that of sheep is in the range of 50 to 80 kpa (Willatt and Puller, 1983). This may result in different compaction intensities over the landscape and hence great variability of penetration resistance. The areas used for flowerbeds were treated separately in this study, as tillage operations affect PR significantly. The PR ranges from 590 to 1950 Kpa within the area used for flowerbeds.

The resistance to penetration of the soil measured by the “penetrologger” used is a measure of compaction or the bearing strength of the ground. The bearing strength of soils is particularly important in grassland farming; because soils with low bearing capacities are more susceptible to treading damage caused by farm animals. The phenomenon of treading includes pugging, soil compaction and creating tracks. Treading plays an important role in reducing pasture production. Recent research by Singleton and Addison (1999) showed that the depression in pasture productivity by cattle treading could vary between 30 and 90% and last for at least two years. Betteridge *et al.* (1999, 1998) and McKay *et al.* (1998) also found that pasture production is severely affected by beef cattle pugging a wet soil, both in the long and the short-term. They found that repeated cattle treading of a soil above its plastic limit can reduce annual pasture growth by around 30-40%, while a single event can result in immediate growth reductions that only recover after six months. This can be related to the 20-80% reductions experienced with pugged dairy pasture, which may last for up to 4-8 months (Ledgard *et al.*, 1996). Stock treading damage decreases farm productivity by affecting pasture growth, soil properties, feed utilization and animal health (Climo and Richardson, 1984).

The PR of soils varies in the landscape horizontally and vertically. Horizontal variability is important in estimating the land area being damaged by stock treading whereas vertical variability is important in estimating the depth of soil being damaged. The vertical PR is a minimum at the soil surface and gradually increases with soil depth. At a given moisture status the magnitude of PR at different soil depths has a relationship with soil types.

No PR studies have been carried out in this area before. This property is mostly dependent on the moisture status of the soil. Therefore, to get a clear picture of the variability, field measurements should be carried out a number of times during a year, preferably during a rainy season at different moisture levels and during a dry season. Time constraints limited this investigation to a single snapshot when all measurements were carried out within two days. This study aims to investigate the following:

- Whether there is a relationship between penetration resistance of the topsoil in the study area and the soil map units mapped at different intensities.

- If there is a relationship, what is the most suitable mapping scale of P-retention classes.

## **5.5.2. Materials and Methods**

### **5.5.2.1. Experimental Design**

Penetration resistance measurements were taken in blocks A, B and C on an intensive grid (see Figure. 5.4). No measurements were taken on the 100 m grid between each block.

### **5.5.2.2. Equipment**

Penetration resistance of a soil is usually measured by using a penetrometer. The “Penetro Logger” (Figure. 5.31) has been developed to measure the resistance to penetration of the soil by Eijkelkamp Agrisearch Equipment Company of the Netherlands (Eijkelkamp, 1999). This equipment has some advantages compared to manual penetrometers. The “Penetro Logger” is able to save and process 500 sets of measured data at a time, which is ideal for carrying out large numbers of measurements. The measured results can be digitally processed on a computer. Another advantage is that this equipment can measure and store penetration measurements at 10 mm intervals to a total depth of 800 mm. It is lightweight and easy to use and powered by two AA batteries. The PR is measured in megapascals (Mpa).

The “Penetro Logger” is available as a complete set which consists of the penetro logger, cones, probing rod, a depth reference plate, a set of tools, a battery charger, a cable, software and a test report. The equipment itself consists of a “Penetro Logger” with an adjustable LCD screen, a control panel and a level. The logger is contained in a water resistant housing with electrically insulated grips. A cone is screwed onto the bottom end of a bipartite probing rod. Depending on the application and the expected resistance to penetration, different cones can be attached. The probing rod consists of two parts and is attached to the impact absorber under the “Penetro Logger”, using a

quick coupling. The smaller cones match the slim probing rod, the broader cones match the broader rod.

During insertion of the cone to the soil, the internal ultrasonic sensor of the “Penetro Logger” accurately registers the depth up to 800 mm, using the depth reference plate. The resistance to penetration registered is saved in the internal logger of the “Penetro Logger”. From these measured data the average and standard deviation can be determined. A cable between the communication port and the computer allows the exchange of data between the logger and the computer. The software enables the graphical and numerical display of the data on the computer as well as in printed form.

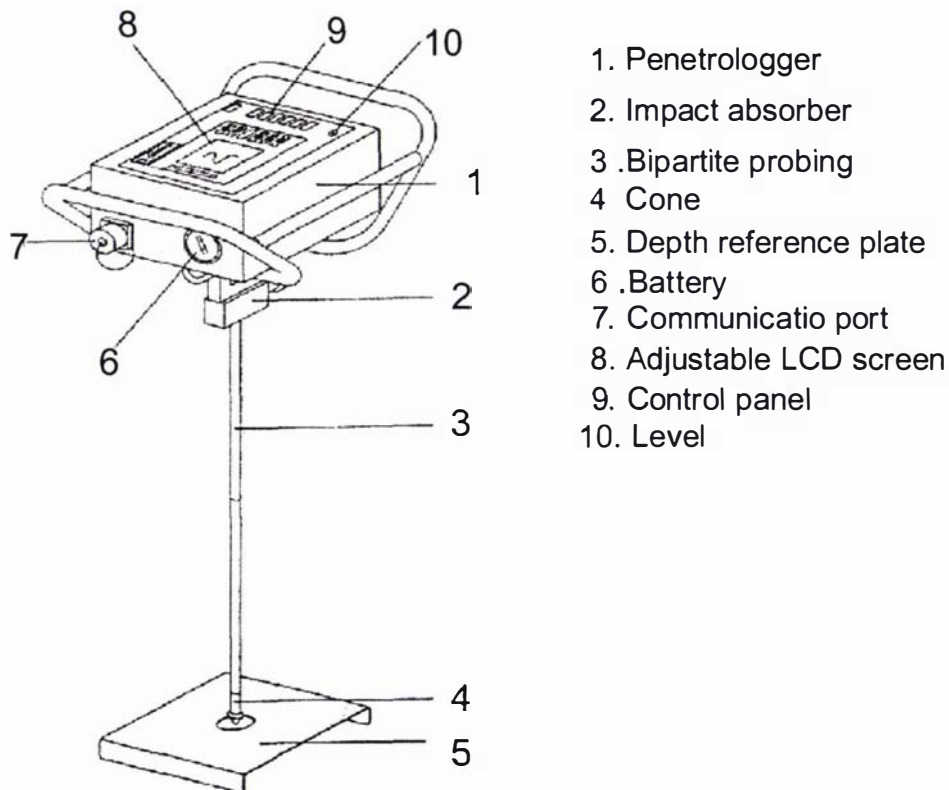


Figure 5.31 A sketch of “Penetro Logger” and its important parts.

### 5.5.2.3. Field Measurements

Penetration resistance was measured at 113 points on each of the 250 m by 300 m blocks (A, B and C) on an intensive grid (see Figure.5.4) giving a total of 339 observation points (3 blocks). Four observations were made within a radius of 0.3 m per point, up to a depth of 100 mm and an average of four readings for the 100 mm depth was taken as the PR at that point. Mean PR within 100 mm was selected, because when the soil is wet the hooves of grazing animals may press into the soil sometimes leaving depressions up to 100 mm depth (Shepherd, 2000; <http://www.maf.govt.nz/>). When taking mean penetration resistance for every 10 mm depth up to 100 mm, average of all 1356 (339\*4 = 1356) observations were taken into account. The operation speed and the cone type used when measurements are taken affect PR measured with the “Penetro Logger”. The cone type was 200 mm<sup>2</sup>, 30<sup>0</sup> and the penetration speed used was 20 mm /sec. PR is known to vary with moisture content. Therefore, all measurements were undertaken over a 2-day period. The fieldwork carried out in spring (October 2000), 6 days after a two-week period of heavy rain. The soil moisture content in 25 topsoil samples, representing different soil types was also measured so that the moisture status of soils at the time of measuring PR was known.

Although the equipment measures the PR in Mpa (1000 Kpa), the units used in the text are Kpa. This unit is more convenient because the units used in literature were Kpa and also it is easy to use whole numbers rather than decimals.

## 5.5.3. Results and Discussion

### 5.5.3.1. Soil Moisture Status in the Field

The resistance to penetration of the soil is related mainly to soil moisture properties (Burke *et al.*, 1964; Marshall and Holmes, 1979; Climo and Richardson, 1984; McLeod, 1992; Horn and Lebert, 1994; McLaren and Cameron, 1996). The moisture status of topsoil samples collected from representative soil types indicate that the volumetric moisture content ranges from about 21 percent to 40 percent (Table 5.3) and is below field capacity. The field capacity of Horoeoka silt loam was not measured, but can be

interpolated from the values for Coulter and Barrow silt loams. Soil moisture content for Ohakea silt loam was also not measured, because the extent of this soil unit in the study area is very limited. The moisture content can be considered to be very close to the values of the Barrow silt loam.

Table 5.3 Soil moisture content (v/v %) of soil samples collected from Coulter, Horoeke and Barrow silt loam soils at 0 - 75 mm depth (Blocks A and B only) at the time of measuring penetration resistance.

Coulter silt loam (well drained)		Horoeke silt loam (moderately well drained)		Barrow silt loam (imperfectly drained)	
32.5	33.7	33.7	35.9	35.7	22.3
30.3	31.4	35.9	40.4	31.2	33.9
32.5		29.2	24.7	30.3	28.5
		32.5	40.4	25	27.6
		30.3	33.7	21.4	32.1
Field capacity					
52.3 (see table 4.23)		No data		49.1 (see table 4.31)	

### 5.5.3.2. Variability of PR of Soils within the Study Area

The frequency distribution pattern of mean PR of top 100 mm of the soil surface shows that a huge spatial variability exists within soils of the study area (Figure. 5.32). Soil moisture conditions remained below field capacity and the whole study area was under improved pastures. The spatial variability may be attributed to the variability of a number of soil properties such as compaction, soil texture, soil structure, organic matter content, bulk density etc. When preparing soil maps these criteria are used in separating soil map units. Therefore, the next step is to investigate whether there is a relationship between topsoil PR and the soil map units mapped at different intensities.

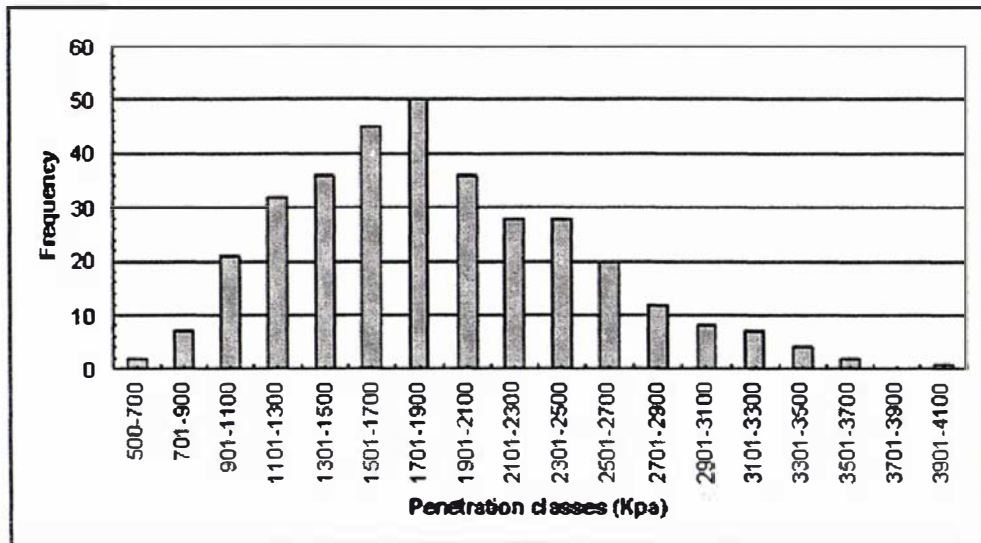


Figure 5.32A frequency distribution of mean penetration resistance (0-100 mm) measured at 339 observation points in the study area.

### 5.5.3.3. Relationship Between PR and Soil Drainage

As stated in Section 5.5.3.1 the penetration resistance of soils is highly dependant on the moisture status of soils. Soil moisture status may vary depending on drainage properties of the soils. Therefore, in this section the relationship between PR and the soil drainage is investigated in a more detailed manner by using mean penetration resistance values at the observation points where drainage is known. The information is gathered from observations made on a 50 m by 50 m grid within blocks A, B, and C (Figure.5.33).

The frequency distribution pattern of PR (Figure 5.34 and Appendix 7) indicates that there is some variability even within soil drainage classes. Even then extreme values belonging to different drainage classes are limited to different ranges and the majority of the observations fall within certain limits. The poorly drained Ohakea soils fall within the range 700 to 1500 Kpa. Most of the imperfectly drained Barrow soils fall within the range 900 to 2300 Kpa. The majority of the moderately well drained Horoeke and well drained Coulter soils fall within the 1500 to 3100 kpa range. These results reveal that there is a relationship between soil drainage and the penetration resistance, but the relationship also depends on other soil factors as well.

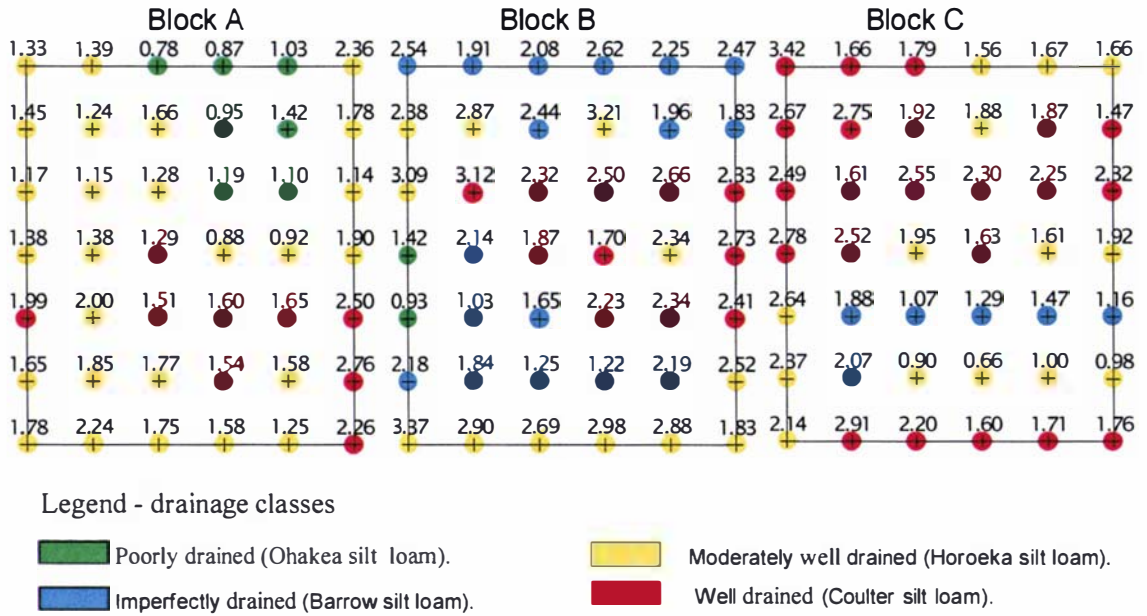


Figure 5.33 Drainage observations made in blocks A, B and C on a 50 m by 50 m grid. Respective penetration resistance values are also given for each observation in Mpa (1 Mpa = 1000 kpa)

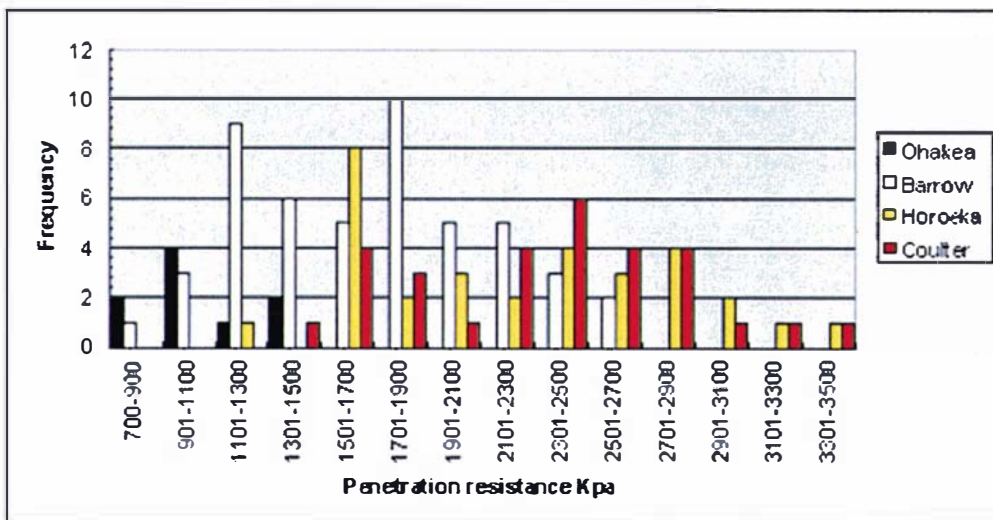


Figure 5.34 The frequency distribution of penetration resistance within different drainage classes.

#### 5.5.3.4. Relationship Between PR and Map Units of the Study Area

The previous section revealed that there is some relationship between the penetration resistance and the soil drainage classes. The map units shown on the soil map of the study area are mainly separated on the basis of soil drainage. Therefore, the main objective of this section is to investigate whether a similar relationship exists with that of map units mapped at different scales.

Parameters used in measuring the variability of PR within soil map units are the range (R), standard deviation (SD) and the co-efficient of variation (CV). The distribution pattern of the different PR classes within map units is investigated using frequency distribution diagrams.

The CV of the PR within the three map units at 1:25,000 scale (Blocks A, B and C) reveals that the variability of PR remains more or less the same (Table 5.4). The frequency distribution (Figure.5.35 and Appendix 8) of PR reveals that 96 out of 113 (85%) observations made in Barrow silt loam map unit fall within the range 760 to 1900 Kpa. A majority of the observations, 99 out of 113 (87.6%), in Horoeke silt loam fall within the range 1501 to 3300 Kpa whereas 94 observations out of 95 (99%) fall within the range 1101 to 3500 Kpa in Coulter silt loam. Although there are some differences between PR values of drainage classes and the 1:25,000 scale blocks having similar drainage status, the values follow a similar trend in that imperfectly drained Barrow silt loams have low PR compared to moderately well drained Horoeke silt loam and well drained Coulter silt loam.

Table 5.4 A comparison of variability of penetration resistance within map units at different intensities.

STD = standard deviation

CV = coefficient of variation

Map unit	Range	Mean	STD	CV%
	P-retention %			
<b>Mapping scale 1:25,000</b>				
Ohakea silt loam	No map unit at 1:25,000 scale			
Barrow silt loam (Block A)	760 - 2760	1500.8	418.7	27.8
Horoeka silt loam (Block B)	930 - 4010	2221.6	581	26.1
Coulter silt loam (Block C)	1070 - 3560	2030.3	545.4	26.8
<b>Mapping scale 1:10,000</b>				
Ohakea silt loam	760 - 1450	1094.5	233.1	21.2
Barrow silt loam	780 - 3150	1633	510.2	31.2
Horoeka silt loam	1010 - 3510	2029.5	585.3	28.8
Coulter silt loam	1470 - 4010	2266.1	496.1	21.8
<b>Mapping scale 1:5,000</b>				
Ohakea silt loam	760 - 2530	1170.5	402.2	34.3
Barrow silt loam	880 - 3070	1676	471.5	28.1
Horoeka silt loam	1230 - 4010	2183.2	629.8	28.8
Coulter silt loam	1470 - 3560	2238.9	483.6	21.5

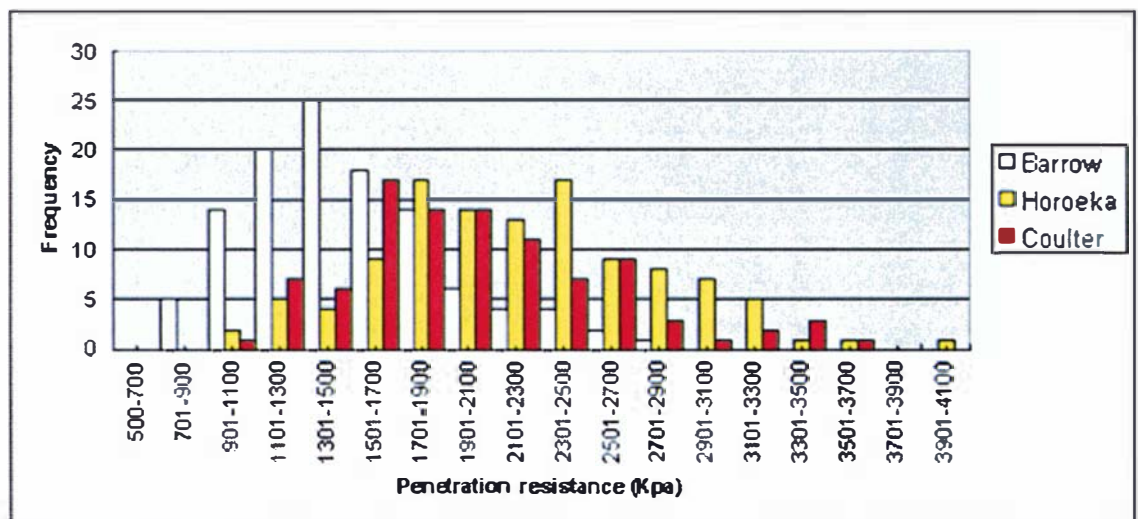


Figure 5.35 The frequency distribution of penetration resistance within Barrow, Horoeka and Coulter silt loam map units at 1:25,000 scale.

On the 1:10,000 scale soil maps, soil units were mapped more precisely (see Section 5.3.3). The new map unit, poorly drained Ohakea silt loam, shows the least variability and the PR values fall between 760 and 1450 Kpa (see Table 5.4). The CV of Barrow silt loam slightly increased at 1:10,000 scale, but the majority of the PR values (87.6%) fall within the range 780 to 2100 Kpa (Figure 5.36 and Appendix 9). The variability of PR within Horoeke soils has slightly increased whereas in Coulter soils it has decreased. The majority of observations, 103 out of 113 (91%), in the Horoeke map unit fall within the range 1101 and 3300 Kpa and for the Coulter Soils 75 observations out of 85 (88%) fall within the range 1501 to 2900 Kpa. These results also suggest that collectively Ohakea soils have the lowest PR of the four soils. Barrow soils have slightly more PR than Ohakea soils. Horoeke and Coulter soils show fairly high PR in comparison with Ohakea and Barrow soils. The PR of the topsoil is lowest in the poorly drained soils and gradually increases with improved drainage status through imperfect, moderately well to well drained conditions.

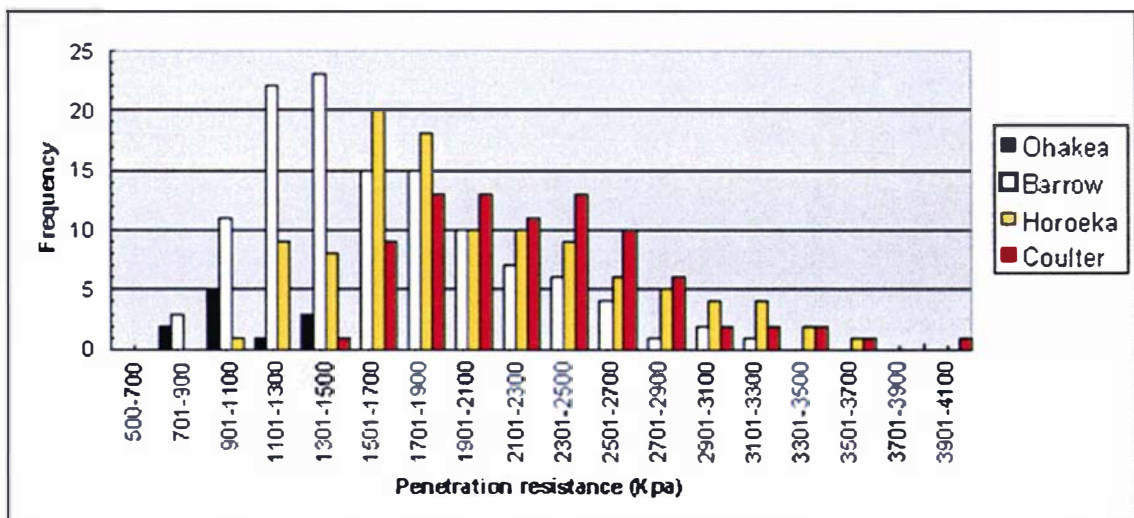


Figure 5.36 The frequency distribution of penetration resistance within Ohakea, Barrow, Horoeke and Coulter silt loam map units at 1:10,000 scale.

On the 1:5,000 scale soil maps the variability of PR in some map units is more and on others slightly lower compared to that of 1:25,000 scale and 1:10,000 scale soil maps (see Table 5.11). The frequency distribution pattern of PR shows no difference to that of 1:10,000 scale (Figure.5.37 and Appendix 10).

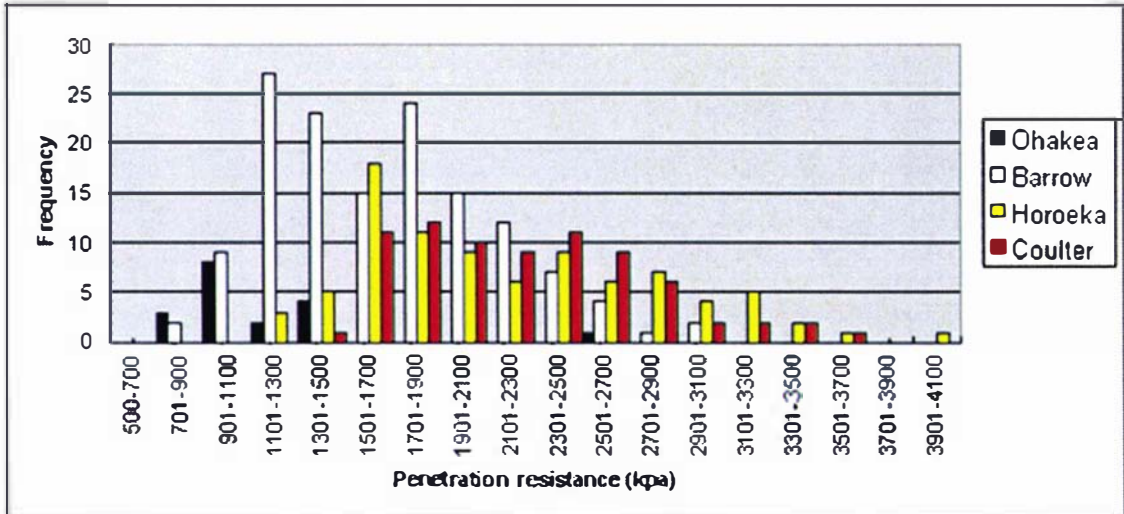


Figure 5.37 The frequency distribution of penetration resistance within Ohakea, Barrow, Horoeaka and Coulter silt loam map units at 1:5,000 scale.

The results suggest that the variability of PR within soil map units has little relationship with the mapping intensity. 1:10,000 scale soil maps have advantages over 1:25,000 scale soil maps, because they can delineate all the soil units present in the landscape. 1:5,000 scale soil maps add little new information to the soil map compared to that of 1:10,000 soil maps. Although there is a huge variability of this property within map units, a majority of the observations made in the poorly drained Ohakea map unit show the lowest PR values in the area. A majority of the observations made in the imperfectly drained Barrow silt loam map unit showed slightly higher values than those of the Ohakea unit. Most of the observations made in both moderately well drained Horoeaka and well-drained Coulter map units showed higher values than that of Ohakea and Barrow silt loam-map units.

The results suggest that because of the variability of PR existing within soil map units, it is not possible to assign an absolute PR value for a soil map unit at a particular moisture level. However, under the given set of conditions susceptibility to treading damage by stock can be arranged as follows:

Ohakea silt loam > Barrow silt loam > Horoeaka silt loam > Coulter silt loam.

Therefore, the soil maps prepared for the study area at 1:10,000 scale can be used as a guide to locate suitable areas for stock grazing, when the soils are wet.

The percentage of land area of different soil types that could potentially be easily damaged by stock treading is more important from the practical land use point of view. Under a given threshold value of PR, the damage occurring on Ohakea, Barrow, Horoeke and Coulter silt loams at different mapping intensities is given as percentages in Table 5.5. The PR values 900, 1100, 1300 and 1500 kpa were selected just arbitrarily. It is clear from the table that at all three mapping scales, below a given PR value, the highest percentage of area damaged occurs in Ohakea soils and the least percentage area damaged occurs in Coulter soils. The sequence of percentage damage occurring in these four different soils is:

Ohakea > Barrow > Horoeke > Coulter.

The soils mapped at 1:25,000 scale do not strictly follow the sequence because each of these map units consist of three to four different soil types (see Section 5.3.3.1)

Table 5.5 The percentage number of observations below penetration resistances of 900, 1100, 1300 and 1500 Kpa within Ohakea, Barrow, Horoeke and Coulter silt loams at 1:25,000, 1:10,000 and 1:5,000 scales.

PR (kpa)	Scale	Ohakea	Barrow	Horoeke	Coulter
< 900	1:25,000	No map unit	4	0	0
	1:10,000	18	3	0	0
	1:5,000	16	2	0	0
< 1100	1:25,000	No map unit	17	2	1
	1:10,000	63	12	1	0
	1:5,000	61	8	0	0
< 1300	1:25,000	No map unit	35	6	8
	1:10,000	72	30	9	0
	1:5,000	72	27	3	0
< 1500	1:25,000	No map unit	57	10	15
	1:10,000	100	49	17	1
	1:5,000	94	43	20	0

### 5.5.3.5. Variability of PR within Different Soil Depths

The mean PR calculated for every 10 mm depth up to a depth of 100 mm using 1356 observation points (4 penetration readings at each of 339 observation points in 3 blocks) within blocks A, B and C reveals that the PR at the soil surface, at the given moisture conditions, is least and gradually increases with soil depth. After 30 mm depth the increment is very little (Figure. 5.38).

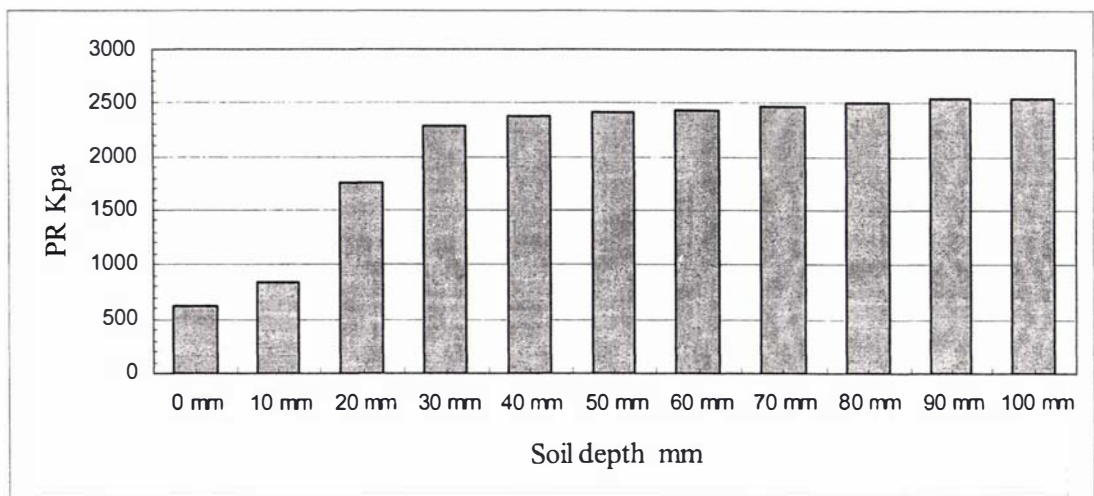


Figure 5.38 The variability of penetration resistance within the top 100 mm depth of soil in the study area.

A similar investigation was carried out for each of the four different soil types. The PR values were selected from the observation points where the soil type is known (50 m by 50 m grid e.g. 1:5,000 scale). The number of observation points used is 9 from Ohakea, 49 from Barrow, 35 from Horoeke and 33 from Coulter silt loams. The results reveal that all the four soils follow the same pattern (Figure.5.39 and Appendix 11). The four different soils clearly show that they have different bearing capacities and can be arranged as follows.

Ohakea < Barrow < Horoeke < Coulter.

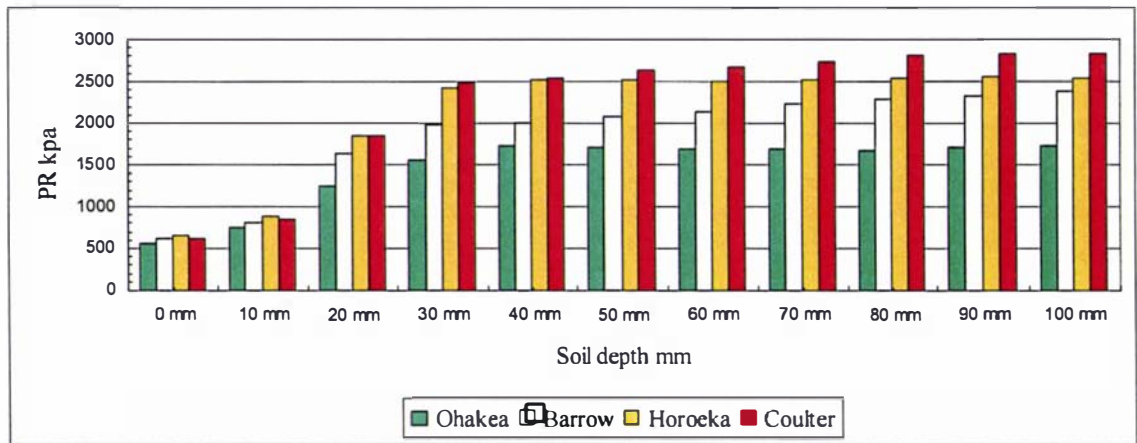


Figure 5.39 Variability of penetration resistance within the top 100 mm of the Ohakea, Barrow, Horoeoka and Coulter silt loam soils.

The PR of the topsoil is a guide to trafficability. Penetration resistance for any particular soil is related to its moisture content; the higher the moisture content the lower the penetration resistance. A critical PR value for trafficability has not been worked out for this area before. A resistance of 500 Kpa has been used as a critical value in some other studies carried out in northern Matamata County, New Zealand (McLeod, 1992) below which trafficability is inadequate and pugging can easily occur. Values between 500 Kpa and 750 Kpa are considered to represent moderate trafficability, while those higher than 750 Kpa represent adequate trafficability.

According to the results the mean PR of topsoil of the study area is always higher than the critical value (500 Kpa) even in poorly drained soils at the time of taking measurements. When considering the soil depth, again from the soil surface up to 100 mm depth PR is more than the critical value (Table 5.6). The results reveal that after 5 days of heavy rains even the poorly drained Ohakea soils are suitable for grazing. The soils are not in critical condition.

These results reveal that different soils respond to treading effects in a different manner. Poorly drained soils are more susceptible to treading effects, because they have the lowest bearing capacity. When drainage conditions are better the bearing capacity is also increased.

The PR values among the four soil types at 0 mm and 10 mm depths show little difference (Table 5.6), which indicates that all the four soils are almost equally susceptible to stock treading at these depths. The variability of PR within the top 10 mm was investigated in detail.

Table 5.6 Variability of penetration resistance at 0 and 10 mm depths in Ohakea, Barrow, Horoeka and Coulter silt loams. STDV = standard deviation  
CV = co-efficient of variation

	Ohakea	Barrow	Horoeka	Coulter
<b>0 mm depth</b>				
Mean	550	610	660	619
Range	240 - 1060	220 - 1230	190 - 2660	280 - 1070
STDV	148	139	323	152
CV	26.9	22.7	48.9	24.5
<b>10 mm depth</b>				
Mean	750	799	894	843
Range	440 - 1430	380 - 1280	260 - 2660	380 - 1660
STDV	194	172	366	208
CV	25.8	21.5	40.9	24.6

There is a huge variability of PR even within different soil depths (Appendix 12). The CV values suggest that the variability within Horoeka soils is higher than that of other soils (Table 5.6). Although the range of PR values is high the percentage distribution of PR at 0 mm depth shows that a high percentage of observations are concentrated at PR values around 500 – 700 Kpa (Figure 5.40 and Appendix 12)

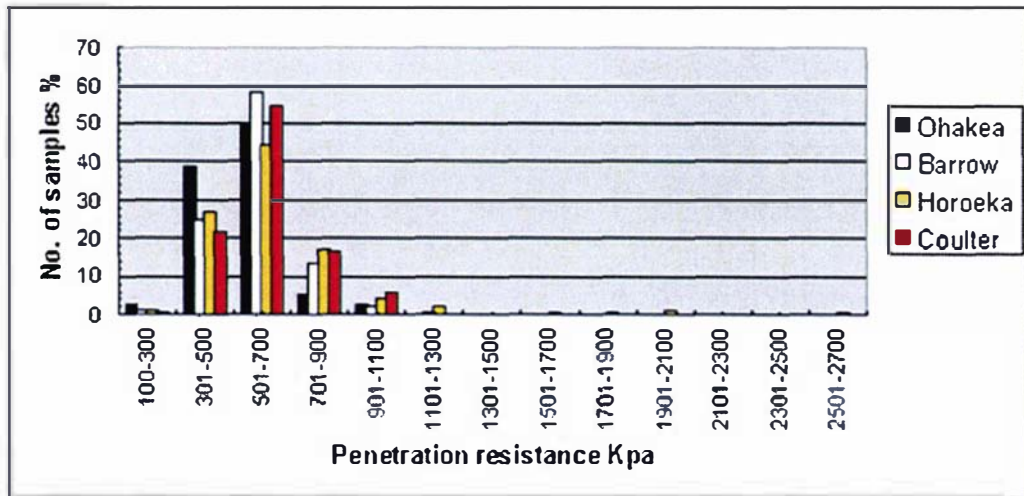


Figure 5.40 The percentage distribution of penetration resistance at 0 mm depth in Ohakea, Barrow, Horoeaka and Coulter silt loams.

At 10 mm depth, the PR values again range greatly, but a high percentage of values are concentrated around PR values of 700 – 900 Kpa (Figure 5.41 and Appendix 13). The extreme values are outliers.

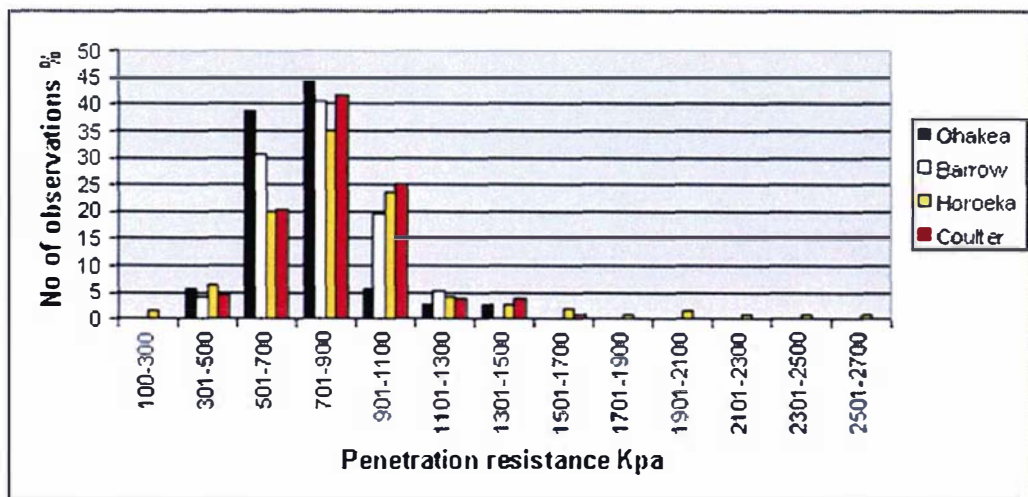


Figure 5.41 The percentage distribution of penetration resistance at 10 mm depth in Ohakea, Barrow, Horoeaka and Coulter silt loams.

The percentage number of observations below certain threshold PR values at 0 and 10 mm depth suggest that there is little difference among different soil types (Table 5.7).

The threshold values selected are just arbitrary. However, Ohakea soils show a greater number of observations below each PR value both at 0 and 10 mm depth, but Barrow, Horoeoka and Coulter soils show little difference. The results suggest that the top most 10 mm of soil is equally susceptible to treading damage irrespective of the soil type.

Table 5.7 The percentage number of observations below penetration resistance of 300, 500, 700 and 900 Kpa within Ohakea, Barrow, Horoeoka and Coulter silt loams at 0 and 10 mm depths.

PR (kpa)	Depth	Ohakea	Barrow	Horoeoka	Coulter
< 300	0 mm	3	1	1	1
	10 mm	0	0	1	0
< 500	0 mm	42	26	29	23
	10 mm	6	4	8	5
< 700	0 mm	92	84	73	77
	10 mm	44	35	28	25
< 900	0 mm	97	97	90	94
	10 mm	89	75	63	67

### 5.5.3.6. Soil Management and Penetration Resistance

It is clear from the previous section that there is a relationship between the penetration resistance of the topsoil and the soil type, but that there is variability within individual soil types. These soils have been put to different land uses. The mean PR values indicate that even under different land uses, the magnitude of PR follows the same sequence as pointed out earlier. The lowest PR values are associated with flower plots (Tables 5.8 and 5.9). The soil surface was disturbed because of tillage operations. Paddocks where sheep are grazed have lower PR values than that of cattle, because cattle exert more pressure on the soil surface than sheep. The relationship between soil types and the PR is thus altered by the influence of land use factors.

Table 5.8 The variability of penetration resistance according to land use within Coulter and Horoeke silt loams.

Management	Coulter silt loam			Horoeke silt loam		
	Mean	STDV	Range	Mean	STDV	Range
Cattle	2510	560	3560 - 1570	2390	420	3340 - 1650
Sheep	2020	370	2750 - 1230	1550	260	2080 - 90
Cattle/sheep/deer	2270	380	3120 - 1810	2820	50	4010 - 1820
Flower	1680	260	1950 - 1050	830	180	1000 - 590

Table 5.9 The variability of penetration resistance according to land use within Barrow and Ohakea silt loams.

Management	Barrow silt loam			Ohakea silt loam		
	Mean	STDV	Range	Mean	STDV	Range
Cattle	1950	300	1140 – 2470	1630	120	1540 - 1780
Sheep	1470	300	920 – 2240	1150	380	1340 - 1420
Cattle/sheep/deer	2010	510	1030 - 3100	1380	60	760 - 2530
Flower	N/A	N/A	N/A	N/A	N/A	N/A

#### 5.5.4. Conclusions

- The penetration resistance of the topsoil in the study area is highly variable and the variability is dependent on soil properties and the type of land use.
- The PR of topsoil and the PR within different soil depths are relatively low in poorly drained soils and gradually increase through imperfect, moderately well to well drained soils.
- There is a relationship between soil types and the PR. Therefore, the soil maps prepared for the study area can be used as a guide to demarcate areas with varying trafficability.
- 1:10,000 scale soil maps are the most suitable soil maps to identify these areas. 1:5,000 scale maps add little new information and are more costly to prepare.

- Well drained Coulter silt loam and the moderately well drained Horoeke silt loam soil are more resistant to pugging hazards compared to poorly drained Ohakea and imperfectly drained, Barrow silt loams. However, the top 10 mm of soil is almost equally susceptible to pugging irrespective of soil type.
- The land can be used for grazing after 5 days without any risk for pugging, even after heavy rains irrespective of soil type.

# **Use of Geostatistics in Quantification of Soil Spatial Variability: Soil Drainage, Phosphate Retention and Penetration Resistance**

## **6.1. Introduction**

In conventional soil surveys, landscapes with variable soil properties are separated into more or less homogeneous segments or management units using soil-landscape relationships. The purpose is to resolve a whole landscape into areas that can be managed uniformly for the purpose or purposes to be served by the soil map.

In northern Manawatu the soil-landscape relationship on the terraces is so complex that no conventional methods of soil mapping can explain and portray the spatial variability of soils. It is evident from the detailed soil mapping exercises conducted at various intensities in the study area near KIWITEA village that the soils occurring on the terrace lands vary spatially even at short distances (Chapter 5). If the soil distribution is spatially variable over short distance, then many soil parameters of significance to farm management are also likely to be variable. Perhaps the spatial scale of the variation of soil parameters such as drainage, phosphate retention and penetration resistance of the surface soils is so intense that small scale soil maps will have little value to farmers in making soil management decisions. If the spatial scale of variation of soil properties could be resolved by statistical means it would help in designing efficient and economical soil sampling schemes in order to adopt desirable soil management practices.

Traditionally, soil management and land use planning have been the main broad aims of soil survey at all scales. However, with increasing concern about environmental issues, soil survey has moved from subjective conjecture to more quantitative modeling with accompanying accuracy and uncertainty issues (McBratney *et al.*, 2000).

Conventional soil survey methods have in the past been criticized, perhaps justifiably, for being too qualitative in character. In response to these criticisms, quantitative models have been developed, especially within the last 30 years or so, which are being used to describe, classify and study the spatial distribution patterns of soil in a more objective way. These quantitative methods enable precise statements to be made about the soil. The methods are collectively categorized in the emerging field of soil science known as Pedometrics (McBratney *et al.*, 2000). Geostatistics is one of the powerful tools used in pedometrics to describe spatial soil variability quantitatively.

This chapter discusses the quantitative assessment of the spatial variability pattern of soil drainage, phosphate retention and penetration resistance of surface soils using geostatistics to investigate the degree of spatial dependence of these three properties on the middle terrace landscape of the northern Manawatu. These three parameters were selected because of their significance to agricultural management in the area.

## 6.2. A New Concept: Pedometrics

Pedometrics is an emerging discipline that concerns the use of numerical and statistical methods in soil science. Pedometrics is not new, as mathematical and statistical methods have been applied to soil science since at least the 1960s. However, it was first formally recognized as a different branch of soil science to traditional pedology just over a decade ago (McBratney *et al.*, 2000).

The term pedometrics was first introduced by A.B. McBratney. The definition of pedometrics in his own words is “Pedometrics is a neologism derived from the Greek roots, pedos [soil] and metron [measurement] and is formed and used analogously to other words such as biometrics, psychometrics, econometrics, chemometrics and the oldest of all geometrics. This definition covers two main ideas associated with

pedometrics but in a highly restricted way. We see that measurement has been restricted to mathematical and statistical methods, and the soil part corresponds to that branch of soil science we call pedology” ([http://www.essc.psu.edu/pedometrics/what\\_is.html](http://www.essc.psu.edu/pedometrics/what_is.html)).

There are a number of pedometric techniques that are presently being used for soil survey data analysis. The most common methods used at present are geostatistics, classical statistics and a combination of the two. Two more recently emergent techniques are fuzzy sets or fuzzy logic and pedodiversity. (McBratney *et al.*, 2000).

There is an enormous potential for application of pedometrics in the fields of soil survey and mapping, evaluation and planning, environmental assessment, precision agriculture, sampling strategy and design, modeling of dynamic processes, error management and decision support. These topics were addressed at the 4<sup>th</sup> conference of the working group on pedometrics of the international union of soil sciences held in Ghent, Belgium in September 2001 (<http://soilman.rug.ac.be/pedometrics2001/pedomframe.html>).

## **6.3. Geostatistics and Its Principles**

### **6.3.1. Initiation and Evolution**

Geostatistics is a young subject that was developed initially in the 1960's. The prefix geo- is usually associated with geology, since geostatistics has its origins in mining geology. Professor George Matheron (1930-2000) is the founder of geostatistics. From 1954 to 1963, while working with the French Geological Survey in Algeria and France, Matheron discovered the pioneering work of the South African school on the gold deposits of the Witwatersrand, and built the major concepts of the theory for estimating resources he named Geostatistics (<http://cg.ensmp.fr/GM/index.shtml/HomePage.html>). Matheron brought together numerous isolated results into a coherent body of theory, and together with his colleagues in the French mining schools developed the theory of regionalized variables. D.G. Krige applied the theory and did empirical work in gold mines of South Africa. The estimation technique known as “Kriging”, that is often used

in geostatistics is so named to honour him for his work towards the development of the subject (Webster and Oliver, 1990; Oliver and Webster, 1991).

Geostatistics seems to have developed separately from the mainstream of statistics. Most of the technical terms used in geostatistics still remain very close to the terms used in mining geology. The subject arose from the need to improve the estimates of ore concentrations in rock and of recoverable reserves from fragmentary information. Miners working in gold mines of South Africa realized that the ore concentrations in the neighborhood of a block were more like those within the block, than those farther away, and they found ways of taking this fact into account to improve their estimates.

Although geostatistics came into practice very recently compared with agricultural and multivariate statistics, its applications are developing rapidly.

Geostatistics involves the analysis and prediction of spatial or temporal phenomena. Nowadays, geostatistics is just a name associated with a class of techniques used to analyze and predict values of a variable distributed in space or time. Such values are implicitly assumed to be correlated with each other, and the study of such a correlation is usually called "variogram modeling." After variogram modeling, predictions at unsampled locations are made using "kriging" (<http://www.ai-geostats.org/geostats>).

### **6.3.2. Spatial Dependence**

Standard statistical methods assume that observations of soils, plant populations, rock samples etc. taken from different places of the earth's surface are independent. But this is rarely true, as properties on the earth surface vary continuously in space. As a consequence, values of sites that are close together tend to be more similar than those from farther apart (Webster and Oliver, 1990). The values of properties at one location depend on the values nearby in a statistical sense. This phenomenon is known as spatial dependence. Geostatistics provides the means of investigating the spatial dependence or the spatial scale of the variability of properties of natural resources and assumes that adjoining points are correlated to each other spatially.

### 6.3.3. Regionalized Variables

Land surface variables such as observations of soils, rock samples, plant populations are known as regionalized variables. They have properties that are intermediate between a fully random variable and a fully deterministic one. This means that although they are continuing over an entire surface the complexity of the surface is such that it cannot be described easily by a deterministic function such as a trend surface. Geostatistics assumes that adjoining points are correlated to each other spatially and continuity can be measured and used for estimation. The semivariance is used to find the rate at which a regionalized variable changes along a specific direction. This is achieved by calculating a type of variance ([http://149.170.199.144/new\\_gis/](http://149.170.199.144/new_gis/)). The concept of a regionalized variable is very important in spatial statistics.

### 6.3.4. The Variogram and its Estimation

The variogram is central to all of geostatistical analysis. It is used to model the way two values in space or time are correlated. It expresses mathematically the way in which the variance of a property changes as the distance and direction separating any two points varies. Most people intuitively know that two values in space that are close together tend to be more similar than two values farther apart. Two distributions might have the same mean and variance, but differ in the way they are correlated with each other. Geostatistics quantifies the correlation between any two values separated by a distance  $h$  (usually called the lag distance). Variograms model this spatial correlation structure. If the variogram shows that there are high correlations; predictions will be feasible at unsampled locations using kriging.

Consider two places some distance apart (called the lag, and denoted by  $h$ ) at which a measured property  $z$ , has values  $z_1$  and  $z_2$ . The variance ( $\sigma^2$ ) between these two values is a measure of how different they are.

Using the variance equation,

$$\sigma^2 = \frac{1}{N-1} \sum_{i=1}^N (z_i - \bar{z})^2,$$

where  $N$  is the number of samples. When considering the case,  $N = 2$

$$\sigma^2 = (z_1 - \bar{z})^2 + (z_2 - \bar{z})^2,$$

where  $\bar{z}$  is the mean of  $z_1$  and  $z_2$ .

So 
$$\bar{z} = \frac{z_1 + z_2}{2}.$$

Therefore, 
$$\sigma^2 = \left(z_1 - \frac{z_1 + z_2}{2}\right)^2 + \left(z_2 - \frac{z_1 + z_2}{2}\right)^2$$

Simplifying this gives

$$\sigma^2 = \frac{1}{2}(z_1 - z_2)^2.$$

This equation can be generalized for any two places as follows.

Let the two places be  $x$  and  $x + h$ . The variance between properties at  $x$  and  $x + h$ , is

$$\sigma^2 = \frac{1}{2} \{z(x) - z(x + h)\}^2.$$

Suppose that  $z$  has been measured at numerous places along a transect at regular spacing or lag distance. The number of paired observations made along the transect is  $M$ . Then we assume that the average of the variance for all the pairs gives us a good indication of how similar the value of property  $z$  at any point along the transect is to the value of property  $z$  at a distance  $x + h$ . This estimate is called the population semivariance and is calculated from the following equation.

$$\hat{\gamma}(h) = \frac{1}{2M} \sum_{i=1}^M \{z(x_i) - z(x_i + h)\}^2,$$

where  $\hat{\gamma}$  is the semivariance and  $x_i$  is the position of each pair of samples. The function relating the semivariance to the lag is called the semi-variogram or sometimes just the variogram.

### 6.3.5. Interpretation of Variograms

The variogram of a soil property may have different shapes and contains some valuable information about the spatial structure of the given soil property.

Typically, the semivariance increases with the lag distance, and reaches a maximum at which it levels out. This maximum is known as the sill. When the semivariance reaches its sill it is bounded. The lag distance at which the sill is reached is called the range. The range marks the limit of spatial dependence of the soil property (Webster and Oliver, 1990). It is evident from the Figure 6.1 (A) and (B) that the semivariance is small at short lags and increases steadily with increasing lag distance. This means that the properties at short distances show a strong correlation or spatial dependence and this dependence weakens as the separation increases. Beyond the range, variance bears no relation to the separating distance.

Alternatively, the semivariance might increase indefinitely as shown in Figure 6.1(B) and is known as unbounded variation. This represents Fairfield Smith's law (1938). He found that as the size of plots increased the variance of yields within the plots increased indefinitely and approximately in proportion to the logarithm of the area. This type of variation is well known in mining geology.

Another characteristic feature of variograms is shown in Figure 6.1(C). By definition, the semivariance at lag zero is itself zero. However, some variograms do not cross the zero point, and seem to approach a positive finite intercept on the ordinate at  $h = 0$ . This intercept is called the nugget variance and the phenomenon is known as the nugget effect. The term nugget effect derives from gold mining, where gold nuggets are sparse and small and occur at distances much smaller than the spacing between the sampling cores. Therefore, the inclusion of a gold nugget in a drill core is regarded as a purely random event (Webster and Oliver, 1990). In soil science and other geostatistical

applications, nugget effects occur frequently, and are interpreted as a random variation that cannot be resolved within the given sampling scheme.

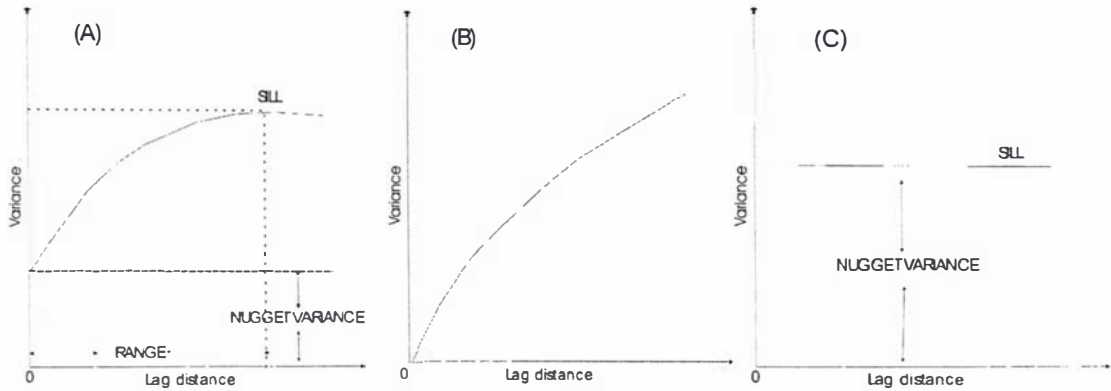


Figure 6.1 Different forms of variograms (A) Bounded, (B) Unbounded (C) Pure nugget

Some variograms appear completely flat (Figure 6.1C) and this phenomenon is known as pure nugget variation. This indicates that there is no spatial dependence in the data. With continuous variables the nugget variance does arise partly from measurement error, though this is usually small in relation to the spatial variation. The principle cause is usually spatially dependent variation that occurs over distances much smaller than the shortest sampling interval. The true shape of the variogram in this range can be identified only by denser sampling (Webster and Oliver, 1990).

## **6.4. Spatial Variability Experimental Design**

### **6.4.1. Field Observations and Soil Sampling Methodology**

Refer to section 5.2 for details of the field experimental design.

### **6.4.2. Construction of Semivariograms (variograms)**

The spatial dependence of soil drainage, phosphate retention and penetration resistance was assessed by means of semivariograms.

#### **Step 1:**

Semivariograms were constructed for Blocks A, B and C (see Figure 5.4), considering observations taken parallel to the direction of the river flow (“along transect” -NW direction), and perpendicular to the direction of the river flow (“across transect”-NE direction) to investigate whether the variation of the three selected soil properties shows any directional variability (anisotropy). The formula given in Section 6.3.4 was used to calculate semivariance. The maximum lag distance considered was 250 m for both directions. The graphs were constructed using Microsoft Excel.

#### **Step 2:**

Semivariograms were constructed for the large window area (2000 m by 300 m) for drainage and P-retention to investigate the long trend variability along transect. The maximum lag distance considered was 1000 m

## 6.5. Spatial Variability of Soil Drainage

### 6.5.1. Methodology

Refer to Figure 5.3 for details of the experimental design and Section 5.3.2.1 for the methodology for soil drainage class mapping. Semivariograms were constructed according to the method described in Section 6.4.2. The four drainage classes were assigned different numeric values in constructing variograms. These values correspond to the depth (cm) to reductimorphic features (see Section 3.2.6). They are: poorly drained = 30; imperfectly drained = 60; moderately well drained = 80 and well drained = 100.

The numbers of paired observations considered in constructing variograms for the individual blocks and the large window area are given in Table 6.1 and Table 6.2 respectively.

Table 6.1 The numbers of paired observations at each lag distance considered when constructing the variograms for blocks A, B and C.

Lag distance (m)	Number of paired observations	
	Along transect	Across transect
50	35	36
100	28	30
150	21	24
200	14	18
250	7	12

Table 6.2 Numbers of paired observations at each lag distance considered when constructing the variograms for the 2000 m by 300m window area.

Lag distance (m)	50	100	150	200	250	300	350	400	450	500
Number of observations	117	140	87	100	68	76	73	84	63	94
Lag distance (m)	550	600	650	700	750	800	850	900	950	1000
Number of observations	63	80	49	66	35	52	36	48	32	44

## 6.5.2. Results and Discussion

The variograms constructed to investigate the variability of soil drainage in block A (Figure 6.2) reveal that the semivariance along the transect increases gradually with increasing lags and reaches its maximum at a distance of about 150 m and then drops. In contrast, although the semivariance across the transect is similar to that along the transect up to 100 m, beyond 100 m the semivariance across the transect continue to increase until it reaches its maximum (sill variance) at 200 m distance.

Typically, the semivariance increases with the lag distance, until it reaches a maximum, at which point it levels out indicating that there is no spatial dependence at greater lags. However, in block A, along and across transect variability reaches the sill variances and then drops again, apparently indicating spatial dependence between observations that are far apart. This situation is possible when similar drainage conditions occur in the field at regular intervals across and along transects over long lags. The soil map produced at 1:5,000 scale (see Figure 5.8A) for block A reveals that a similar soil pattern repeats over and over again when taking traverses along and across the area. The soil pattern across the transect (in the NW direction) changes from Barrow to Horeka, back again to Barrow, and then to Ohakea. The pattern along transect is either from Barrow to Ohakea and back again to Barrow, or from Horeka to Barrow and then to Horeka again.

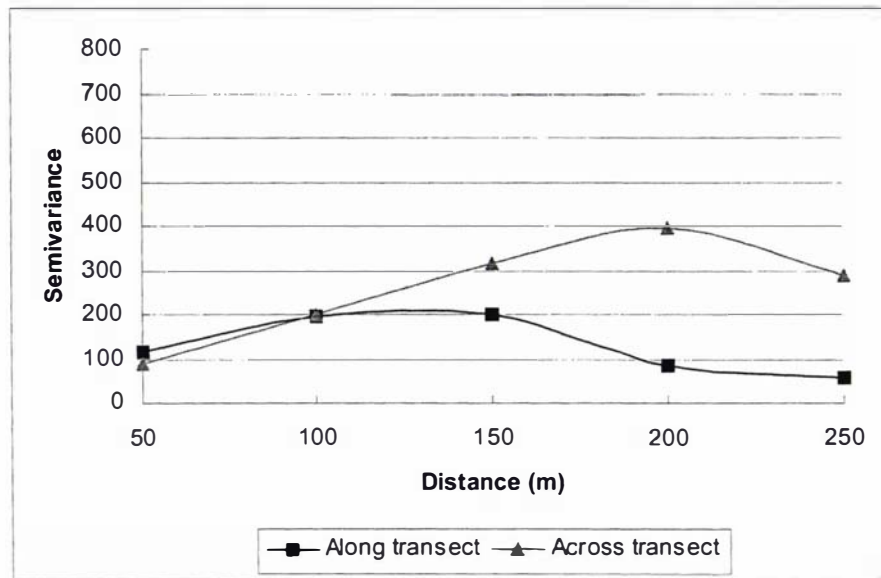


Figure 6.2 A variogram showing directional variability of soil drainage in block A.

Beyond 100 m distance, semivariance across the transect is greater than that along the transect at every lag distance indicating greater variability of drainage properties across the block than along the block at longer lags. The soil map at 1:5,000 scale (see Figure 5.8A) shows that the drainage properties across the block range from poor through imperfect to moderately well drained, indicating greater variability compared to the drainage properties along the block that range either from imperfect to poor, or imperfect to moderately well drained.

The variogram (Figure 6.2) shows that there is little difference between semivariances in either direction up to a distance of 100 m indicating similar variability of soil drainage, along and across the block at short lags. Thus, the variability is isotropic, up to a distance of 100 m. Beyond that the variability of soil drainage in block A is anisotropic with the variability being greater across the block than along the block (Table 6.3).

In block B, semivariance along the transect increases with the lag distance (Figure 6.3) and has not reached its sill within the maximum lag distance investigated (250 m). This shows that the observations are still showing spatial dependence out to this distance.

However, semivariance across the transect reaches its sill around 100 m distance and drops again indicating greater correlation between observations that are far apart. The repetitive nature of the soil drainage pattern at longer lags is evident from the soil map at 1:5,000 for block B (see Figure 5.8B).

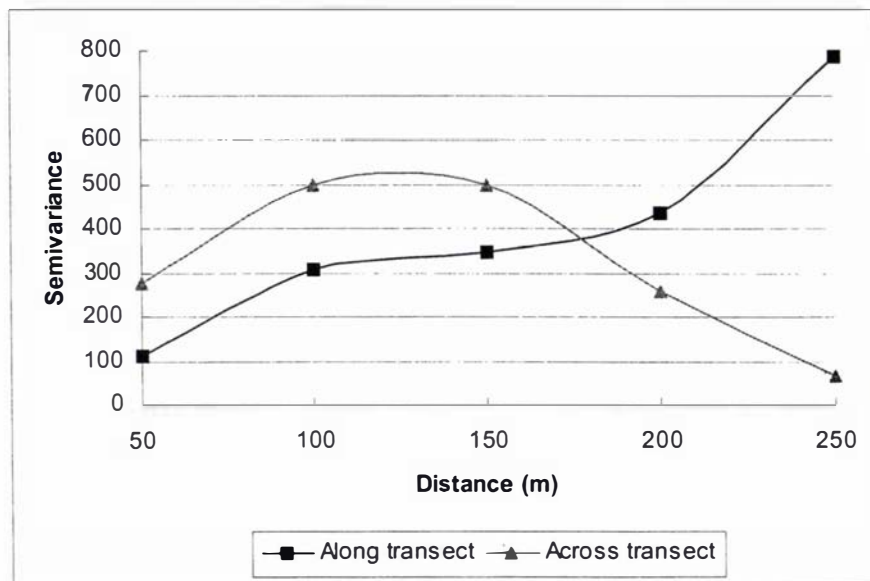


Figure 6.3 A variogram showing directional variability of soil drainage in block B.

The semivariance across the transect is greater than that along the transect up to about 175 m and beyond that it reverses. As explained for block A, the drainage pattern changes quite frequently across the block at short lags (see Figure 5.8B) compared to the drainage pattern along the block. However, at longer distances the semivariance along the block is greater because the transect cuts through soils ranging from poorly drained to well drained.

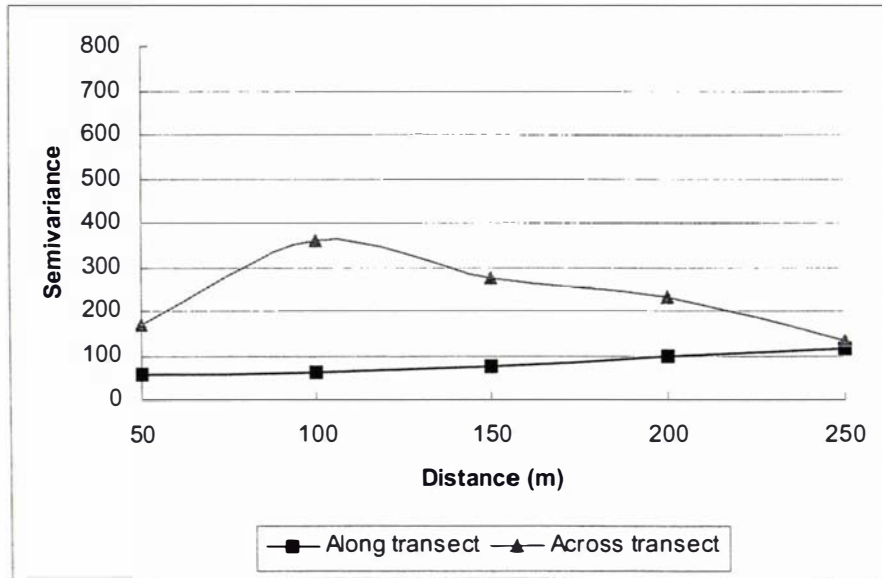


Figure 6.4 A variogram showing directional variability of soil drainage in block C.

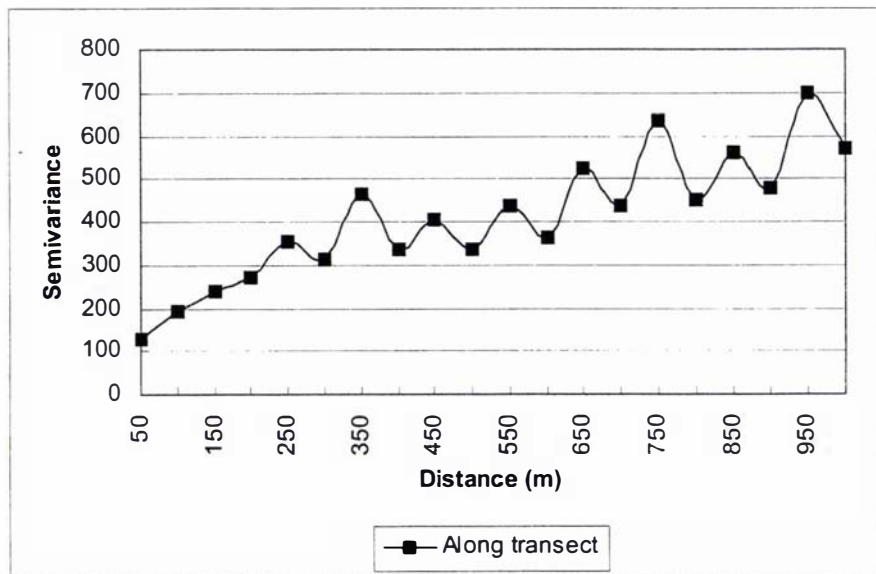


Figure 6.5 A variogram showing along transect variability of soil drainage in the 2000 m by 300 m window area.

In block C drainage variability is also anisotropic. Along-transect variability increases with the lag distance (Figure 6.4) and has not reached its sill within the maximum

distance investigated (250m). The semivariance across-transect reaches its maximum at 100 m distance and then decreases until it is very close to the along transect semivariance at 250 m. As explained for blocks A and B, the soil drainage pattern (see Figure 5.8C) across block C varies rapidly compared to the drainage pattern along the block. The semivariance along the block is very low and increases only slightly with increasing lag, because the transect along the block cuts through similar drainage classes most of the time (see Figure 5.8 B).

The analysis of variograms reveals that the semivariances along the transect in blocks B and C have not reached the sill variances within the lag distance considered (250 m). Therefore, a variogram was constructed taking longer lags for the 2000 m by 300 m window area (Figure 6.5) to investigate whether the semivariance parallel to the direction of the river flow eventually reaches a sill variance. The variogram shows that the semivariance keeps increasing with increasing lag, even up to 1000 m, indicating its unbounded nature.

Although there are some differences between along and across-transect variability within the blocks, in general across-transect variability of soil drainage is greater in this middle terrace. This may be due to the different physical properties, influencing soil drainage, of alluvial sediments, deposited parallel to the river. The properties of alluvial sediments along the river can be expected to be less variable compared to across transect. This is explained more fully in Section 6.8.

The information presented above can be used to design soil-sampling programs particularly for soil mapping. It is apparent that there is spatial dependence up to 100 – 200 m across the blocks and up to 150 m to >>250 m along the blocks (Table 6.3). This gives an approximate idea of the “size” of the land unit that has at least some commonality in soil properties. This size is significant for two reasons.

Firstly, it is of a scale (1-3 hectares) that is directly relevant to the management of individual farms. Paddocks are typically of this size, and so knowledge of soil properties at this scale can inform decisions on sub-division, timing of grazing and cultivation, and selection of crops or varieties. In contrast, if the sill semi-variance is reached at lags of 1-30 m there may be little of practical benefit to the farmer in taking account of the variation in soil properties. Also, if semi-variance is large only at lags of

several kilometres, then this may influence a decision of where to purchase a farm, but not day-to-day management decisions within a farm.

Secondly, the extent of spatial dependence gives some idea of the maximum distance at which samples should be taken. If samples are taken at distances greatly in excess of this lag, it is likely that “units” of land with completely contrasting properties will not be mapped. Given that the differences in soil properties (well drained - poorly drained) between soils are large enough to have management implications, and that the sizes of the land units are relevant to farming operations, and are large enough to be mapped in a practical sense, it would be undesirable if the scale of mapping was such that whole “units” of soil could be missed.

Table 6.3 A summary of lag distances and maximum semivariances (sill) reached for soil drainage in blocks A, B, C and the 2000 m by 300 m large window area.

Study area	Across transect		Along transect	
	Lag distance (m)	Sill variance	Lag distance (m)	Sill variance
Block A	200	397	150	198
Block B	100	500	250	786 *
Block C	100	360	250	114*
Large window area	ND	ND	950	700

\* This is not the sill variance reached within blocks. It is the maximum semivariance reached within a lag distance of 250 m.

Although the exact implications of the variograms to soil sampling require further investigation, it is clear that the soils vary more quickly with distance across the blocks than along them. Therefore, sampling schemes that are optimized to produce the best information per unit of resource input (time/money) should have a greater sampling intensity across the blocks than along them in this landscape.

This was demonstrated in the soil mapping exercise in the area. The soil map produced at 1:25,000 scale (map 1) taking observations at 250 m apart was unable to show all the drainage classes within 300 m by 250 m blocks. However, when observation intervals reduced to 100 m and 50 m (see Figures 5.7 and 5.8) all the drainage classes could be mapped within the blocks.

If a particular land use was very dependant on a soil property, then more detailed soil mapping might be required. However, sampling distance should be less than the maximum lag distance.

## 6.6. Spatial Variability of Phosphate Retention

### 6.6.1. Methodology

Semivariograms for P-retention were constructed according to the method described in Section 6.4.2. Refer back to Figure.5.4 in Section 5.2 for the details of the experimental design and to Sections 5.4.2.1 and 5.4.2.2 for methods of soil sampling and chemical analysis respectively.

The numbers of paired observations considered in constructing variograms for the large window area and individual blocks are given in Table 6.4 and Table 6.5 respectively.

Table 6.4 Numbers of paired observations at each lag distance considered when constructing the variograms for blocks A, B and C.

Lag distance (m)	Number of paired observations	
	Along transect	Across transect
25	70	72
50	93	96
75	56	60
100	73	79
125	42	48
150	53	62
175	28	36
200	33	45
225	14	24
250	13	28

Table 6.5 Numbers of paired observations at each lag distance considered when constructing the variograms for the 2000 m by 300m window area.

Lag distance (m)	25	50	100	150	200	250	300	350	400	450
Number of observations	210	117	140	87	100	68	76	73	84	63
Lag distance (m)	500	550	600	650	700	750	800	850	900	950
Number of observations	94	63	80	49	66	35	52	36	48	ND

## 6.6.2. Results and Discussion

Data on the directional variability of P-retention in block A (Figure 6.6), block B (Figure 6.7) and block C (Figure 6.8) reveal that the semivariance along the transect keeps increasing with the increasing lags, so that the variograms appear to be unbounded within the distance of 250 m. However, data from the 2000 m by 300 m window (Figure 6.9) suggest that the semivariance at lags of 250 m along the transect is in fact very similar to the sill variance parallel to the river on the terrace (Table 6.6). The slopes of the graphs and the magnitudes of the semivariances (Table 6.6) indicate that the variability of P-retention along the transect increases in the order block B > block A > block C. This trend is the same as the one for drainage variability along the transect (see Table 6.3).

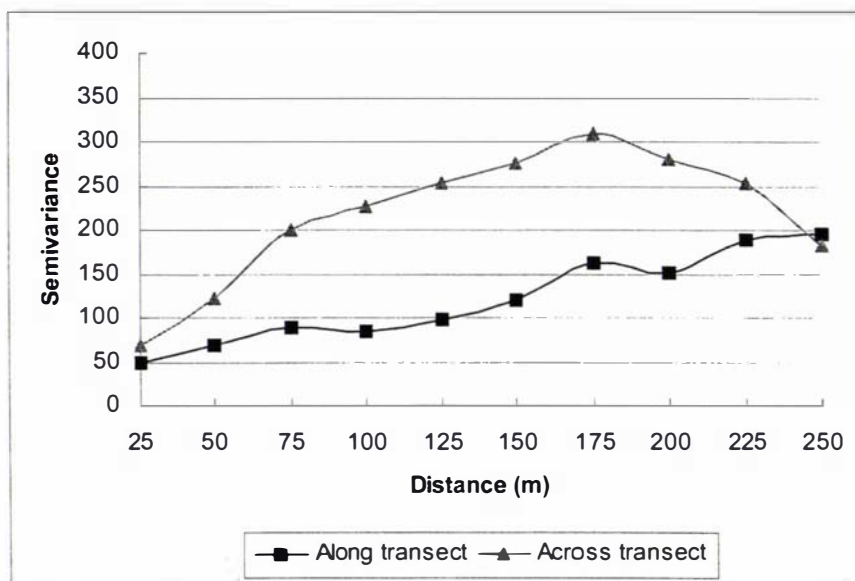


Figure 6.6 A variogram showing directional variability of P-retention in block A.

The semivariances across the blocks are greater than those along the blocks at short lags, indicating that the variability of P-retention within the blocks is anisotropic within short distances. The soil maps at 1:10,000 (see Figure 5.7) and 1:5,000 (see Figure 5.8) scale for blocks A, B and C also suggest that the soil drainage variability pattern is greater across the transect compared to along the transect.

The semivariances across the blocks reach their maximum at lags of 175 m in block A (Figure 6.6), 150 m in block B (Figure 6.7) and 100 m in block C (Figure 6.8), and then drop again, indicating greater correlation between observations that are far apart.

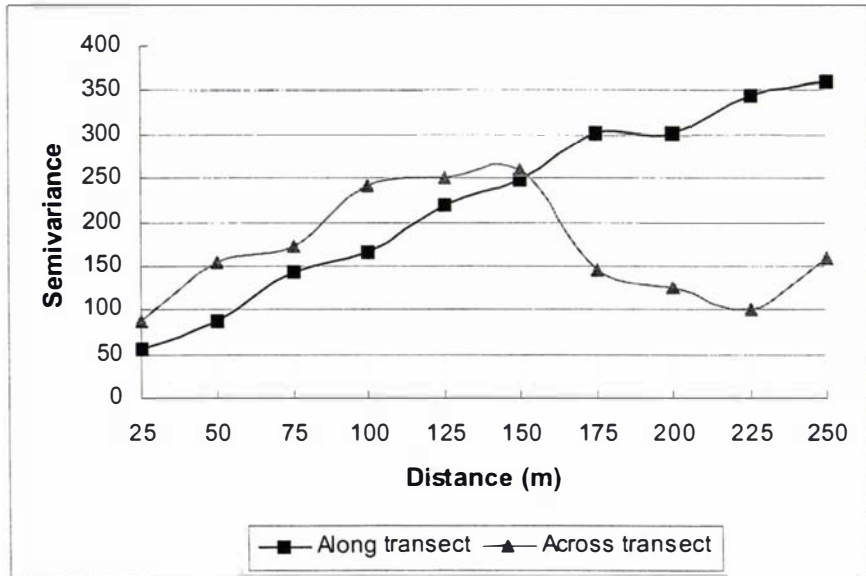


Figure 6.7 A variogram showing directional variability of P-retention in block B.

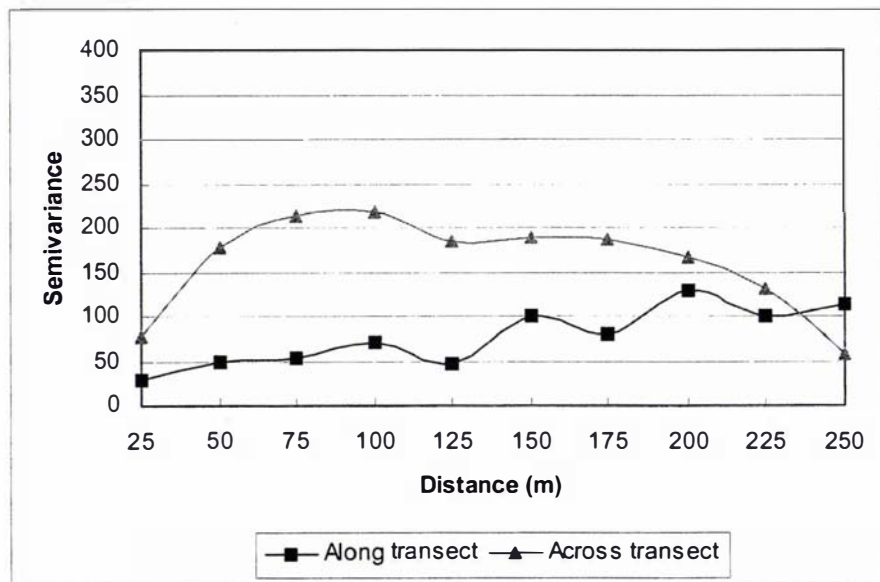


Figure 6.8 A variogram showing directional variability of P-retention in block C.

This is possible, because of the repetition of the soil pattern as explained for the drainage variability in the previous section. This indicates that the maximum variability of P-retention across the blocks lies between 100 - 175 m.

As discussed in Section 5.4.3.4, there is a close relationship between soil drainage and P-retention. The variability of drainage along and the across the area follows a similar pattern to the variability of P-retention along and across the area.

The variogram constructed to investigate the maximum spatial dependence of P-retention along the transect at longer lags ( $> 250$  m) considering the 2000 m by 300 m window area (Figure 6.9), reveals that the semivariance reaches its maximum at 500 m.

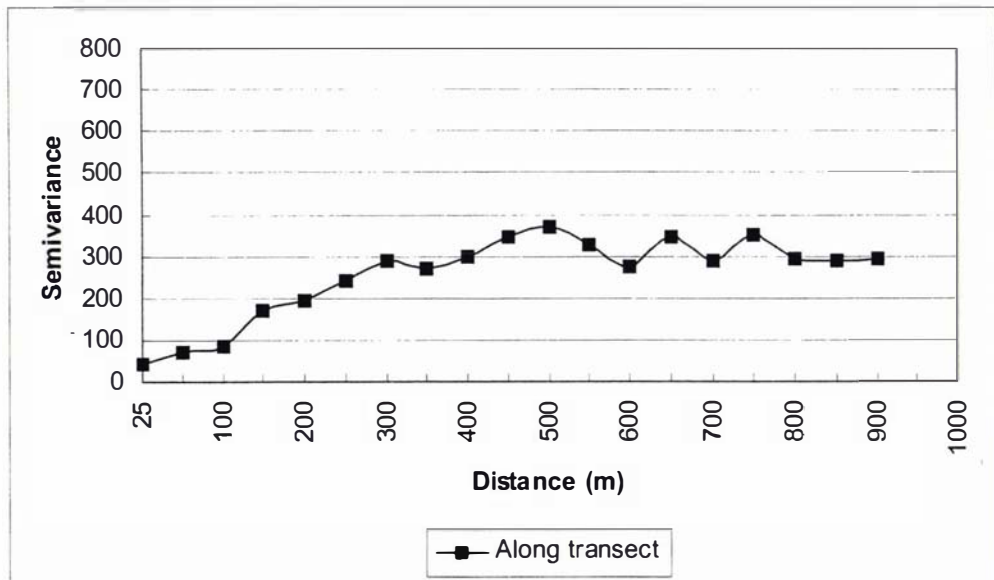


Figure 6.9 A variogram showing along transect variability of P-retention in the 2000 m by 300 m window area.

Table 6.6 A summary of lag distances and maximum semivariances (sill) reached for P-retention in blocks A, B, C and the 2000 m by 300 m large window area.

Study area	Across transect		Along transect	
	Lag distance (m)	Sill variance	Lag distance (m)	Sill variance
Block A	175	310	250	195*
Block B	150	260	250	360 *
Block C	100	217	250	129*
Large window area	ND	ND	500	367

\* This is not the sill variance reached within blocks. It is the maximum semivariance reached within a lag distance of 250 m.

There is a spatial dependence of P-retention up to 100 – 175 m across the area and up to 500 m along the area. As discussed in the previous section for drainage variability, this scale of variability is relevant to farming decisions, such as calculation and application of appropriate rates of fertilizer. This is particularly the case in the present study as the range in P retention (15-86%) is large enough to have significant implications for fertiliser use. To obtain sufficiently detailed soil maps for this purpose the maximum sampling distance across the area should be between 100-175 m and along the area at 500 m intervals (Table 6.6). Thus, P-retention maps at 1:10,000 (100 m by 100 m) would be more than sufficient for practical use, but maps at 1:25,000 would not. There would, however, be scope to expand the sampling interval along the terrace to spacings appropriate for 1:25,000 scale, or even 1:50,000, as long as the sampling interval across the terrace was maintained at spacing appropriate for 1:10,000 scale.

## 6.7. Spatial Variability of Penetration Resistance

### 6.7.1. Methodology

Variograms for penetration resistance (PR) were constructed according to the method described in Section 6.4.2. Refer back to Figure 5.4 of Section 5.2 for the details of the experimental design and to Section 5.2.2.3 for the details of penetration resistance measurements. The numbers of paired observations at each lag distance considered when constructing the variograms for blocks A, B and C are give in Table 6.5

### 6.7.2. Results and Discussion

The variograms for block A (Figure 6.10), block B (Figure 6.11) and block C (Figure 6.12) reveal that semivariances along the transect increase with increasing lag distance and are unbounded within the distance of 250 m. The maximum semivariance reached within blocks is 0.8 in block C, 0.62 in block B and 0.22 in block A (Table 6.7). These values indicate the maximum semivariance of PR that can occur along the transect within each block. This sequence block C > block B > block A is different from that of drainage and P-retention (block B > block A > block C).

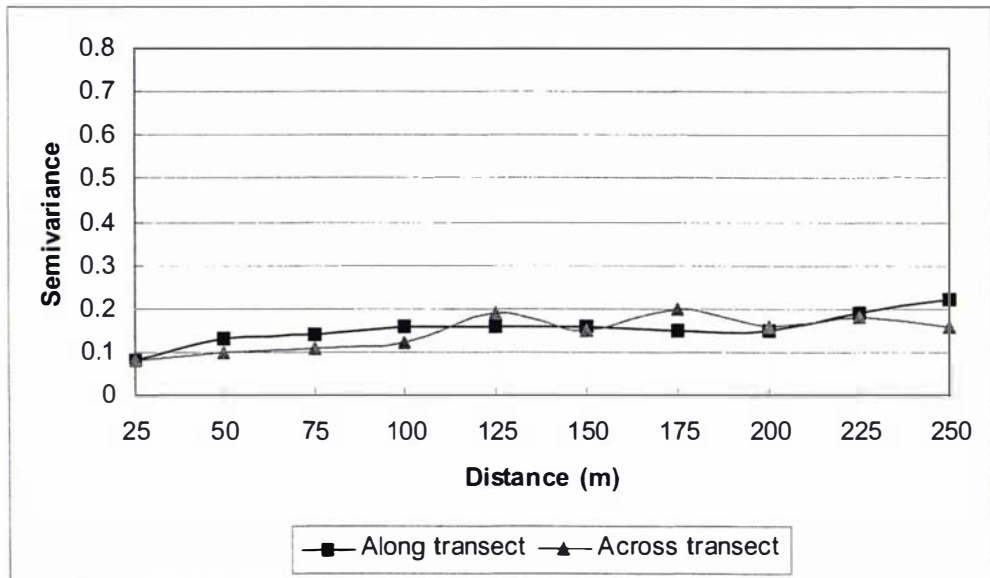


Figure 6.10A variogram showing directional variability of penetration resistance in block A.

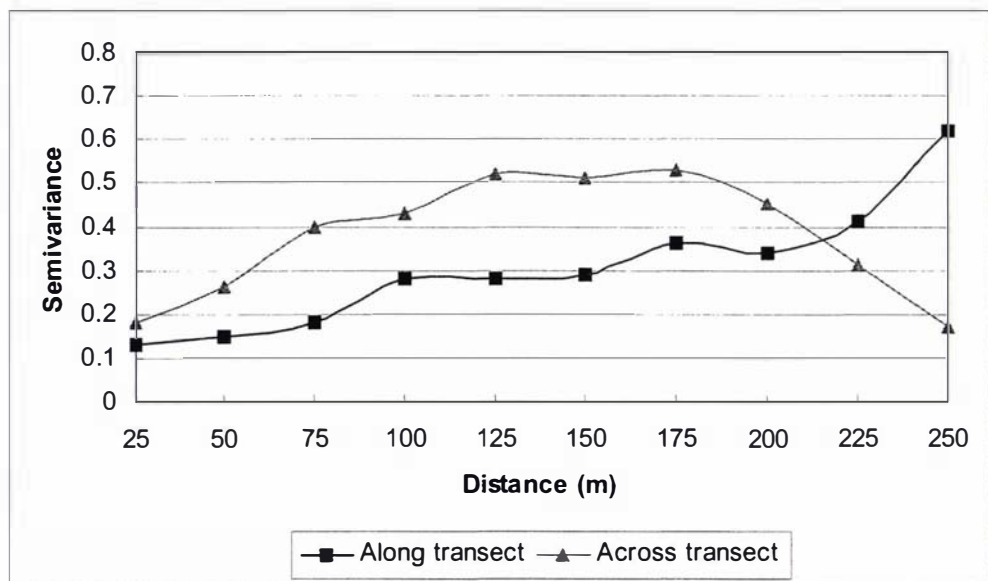


Figure 6.11A variogram showing directional variability of penetration resistance in block B.

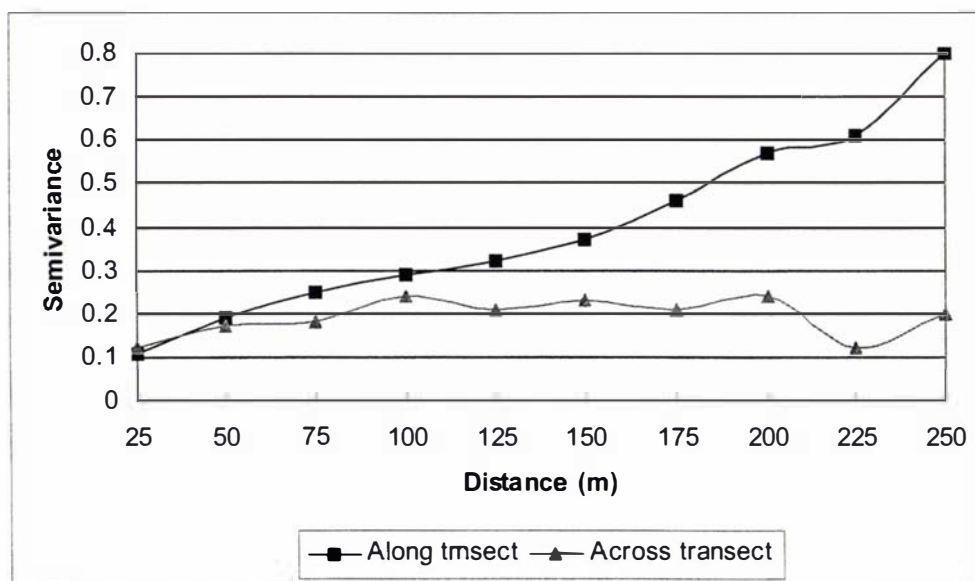


Figure 6.12 A variogram showing directional variability of penetration resistance in block C.

Semivariance across the transect also increases with increasing lag and comes to a maximum at 175 m in block A and block B and at 100 m in block C. Beyond the sill semivariances again decrease.

The variograms show that the variability of PR in block A is very close to isotropic (Figure 6.10). However, the variability is anisotropic in both blocks B and C, with variability of PR across block B being greater than that along the block at short lags (Figure 6.11).

Although there is a close relationship between soil drainage and penetration resistance (see Section 5.5.3.3), the sequence of drainage variability does not follow the sequence of PR variability. This is because land use and soil management practices also influence the PR of the topsoil (see Section 5.5.3.6).

Table 6.7 A summary of lag distances and maximum semivariances (sill) reached for PR in blocks A, B and C.

Study area	Across transect		Along transect	
	Lag distance (m)	Sill variance	Lag distance (m)	Sill variance
Block A	175	0.20	250	0.22*
Block B	175	0.53	250	0.62 *
Block C	100	0.24	250	0.80*

\* This is not the sill variance reached within blocks. It is the maximum semivariance reached within a lag distance of 250 m.

As explained for the variability of soil drainage and P-retention, the maximum variability of PR also ranges from lags of 100-175 m across the blocks. The maximum spatial dependence along transect was not investigated. The lag distance is similar to the “size” of a management unit. Therefore, mapping of different PR classes may be useful in adopting land use and management practices.

Maximum sampling distance across the terrace can be between 100-175 m. Along the terrace the distance can be maintained at 250 m intervals. PR maps at 1:10,000 or larger scale would be able to separate different PR classes.

## 6.8. Summary and Conclusions

The spatial variability of soil drainage, phosphate retention and penetration resistance of the topsoil is anisotropic over the intermediate terrace. The variability is greater across the terrace than along the terrace (Table 6.5). The maximum variability occurs at shorter lags across the terrace and at longer lags along the terrace.

The maximum variability of soil drainage, P-retention and PR across the terrace occurs at lags that range from 100 - 200 m whereas the maximum variability along the terrace is reached at 500 m for P-retention and has not been reached within 1000 m for drainage (Table 6.5).

The greater variability of soil properties across the area perpendicular to the river flow direction can be attributed to the greater variability of original alluvial sediments

deposited across the area. The pattern of variability can be attributed to a “fluvial” pattern of soil map units, reflecting fluvial depositional processes. Such “fluvial” patterns are seen for example in Paparua County (Cox, 1978), Waikato (Molloy, 1993) and Piako County (Wilson, 1980).

Table 6.8 A summary of lag distances and maximum semivariances (sill variance) reached for soil drainage, P-retention and PR in blocks A, B, C and the 2000 m by 300 m large window area.

Study area	Across transect		Along transect	
	Lag distance (m)	Sill variance	Lag distance (m)	Sill variance
Soil drainage				
Block A	200	397	150	198
Block B	100	500	250	786 *
Block C	100	360	250	114*
Large window area	ND	ND	1000	700
P-retention				
Block A	175	310	250	195*
Block B	150	260	250	360 *
Block C	100	217	250	129*
Large window area	ND	ND	500	367
Penetration resistance				
Block A	175	0.20	250	0.22*
Block B	175	0.53	250	0.62 *
Block C	100	0.24	250	0.80*

\* This is not the sill variance reached within blocks. It is the maximum semivariance reached within a lag distance of 250 m.

Knowledge of the soil variability pattern along and across the area is useful in designing soil-sampling schemes. The variogram gives an indication of the maximum range of variability of soil properties within the area. Soil sampling distance should be within the range of maximum variability in order to capture all the variations. Further variogram analysis is required to decide exact sampling intervals. Exact sampling intervals are also dependant on the precision required to be shown on maps. This is dependant on the significance of observed difference in soil properties to land use practices.

Geostatistical results also reveal that 1:10,000 scale soil maps (100 m by 100 m sampling interval) are capable of capturing variability of soil drainage, P-retention and PR of soils within the area. Therefore, for detailed farm scale planning the most suitable

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scale of soil mapping is 1:10,000. However, soil sampling intensity can be increased to 250 m instead of 100 m intervals along the area. This will help save time and cost in soil survey.

## **Factors Influencing Soil Spatial Variability in the Study Area**

### **7.1. Introduction**

The spatial distribution pattern of drainage, phosphate retention and penetration resistance of soils of the study area was discussed in detail both qualitatively in Chapter 5 and quantitatively in Chapter 6. This chapter is devoted to discuss the possible reasons for such variability in soil drainage and the phosphate retention within the landscape of the study area.

It is clear that the drainage properties of soils on the intermediate terrace are highly variable even within a short distance and also have little relation to the topography of the land surface (Chapter 5). There is a clear relationship between soil drainage properties and the phosphate retention (Chapter 5). Furthermore well-drained soils with high phosphate retention properties contain allophane in their clay fraction whereas imperfectly to poorly drained soils with low phosphate retention properties have no allophane in their clay fraction (Chapter 4). From these observations it is apparent that soil drainage, phosphate retention and presence or absence of allophane in the clay fraction is all interrelated. Also, many soil management practices in the area are governed by soil drainage and presence or absence of allophane in the clay fraction.

Various explanations (Milne, 1973a; Parfitt *et al.*, 1984) have been advanced to explain the variability of drainage and related properties within soils occurring on terrace lands of Manawatu. The theories attempt to explain the formation of soils with different drainage properties in relation to the prevailing climatic factors (rainfall), and the past

and present vegetation in the area. Transition of soil drainage and related soil properties, within a climosequence can probably be explained using these hypotheses. However, variability of local drainage and related properties occurring within short distances can hardly be explained. According to the information available in the literature, soil drainage affects weathering of volcanic glass and formation of allophane (Parfitt *et al.* 1984), but the reasons for the local variations of soil drainage properties are still a mystery. Plausible reasons for the variability of soil drainage in the soils of the intermediate terrace are discussed in this chapter.

## 7.2. Previous Hypotheses on Drainage Variability in Soils of Terrace Lands

Some hypotheses suggested by early workers to explain the transition of drainage and related properties within soils occurring on terrace lands of Manawatu are discussed below.

Prior to 1964 it was believed that the Pallic Soils<sup>2,3</sup> (Poorly to imperfectly drained soils) were formed from old alluvium whereas Brown Soils<sup>4,5</sup> (well-drained soils) were formed from tephra, which mantled the old alluvium.

Cowie (1964a) showed that in the Manawatu region a rhyolitic tephra, the Aokautare Ash (now known to be 24,000 calendar years old), is found at comparable depths in both old alluvium and the mantling tephra and he concluded that the old alluvium and the tephra were both in fact loess. Cowie further concluded that the soil transition was due to soil processes rather than parent material differences.

Milne (1973a) introduced a hypothesis in support of Cowie's views to show how Pallic Soils and Brown Soils can form from a common parent material in Manawatu. Milne's

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<sup>2</sup> Yellow-grey earths (Taylor, 1948)

<sup>3</sup> Aqualfs (Soil Survey Staff, 1999)

<sup>4</sup> Yellow-brown earths (Taylor, 1948)

<sup>5</sup> Dystrudepts (Soil Survey Staff, 1999)

hypothesis was that in dry areas summer drying causes a dense subsoil which then results in water logging in winter, and hence in the formation of Pallic Soils. Water logging conditions form reductimorphic features in the subsoil. For the Brown Soils, Milne hypothesized that the subsoils in their early stages of formation did not become so desiccated and hence dense and consequently no significant water logging occurred during winters. Because there was no significant water logging there was no significant swing in redox conditions too.

To test this hypothesis, a small area of the Pallic Soils to Brown Soils transition zone in the northern Manawatu region was studied (Milne and Withers, 1981). The parent material for the soils in the area was loess intermixed with tephra and volcanic ash.

The soil distribution pattern was mapped at 1: 15,840 and found that the Marton<sup>6, 7</sup> (Argillic Perch-gley Pallic Soils), Kiwitea<sup>8, 9</sup> (Typic Orthic Melanic Soils) and Dannevirke<sup>10, 11</sup> (Typic Orthic Allophanic Soils) soils were distributed in an irregular pattern throughout the area. According to Milne's hypothesis there should be an abrupt transition between the soils. The irregular soil pattern however, indicates that local site factors have an influence on which profiles actually dry out in summer and hence develop into the Marton soils. The pedogenesis would need to be triggered at a fairly early stage. One factor could be vegetation that could influence leaching by intercepting rainfall and influencing soil water uptake. It is tempting to suggest that the study area straddle the Pleistocene tree line, which because of the low relief in the area itself had an irregular pattern due to frost hollow effects. If so, the Marton soils could have developed under sub-alpine shrubs and trees, and the Dannevirke soils could have developed under tussocks.

Parfitt *et al.* (1984) suggested a hypothesis to explain the formation of soils with different drainage properties in the southern North Island, New Zealand. He studied the

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<sup>6</sup> Yellow-grey earths (Taylor, 1948)

<sup>7</sup> Aqualfs (Soil Survey Staff, 1999)

<sup>8</sup> Yellow-brown earths (Taylor, 1948)

<sup>9</sup> Eutrudepts (Soil Survey Staff, 1999)

<sup>10</sup> Yellow-brown loam (Taylor, 1948)

<sup>11</sup> Andic eutrudepts (Soil Survey Staff, 1999)

climosequence of soils developed from quartzo-feldspathic loess and tephra occurring under a rainfall gradient ranging from 1050 to 1600 mm. He observed that the bulk densities of the subsoil decrease as rainfall increases, falling from 1.7 Mg m<sup>-3</sup> in the Tokomaru soil<sup>12, 13</sup> (Argillic-fragic Perch-gley Pallic Soils) (1050 mm y<sup>-1</sup>) to 1.5 Mg m<sup>-3</sup> in the Levin soils<sup>14, 15</sup> (Pedal Allophanic Brown Soils) (1300 mm y<sup>-1</sup>) and to 1.3 g cm<sup>-1</sup> in the Ramiha soils<sup>16, 17</sup> (Allophanic Brown soils) (1450 mm y<sup>-1</sup>) and Dannevirke soils<sup>18, 19</sup> (Typic Orthic Allophanic Soils) (1600 mm y<sup>-1</sup>).

The Tokomaru soils have high bulk density, impeded drainage in winter and argillic horizons with degraded chlorite, halloysite and vermiculite clays whereas Dannevirke soils have lower bulk density, free drainage, ferrihydrite, allophane, humus- (Al, Fe) complexes and no argillic horizons.

Tokomaru soils experience a water deficit of over 200 mm in very dry summers. Plant roots exert suction of several bars in the subsoil (Scotter *et al.*, 1979a). Suction of several bars can be transmitted in the subsoil, since silt loam soils have a large volume of interconnected pores which drain between matric potentials of -1 and -15 bar (-0.1 to -1.5 Mpa) (Scotter *et al.*, 1979a). This is equivalent to putting the soil material under an isotropic compressive stress of several bars (Russel, 1973), which causes the bulk density to increase. The fragipan probably developed by this mechanism. This type of fragipan has characteristic brittleness and polygonal structures. Cracks, which formed between the polygonal structures, have become filled with soil from upper layers and appear as light grey continuous veins called gammations (Pollock, 1975). The high bulk density polygonal structures are very impermeable (Scotter *et al.*, 1979a) and the soils tend to become water logged above the fragipan in winter.

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<sup>12</sup> Yellow-grey earths (Taylor, 1948)

<sup>13</sup> Fragiaqualfs (Soil Survey Staff, 1999)

<sup>14</sup> Yellow-brown earths (Taylor, 1948)

<sup>15</sup> Dystrudepts (Soil Survey Staff, 1999)

<sup>16</sup> Yellow-brown earths (Taylor, 1948)

<sup>17</sup> Dystrudepts (Soil Survey Staff, 1999)

<sup>18</sup> Yellow-brown loam (Taylor, 1948)

<sup>19</sup> Andic eutrudepts (Soil Survey Staff, 1999)

Parfitt's hypothesis is that the dense horizons in the Pallic soils arise largely from hydraulic suctions exerted by roots during periods of high summer water deficits. The consequent loss of porosity leads to impeded drainage in winter causing gleying and enhanced clay formation. In the Brown soils and the Allophanic soils the summer deficits are lower and consequently the soils have lower bulk densities and remain free draining.

The hypotheses of Milne (1973a) and Parfitt *et al.* (1984) are very similar to each other. They explain the formation of soils with different drainage properties, including some other properties as well, within different rainfall regimes from the same parent material. Soil drainage variability occurring within short distances under the same climatic conditions cannot be explained using the same hypotheses.

### **7.3. Proposed Hypotheses for the Spatial Variability of Soil Drainage in Current Study**

As indicated above the variability of soil drainage within short distances (few metres) cannot be attributed to the variability of soil forming factors such as climate or vegetation. Therefore, a number of plausible hypotheses were tested in the current study to understand the short distance drainage and related variations of the soils on terrace lands. They are discussed below.

#### **7.3.1. Depth to Underlying River Gravels and Soil Drainage Variability**

The first hypothesis was that the variability in drainage could be related to depth to underlying gravels. It was pointed out in Section 5.3.3, that the topography of the underlying terrace gravels changes within a short distance. Deep auger observations made in block B of the study area on a 50 m interval grid reveals that in some places the gravels lie far below the soil surface (1.45 m) whereas in other places they lie close to the soil surface (0.2 m). In winter and spring a perched water table is developed on the

gravel layer (Section 5.3.3.1). Therefore, it was thought that the local drainage variability is associated with the perched water table and in turn topographic variations of the gravel layer. However, the study conducted in the area reveals that there is no relationship between soil drainage and depth to the underlying gravels (see Section 5.3.3 and Figure. 5.14).

### **7.3.2. Ground Water Movement on the River Gravels and Soil Drainage Variability**

It was then thought that there could be a correlation between soil drainage and the flow direction of ground water within soils. This hypothesis was tested in block B.

Deep auger observations made at 50 m intervals using the ground surface as a datum on block B revealed that the ground water table was developed in some places on the river gravels (see Section 5.3.3). Because of the uneven topography of the underground gravel layer, water, accumulating in some places through infiltration and deep percolation, may tend to flow towards lower positions due to gravity. The uneven topography of the gravel surface is likely to be bar and swale topography, but there was no strong evidence of this. The predicted flow directions of water at observation points are shown with arrows in Figure. 7.1.

It was expected that well drained and allophane rich soils would occur at observation points where the water flows away from that point. The reason being when water flows out of observation points silica in the soil solution also flows out and then the environment is favourable for the formation of allophane (Parfitt *et al.*, 1984, Singleton *et al.*, 1989). Therefore, soils formed at these sites would be well drained and allophane rich and those formed where subsoil water accumulates would be poorly drained and halloysite rich.

This hypothesis too is difficult to prove. When observation numbers 17 and 26 are compared, depth from the soil surface to gravel layer (55 cm) and the water flow direction should be the same for both observations, but the soil drainage status at the two observation points is completely different. At observation numbers 18 and 34 water

flow direction should be towards the observation point, but the soils are well drained and moderately well drained respectively. Therefore, it appears from these observations that local drainage variations within short distances cannot be attributed to the perched water table developed on the gravel layer or its consequent flow direction.

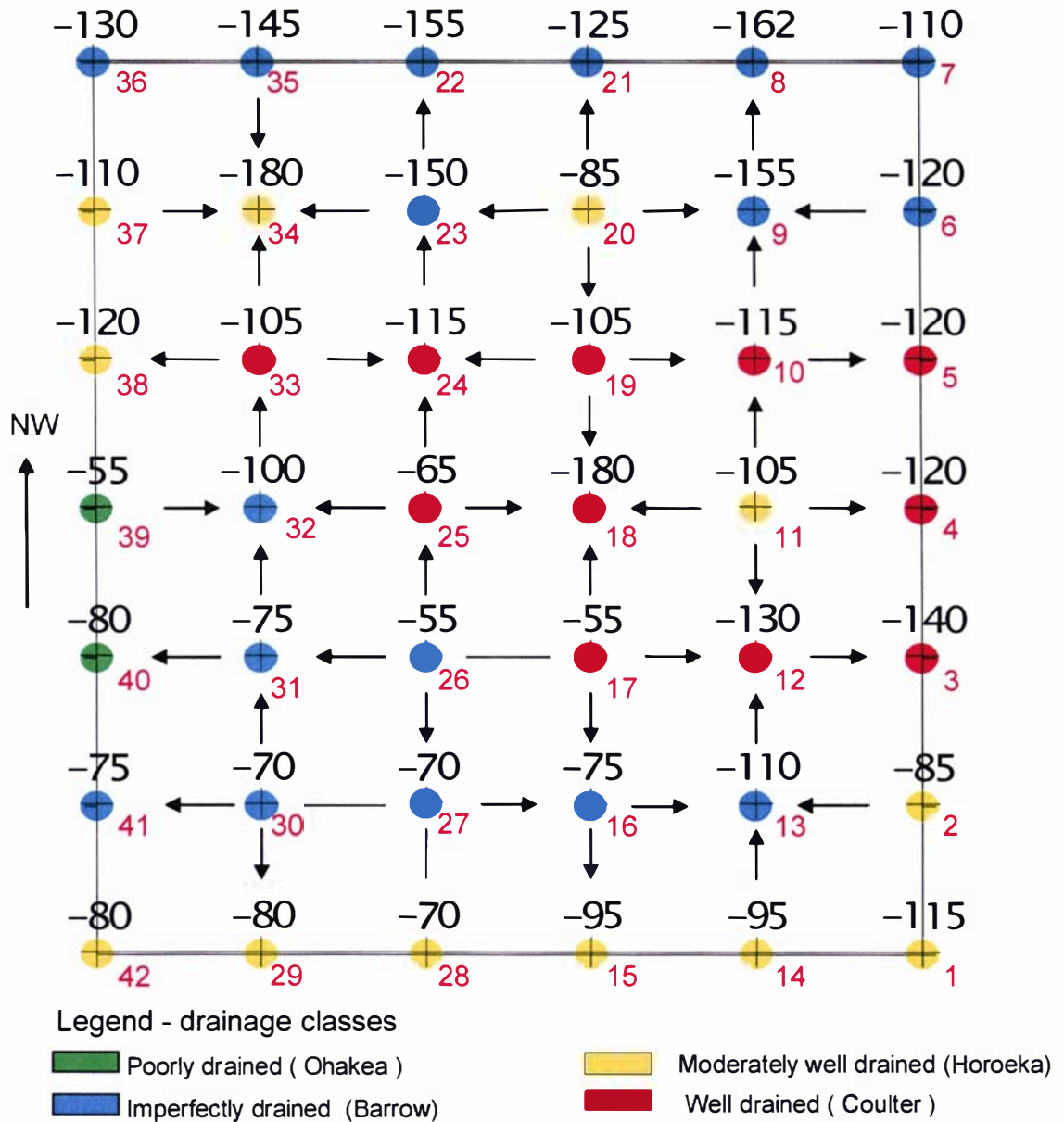


Figure 7.1 The depth to river gravels, and soil types at 50 m interval observation points in Block B. Arrows indicate the possible flow direction of ground water within the area. The numbers with negative signs indicate the depth to gravels in cm from the soil surface. Red numbers indicate the observation numbers.

### 7.3.3. Soil Physical Properties and Drainage Variability

This section examines whether slight textural variations in the original alluvial parent material could have resulted in the formation of soils with variable drainage status.

Auger observations made on the intermediate terrace revealed that mottled and gleyed subsoil horizons of poorly drained and imperfectly drained soils have silty clay, clay or clay loam textures whereas subsoil horizons of well drained soils have silt, silt loam or silty clay loam textures.

Soil texture is an inherent property from its parent material. Textural properties of parent materials do not alter very much during soil formation. Therefore, soil textural properties are similar to the textural properties of the parent material from which the soil is formed.

The parent material from which the soils of the area are derived is largely quartzo-feldspathic alluvium, colluvium and loess intermixed with volcanic ash (Chapter 4). The quartzo-feldspathic sand mineralogy suggests that the source of alluvium is mainly from greywacke and argillite (N.Z. Soil Bureau, 1968; Cowie, 1978). Greywacke is a sedimentary rock, which is made up of fine to coarse particles and is a type of muddy sandstone. Argillite is a brittle mudstone. The alluvial deposits laid down by the river are also a mixture of fine, medium and coarse particles. These deposits are of Ohakean age, 10,000 to 25,000 years old. The terrace gravels were deposited in the early and middle parts of the Ohakean period and the overlying alluvium, colluvium, tephra and loess towards the end (refer to Section 2.4.3). The alluvial layers with slightly contrasting textural properties were deposited just prior to the river beginning to down cut.

The slight textural variations in the parent material described above probably then affected soil structural development. Silt loam soil textures are associated with nutty structure while silty clay loam; clay loam or clay soil textures are associated with blocky structures (Table 7.1 and 7.2).

Table 7.1 The physical properties of Coulter silt loam related to water movement in soil.

Horizon	Depth (cm)	Texture	Structure	Macro-porosity (%)	Ksat (mm hr <sup>-1</sup> )
Ap	0-20	silt loam	moderate fine to medium nutty	6 to 7	8
Bw1	20-65	silt loam	moderate fine to medium nutty	11	8
Bw2	65-95	silt loam	moderate fine to medium nutty and moderate medium blocky	8	4.3
2Ab	95-125	clay loam	moderate medium to coarse blocky	5	4.6

Table 7.2 The physical properties of Barrow silt loam related to water movement in soil.

Horizon Depth (cm)	Texture	Structure	Macro-porosity (%)	Ksat (mm hr <sup>-1</sup> )
Ap 0-21	silt loam	strong fine to medium nutty	4 to 8	6.4 to 14
Bg1 21-34	silty clay loam	strong very fine, fine and medium nutty and moderate medium blocky	12	0.9
Bg2 34-65	fine sandy clay loam	strong medium to coarse nutty	9	7.6
Bg3 65-82	clay loam	moderate medium to coarse blocky	3	0.8

It is hypothesised that it is these differences in soil structure that then largely caused the differences in drainage status. Macro-pores in soils are important in drainage of excess water from soil. If macro-pores are not interconnected within soil aggregates they do not help much in drainage. The arrangement of soil aggregates is rather loose in nutty structured soils and macro-pores may be interconnected. Scotter *et al* (1979a) pointed out that silt loam soils have a large volume of interconnected pores, which drain between metric potentials -1 to -15 bars. The arrangement of soil aggregates within soils having blocky structure is compact and the macro-pores are not interconnected.

Saturated hydraulic conductivity values in the Bg1 and Bg3 horizons (0.9 and 0.8 mm/hr) are very slow in Barrow soils, which can be attributed to the fine texture and blocky structure of these horizons. Permeability (K sat) ranges from moderately slow to

moderate in soils having blocky structures (Griffiths, 1985) Although macro porosity is more or less similar to that of Coulter soils, they may not be interconnected within soil aggregates, because blocky structure is rather compact compared to nutty structure (Griffiths, 1985). Therefore, water moves very slowly within soils, creating poor drainage conditions. Ksat values in the Bg2 horizon are higher than the two surrounding horizons, probably because of the sandier texture of this horizon.

Ksat values in soil horizons of the well-drained Coulter soils are higher than that of the imperfectly drained Barrow soils (Table 7.1 and 7.2). The soil textures of Coulter soils are silt loam and the structures are nutty. Permeability is moderately rapid in soils with nutty structure (Griffiths, 1985). The macro-pores may be interconnected within soil aggregates as explained above. Therefore, water can move through soils more rapidly and hence soils are well drained.

From these observations it is possible that the drainage variability of soils within short distances on the intermediate terrace may be associated with the slight textural variations of the original alluvial parent materials from which the soils are formed and the resulting development of contrasting soil structure.

This theory, though, does not explain the similar pattern of well to poorly drained soils on the upper terrace, where the parent material is loess, which can be expected to be more uniform in texture.

## **7.4. Soil Colloids Involved in Phosphate Retention**

Phosphate ions can be adsorbed on the surface of several types of colloidal particles in soils. The most important of these are hydrous oxides of iron and the short-range order sesquioxides, allophane and immogolite. All these minerals have amphoteric surfaces containing Fe-OH and/or Al-OH groups, which, depending on the pH, can develop positive or negative charge. Phosphate can also be adsorbed by phyllosilicate clay minerals, but in most soils amounts adsorbed by these materials will be far smaller than the hydrous oxides and the short-range order sesquioxides. Adsorption by phyllosilicate clays is thought to take place through Al-OH groups exposed at the edge sites of

octahedral Al layers or, in the case of 1:1 clays, where octahedral Al layers are exposed at the crystal surface. The mechanisms involved in P-retention or adsorption are not discussed in detail here, as it is beyond the scope of this chapter.

## 7.5. Factors Influencing the Spatial Variability of P-retention

The relationship between P-retention and soil drainage in the study area was discussed in detail in Section 5.4 and clearly indicated that well drained and moderately well drained soils in the area have high P-retention whereas poorly drained soils have low P-retention. P-retention in imperfectly drained soils ranged from low to high, but the majority had medium P-retention.

The presence of volcanic glass in the sand fraction (Table 7.3) and the presence of hypersthene, augite, hornblende and magnetite in the heavy mineral fraction of Coulter, Kawhatau and Barrow silt loams (Table 7.4) shows that the parent materials of the soils are intermixed with rhyolitic and andesitic tephra material (Chapter 4).

According to Parfitt *et al.* (1984) weathering of rhyolitic tephra is controlled by Si in soil solution. When Si concentration in the soil solution is low (possibly  $< 10 \mu\text{g cm}^{-3}$ ), due to leaching, allophane is formed from volcanic glass whereas if Si concentration is high (possibly  $> 10 \mu\text{g cm}^{-3}$ ), in the soil solution due to impeded drainage conditions, halloysite is formed. They studied soils in a climosequence having mean annual rainfall ranging from 1100 mm to 1800 mm and found that halloysite dominated the clay fraction of Tokomaru silt loams with impeded drainage conditions occurring in the low rainfall area of the climosequence. Allophane dominated the clay fraction of the Dannevirke silt loams with well drained conditions occurring in the high rainfall area.

Table 7.3 The percentage minerals present in the sand fraction of different soil types.

Soil Type	Drainage	Qu	Feld	HM	VG	Mica	Chl	Crist	Aggre
Intermediate terrace									
Kawhatau stony silt loam	W.D	45-60	20-25	1-5	1-3	1-3	2-4	0	5-20
Coulter silt loam	W.D	41-56	23-32	5-16	4-15	0	0	0	0
Barrow silt loam	Im.D	50-61	24-32	4-10	3-21	0	0	0	0

Table 7.4 The percentage heavy minerals present in the heavy mineral fraction of different soil types. NR = not reported.

Soil Type	HB	Pyrox	Mag	Epi	Chl	Aug	Ilm	Hyp
Intermediate terrace								
Kawhatau stony silt loam	10-20	25-30	20-35	20	0-15	NR	0	NR
Coulter silt loam	9-13	NR	17-48	10-41	1-16	6-21	0-4	9-33
Barrow silt loam	13-45	NR	0-13	9-30	2-8	5-30	3-6	8-48

Table 7.5 The relationship between drainage, clay minerals and phosphate retention of well drained and imperfectly drained soils of the intermediate terrace. The range of percentage values given are within the profiles.

Soil Type	Drainage	Kandite %	Allophane %	P-ret %
Intermediate terrace				
Kawhatau stony silt loam	well drained	10-15	0-5	54-90
Coulter silt loam	well drained	13-52	0-22	86-90
Barrow silt loam	im.perfectly drained	24-47	0	25-79

Singleton *et al.* (1989) pointed out that low Si in soil solution and the presence of allophane was associated with well-drained soil horizons. High Si in soil solution, the absence of allophane and predominance of halloysite was associated with poorly drained soil horizons.

The sand fractions of both the well drained and imperfectly drained soils on the intermediate terrace contain volcanic glass (see Table 7.3). But the clay fraction of the well-drained soils contains allophane whereas the clay fraction of the imperfectly drained soils contains no allophane. The P-retention also varies accordingly (Table 7.5). The presence of allophane in the clay fraction of Coulter silt loam can be attributed to weathering of volcanic glass under well-drained conditions. Under well-drained

conditions Si is leached from the profile and allophane forms. Imperfectly drained Barrow silt loam contains no allophane in the clay fraction due to accumulation of Si in the profile and formation of kandite minerals (kaolinite+halloysite).

## 7.6. Conclusions

- Drainage variability within short distances in the study area cannot be explained using the existing theories.
- Drainage variability within short distances on the intermediate terrace is related to the physical properties of subsoil such as soil texture, structure and saturated hydraulic conductivity. These are perhaps a result of slight differences in deposition of parent material that then lead on to contrasting drainage characteristics and leaching environment.
- Soil drainage, weathering of volcanic glass and P-retention are interrelated. Soil drainage variability is the driving force behind the variability of soil properties, which are important for soil management practices in the area.
- Phosphate retention of soils in the study area is mainly controlled by allophane present in the clay fraction of the soils.
- Further research in this area is required to fully understand the drainage variability with the soils of the upper terrace.

## **Implications of Soil Spatial Variability**

### **8.1. Introduction**

The detailed soil survey conducted in the terraced landscape of northern Manawatu revealed that many important soil properties related to the agricultural management practices of the area vary across the landscape in a way that makes it difficult to detect and portray the soil distribution pattern using conventional soil survey methods (Chapter 5). The quantitative measurements made on the spatial variability of the three selected soil properties (soil drainage, P-retention and penetration resistance) showed that the variability is not the same along and across the terrace (Chapter 6). The spatial scale of variability of these soil properties is also variable over the landscape, leading to the soil distribution pattern being even more complex. The complexity of the spatial soil variability in the study area has implications for soil mapping, land use, soil management practices and land evaluation. The implications and possible measures to deal with the soil variability are discussed in this chapter.

### **8.2. Implications to Soil Mapping**

The relationship between soils and topographic features of the landscape is one of the most important criteria used in soil mapping. However, this relationship cannot easily be used in soil mapping on terraced lands because the soil drainage pattern does not always follow the topography. (see Section 5.3.3.1). Small-scale soil maps are, in general, produced by using these soil landscape relationships combined with limited ground observations. Therefore, in situations where soils vary over short distances,

these maps are not capable of displaying a reliable soil distribution pattern at a farm scale and hence have little interpretative value for practical farm scale soil management practices. As discussed earlier (see Section 5.3.3.1), at least 1:10,000 or larger scale soil maps are required for farm level planning in this area. Ground observations at 100 m or less are required to produce valid maps. Such a mapping scale implies the resolution of soil types to within approximately 100 m which is of a scale comparable to many farming operations, such as subdivision, cultivation and irrigation design. Grid survey is the only reliable conventional soil survey method which can be employed to map at such a scale. However, conventional soil surveys at this large scale have some practical implications with regard to the cost of soil map production and time involved in the survey. At this scale the surveyor has to make 1 observation per hectare. Generally, the maximum number of auger observations that can be made a day is 25 (personal experience). The cost is NZ\$ 400-1000 a day, depending on the charge-out rate of the pedologist.

To increase efficiency of the production of these detailed maps it would be helpful to have a measure of the actual scale of variability within the landscape. Variogram modelling is one of the most effective ways of understanding and detecting the spatial scale of soil variability over the landscape in such a complex system (Chapter 6). The variogram models for the area show that the variability of soil properties is not the same over the landscape, parallel to and perpendicular to the direction of the river flow. The variability is greater perpendicular to the direction of the river flow than parallel to the direction of the river flow. The information gathered from variograms can successfully be used in making soil observations and in designing soil sampling strategies in such landscapes. The use of variogram models to select the most suitable soil mapping scale for detailed farm planning was discussed in Chapter 6.

As already discussed (Chapter 5), the EM38 can successfully be used to map soils reliably and less costly, in areas having such a complex soil pattern.

## 8.3. Implications to Land Use and Management

### 8.3.1. Implications to Pastoral Farming

The predominant land use in northern Manawatu Region is pastoral farming. Pugging is one of the most common soil management problems associated with grazing animals, particularly in wet seasons. Penetration resistance of the topsoil is an indirect measurement, which can be used to judge the relative susceptibility of damage to soil and pastures by grazing farm animals. As discussed already, (see Section 5.5.5.3) poorly and imperfectly drained soils are more prone to pugging than moderately well drained and well drained soils. From the practical land use point of view, the percentage of land area that is going to be damaged by farm animals through pugging is more important.

The observations of soil drainage status made in blocks A, B and C from the intermediate terrace reveals that the distribution of drainage classes is complex. Each block is comprised of three to four different drainage classes. However, the percentage area of poorly drained soils decreases from block A through B to C (Table 8.1). Similarly, imperfectly drained soils also decrease from block A through B to C. About 79% of the area of block A is prone to pugging whereas it is 45% in block B and is only 14% in block C.

Table 8.1 The percentage of land area occupied by different drainage classes in blocks A, B and C of the intermediate terrace. Percentages are calculated using drainage observations made on the 50 m by 50 grid (see Figure 5.28(a)).

Soil drainage class	Percentage land area occupied by different drainage classes		
	Block A	Block B	Block C
Poorly drained	17	5	0
Imperfectly drained	62	40	14
Moderately well drained	21	29	33
Well drained	0	26	53

The present land use in the area is mostly dairying; beef, sheep and deer farming (see Section 2.4.4). Cattle are more damaging to soils than sheep because of their greater body weight and deer because of weight, hoof size and habits (see Section 5.5). Also, the damage is greater when the numbers of animals are high in a paddock or left confined in small area for a long time. Therefore, the land with a higher percentage of well drained and moderately well drained soils towards the northeastern end of the terrace is more suitable for dairy and beef farming. Land with a higher percentage of poorly and imperfectly drained soils towards the southwestern end of the terrace is more suitable for sheep farming than dairying.

### 8.3.2. Implications to P Fertilizer Management

Phosphate fertilizers play a dominant role in pastoral farming in New Zealand (see Section 5.4.1). Traditionally, the amount of P to be applied is determined in part on the basis of the Olsen P status of the soil. Fertilizers are applied as a blanket application to maintain a certain level of Olsen P in the soil, according to the requirement of crops grown. However, this method has some disadvantages especially in the study areas where soils have varying P-retention capacities.

There is a great interest in precision farming or site specific farming today. Site-specific farming is based on the idea that the right inputs can be applied at the right place at the right time. The situation prevailing in the study area is such that blanket application of P fertilizers would result in over-application of nutrients in parts of the field and under-application in others. Over-application is a concern because it may result in runoff losses to surface water. Under-fertilization may also be a concern because it can result in a reduction of potential crop yield. So it is clear, from both economic and environmental points of view, that soils within different P-retention groups should be treated differently.

One of the first available pieces of site-specific application equipment has been the variable-rate fertilizer applicator. Equipment that allows variable-rate application now operates automatically using application data in the on-board computer. Together, with

Global Positioning Systems (GPS), fertilizer is applied at the recommended rates with much more accuracy and assurance than in the past.

Soil sampling is needed to determine the rates that should be used and where the high, medium and low P-retention areas are located. P-retention maps are useful tools to identify areas having different P retention capacities in the field. Variogram modeling can successfully be used to determine soil sampling distances for producing P-retention maps (Chapter 6). Computerized P-retention maps can then be used in combination with GPS technology to apply correct amounts of fertilizer to soils having variable P-retention. This technology is already being used in countries such as U.S.A, in site-specific fertilizer application (<http://www.ext.nodak.edu/>).

## **8.4. The Implication of Soil Spatial Variability to Land Evaluation**

### **8.4.1. Importance of Land Evaluation**

Pastoral farming has been the traditional land use in the northern Manawatu Region for nearly 150 years. Farmers are fairly familiar with land use requirements and the management practices required for pastoral farming. However, in the recent past, the land use pattern has diversified into other agricultural uses such as root vegetable crops, maize, barley, potatoes, cut flowers and bulbs (see Section 2.4.4). Future changes of land use in this area are probable. The soil requirements and management practices for the new land uses are quite different from the soil and management requirements of pasture. Large capital investments for new enterprises are quite risky without knowing the potential and limitations of land for its intended use. Therefore, land suitability evaluation for specific land uses is an important issue in this area.

## 8.4.2. Methods of Land Evaluation

Land evaluation is concerned with assessing the degree of suitability of land for a specific use. There are a number of land evaluation methods available and used in different parts of the world. The methods can be broadly grouped in different ways as follows; qualitative and quantitative classifications; actual and potential suitability classifications; general and crop-specific land suitability classifications (Sys *et al.*, 1991).

Some of the general land classification systems widely used in various parts of the world are the USDA land capability classification (Klingebiel and Montgomery, 1966), the Parametric Method for land evaluation (Riquier *et al.*, 1970, Sys *et al.*, 1991, Van Diepen *et al.*, 1991), and the Land Capability Classification for the Humid Tropics (Sys and Frankart, 1971). A Framework for Land Evaluation (FAO, 1976) is one of the most widely used crop specific land evaluation systems.

A review of land evaluation classifications being used in New Zealand is given in “The Manual of Land Characteristics for Evaluation of Rural Land” by Webb and Wilson (1995). These are largely qualitative, general-purpose classifications based on the concept of soil limitations. The classifications have included suitability of lands for pastoral use (Gibbs, 1963), cash cropping (Cutler, 1967), commercial forestry (Cutler, 1967; Mew, 1980), horticulture (Cowie, 1974) and assessment of the actual and potential value of land for food production (Cowie, 1974). Another land use classification by McIntosh and Hewitt (1992) is classification of lands in Southland and Otago for horticulture, forestry and urban use.

The Ministry of Works and Development classified all land in New Zealand according to the Land Capability System (National Water and Soil conservation Organization, 1979). This system, as practiced in New Zealand, assesses the general capability of land for cropping, pastoral farming, forestry and soil and water conservation, rather than its suitability for particular land uses and crops.

Classification of land according to its versatility is another system of land evaluation practiced in New Zealand (Molloy, 1980). Soil versatility classes are defined by the physical characteristics of the root zone and applied within climatic zones.

“A Manual of Land Characteristics for Evaluation of Rural Land” (Webb and Wilson, 1995) is a quantitative land evaluation system. This manual aims to attain constant land evaluation classifications within and between regions of New Zealand, by the development of a common methodology and by adoption of a common set of land characteristics and ratings.

The land evaluation systems commonly available (except for the last) are mostly qualitative systems. They can include economic analysis to estimate the economic suitability of each land unit for different land uses. Economic evaluations require detailed data on the cost of inputs and returns. Land evaluation systems, which take into account economic parameters, are a particular form of quantitative systems. The Automated Land Evaluation System (ALES) can be given as an example (Rossiter, 1990).

### **8.4.3. Commonalities Among Land Evaluation Methods**

Most systems of land evaluation are interpretative classifications. Soil and climatic conditions are the parameters that are considered in the evaluation procedure. Climatic parameters, landscape, soil physical and soil chemical parameters (land characteristics) are taken into account particularly in crop specific land evaluation systems (FAO, 1976; Sys *et al.*, 1991). In contrast, particular importance is given to soil physical parameters that are made available after a soil survey, in general land evaluation systems (e.g. Land Use Capability Classification and the USDA Land Capability Classification). It is clear that soil physical properties have a particular importance in any land evaluation method.

The physical and chemical parameters considered in land are taken from representative soil profiles. It is assumed that soil profiles represent whole soil map units and soil spatial variability is not taken into account in most land evaluation systems. However, soil spatial variability has been taken into account in the land versatility classification now used in New Zealand (e.g. “Classification of Lands According to its Versatility for

Orchard Crops Production” by Webb and Wilson, 1994). A variability index is included in the classification system to indicate the level of reliability related to soil variability within map units.

Soil drainage is one of the most important physical properties that is considered in land evaluation. Well drained soils are considered more suitable for crops than imperfectly or poorly drained soils in any evaluation system. For example, in the “USDA Land Capability Classification”, well drained soils are Class I land, whereas poorly drained soils are Class VI land. Webb and Wilson (1995) assigned ratings for the different drainage classes ranging from 1-7. The ratings increase as soil drainage changes from well drained to poorly drained.

In crop specific land evaluation systems (FAO, 1976), crop requirements are compared with land characteristics or land qualities and land suitability classes are assigned to land units. Land suitability classes range from suitable, (S1) through moderately suitable, (S2), marginally suitable, (S3) to not suitable (N). Imperfect and poor drainage properties are considered as limitations to crop growth. Therefore, depending on the drainage conditions of land and crop requirements, land will be downgraded to moderate, marginal or to not suitable suitability classes.

The discussion above shows the importance of soil physical properties, more importantly soil drainage, in land suitability or versatility classification systems. The variability of soil drainage properties within land units, which are represented by soil profile data, has implications to land evaluation.

#### **8.4.4. Implications for Applying Evaluations to Land in Northern Manawatu**

The importance of land evaluation in northern Manawatu was stressed in Section 8.4.1. However, short distance variability of soil properties imposes some practical difficulties in practicing land evaluation exercises in the area in a meaningful way.

The detailed soil survey conducted in the area (Chapter 5), and subsequent variogram modeling (Chapter 6), showed that soils, especially the soils of the intermediate terrace,

are variable in their drainage properties at a paddock scale. As soil drainage has a significant influence on the suitability of land for any kind of land use, the spatial variability of soil drainage also affects the degree of suitability for use. Small-scale soil maps (e.g. 1:50,000) cannot portray the drainage variability at paddock scale (Chapter 5).

If soils are highly variable one soil profile will not represent the whole map unit. Further selection of a representative site from a map unit is highly subjective. Therefore, judging the real suitability is a difficult task in highly variable soils.

To demonstrate the implications of land evaluation related to soil drainage variability, soils mapped at 1:25,000 scale and at 1:10,000 scales in blocks A, B and C of the intermediate terrace were evaluated for growing carrots. Land suitability classes (S1, S2, S3, N1 and N2.) were assigned according to the FAO Framework for Land Evaluation (FAO, 1976). Climatic conditions were not taken into account in this example. Instead, the evaluation focused on the variability of soil properties, particularly soil drainage. Land characteristics and crop requirements used in the classification are directly adopted from crop requirement tables (Sys *et al.*, 1993). They were not adapted to the local conditions.

The four soil types considered in the evaluation are Coulter silt loam (well drained), Horoeke silt loam (moderately well drained), Barrow silt loam (imperfectly drained) and Ohakea silt loam (poorly drained). The chemical properties of Horoeke silt loam were assumed to be similar to Coulter silt loam. The land characteristics considered in the evaluation are:

***Slope:*** slope of land as a percentage (%).

***Drainage:*** soil profile drainage properties.

***Soil texture/structure:*** field soil texture was used in the evaluation.

***Soil depth (cm):*** depth to underlying river gravels.

**Apparent CEC:** CEC ( $\text{cmol}_e \text{ kg}^{-1}$ ) of the clay fraction to a depth of 50 cm without correction for organic matter has to be considered. However, the percentage clay was not available and the CEC of soil to a depth of 50 cm was used instead.

**Sum of basic cations:** weighted average of Ca+Mg+K expressed in  $\text{cmol}_e \text{ kg}^{-1}$  to a depth of 25 cm.

**PH:** weighted average of pH (water) to a depth of 25 cm.

**Organic carbon (Org.C):** weighted average of organic carbon as a percentage to a depth of 25 cm.

Table 8.2 The optimum land characteristic conditions required for carrots (Sys, 1993).

Land characteristics (L.C)	Optimum conditions
Slope	0 - 4 %
Drainage	Well drained
Texture/structure	sandy to loamy
Depth	> 90 cm
Apparent CEC	> 24 $\text{cmole kg}^{-1}$
Sum of basic cations	> 4 $\text{cmole kg}^{-1}$
pH (water)	6 to 7
Org. carbon	> 2%

The optimum soil conditions for growing carrots (Table 8.2) were compared with the soil conditions of Coulter, Horoeke, Barrow and Ohakea silt loam and suitability ratings were assigned to each land characteristic (Table 8.3). The final suitability of each land unit was attributed according to the least favourable land characteristic (simple limitation method, Sys *et al.*, 1991). The suitability of land without any improvements is known as the current suitability. Some soil limitations, such as soil acidity, can be easily overcome by the application of lime. The suitability, after some easy improvements have been made, is known as potential suitability (Table 8.3).

The evaluation shows that the Coulter silt loam (a well drained soil) has no limitations (Table 8.3 and Figure 8.1C) and these soils are suitable for growing carrots (Table 8.4). Horoeke soil is limited only by soil depth (Table 8.3 and Figure 8.1B). The particular soil profile considered for the evaluation is 80 cm deep, but generally soil depth is variable ranging from 60-120 cm. However, the soils are moderately suitable according

to the system of evaluation (Table 8.4). Barrow soils have two soil limitations; soil drainage and acidity (Table 8.3 and Figure 8.1A). Soil pH can be corrected by applying lime. Therefore, the major limitation is soil drainage and the evaluation is moderately suitable (Table 8.4). Ohakea soils have three limitations. They are soil drainage, depth and acidity (Table 8.3). The acidity problem can be easily corrected. Soil depth is also variable. Soil drainage is the most important limitation. The texture of these soils is loamy to clayey and artificial drainage, no matter how intense, does not overcome the limitation for horticulture. The current suitability of Ohakea soils is marginal (Table 8.4).

Table 8.3 Evaluation of land characteristics of the Coulter, Horoeke, Barrow and Ohakea silt loam soils for growing carrots, with suitability ratings.

Land characteristics	Coulter soils		Horoeke soils		Barrow soils		Ohakea soils	
	L.C. <sup>1</sup>	Rating	L.C. <sup>1</sup>	Rating	L.C. <sup>1</sup>	Rating	L.C. <sup>1</sup>	Rating
Slope %	0-2	S1	0-2	S1	0-2	S1	0-2	S1
Drainage	W.D. <sup>2</sup>	S1	M.W.D. <sup>3</sup>	S1	Im.D. <sup>4</sup>	S2	P.D. <sup>5</sup>	S3
Texture/structure	si.l. <sup>6</sup>	S1	si.l. <sup>6</sup>	S1	si.l. <sup>6</sup>	S1	si.l. <sup>6</sup>	S1
Depth cm.	125	S1	80	S2	95	S1	66	S3
Apparent CEC cmole kg <sup>-1</sup>	13	S1 <sup>7</sup>	13	S1 <sup>7</sup>	15	S1 <sup>7</sup>	73	S1 <sup>7</sup>
Sum of basic cations cmole kg <sup>-1</sup>	9.7	S1	9.7	S1	8.2	S1	9.8	S1
pH	6.1	S1	6.1	S1	5.7	S2	5.3	S3
Org. carbon %	5.1	S1	5.1	S1	3.2	S1	4.5	S1
Current suitability	S1		S2d		S2dr, a		S3dr, d, a	
Potential suitability	S1		S2d		S2dr		S3dr, d	

<sup>1</sup> L.C = Land characteristics; <sup>2</sup> W.D = well drained; <sup>3</sup> M.W.D = moderately well drained; <sup>4</sup> Im.D = imperfectly drained.; <sup>5</sup> P.D = poorly drained; <sup>6</sup> si.l. = silt loam

<sup>7</sup> Rating is S1 because apparent CEC will be > 24 cmole kg<sup>-1</sup>.

Table 8.4 Land suitability ratings and limitations of Coulter, Horoeke, Barrow and Ohakea silt loam soils for growing carrots.

Soil unit	Rating	Suitability	Limitations
Coulter silt loam	S1	suitable	no limitations
Horoeke silt loam	S2d	moderately suitable	depth (d)
Barrow silt loam	S2dr,a	moderately suitable	drainage (dr), pH (a)
Ohakea silt loam	S3dr, d, a	marginally suitable	drainage (dr), depth (d), pH (a)

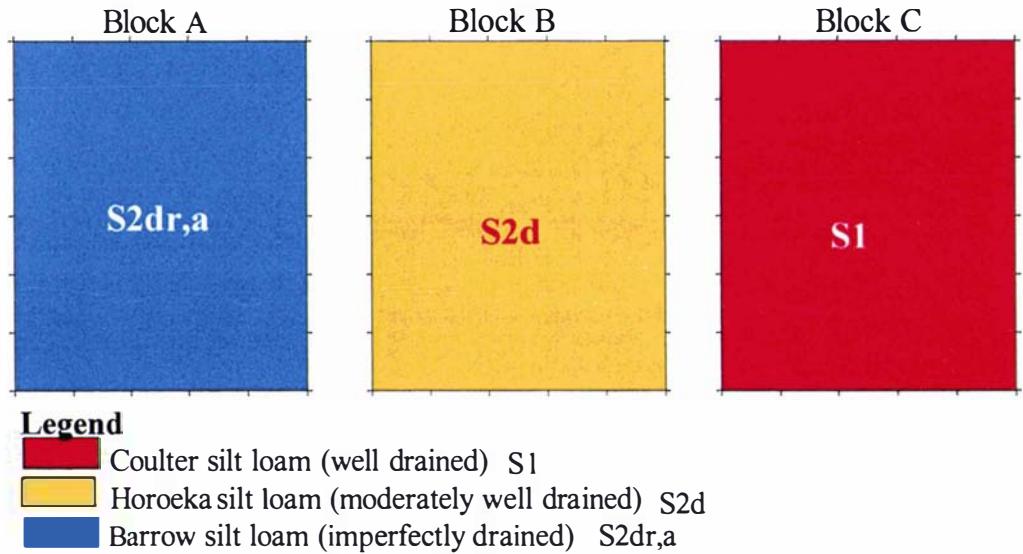


Figure 8.1 The suitability of soils in blocks A, B and C for growing carrots when mapped at 1:25,000 scale. S1 = suitable; S2 = moderately suitable; dr = drainage limitation; a = pH limitation; d = soil depth limitation.

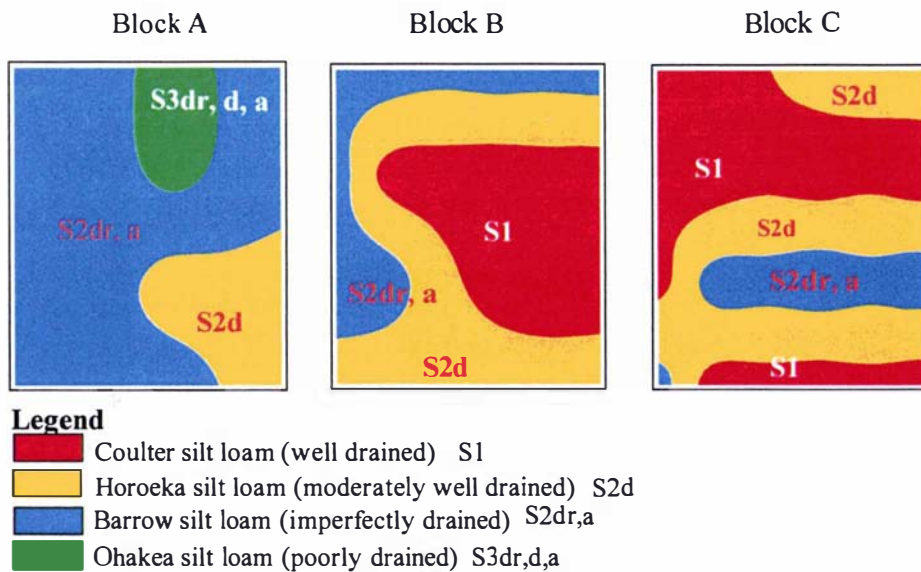


Figure 8.2 Suitability of soils in blocks A, B and C for carrots when mapped at 1:10,000 scale. S1 = suitable; S2 = moderately suitable; S3 = marginally suitable; dr = drainage limitation; a = pH limitation; d = soil depth limitation.

Table 8.5 Percentage areas in different suitability classes when soils of blocks A, B and C are mapped at 1:25,000 and at 1:10,000 scale. Percentage areas are adopted from Figure 8.2 and Table 8.1.

S1 = suitable; S2 = moderately suitable; S3 = marginally suitable; dr = drainage limitation; a = pH limitation; d = soil depth limitation.

Suitability ratings	Block A		Block B		Block C	
	1:25,000	1:10,000	1:25,000	1:10,000	1:25,000	1:10,000
S1	0	0	0	26	100	53
S2d	0	21	100	29	0	33
S2dr,a	100	62	0	40	0	14
S3dr,d,a	0	17	0	5	0	0

It is clear from this exercise that there is a huge gap between the suitability ratings obtained using large-scale maps (1:10,000) and the suitability ratings obtained using small scale (1:25,000) maps. The reliability of suitability classes in block A is 62%; block B is 29% and block C is 53% (Table 8.5).

In block A, land that appears to be moderately suited to growing carrots at 1:25,000 scale actually has 17% of marginally suitable land (Table 8.5). Block B is considered moderately suited to growing carrots, with a depth limitation at 1:25,000 scale. However, at 1:10,000 scale 40% of land has additional limitation of drainage and acidity; 5% is marginally suitable and 26% has no limitations. Block C is considered suitable at 1:25,000 scale, but is shown to be only half suitable at 1:10,000 scale, with 47% being moderately suitable for growing carrots.

If soils vary only gradually over large distances ( $\gg$  paddock scale), then land evaluation exercises can be carried out more reliably and there will be fewer implications of land evaluation at a management unit scale. However, the land evaluation exercise described above makes it clear that the interpretative land evaluation methods can not give reliable results on land having highly variable soil properties, without reliable soil information. Some of the practical limitations, which hinder use of crop specific land evaluation systems, are as follows:

- Detailed soil information, including soil maps and analytical data, is not available. As explained in Chapter 5 and Chapter 6, at least 1:10,000 scale soil

maps are required for practical use. Only small areas of New Zealand have been mapped at large scale. For example at 1:15,000 scale Otaki area (unpublished); at 1:15,840 scale, Soils of Palmerston North City; at 1:15,840, Flock House Farm, Bulls; at 1:15,840 scale, Soils of Oroua Downs, Taikorua and Glen Oroua districts. The SUBS programme (Soils Underpinning Business Success) organized by the Massey University in collaboration with AgResearch and Horizons.nw teaches farmers to map own farms at 1:5,000 and 1:10,000 scales. This shows the importance of detailed soils maps for farm scale planning.

- Climatic data such as mean temperature, maximum and minimum temperature, relative humidity, wind velocity and sunshine hours are important in crop specific land evaluation in addition to rainfall. No agro climatologic data is available for the study area.
- Optimum crop requirements are not fully known for many crops or varieties of crops.
- Crop-specific land evaluation methods must be developed according to local requirements. Direct application of land evaluation systems, which are developed for different environments, may create numerous problems. For example, the crop requirement for carrots (Sys *et al.*, 1993) has been studied with regard to climate, landscape and soil conditions in the tropical and sub tropical regions.
- Data such as seasonal water table fluctuations, flooding intervals and depth to underlying river gravels are more important in some land uses.
- The EM38 may provide maps, that once classified, allow judgements of land suitability to be made.

# Summary, Research Findings, Recommendations and Future Research

## 9.1. Available Soil Information and Future Needs

The literature survey on previous soil studies in the Manawatu Region (Chapter 2) reveals that there are no published detailed soil maps and reports available for the northern Manawatu area, formally known as KIWITEA County. The only available sources of soil information are the General Survey of the Soils of North Island, New Zealand (1954) and the New Zealand Land Resource Inventory (1979) (Table 10.1).

The available maps for the other counties are also small-scale soil maps. The main objective of soil survey programmes at the time these studies were done was the identification and evaluation of the potential of soils for broad land use categories such as pastoral farming, food crops, forestry etc. The small-scale soil maps would have catered for the intended purposes during that period. However, for detailed planning purposes these soil maps have little use. No new soil maps have been published since 1979 for any of the Manawatu Region, including northern Manawatu (KIWITEA County) (Table 10.1).

The agricultural history of the Manawatu Region dates back to the 1860's. Since then, the area has undergone different stages of agricultural development.

- **1860's to 1900's:** The area was under unimproved pastures and the economy was mainly based on sheep farming and some dairying.

- **1900's to 1980's:** Super phosphate was introduced as a source of fertilizer and the unimproved pastures were replaced by improved pastures and clover. Main sources of income were dairying, sheep farming and beef farming.

Table 9.1 A summary of soil information available for the Manawatu Region.

Year	Name of soil report/ soil map	Publishing scale	Area covered
1954	General Survey of the Soils of North Island, New Zealand	4 miles to an inch	Entire Manawatu Region
1958	Soils and Agriculture of Oroua Downs Taikorea and Glen Oroua Districts, Manawatu County.	1:15,840	Manawatu County
1965	Soils and Agriculture of Flock House, Bulls.	1:15,840	Rangitikei County
1967	Soils of the Manawatu-Rangitikei Sand Country.	1:63,360	Rangitikei and Manawatu Counties and part of Horowhenua County
1971	The National Resource Survey Part VII	1:500,000	Rangitikei County
1974	Soils of Palmerston North City and Environs.	1:15,840	Kairanga County
1977	Soils of Manawatu County, North Island	1:63,360	Manawatu County
1977	Soils of Pohangina County	1:63,360	Pohangina County
1978	Soils and Agriculture of Kairanga County	1:63,360	Kairanga County
1979	New Zealand Land Resource Inventory	1:63,360	Entire Manawatu Region
1979	Soils of Rangitikei County	1:63,360	Rangitikei County
	Unpublished soil map	1:63,360	Oroua County

- **1980's to present:** The traditional pastoral land use pattern has gradually changed to other agricultural uses such as cut flowers and bulbs for the foreign market, maize, barley and contract vegetables. Large areas of land previously used for sheep farming have been converted to dairy farming mainly due to removal of agricultural subsidies for sheep farming in 1984.
- **Present and into the future:** Development and expansion of Feilding and Marton townships within the region may cause additional land use issues. Regional Councils,

District Councils and City Councils may need to find suitable soils for non-farm uses such as housing, factories, storage houses, waste disposal and recreation. A new meat processing plant to be situated near Marton required a detailed soil survey for selecting a waste disposal site. Real estate agencies, investors and the other agencies dealing with land-based enterprises may need to consult soil maps to evaluate and estimate land value and make decisions about their investment. People are also more concerned about environmental issues related to agricultural practices. Therefore, precision agriculture is becoming more and more important.

### **9.1.1. Recommendations**

The literature shows that availability of soil information for the area has not been advanced in phase with the requirements. This is, despite detailed information on soils, becoming more and more important due to the introduction of new land uses, site specific or precision agricultural management practices, non farm use of soil resources and growing concern about environmental issues. Therefore, it is recommended that the soil resources of the area be mapped and understood in order to be described in ways that will enable increased farm productivity and decisions to be made on non-farm use of soils, while conserving soil resources and the surrounding environment.

## **9.2. Physical Environment**

The study area in northern Manawatu is characterized by a terraced landscape having three major terraces; a lower terrace, a last-glacial intermediate terrace and a loess-covered upper terrace.

The area is characterized by warm, dry summers and wet, mild winters. The annual rainfall ranges from 900-1200 mm and the mean annual temperature ranges from 12 °-13.5 ° C.

The parent materials of the lower terrace soils are recent alluvium. Those of the intermediate terrace are a mixture of old alluvium, colluvium, loess and tephra and the parent materials of the upper terrace soils are a mixture of loess and tephra.

### **9.3. Soil Mapping and Characterization**

The first step of this research work was to study soils, their properties and the distribution pattern over the northern Manawatu landscape. A detailed soil survey was conducted at a 1:25,000 mapping scale in a representative area of about 2000 ha near Kiwitea village. A soil map was produced for the area. Four soil profiles were selected; two profiles from the intermediate terrace and another two profiles from the upper terrace were characterized for physical, chemical and mineralogical properties.

A large window area (2000 m by 300 m) was selected from the intermediate terrace and mapped at a 1:10,000 scale and subsequently another three small window areas (300 m by 250 m), within the large window area, were mapped at a 1:5,000 scale.

#### **9.3.1. Spatial Variability of Soil Drainage Status**

##### **9.3.1.1. Research Findings**

- The detailed soil mapping exercise carried out at 1:10,000 and 1:5,000 mapping scales in three selected window areas (300 m by 250 m) from the intermediate terrace revealed that each window area (each apparently consisting of only one soil when mapped at a 1:25,000 scale) actually comprised three or four different drainage classes; well drained Coulter soils, moderately well drained Horoeke soils, imperfectly drained Barrow soils and poorly drained Ohakea soils (Chapter 5).

- Soil drainage properties on the intermediate terrace show no relationship either to topographic variations or depth to the underlying river gravels.
- It became apparent that a number of soils identified, particularly on the intermediate and upper terraces, are not appropriate to be, or cannot be correlated with the existing soil series defined in previous Manawatu regional soil surveys (Chapter 3). This is mainly due to two reasons. Firstly, soils of the upper and the intermediate terraces are developed from two different parent materials (Chapter 2). Secondly, the suitability of soils having different drainage status for crops and management practices are not the same.

### 9.3.1.2. Recommendations

#### *(A) Introduction of New Soil Series*

As noted in the previous section and Chapter 3, a number of soils in the study area are not appropriate to be, or cannot be correlated with the existing soil series that were defined in previous Manawatu regional soil surveys. To overcome this, a number of new soil series are proposed.

The introduction of new soil series is justified based on the following observations.

- The properties of soil series introduced in the previous surveys are quite different from the properties of some soils mapped in the present survey. For example, previously mapped Kawhatau stony soils have different properties compared to presently mapped Coulter soils (Chapter 4).
- Soils of the upper terrace and the intermediate terrace are developed from different parent materials (Chapter 2). Therefore, it is not appropriate to correlate soils mapped on the intermediate terrace with the previously introduced soils occurring on the upper terrace. For example, the presently mapped Coulter soils cannot be correlated with the previously mapped Dannevirke soils.

- Soil drainage is important in soil management practices (Chapter 5) and land evaluation. The suitability of poorly drained soils for most cases is inferior to imperfectly drained soils (Chapter 8). Therefore, imperfectly drained and poorly drained soils should be identified separately. For example, previously mapped Marton soils were split into two soil series in the present survey; the poorly drained soils as Marton series and the imperfectly drained soils as Feilding series.
- Definition of new soil series based on drainage criteria avoids problems in classifying some old soil series according to the New Zealand Soil Classification System (Hewitt, 1992). For example, the poorly drained to imperfectly drained Marton series is a yellow grey earth according to the Genetic Classification System (Taylor, 1948). According to the New Zealand Soil Classification System it may be either a Pallic Soil or a Gley Soil.

Therefore, the introduction of new soil series, based on drainage criteria and parent material, as listed in the Table 10.2 is proposed. These soil series names are recommended to be used in future detailed soil mapping programmes in the area.

Table 9.2 Separation of existing soil series into new soil series considering parent material and soil drainage.

Existing soil series	Drainage class	New soil series
Intermediate Terrace		
Kawhatau	Well drained	Coulter
	Mod.well drained	Horoeka
Ohakea	Imperfectly drained	Barrow
	Poorly drained	Ohakea
Upper Terrace		
Kiwitea mottled	Mod.well drained	Cheltenham
Marton	Imperfectly drained	Feilding
	Poorly drained	Marton

### ***(B) Soil Mapping Scale***

It is apparent that on the intermediate terrace, soils that appear reasonably uniform when mapped at a 1:25,000 scale are highly variable when mapped at larger scales. The magnitude of changes in soil properties, for example drainage status, can potentially have a major effect on farm management decisions such as timing of cultivation or grazing.

Qualitative inspection of the detailed soil survey data also suggests that the areas of individual mapping units are of roughly the same “scale” as that considered in day-to-day farm management decisions ( i.e. between 1 and 5 hectares). When mapping units are this size there is the potential to optimize farm performance by modifying subdivision to ensure that, as much as possible, different soil types are fenced separately, even if only temporarily during mob stocking. There may also be the opportunity to modify fertiliser application rates, cultivar selections or planting densities, even within a paddock, to take account of different soil types.

When mapping units are very much larger they may impact on between-farm variations in management systems, but soil variation has less impact at the individual farm level. Similarly, it is often not economically feasible to modify farm management practices to take account of soil variation when the boundaries between soil types are only a few tens of metres apart.

From these considerations it can be concluded that on the intermediate terrace in this study area, a mapping scale of 1:25,000 is inappropriate for most practical land use purposes. A mapping scale of 1:10,000 appears to be optimum, in that it identifies all the soils present in quantities likely to be of practical significance and gives a reasonable idea of the location of the boundaries between them. Mapping at a 1:5,000 scale enables a more precise location of soil boundaries, but appears not to reveal the presence of additional soil types. With current land uses it would be difficult to justify the additional expense associated with this more intensive mapping.

The lack of any obvious relationship between topography and soil drainage properties on the intermediate terrace makes “free” mapping difficult and therefore a grid survey is the most suitable traditional method of soil survey for this area.

### 9.3.2. Spatial Variability of P-retention

Fixation of soluble and plant available phosphates into unavailable forms in the soil is one of the well-known problems in agricultural soils. The ability of soils to fix phosphate is indirectly measured by a P-retention test.

Mineralogical and chemical analyses on the 4 representative soil profiles described in Chapter 4 reveal that the sand fraction of soils on both the upper terrace and intermediate terrace contain volcanic glass, indicating the presence of tephra in the parent materials of the soils. The clay fractions of well-drained soils contain allophane and some kandite, indicating weathering of volcanic glass, mainly into allophane. These soils also have high P-retention.

The clay fractions of the imperfectly and poorly drained soils contain mostly kandite with no allophane, indicating weathering of volcanic glass, mainly into kandite. These soils have low P-retention.

The detailed soil mapping exercise described earlier revealed a complex pattern of soils having widely varying drainage properties. This provided the opportunity to explore further the tentative relationship between soil drainage status and P-retention suggested in the analysis of the 4 representative soil profiles. Accordingly, soil samples (0-7.5 cm) were collected on a grid from blocks A, B and C of the intermediate terrace analysed for P-retention (Chapter 5).

#### 9.3.2.1. Research Findings

The findings of the study are as follows.

- P-retention of the topsoil (0-75 mm) in the study area is highly variable. The values range from 15 – 86% and belong to low, medium and high P-retention classes as defined by Saunders (1965). The magnitude of this variation has clear implications to management practices such as fertiliser application.

- There is a relationship between P-retention and soil drainage in the study area. Low P-retention values are associated with poorly drained soils and high P-retention values are associated with well drained soils.
- Soil maps at 1:25,000 mapping scale are of little use in identifying different areas of P-retention in the field as map units at 1:25,000 scale encompass soils with a range of P-retention values. Drainage class maps at 1:10,000 mapping scale can be used successfully to identify areas of low and high P-retention through the close association of drainage status and P-retention. The relationship is less clear-cut in soils that have medium P retention and generally are imperfectly drained or moderately well drained..
- Although 1:5000 mapping scale maps are more precise and less variable, there is little advantage in using them instead of 1:10,000 maps when the additional cost of producing the maps is taken into account.

### 9.3.2.2. Future Research Needs

The above relationship between P-retention and soil drainage status has also been noted by other workers. Parfitt *et al.* (1984) and Singleton *et al.* (1989) pointed out that allophane is predominant in well drained soils where soil solution Si concentration is low and halloysite is predominant in poorly drained soils where soil solution Si concentration is high.

Although the mechanisms proposed by Parfitt *et al.* (1984) and Singleton *et al.* (1989) can perhaps explain “after the fact” the very large variations in P retention observed in this study, it is a very different matter to predict the extent to which similar processes will operate on other terrace lands in the Manwatu Region and beyond. Considerably more work is required to understand the pedological processes that have resulted in very large variations in soil mineralogy over short distances in soils formed on similar topography and with apparently similar parent materials. This is discussed in more detail in Section 10.5.1.

### 9.3.3. Spatial Variability of Penetration Resistance (PR)

Animal treading in grazed pastures, associated with excess moisture in rainy seasons and poor soil drainage conditions, is another important soil management problem in the study area. Penetration resistance (PR) of the topsoil is an indirect measurement of the relative susceptibility of soils to pugging. The spatial variability of PR was measured using a “Penetro Logger” in the same window areas and using the same grid as used for P-retention.

Soils in the field were not excessively moist at the time of measuring PR. The moisture content in the soils was below field capacity.

#### 9.3.3.1. Research Findings

The findings are as follows.

- The penetration resistance of the topsoil (100 mm) in the study area is highly variable. The variability is dependent on soil properties (particularly soil drainage) and the type of land use.
- The PR of the topsoil (average PR within 100 mm of the soil surface) is relatively low in poorly drained soils and gradually increases from imperfectly drained soils to moderately well drained soils and then to well drained soils.
- When the PR of every 10-mm depth down to a depth of 100 mm is considered individually, the PR of the top 10 mm of all four soils show little variation, irrespective of drainage status, at the soil moisture content when these measurements were made. However, below 10 mm depth, the PR increased in the order poorly drained soils < imperfectly drained soils < moderately well drained soils < well drained soils.
- There is a relationship between soil type and PR. Therefore, the detailed soil maps at 1:10,000 mapping scale can be used as a guide to demarcate areas which are susceptible to pugging hazards. Maps at 1:5,000 scale add little new information.

### 9.3.3.2. Future Research Needs

Penetration resistance studies have not been carried out in this area before. This property is mostly dependent on the moisture status of the soil. Therefore, to get a clear picture of the spatial variability, field measurements should be carried out a number of times during a year, preferably during a rainy season at different moisture levels (below field capacity, at field capacity and above field capacity) and during a dry season.

Penetration resistance of the topsoil is normally considered as the average PR of the top 100 mm. However, depending on the moisture conditions of soil, the PR at different depths (e.g. 10 mm, 20 mm, 30 mm etc.) may not be the same as the PR value obtained for the 100 mm depth. Sometimes the average PR value for the first 100 mm may remain greater than the threshold value, but the PR in the top 10 or 20 mm depth may be lower than the threshold value. Therefore, the hooves of grazing animals can easily penetrate into soil to about 20 mm. The pugging damage to the top few mm is important because apical tissues of pasture can be easily damaged. The present study revealed that the top 10 mm of soil is more or less equally susceptible to pugging, irrespective of the soil type. More PR studies have to be carried out to fully understand the situation.

Threshold values for pugging hazards by sheep, deer and cattle need to be worked out for the major soil series and soil types occurring on terraced lands of the northern Manawatu where pastoral farming is practiced.

## 9.4. Spatial Scale of Soil Variability

As noted in Section 10.3.1.2, soil maps at a scale of 1:25,000 are not adequate to capture the variations in soil properties that are important for farming operations. A scale of 1:10,000 appeared to be more appropriate. To further investigate the spatial scale of the variability in soil properties on the intermediate terrace, a variogram modelling exercise was carried out (Chapter

6). It was hoped that the information derived from this exercise could be used to devise optimum soil sampling and soil mapping protocols.

An EM38 electromagnetic sensor, coupled to a GPS, was also used to map soil variability in one of the small 300 by 250 m window areas to evaluate the potential of this technology to assist in the production of detailed soil maps.

### 9.4.1. Research Findings

The findings from the variogram modelling for the intermediate terrace are as follows.

- The spatial variability of soil drainage, P-retention and penetration resistance of the topsoil is not the same in all directions (i.e. it is anisotropic) over the intermediate terrace.
- The variability is greater across the terrace than along the terrace. The maximum variability of soil drainage, P-retention and PR across the terrace occurs at lags that range from 100 - 200 m, whereas the maximum variability along the terrace is reached at 500 m for P-retention and has not been reached within 1000 m for drainage.
- The greater variability of soil properties across the area perpendicular to the river flow direction can be attributed to the greater variability of original alluvial sediments deposited across the area. The pattern of variability can be attributed to a “fluvial” pattern of soil map units, reflecting fluvial depositional processes. Such “fluvial” patterns are seen for example in Paparua County (Cox, 1978), Waikato (Molloy, 1998) and Piako County (Wilson, 1980).
- Knowledge of the soil variability pattern along and across the area is useful in designing soil-sampling schemes. The variogram gives an indication of the maximum range of the variability of soil properties within the area. Soil sampling interval should be within the range of maximum variability in order to capture all the variations. Further variogram

analysis is required to decide exact sampling intervals. Exact sampling intervals are also dependant on the precision required to be shown on maps. This is determined by the significance of observed differences in soil properties to land use practices.

- An electromagnetic sensor (EM38), coupled with a GPS, can be used successfully as an indirect method of soil mapping, as discussed in Chapter 5. The results demonstrate that the EM38 sensor can assess drainage variability in this landscape more precisely than the conventional grid survey. A few soil observations are required from different drainage classes to establish a relationship between soil drainage and the EC, so that the EC map can be interpreted in terms of soil drainage classes. The number of field observations required is less than for a conventional survey and the results are more accurate than any other system of traditional soil mapping, if the classification is correct.

### **9.4.2. Recommendations**

An EM38 sensor is recommended for mapping soil drainage classes rapidly, more reliably and with less cost in areas where soils are highly variable.

### **9.4.3. Future Research Needs**

Most of the river terraces of the Manawatu Region, except for the loess covered upper terraces, are covered with old or recent alluvial deposits intermixed with air fall volcanic tephra. The variability of soil properties in these soils can be expected to be very similar to that of the present study area. The greater variability across the terrace than along the terrace, has not been reported previously in the literature. Therefore, variogram-modeling studies are recommended for a few more river terraces to investigate the spatial scale of variability, particularly soil drainage and the directional variability. This would help planning soil mapping and sampling schemes, as discussed earlier.

It is suggested that variogram modelling may be useful to gain a better understanding of the scale of spatial variability of soil drainage on the upper terrace where soils are developed from wind blown loess deposits. The mode of deposition of loess is different from the mode of deposition of alluvium. However, the soil mapping study (1:25,000 scale) showed that soil drainage has little relation to topographic variations of the landscape of the upper terrace too. Therefore, variogram modelling may be useful to investigate whether the variability of soil properties follows a similar or different trend on the upper terrace.

## 9.5. Factors Influencing Soil Drainage Variability

The soils on the intermediate terrace vary in their morphological properties, some physical and chemical properties and clay mineralogy (Chapter 4). The significant differences between the four soils are

- **Morphological differences:** presence or absence of reductimorphic horizons or redox-mottled horizons at different depths of the soil profile (Chapter 3).
- **Physical properties:** soil textural and structural variations in the subsoil horizons (Chapter 4 and Chapter 7).
- **Chemical properties:** the P-retention of the topsoil ranges from low through medium to high and is closely related to soil drainage.
- **Clay mineralogy:** the clay fractions of well drained and moderately well drained soils contain more allophane and less kandite, whereas the clay fractions of imperfectly and poorly drained soils contain no allophane and more kandite. (Chapter 4).

It appears that the major differences between the four soils are caused by the action of variable drainage conditions on the mixed tephra/alluvium parent material over a period of time.

A number of possible hypotheses tested to explain the short-distance drainage variability of the soils on the intermediate terrace of the study area are given below:

- Whether the variability in drainage could be related to depth and topography of underlying terrace gravels.
- Whether there is a correlation between soil drainage, the perched water table developed on the terrace gravels and the expected flow direction of ground water within soils.
- Whether slight textural variations in the original fluvial deposits could have resulted in the formation of soils with variable drainage status.

### **9.5.1. Research Findings**

- Drainage variability within short distances on the intermediate terrace of the study area cannot be explained using the existing theories.
- There is no relationship between soil drainage and depth to the underlying terrace gravels of the intermediate terrace.
- Local drainage variations within short distances cannot be attributed to the perched water table developed on the terrace gravels or its consequent flow direction.
- The drainage variability within short distances on the intermediate terrace appears to be related to physical properties of the subsoil, such as soil texture, structure and saturated hydraulic conductivity. These are perhaps a result of slight differences in the deposition of alluvial parent material.
- The slight textural variations of the alluvial parent material at the time of deposition may have resulted in the formation of different soil structures that, in turn, influenced the water movement within the soil, leading to different drainage properties. Weathering of volcanic glass in the tephra has been influenced by soil drainage in the process of soil

formation. In well drained sites Si from tephra is leached down and removed from the soil profile, creating an environment conducive for the formation of allophone (Parfitt *et al.*, 1984; Singleton *et al.*, 1989). In poorly and imperfectly drained sites Si does not readily move from the soil profile and this creates an environment conducive for the formation of halloysite. The process has taken place for about 10,000 – 15,000 years and has ended up with the formation of soils having completely different morphological, chemical and mineralogical properties. The soil drainage status and the tephra rich mixed parent material are the driving forces behind the variability of soil properties important for soil management practices of the northern Manawatu area.

### **9.5.2. Future Research Needs**

Drainage variability of soils developed from a mixture of alluvial and tephra in the intermediate terrace can be explained using slight textural variations of alluvial parent material at the time of deposition. However, soils of the upper terrace are developed from wind blown loess deposits. The short distance drainage variability apparent on the upper terrace cannot be explained using the same hypothesis. Likewise, the variability cannot be explained using existing theories discussed in Chapter 7. The complexity of the spatial soil variability in the study area has implications for soil mapping, land use, soil management practices and land evaluation (Chapter 8). Therefore, further research is needed to fully understand the principal cause of drainage variability on the terraced landscape of the northern Manawatu.

## **9.6. Implications of Soil Variability for Land Use, Management and Land Evaluation**

The important soil properties related to agricultural practices such as soil drainage, P-retention and susceptibility to pugging are highly variable over the terraced landscape of the northern Manawatu Region (Chapter 5). The magnitude of variability of these soil properties is

important because the “size” of the land unit that has some commonality in soil properties is typically the size of a farm paddock (Chapter 6). Therefore, the magnitude of soil variability in the area has a significant influence on the farm scale management decision making.

Grazing stock has unfavourable impacts on poorly and imperfectly drained soils, particularly in wet seasons, because these soils are more prone to pugging (Chapter 5). The percentage land area prone to pugging ranges from 14% through 45% to 79% within three different land blocks (7.5 ha) studied in the intermediate terrace of the area (Chapter 8). The variability of the P-retention capacity of soils also has marked influence on P-fertiliser management practices (Chapter 5). The sample land evaluation exercise revealed that the suitability ratings obtained for growing carrots are reliable only 62% through 29% to 53% in the same 3 blocks at a 1:25,000 soil mapping scale (Chapter 8).

### **9.6.1. Recommendations**

- To minimize implications for land use, land management and land evaluation, it is recommended that the soils of northern Manawatu farmlands be mapped at 1:10,000 scale.
- Realignment of paddock boundaries is recommended following, as much as possible, the soil drainage classes mapped at a 1:10,000 scale. It would help P-fertiliser management practices as well.
- Select well drained and moderately well drained soils for dairying and deer farming and imperfectly drained and poorly drained soils for sheep farming to minimize pugging damage to soils.
- All land evaluation systems used, even based on a 1:10,000 scale soil mapping, need to include consideration of soil variability in their assessment.

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## Appendices

Appendix 1 The frequency distribution of P-retention classes within the Ohakea silt loam (poorly drained) map unit at 1:10,000 and 1:5,000 scales.

P-retention class	Frequency 1:10,000 scale	Frequency 1:5,000 scale
16-20	0	2
21-25	4	6
26-30	5	7
31-35	0	1
36-40	1	0
41-45	1	1
46-50	0	0
51-55	0	1

Appendix 2 The frequency distribution of P-retention classes within the Barrow silt loam (imperfectly drained) map unit at 1:25,000, 1:10,000 and 1:5,000 scales.

P-retention class	Frequency 1:25,000	Frequency 1:10,000 scale	Frequency 1:5,000 scale
10-15	1	1	1
16-20	3	3	1
21-25	11	8	7
26-30	13	9	8
31-35	6	6	7
36-40	10	12	16
41-45	15	15	19
46-50	9	15	15
51-55	14	22	20
56-60	14	14	15
61-65	11	11	12
66-70	5	6	8
71-75	1	1	8
76-80	0	0	1

Appendix 3 The frequency distribution of P-retention classes within the Horoeke silt loam (moderately well drained) map unit at 1:25,000, 1:10,000 and 1:5,000 scales.

P-retention class	Frequency 1:25,000	Frequency 1:10,000 scale	Frequency 1:5,000 scale
21-25	2	1	0
26-30	2	1	0
31-35	2	3	1
36-40	4	4	1
41-45	4	4	1
46-50	2	4	2
51-55	10	6	7
56-60	4	11	10
61-65	15	13	15
66-70	15	16	16
71-75	29	20	19
76-80	19	19	21
81-85	4	7	7
86-90	1	1	0

Appendix 4 The frequency distribution of P-retention classes within the Coulter silt loam (well drained) map unit at 1:25,000, 1:10,000 and 1:5,000 scales.

P-retention class	Frequency 1:25,000	Frequency 1:10,000 scale	Frequency 1:5,000 scale
31-35	1	0	0
36-40	3	0	0
41-45	2	0	0
46-50	5	0	0
51-55	6	1	1
56-60	7	0	0
61-65	6	7	4
66-70	11	10	8
71-75	16	23	18
76-80	29	28	27
81-85	26	23	23
86-90	1	1	2

Appendix 5 The relationship between soil drainage classes and P-retention classes in the three mapping units. The table is constructed using the information given in Figure 5.29. LP-ret = low P-retention; MP-ret = medium P-retention; HP-ret = high P-retention.

Drainage class	Blocks A+B+C			Blocks A+B+C		
	Total number of observations			Percentage number of observations		
	LP-ret	MP-ret	HP-ret	LP-ret%	MP-ret%	HP-ret%
Poorly drained	9	0	0	100	0	0
Imperfectly drained	4	34	11	8.2	69.4	22.4
Moderately well drained	0	5	29	0	14.7	85.3
Well drained	0	0	34	0	0	100

Appendix 6 The frequency distribution of P-retention within profile classes of four different soil types.

P-ret class	Frequency distribution of P-retention within profile class			
	Ohakea	Barrow	Horoeke	Coulter
20-25	6	1	0	0
26-30	3	3	0	0
31-35	0	2	0	0
36-40	0	5	1	0
41-45	0	5	0	0
46-50	0	8	0	0
51-55	0	7	1	0
56-60	0	7	4	0
61-65	0	5	4	1
66-70	0	4	9	1
71-75	0	2	6	10
76-80	0	0	8	12
81-85	0	0	2	8
86-90	0	0	0	1

Appendix 7 The frequency distribution of penetration resistance within Ohakea, Barrow, Horoeke and Coulter drainage classes.

Penetration resistance Kpa	Number of observations			
	Ohakea	Barrow	Horoeke	Coulter
700-900	2	1	0	0
901-1100	4	3	0	0
1101-1300	1	9	1	0
1301-1500	2	6	0	1
1501-1700	0	5	8	4
1701-1900	0	10	2	3
1901-2100	0	5	3	1
2101-2300	0	5	2	4
2301-2500	0	3	4	6
2501-2700	0	2	3	4
2701-2900	0	0	4	4
2901-3100	0	0	2	1
3101-3300	0	0	1	1
3301-3500	0	0	1	1

Appendix 8 The frequency distribution of penetration resistance within Barrow, Horoeke and Coulter silt loam map units at 1:25,000 scale.

Penetration resistance (Kpa)	Number of observations		
	Barrow	Horoeke	Coulter
500-700	0	0	0
701-900	5	0	0
901-1100	14	2	1
1101-1300	20	5	7
1301-1500	25	4	6
1501-1700	18	9	17
1701-1900	14	17	14
1901-2100	6	14	14
2101-2300	4	13	11
2301-2500	4	17	7
2501-2700	2	9	9
2701-2900	1	8	3
2901-3100	0	7	1
3101-3300	0	5	2
3301-3500	0	1	3
3501-3700	0	1	1
3701-3900	0	0	0
3901-4100	0	1	0

Appendix 9 The frequency distribution of penetration resistance within Ohakea, Barrow, Horoeke and Coulter silt loam map units at 1:10,000 scale.

Penetration resistance (Kpa)	Number of observations			
	Ohakea	Barrow	Horoeke	Coulter
701-900	2	3	0	0
901-1100	5	11	1	0
1101-1300	1	22	9	0
1301-1500	3	23	8	1
1501-1700	0	15	20	9
1701-1900	0	15	18	13
1901-2100	0	10	10	13
2101-2300	0	7	10	11
2301-2500	0	6	9	13
2501-2700	0	4	6	10
2701-2900	0	1	5	6
2901-3100	0	2	4	2
3101-3300	0	1	4	2
3301-3500	0	0	2	2
3501-3700	0	0	1	1
3701-3900	0	0	0	0
3901-4100	0	0	0	1

Appendix 10 The frequency distribution of penetration resistance within Ohakea, Barrow, Horoeke and Coulter silt loam map units at 1:5,000 scale.

Penetration resistance (Kpa)	Number of observations			
	Ohakea	Barrow	Horoeke	Coulter
500-700	0	0	0	0
701-900	3	2	0	0
901-1100	8	9	0	0
1101-1300	2	27	3	0
1301-1500	4	23	5	1
1501-1700	0	15	18	11
1701-1900	0	24	11	12
1901-2100	0	15	9	10
2101-2300	0	12	6	9
2301-2500	0	7	9	11
2501-2700	1	4	6	9
2701-2900	0	1	7	6
2901-3100	0	2	4	2
3101-3300	0	0	5	2
3301-3500	0	0	2	2
3501-3700	0	0	1	1
3701-3900	0	0	0	0
3901-4100	0	0	1	0

Appendix 11 Variability of penetration resistance within the top 100 mm of the Ohakea, Barrow, Horoeke and Coulter silt loam soils.

Soil depth mm	Soil Types			
	Ohakea	Barrow	Horoeke	Coulter
0	550	610	660	619
10	750	799	894	843
20	1250	1641	1850	1843
30	1550	1975	2419	2479
40	1730	1996	2515	2542
50	1710	2071	2513	2631
60	1690	2138	2498	2679
70	1690	2222	2512	2729
80	1680	2295	2532	2804
90	1710	2323	2554	2832
100	1730	2383	2529	2828

Appendix 12 Percentage distribution of penetration resistance at 0 mm depth in Ohakea, Barrow, Horoeke and Coulter silt loams.

Penetration resistance (Kpa)	Ohakea	Barrow	Horoeke	Coulter
100-300	2.7	1	1.4	0.7
301-500	38.8	24.6	27.1	21.9
501-700	50	58.4	44.2	54.5
701-900	5.5	13.3	17.1	16.6
901-1100	2.7	2	4.2	6
1101-1300	0	0.5	2.1	0
1301-1500	0	0	0	0
1501-1700	0	0	0.7	0
1701-1900	0	0	0.7	0
1901-2100	0	0	1.4	0
2101-2300	0	0	0	0
2301-2500	0	0	0	0
2501-2700	0	0	0.7	0

Appendix 13 Percentage distribution of penetration resistance at 10 mm depth in Ohakea, Barrow, Horoeke and Coulter silt loams.

Penetration resistance (Kpa)	Ohakea	Barrow	Horoeke	Coulter
100-300	0	0	1.4	0
301-500	5.5	4.1	6.4	4.5
501-700	38.8	30.7	20	20.4
701-900	44.4	40.5	35	41.6
901-1100	5.5	19.4	23.5	25
1101-1300	2.7	5.1	4.2	3.7
1301-1500	2.7	0	2.8	3.7
1501-1700	0	0	2.1	0.7
1701-1900	0	0	0.7	0
1901-2100	0	0	1.4	0
2101-2300	0	0	0.7	0
2301-2500	0	0	0.7	0
2501-2700	0	0	0.7	0

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## Appendix 14 Soils of the Kiwitea District

# Soils of the Kiwitea District

## Introduction

The Kiwitea District is one of the important agricultural areas of northern Manawatu Region. However, as discussed in previous chapters, there is no detailed soil information available for this area. Therefore, Kiwitea area was selected to carryout the soil spatial variability study.

This chapter “Soils of the Kiwitea District” is designed to be published as a soil survey report. The report is written in a simple format, particularly for farmers, rather than a technical report, which, non technical people may not have difficulties in understanding and interpreting. This report explains some of the fundamentals of soil science, necessary to understand the subject, in a simple language using diagrams where appropriate and taking examples from the study area. The soil distribution pattern is mapped at a 1:25,000 scale.

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## **1. Introduction**

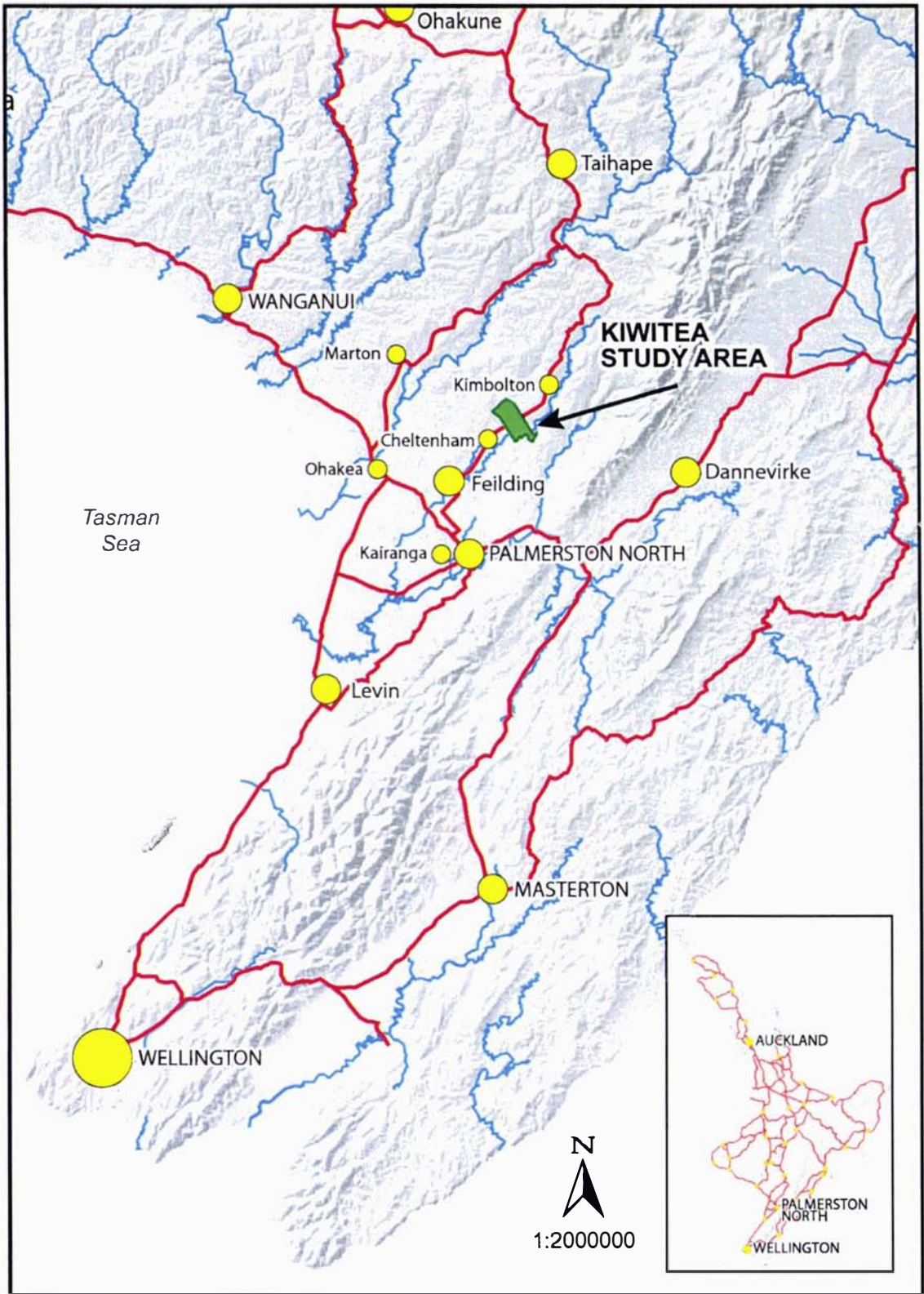
Soil maps and soil reports are not new to New Zealand farmers. They are well aware of the importance of these documents in farming activities. Northern Manawatu, formally known as KIWITEA County, is one of the important agricultural regions of New Zealand and has nearly 150 years of agricultural history. However, it is unfortunate that there are no published detailed soil maps and reports in this region.

This bulletin provides a detailed soil survey report and a soil map for an area near KIWITEA village. The soil survey covered 2000 ha of farmland on a terraced landscape, which is the common landform in the northern Manawatu Region. The soil survey was conducted in 1998/99 as a part of a doctoral research project undertaken at Massey University. The research project was mainly focused on the study of the variability of soil drainage, phosphate retention of topsoils and susceptibility to pugging damage by stock over the terraced landscape of this area. This area is typical of other areas of terraced landscape in northern Manawatu.

## **2. Location of the Survey area**

The survey area near KIWITEA village is situated 40 km. north of Palmerston North, the principal city of the Manawatu Region, on the Cheltenham-Kimbolton road. The nearest urban area, Feilding, is 20 km south of KIWITEA (Map.1).

KIWITEA is easily accessed through State Highway 54. The outer boundaries of the survey area are Oroua River, Barrow Road, Haynes Line, Levett Line, Perry Line and Coulter Line (see map .2).



Map 1 Location of the study area near KIWITEA village, northern Manawatu.

### **3. Agricultural Importance of Northern Manawatu**

Agriculture has been the major source of income in Manawatu for nearly 150 years. Until the 1860s many parts of the Manawatu Region were covered with native forest. The native forest was cleared by early European settlers and the region was gradually converted to an agricultural area, mainly grassland farming. In the 1900's new improved varieties of grasses and clover were introduced to the area with the introduction of super phosphate. Since then, Manawatu has become an important agricultural area in the North Island of New Zealand.

The Manawatu area has long been well known for top Romney lamb ram farms. The stretch from Cheltenham to KIWITEA on Kimbolton road in northern Manawatu was known as "Ram Ally" or the "Golden Mile". Establishment of the first dried milk factory followed by a butter factory in 1904 near Bunnythrope allowed the Manawatu region to become an important dairying area. The traditional land use pattern used to be grassland farming of sheep, dairy and beef. This land use pattern has gradually changed over the last few decades into other agricultural uses such as cut flowers and bulbs for the foreign market, maize, barley, dairy conversion, and contract vegetables for Heinz Watties.

Northern Manawatu has had a proud agricultural history and has the potential to grow into an even more important agricultural area. Therefore, the soil resources of the area need to be mapped and understood in order to increase farm productivity while conserving soil resources and the surrounding environment.

### **4. Climatic Conditions of the Area**

Climate is equally important, as soils, in agriculture. Day to day weather conditions and the overall climatic conditions throughout the year influence pasture growth, crop production and animal production. The effect of rainfall, temperature, evapotranspiration, number of sunshine hours, wind, frosts and hail determine the climatic conditions of the study area.

There are no weather stations situated within the survey area, except for privately owned rainfall stations. Weather stations situated closest to the survey area are at Ohakea, Kairanga, Marton, and Palmerston North (see map.1).

Annual rainfall ranges from 900 mm to 1200 mm. The area receives more rain in winter and spring than in summer and autumn (Table.1).

Table 1 Summary of climatic data for the Kiwitea district.

Climatic data and Location	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	year
Rainfall (mm) Kiwitea	78	80	95	91	91	102	111	91	98	116	105	95	1152
Evapotranspiration (mm) - Ohakea	156	121	97	59	36	25	26	42	65	97	126	149	999
Mean air T °C Marton	16.3	16.9	15.3	12.7	10.4	8.3	7.4	8.3	9.8	11.6	13.2	15.1	12.1
Mean soil T °C (at 10 cm depth) - Marton	17.9	17.7	15.5	12.4	9.4	7.5	6.2	6.8	9.1	11.9	14.4	16.8	12.1
Sun shine hours - Ohakea	242	213	185	159	128	111	119	137	157	191	211	227	2080
Mean daily wind speed (Km/hr) - Ohakea	18	18	17	17	17	17	15	17	18	18	20	18	17
Average days of air frost - Ohakea	0	0	0	0.4	1.6	5.9	7	4.8	2	0.6	0.3	0	22.6
Average days of ground frost - Ohakea	0	0	0	0	0.2	1.3	1.8	0.6	0.2	0	0	0	4.1

The area experiences very mild temperatures without any extremes enabling stock year round grazing. Mean annual air temperatures ranges from 12 ° C to 13.5 ° C. Mean winter temperatures range from 7 ° C to 8 ° C whereas mean summer temperatures range from 15 ° C to 17 ° C. The optimum soil temperature for seed germination is 12 ° C, conditions which prevail in the area from October to April.

The total number of sunshine hours ranges from 1800 to 2100 hours per year. In winter total cloud cover is greatest and about 10 to 15 percent of days are cloudy. In summer 5 to 10 percent of days have no sunshine.

The predominant wind flow over Manawatu is westerly. Average wind speed is about 15 to 18 km/hr. Seasonal variation in wind speed is not great, but winds are a little stronger in spring and summer.

Air frost is quite common a few days each month except in summer. Ground frosts usually occur between March and November, but are most likely on clear, calm nights in winter. However, severe frost is not common in this area.

## 5. Evapotranspiration

Moisture stored in soil is lost into the air through evaporation from the soil surface and transpiration from plants. Water loss from the soil through these two processes is called evapotranspiration (ET). In summer months ET rates are high (4-5 mm water lost per day) due to warm temperatures and strong winds. In winter the ET rate decreases to 1 to 2 mm per day. Shallow sandy or gravely soils can store very little water, therefore pastures and crops grown on these soils (e.g. Manawatu fine sandy loam shallow phase soils and Kawhatau silt loam soils) may suffer from a lack of soil moisture during summer.

## 6. Landscape Features

The study area features by a terraced landscape (Plate.1) with three dominant terraces at different heights:

<b>Terrace</b>	<b>Height (metres)</b>
Lower Terrace	180
Intermediate Terrace	200 –240
Upper Terrace	240 – 300

The terraces are made up of thick layers of rounded gravels. These gravels are very similar to the gravels found on river flood plains. Therefore, we can deduce that the terrace gravels were also once transported by rivers. How were the gravels transported by water, when presently the river is about 120 metres below the upper terrace? Why is the landscape terraced? What types of soils are found on the terraces? These questions come to mind when looking at the landscape carefully.

All these landscape features are related to past climatic conditions prevailing in New Zealand about 10,000 to 80,000 years before present. The climate was very cold and quite different from today's climate. This cold period is known as the last glacial period. Even within glacial periods, there were some warm periods between very cold periods. The very cold periods are known as glacial maxima, when the average annual temperatures were 4° C to 5° C lower than today's annual average temperatures. Scientists have identified three such glacial maximum periods in this area during the last glacial period. These periods are identified by different names.

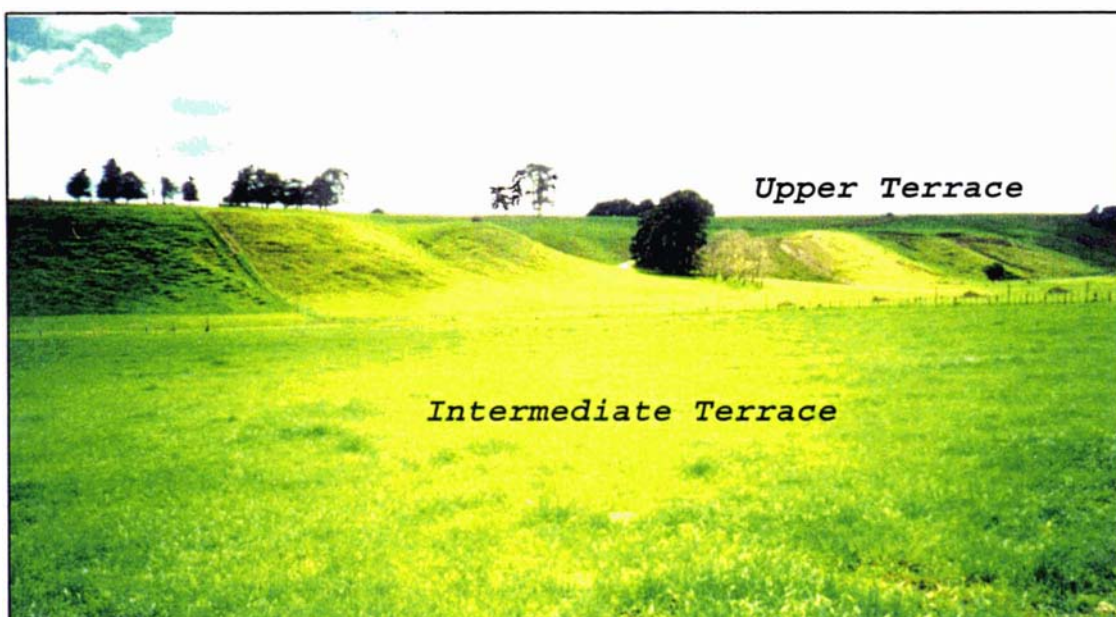


Plate.1 Terraced landscape of the study area.

<b>Period</b>	<b>Years before present</b>
Porewan	80,000 to 60,000
Ratan	50,000 to 30,000
Ohakean	25,000 to 10,000

During glacial periods there was increased snow cover on the adjacent Ruahine Range. Mt. Ruapehu and the Kaimanawa Mountains had glacial ice covers. There was much less vegetation on the ranges and the tree line was lowered, possibly below present sea level.

Sea level was about 130 m lower and the shoreline was about 50 km seaward to that of the present day.

The bare mountaintops were prone to erosion and a lot of rock material was transported through rivers and deposited down stream, causing the rivers to build up. The main upper terrace in the KIWITEA area formed at least 80,000 to 60,000 years ago, while the intermediate terrace formed 25,000 to 10,000 years ago.

During relatively warm periods between glacial maximum periods, the mountains and hill country were once again protected by forests. There was much less rock material to transport, so the rivers started to cut down through the previously deposited gravels. The ancient riverbeds are preserved as terraces by uplift of the land.

The river gravels of the lower and intermediate terraces are covered by fine material transported by the Oroua River. The upper terrace is covered by fine wind blown material known as loess. Volcanic ash has intermixed with materials on both terraces from time to time.

## **7. Soil Forming Materials**

The material from which soils are formed is known as parent material. Soils can be formed from many different types of parent materials and the process may take thousands of years.

The fine material transported by rivers or streams and deposited on land is known as alluvium. Alluvium is the parent material of soils found on the lower and intermediate terraces, for example. Manawatu fine sandy loam and Manawatu silt loam soils are developed from alluvium laid down by the Oroua River on the lower terrace.

Some of the material on the terraces is derived locally from material eroded from adjacent hills or risers between terraces. Such earth material is called colluvium. The parent material for most of the Ohakea silt loam soils on the intermediate terrace at the edge of the Upper Terrace is colluvium from the terrace risers.

The soils of the Upper Terrace are formed from loess deposits. This loess is silt that was blown from the intermediate terrace about 10,000 to 25,000 years before present. During this period southwesterly winds were very strong and the fine silty material on the former river flood plain was carried by the wind and deposited on the upper terrace. Kiwitea silt loam and Feilding silt loam are two examples of soils developed from loess.

Volcanic ash, the fine material ejected during volcanic eruptions, is a very common soil parent material in New Zealand. Alluvium, colluvium and loess parent materials in the area are intermixed with volcanic ash from Egmont and Ruapehu volcanic centres. Coulter, Barrow and Horoeke silt loam soils on the intermediate terrace are developed from alluvium intermixed with volcanic ash while Dannevirke, Kiwitea, Cheltenham and Feilding silt loam soils on the upper terrace are developed from loess intermixed with volcanic ash.

The fine alluvium comes from hard rocks called greywacke and argillite. The mountain ranges of New Zealand are made up of greywacke-argillite rocks. Running water breaks down solid rocks into finer particles, which are transported and deposited as alluvium. The Oroua River also cuts through thick deposits of Pleistocene, (less than 2.5 million years old) unconsolidated sand, silt and pumice.

Most commonly soils are formed from rocks of many different kinds. The unchanged rock from which a soil is made is called the parent rock. The parent rock is turned into a parent material by weathering and erosion. Next we will see how parent material is slowly turned into soil.

## **8. Soil Formation**

Parent material gradually changes into a soil, a process known as soil formation. It is a very slow process and takes thousands of years. Therefore, soil that is eroded or damaged is not replaced in our lifetime.

What changes take place in the parent material to form a soil? Some changes we can see clearly, but others we cannot. The changes that we can see are called physical changes. The soft parent material is a good medium for growth of small plants like moss and

grasses. When plants die they become compost and humus. As this process goes on, the topmost layer of the parent material becomes dark in colour. Organic matter helps to bind small particles together and form small aggregates. These aggregates combine together to form soil structure. At this stage we can see a dark coloured topsoil and light coloured subsoil. The semi horizontal zones developed are called soil horizons.

The processes that we cannot see are known as chemical changes. Rocks are made up of various minerals such as quartz, feldspars, mica, hornblende etc., which are chemical compounds. These compounds are made up dominantly of silicon and aluminium as well as plant nutrients such as potassium, phosphorus, calcium, magnesium, iron etc. When parent material is changed into soil these minerals also change chemically to clay minerals. As an example, volcanic glass present in parent materials rich in volcanic ash is changed into a clay called allophane during soil formation. In addition to the formation of clay minerals, a lot of plant nutrients are released to the soil. These nutrients are taken up by plants, or leached out of the soil by rain. When minerals change their composition, the mineral colour is also changed. Therefore, soil colour also becomes different to the colour of the original parent material. Most commonly the soil material becomes brown because iron compounds, released during weathering, coat other mineral grains.

Now it is clear that soil is quite different from the original parent material. Soils have a structure, humus rich topsoil, different soil horizons, clay minerals, plant nutrients etc. that parent material does not have. Soils also become home to numerous small animals and micro-organisms.

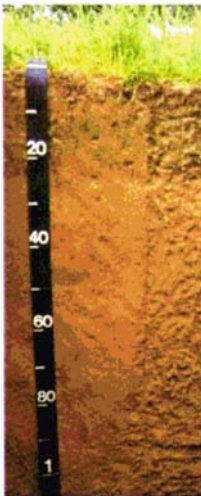
## **9. The Soil Profile**

When a soil pit is dug we can clearly see a vertical cross section of soil. This cross section is made up of soil horizons. The arrangement and the succession of soil horizons are called a soil profile. Soil profiles are very useful in identifying soils. By studying various properties of soil horizons soil scientists group them into different classes. For example, look carefully at the soil profiles of Coulter, Horoeka, Feilding and Marton silt

loam soils (Plate .2). They look quite different from each other. They are four different soils, with different properties and contrasting agricultural potential.

When we examine a soil profile on the intermediate terrace and compare it to those on the lower terrace we see considerable differences, even though soils on both are developed in alluvium. Soil horizons are clear in the subsoil and the soil parent material has almost completely changed to soil. Soil colours are red or yellowish. Unweathered primary minerals are not present, indicating that the soil profiles of the intermediate and upper terraces are more developed than that of the lower terrace. That means soil formation has taken place for a longer period. These soils have been forming for at least 10,000 years whereas soils on the lower terrace are less than 2000 years old.

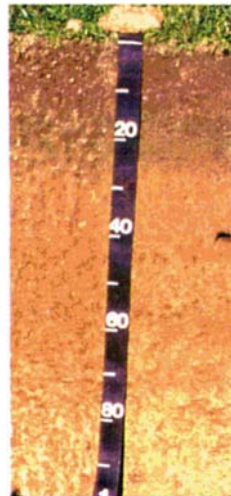
**Coulter silt loam**



**Horoeaka silt loam**



**Feilding silt loam**



**Marton silt loam**



Plate.2 Four different soil profiles from well drained (Coulter soils), moderately well drained (Horoeaka soils), imperfectly drained (Feilding soils) and poorly drained (Marton soils).

When we examine a soil profile of Kiwitea silt loam from the upper terrace, we find a whitish volcanic ash layer about 80 cm below the soil surface. This layer is known as “Kawakawa Tephra”, a volcanic ash that was deposited about 24, 000 years ago from Taupo volcanic centre. However, Kiwitea soils are not developed solely from volcanic ash. The parent material cannot be alluvium. If it were alluvium, the Kawakawa Tephra layer would not be preserved in the soil and it would have been washed away. The only

possibility is that the parent material has been transported by wind and deposited on the upper terrace. Therefore, soils on the upper terrace are developed from wind blown silt called loess. The loess was deposited on the terrace after the tephra deposits. Therefore, soils on the upper terrace are younger than 24,000 years

## 10. Soil Components

Soil is made up of four major components (Figure.1). They are:

1. Mineral materials
2. Organic matter
3. Water
4. Air.

Examination of a soil sample shows that the inorganic part of a soil is variable in amount and composition. It is normally composed of rock fragments and minerals of various kinds. The rock fragments are remains of parent rock from which the parent material is formed. The minerals are also variable in size. Some are as large as the smaller rock fragments while others, such as clay minerals, are so small that we cannot see them, even with an aid of a microscope. The minerals found in soils that have not changed (as they are found in rocks) during soil formation, are called primary minerals. Quartz, feldspars, hornblende, augite and mica are some examples of primary minerals.

Some minerals change their composition and appearance during soil formation and become secondary minerals. Most are very tiny clay minerals. Kaolinite, vermiculite and smectite are a few examples.

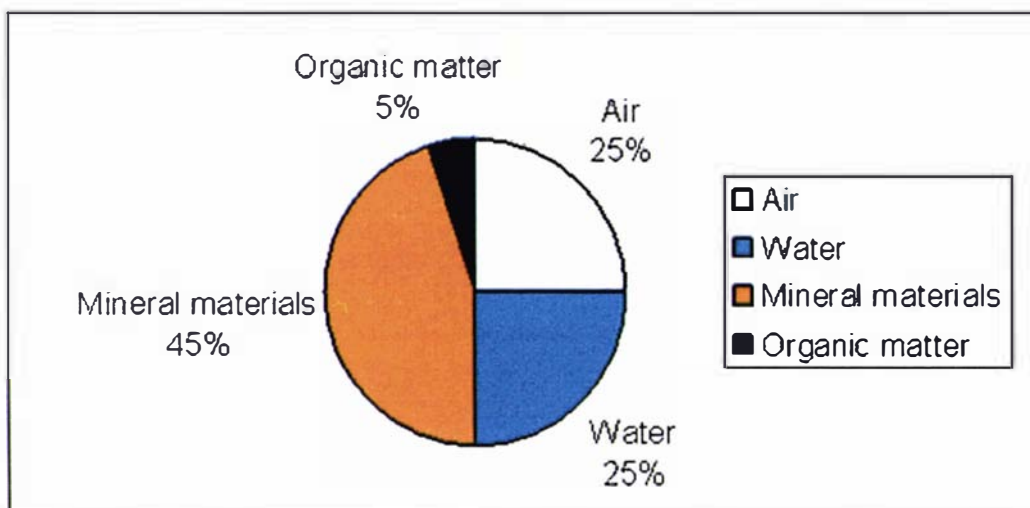


Figure.1 Four major components of soils.

When plant and animal residues are decayed, they become part of soil as organic matter. The organic matter content varies from 5 to 10 percent by weight in most topsoils of the study area. Organic matter has a number of functions in soils such as structural development, water retention, plant nutrients retention, microbial activities etc.

The nonsolid or pore spaces in the soil are occupied by either water or air. A good, fertile soil usually contains about 50 percent pore spaces of its volume. Porosity ranges from 50 to 60 percent in the soils of the study area. Large pores help drain out excess water from soil. They are usually filled with air. Small pores are useful in retaining water in soils. The proportion of water and air in a soil are interrelated, as one increases the other decreases and vice versa. For best plant growth, an optimum balance between water and air must be maintained.

Soil aeration is important for root growth and microbial activity in soils. Large pores are responsible for maintaining good aeration. When a soil is water logged, there is no remaining air. This situation is not favourable for plant roots and microorganisms.

## 11. Plant Nutrients

Plants like animals need food. Plants can make their own food using air, water and other nutrients taken up from the soil. More than 95 percent of plant materials made up of:

**carbon (C)**

**hydrogen (H)**

**oxygen(O).**

They are also components of air and water.

The rest (5 percent or less) is taken up from soils. It is the nutrient elements obtained from the soil that usually limits crop growth and development. Fourteen elements are obtained from the soil by plants. Six of them are used in relatively large quantities and known as macronutrients. They are:

**nitrogen (N)**

**calcium (Ca)**

**phosphorus (P)**

**magnesium (Mg)**

**potassium (K)**

**sulphur (S).**

Nitrogen, phosphorus and potassium are commonly supplied to the soil as farm manure and as commercial fertilizers. Therefore, they are often called fertilizer elements. Calcium and magnesium are commonly applied as lime and are called lime elements. Sulphur, other than that present in rainwater, is usually applied to the soil as an incidental ingredient of such fertilizers as farm manure, superphosphate and sulphate of ammonia.

Plants use the other nutrient elements in very small amounts. Therefore, these elements are known as micronutrients or trace elements. They are:

**iron (Fe)**

**manganese (Mn)**

**copper (Cu)**

**zinc (Zn)**

**boron (B)**

**molybdenum (Mo)**

**chlorine (Cl)**

**cobalt (Co).**

Both macro and micronutrients are equally important for plant growth.

In Section .8 “soil formation” we discussed rocks and minerals. Minerals are made up of one or more elements. During the process of soil formation minerals decay or weather releasing different elements and become plant nutrients. (e.g. when feldspars weather potassium is released into the soil; mica releases iron and magnesium; apatite releases phosphate)

## 12. Plant Available Forms of Plant Nutrients

Plant nutrients are absorbed by plants in the form of positively charged ions (cations) or negatively charged ions (anions). These cations and anions are present in soil, either attached loosely to tiny clay and humus particles, or in water present among soil particles known as the soil solution (Figure.2). Plant roots absorb these nutrients whenever they need.

Forms of nutrients absorbed by plants:

### Cations:

potassium  $K^+$   
 calcium  $Ca^{++}$   
 magnesium  $Mg^{++}$   
 iron  $Fe^{++}$  or  $Fe^{+++}$   
 manganese  $Mn^{++}$  or  $Mn^{++++}$   
 copper  $Cu^+$  or  $Cu^{++}$   
 zinc  $Zn^{++}$   
 nitrogen  $NH_4^+$ .

### Anions:

nitrogen  $NO_3^-$   
 phosphorus  $HPO_4^{--}$  or  $H_2PO_4^-$   
 sulphur  $SO_4^{--}$   
 boron  $BO_3^{---}$   
 molybdenum  $MoO_4^{--}$   
 chlorine  $Cl^-$

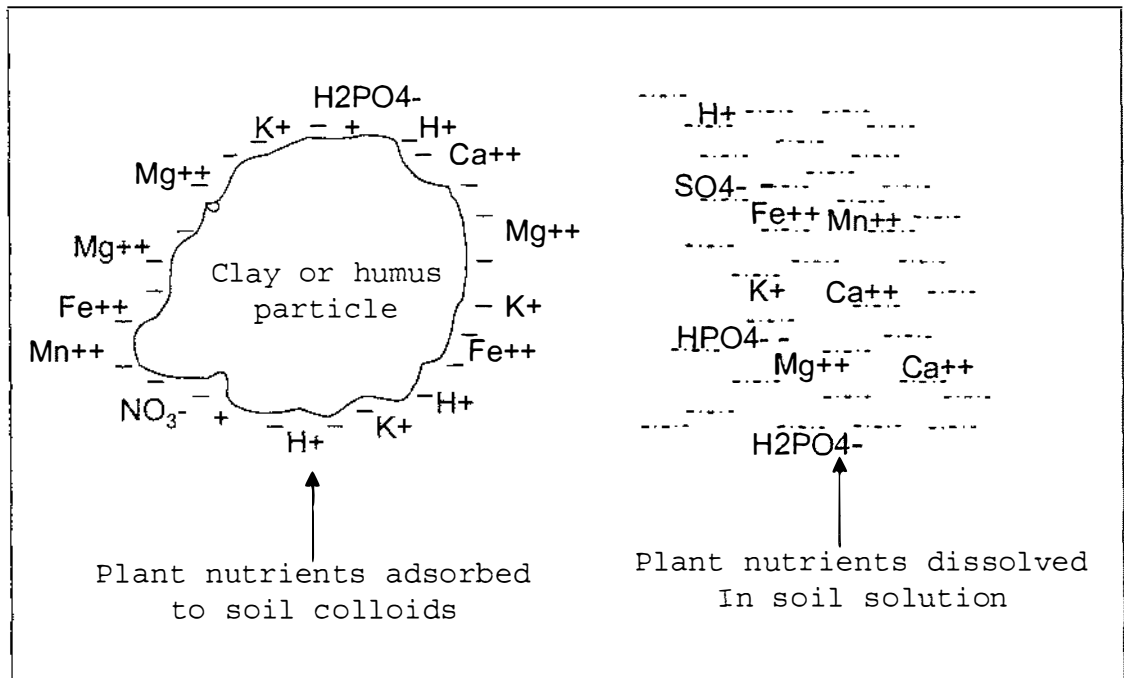


Figure.2 Plant nutrients attached to soil colloids and dissolved in soil solution.

### 13. Soil Variability in the Study Area

Farmers are well aware, by experience, that soils on their farms are not the same everywhere. The soil map of the study area shows there to be thirteen different soil types. One soil may be different from another soil by one or more soil properties. The differences among soils are known as soil variability.

What are the variations among soils of the study area? We consider here, only the variable soil properties that have a substantial effect on soil management practices. Soil drainage is one such property. The soils in the area belong to four different drainage classes. They are well-drained, moderately well drained, imperfectly drained and poorly drained classes. Dannevirke, Kiwitea, Coulter, Kawhatau, and Manawatu soils are well drained. Cheltenham and Horoeke are two moderately well drained soils. Barrow and Feilding are imperfectly drained while Ohakea and Marton soils are poorly drained. Poorly and imperfectly drained soils become water logged in rainy seasons, particularly in winter and spring. Water logged conditions are not suitable for crops. Poorly drained soils are also prone to pugging under heavy stock. Therefore, grazing stock may damage

both pastures and the topsoil. It is clear that these soils need special care compared to well drained and moderately well drained soils.

Phosphate (P) retention is another variable property in this area. P-retention ranges from 10 to 90 percent in topsoil samples analyzed from the intermediate terrace. P-retention of soils is important in phosphate fertilizer application. Soils having low P-retention values need relatively low applications of phosphate fertilizers whereas soils having high P-retention values should be treated frequently with high applications. It is clear that P-retention of soils is important in phosphate fertilizer management.

Phosphate retention is strongly related to soil clay mineralogy. If a soil is rich in the clay mineral allophane, the soil has a high P-retention. The allophane is a result of weathering of volcanic glass. Volcanic glass is common in parent materials from volcanic ash. In previous sections it was explained that alluvium, colluvium and loess parent materials on terrace lands are intermixed with volcanic ash. During soil formation volcanic glass weathers to allophane clay minerals under well-drained conditions. Volcanic glass weathers to other clay minerals with low P-retention under poorly drained conditions. Therefore, soil drainage affects allophane formation and then allophane affects the P-retention of soils. It is clear now that the variability of soil drainage is an important factor in soil management problems in the study area.

Soil properties are variable even within one soil. For example, if we analyse the P-retention of a number of soil samples from Kiwitea silt loam soil we may get different results. Variable soil properties such as this are not taken into account in soil mapping.

## **14. Soil Survey**

It is clear from the previous section that some important properties of soils in the study area are highly variable. The variability of soil properties affects soil management practices. Where there are large differences among soil properties, all land cannot usually be managed in the same way. For example, management practices needed for poorly drained soils are quite different to that of well-drained soils. Soils with low P-retention need to be managed differently from soils with high P-retention. Therefore,

in soil surveys, soil scientists try to separate the landscape with variable soil properties into more or less uniform divisions. These divisions are shown on soil maps as map units. A map unit is an area or group of areas in which the soil is less variable than in the larger landscape.

The first step in soil survey is the identification of different soils. Once the soils are identified, the next step is soil mapping to show the distribution pattern of soils on a soil map.

## 15. Soil Identification

Soil scientists examine soil profiles and study the soil horizons and their properties. These properties, such as soil colour, texture, structure and consistency, are quite easy to identify in the field. These soil properties are quite variable among different soils. Soils that have the same profile properties, even if their locations are a long way apart, are given the same name.

For example, consider Coulter silt loam soils and Barrow silt loam soils on the intermediate terrace of the study area. These two soils are formed from the same parent material. Then why are these two soils so different from each other? When we compare the properties of the two soils we see that they are not the same (Table.2). All the thirteen soils identified in the survey area possess different soil properties.

Soils are given local names in a soil survey. If properties of a soil are similar to a soil identified in a previous survey, the soil is identified with the same name. For example, the properties of soils on the lower terrace are similar to Manawatu soils identified in previous soil surveys, therefore, the soils on the lower terrace are named as Manawatu soils.

If the soil properties are quite different to previously identified soils, they are given new local names. For example, properties of Coulter, Barrow, Horoeka, Feilding and Cheltenham soils are not similar to any previously identified soils. Therefore, all were named with new local names.

Table.2 Properties of two different soils (Coulter and Barrow silt loams), developed from the same parent material.

Soil properties	Coulter silt loam	Barrow silt loam
Parent material	mixture of alluvium, colluvium, loess and volcanic ash	mixture of alluvium, colluvium, loess and volcanic ash
Drainage	well drained	imperfectly drained
Subsoil colour	dark yellowish brown	olive and olive grey
Texture	silt loam	variable- silty clay loam clay loam and fine sandy clay loam
Structure	nutty and blocky	nutty and blocky
Consistency	non sticky and non plastic	sticky and plastic
Mottles and gleying	no mottles or gleying	mottles and gleying below 30 cm

## 16. Soil Mapping

In a soil survey soil scientists study only a limited number of soil profiles in an area. This will help them to identify different soils in the landscape. However, it is difficult to give a picture of the distribution of different soils in the landscape, because we cannot see any of the soil properties from the outside; they are hidden underground. Therefore, soil scientists often relate soil properties to landscape features such as terrace edges, slopes, humps, depressions etc. that can be seen at the surface. The landscape features enable them to draw soil boundaries more accurately. The soil surveyor will dig holes to optimise determination of soil distribution.

However, there are some instances where there is no relationship between soil properties and landscape features. This is the situation prevailing in the study area. A 300 m by 250 m block from the intermediate terrace of the study area (Figure.3) shows that there is little relationship between soils and the landscape. Barrow, Horoeke and Coulter soils are three different soils that occur at the same height in the landscape. Barrow soils occur on higher positions as well as on lower positions of the landscape. The relationship of soil to landscape is difficult to predict in the study area.

Therefore, another method of soil survey was used to map the soils. In this method soil observations were made at 250 m intervals (Figure.4A). Soil boundaries were drawn according to the observations to separate map units as shown in Figure 4B.

Each soil observation is 250 m from the next. We do not know whether there are other different soils present between each observations. Therefore, the soil boundaries shown on the soil map are somewhat arbitrary. The map unit shown as Barrow soils (Figure 4B) may include small areas of Horoeoka soils. Similarly the Horoeoka map unit may include some Coulter soils, and the Coulter map unit may include profiles of Horoeoka soil. We would have to dig many more closely spaced holes to be more certain

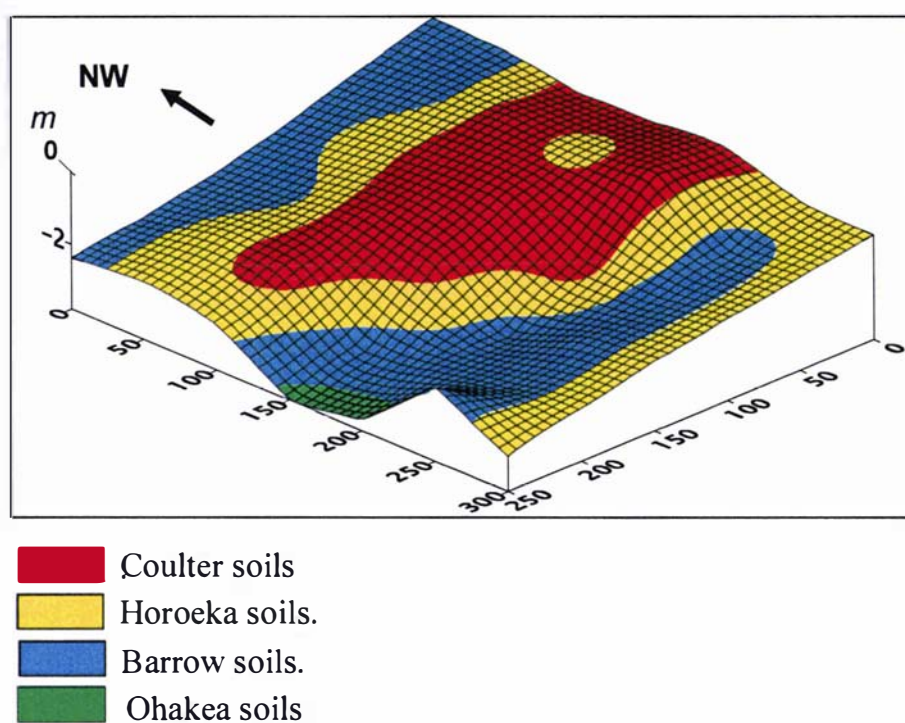


Figure.3 A 300 m by 250 m block from the intermediate terrace to show that there is little relationship between landscape and soils in the study area.

These other soils that may also be present within a map unit in small quantities are called inclusions. Inclusions sometimes affect intended soil management practices. For instance, imperfectly drained Barrow soils included within well drained Coulter soils may affect soil management practices in Coulter soils (for example, causing uneven ripening of grain). But Horoeoka soils included in Coulter map units may not have much effect on the management of Coulter soils and lower the value of that block of land.

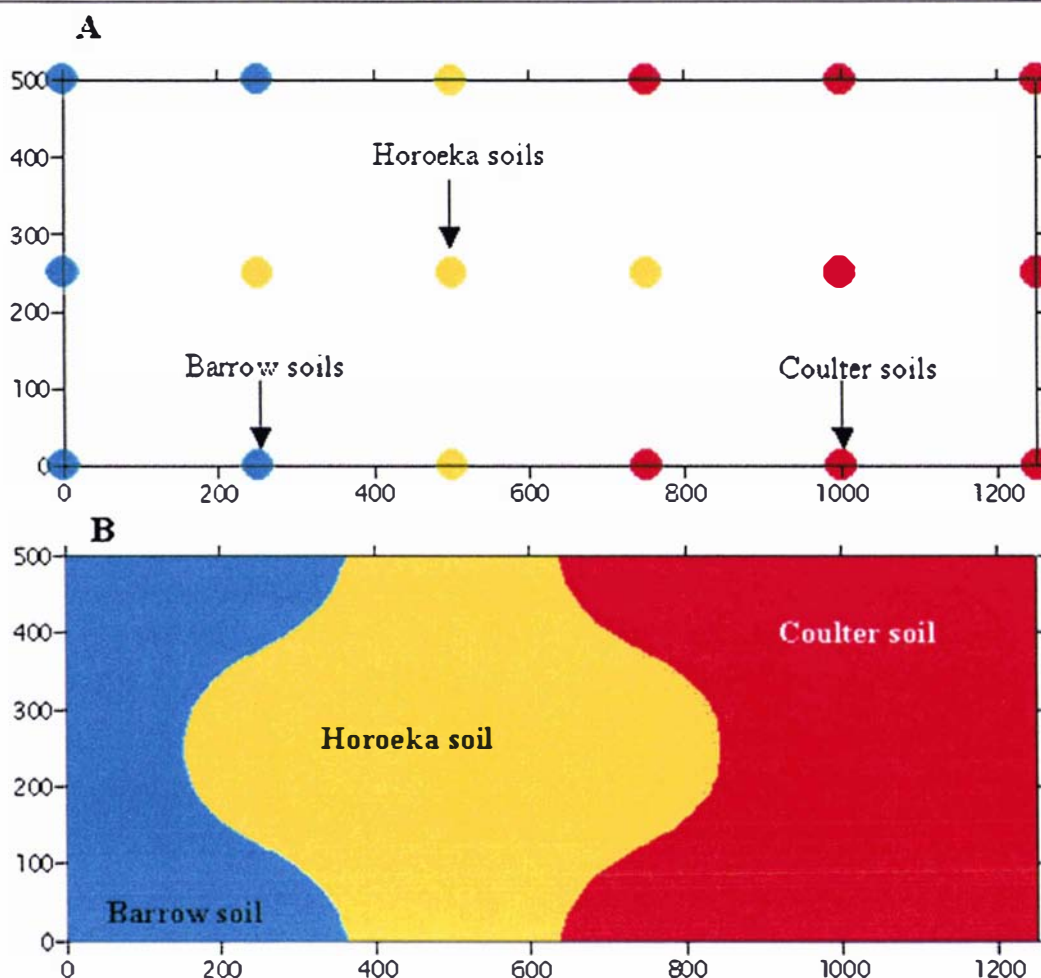


Figure.4 Soil observations made at 250 m intervals (A) and separation of map units (B) based on soil observations made in field.

## 17. Soil Mapping Scale and the Nature of Map Units

When preparing the soil map of the study area, soil observations were made at 250 metre intervals on the ground and the soil map was prepared at 1:25,000 scale. This means that one centimetre on the map = 25,000 centimetres (250 metres) on the ground and one square centimetre on the soil map = 6.25 ha on the ground. We assume that soils within 250 metres are the same everywhere in the map unit. To test this assumption a 250 metre by 250 metre block (6.25 ha) was selected from the Horoeaka map unit (Figure 5A). When mapped at 1:25,000 scale this block consists of only one soil (Horoeaka soils).

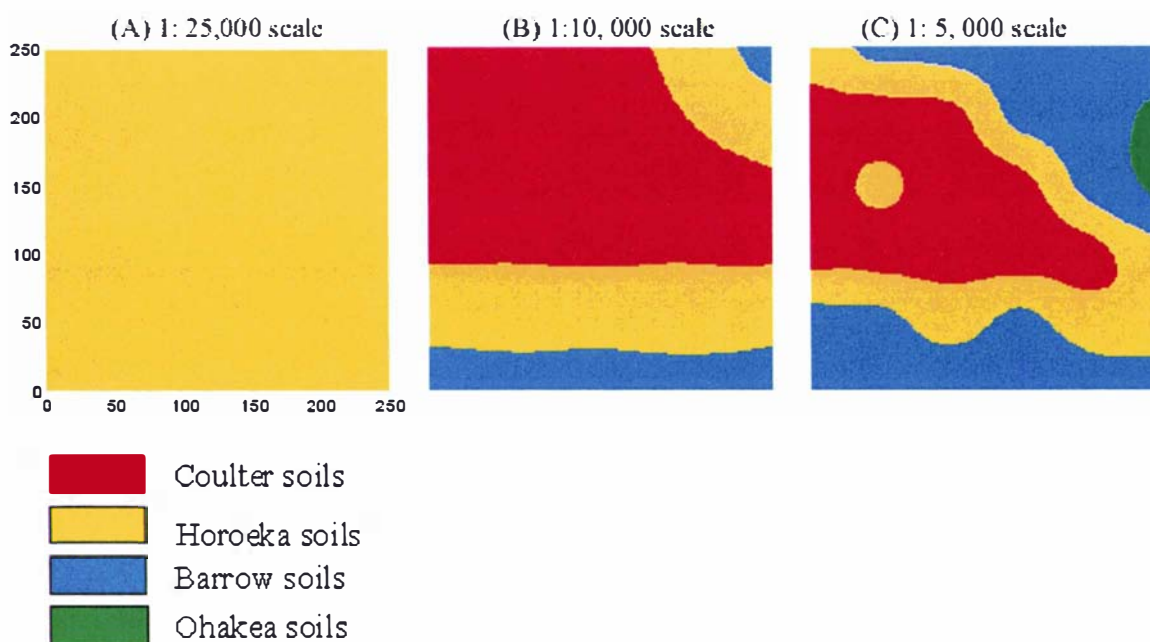


Figure.5 The soil distribution pattern within a single 250 metre by 250 metre block when mapped at 1:25,000, 1:10,000 and 1:5,000 scale.

This block was again mapped, this time taking soil observations at 100 metre intervals (1:10,000 scale). It then became apparent that the single map unit represented in the 1:25,000 scale map is in fact much more complex (Figure..5B). Instead of Horoeke soils there is a mixture of Horoeke, Coulter and Barrow soils present within the mapped area.

The same block was again mapped taking soil observations at 50 metre intervals (1:5,000 scale). A small area of Ohakea soil was also found within the block at this scale (Figure 5C). The soil distribution pattern though is similar to that of the 1:10,000 scale soil map.

From this example, it is clear that soil maps of 1:25,000 scale with observations every 250 m are not capable of showing the soil distribution pattern reliably for farm or paddock scale management. Six hectares covers one or two paddocks in the survey area. Therefore, 1:25,000 scale soil maps have limited use in adopting soil management practices at paddock scale.

For a 1:10,000 scale soil map, one square centimetre on the soil map is one ha. on the ground . This is a reasonable scale to manage soils at farm level. For a 1:5,000 scale soil

map one square centimetre on the soil map represent 0.25 ha on the ground. It seems that for the extra expense and time to map at this more detailed scale, little extra information is gathered. Therefore, a 1:10,000 scale map represents a reasonable compromise between accuracy and time/cost.

## **18. The Soil Map of Kiwitea District**

The soil map covers 2000 ha of land near Kiwitea village and is published at 1:25,000 scale. In view of the above discussion the map shows only the soil distribution at a coarse resolution. Farm managers are advised to seek mapping services at 1:10,000 scale when planning detailed management practices on their farms. Thirteen soil map units shown in the map are soil types, complexes of soil types and phases of soil types.

### ***Soil Type:***

Soil types are formed from the same parent material. If you compare two soil profiles from the same soil type, their properties are the same including the textural properties of the topsoil. For example, Manawatu fine sandy loam and Manawatu silt loam are two soil types occurring on the lower terrace. They are formed from sandy river alluvium. Manawatu is the soil series name, and fine sandy loam and silt loam refer to the topsoil texture. Therefore, soil types are subdivisions of a soil series and the sub division is made on the basis of topsoil texture, which is an important soil management property.

### ***Soil series:***

When you compare properties of two or more soil profiles from one soil series, all the properties are broadly similar to each other except for the topsoil texture. If soil profile properties, e.g. drainage, are different from each other, those soils are identified as two soil series. For example, Coulter series, Barrow series, Horoeka series and Ohakea series are four soils with different drainage properties that occur on the intermediate terrace of the study area.

***Soil complex:***

There are some instances where the soil pattern on the terrain is so complex and unpredictable that individual soil types cannot be shown separately on soil maps. Therefore, these soils are shown on the soil map as a complex. For example, Marton+Feilding complex is made up of Marton silt loam and Feilding silt loam soil types.

***Soil phase:***

Sometimes there are other differences among soil types or soil series, such as soil depth, slope, stoniness etc. For example, Manawatu fine sandy loam (shallow phase) is the same soil as Manawatu fine sandy loam except for a shallower depth to stones. Marton silt loam rolling phase occurs on terrain with slopes ranging from 5 to 9 degrees.

## **19. Soil Properties and Their Importance**

The functions of a soil are to provide plants with air, water, nutrients, a rooting medium and physical support. Soil properties dictate how well a soil can supply these facilities to growing plants. Soil properties can be assessed or measured to judge favourable or unfavourable soil conditions for plant growth and to correct them, where necessary and where possible. For example, soil pH gives us an indication of the need to lime; N. P. K levels tell us about soil fertility; soil texture tells us about soil moisture storage capacity etc. In this section we shall discuss some soil properties which are related to agricultural management.

## 20. Soil Morphological Properties

Soil properties, which we can see or feel, are known as morphological properties.

### 20.1 Soil Colour

Soil colour is the most obvious and easily determined soil property. It has little direct effect on the soil, but is an indicator of a number of other soil properties.

The topsoil is dark compared to the subsoil because of organic matter incorporated by the residues of plants and animals. More organic matter generally leads to a darker soil. Dark coloured soils absorb more heat so they warm up more quickly and have higher mean soil temperature compared to light coloured soils. Colour also can indicate age and weathering where young unweathered soils are grey and old weathered soils are brown or in extreme cases red.

Soil colour is very important in judging soil drainage properties. When we examine a soil profile of a poorly drained soil we can see grey colours throughout the soil profile from the lower part of the topsoil. In imperfectly drained soils red and yellow mottles can be seen in some parts of upper subsoil and grey colours can be seen in the lower subsoil. Well drained soils have no grey colours or red and yellow mottles until a depth of at least 80 cm is reached.

Soil scientists use a set of standard colour charts to describe soil colours. These charts are called the *Munsell Colours*. They compare soil colours with the colour chips on the Munsell Colour Book (Figure.6). The colour chips are referred to a set of standard colour names. Soil colours are identified by these standardised names after compariso

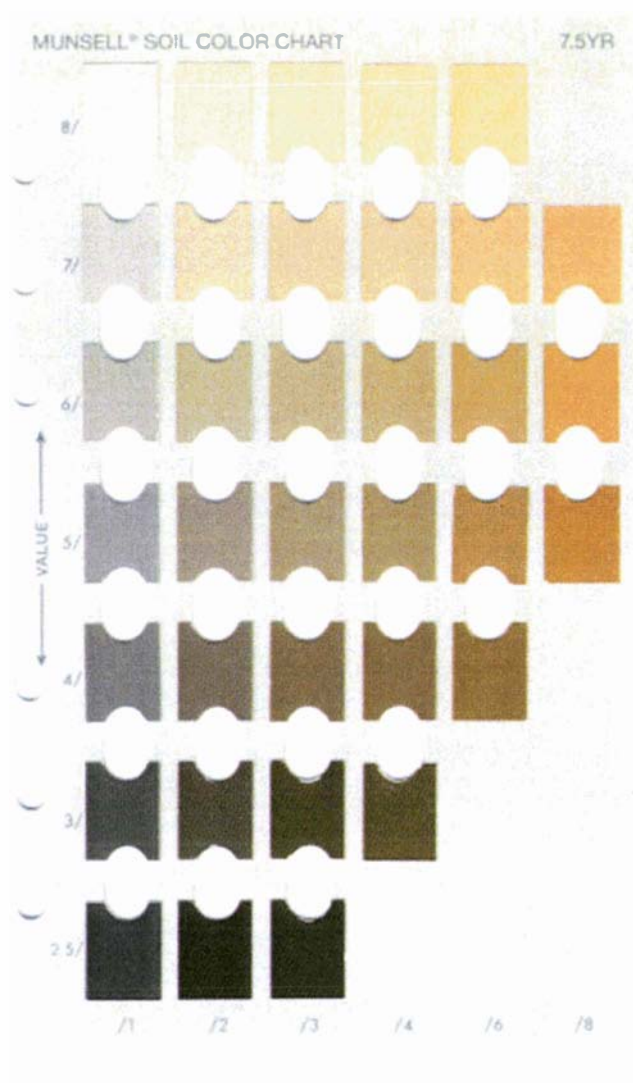


Figure.6 One page of a Munsell Colour book ( Source: Munsell Color Charts, 1994).

## 20.2 Soil Texture

Soil texture is the degree of fineness or coarseness of the soil. It is an expression of the relative amounts of sand, silt and clay. Rubbing soil between the thumb and forefinger is the simple field test that can be used to estimate soil texture. Generally the terms sand, silt and clay refers to different size particles in soils.

Sand	2.0 – 0.06 mm
Silt	0.06 – 0.002 mm
Clay	less than 0.002 mm.

Sand particles may be seen with the naked eye. Silt particles may be seen with a good microscope whereas clay can only be seen with an electron microscope. For example, the relative size of these particles can be given as:

Sand	=	basketball
Silt	=	golf ball
Clay	=	pin head.

Silt loam, clay loam, fine sandy loam, clay and sand are some of the textural classes of soils in the survey area. The term loam indicates roughly equal amounts of sand, silt and clay. A silt loam, therefore, contains a large proportion of silt and smaller quantities of sand and clay. Textural classes can be broadly grouped into three; coarse, medium and fine.

Coarse textured soils (sands and loamy sands) hold small amounts of water and plant nutrients. These soils may have to be irrigated and fertilized frequently. Water moves through the soil rapidly and they have large number of air filled pores. Cultivation is generally easy, but structure may be poor.

Fine textured soils (clays, sandy clays, silty clays) hold large amounts of plant nutrients and water. However, not all the water is available to plants. Water infiltrates slowly and the soils have fewer air filled pores. The soils may crack during dry seasons, depending on the type of clay minerals present. Cultivation requires more power and passes by the tractor.

Medium textured soils (loams, clay loams, sandy loams, silt loams) have properties in between the other two textural classes. If a soil is rich in silt, the soil has high plant available water holding capacity.

Soil texture is an inherent property of a soil and cannot change by soil management practices, except by addition of materials.

## 20.3 Soil Structure

When we examine soils we see that soils are made up of aggregates having different shapes and sizes known as soil structure. Sand, silt and clay particles in soils combine together to form aggregates called peds or structural units (Figure.7).

Soil structure is formed during soil formation. Soil organic matter, clay particles and often lime and iron are important in the formation of soil structure. These materials act as cementing agents to combine primary sand, silt and clay particles together to form soil aggregates.



Figure.7 An example of various sizes of nutty aggregates.

Soil aggregates take different shapes, Prismatic, columnar, blocky, subangular blocky (nutty), platy and granular are the most common types of structural units (Figure.8).

Topsoil under pasture generally has a very good structure. This may be due to large amounts of organic matter associated with the high number of plant roots. Most topsoil under pasture have granular or nutty structure. These aggregates are highly porous because there are pores within the aggregates as well as broken aggregates.

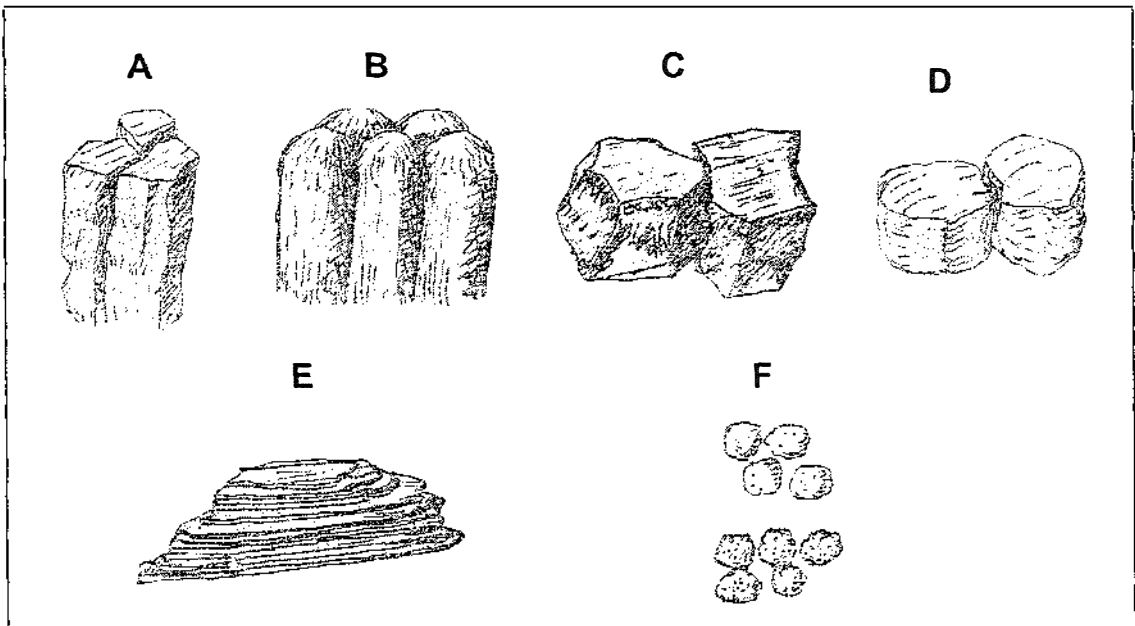


Figure.8 Types of soil structural units. A, prismatic; B, columnar; C, blocky; D, sub angular blocky (nutty); E, platy; and F, granular.(Source: Brady, N.C., Weil, R.R. The Nature and Properties of Soils).

Prismatic, columnar, blocky and platy structures are not common in agricultural soils in New Zealand. Platy and blocky structures are common, however, in hard pans and prevent air and water movement in soils.

Soil structure regulates air and water movement. Good soil structure increases infiltration of water, thus reducing runoff and erosion and increasing the amount of plant available water. It improves seedling emergence, root growth and rooting depth; and develops large continuous pores to allow increased water movement within soils improving soil drainage.

Continuous cultivation of crops, usage of heavy agricultural machinery and pugging can cause soil structural damage. Maintenance of structure in agricultural soils is very important in the maintenance of quality soils. The following practices help to maintain soil structure:

- Cultivate soil only at the proper moisture content. Never cultivate when the soil is too wet. This will cause the soil to become cloddy. Soil aggregates are easy to destroy when wet.

- Add the optimum amounts of lime and fertilizer. This practice helps to maintain healthy plant growth and leads to the development of good soil structure.
- Grow grass and legumes following crops. These plants help to form stable aggregates.
- Legumes also promote more microorganism activity in the soil such as certain beneficial fungi, which will stabilize aggregates..
- Maintain or increase the organic matter content of the topsoil.

Soil structure is described using three parameters. They are grade, class and type of structure. The grade of structure is the degree of aggregation. The terms used to describe the grade of soil structure are structureless (single grain when soil is moist; massive when soil is moist), weak, moderate and strong.

The class of structure describes the average size of individual aggregates. The terms used to describe the class of structure are very fine, fine, medium, coarse and very coarse.

The type of structure describes the shape of individual aggregates. The terms used are prismatic, columnar, blocky, nutty, platy and granular.

## 20.4 Soil Consistence

Soil consistence is a term used to describe the physical condition of a soil at various field moisture conditions. It describes the resistance of a soil at various moisture contents to mechanical stress or manipulation.

Terms that are commonly used to describe soil consistence are:

Wet soils:      non sticky, slightly sticky, sticky, very sticky - stickiness describes how soil adheres to hooves, tyres, spades and boots;

                    non plastic, slightly plastic, plastic and very plastic – plasticity describes the ability of wet soil to be moulded like modelling clay.

Moist soils: loose, very friable, friable, firm, very firm and extremely firm. The ease with which a seedbed is formed.

Dry soils: loose, soft, slightly hard, hard, very hard and extremely hard. These terms relate to risk of wind erosion and ease of seedbed formation.

Consistency gives a good indication of how the soil will react to usage of agricultural implements for land preparation practices, traffic, digging or similar activity at various field soil moisture conditions. For example, sandy soils are not sticky or plastic when wet; and are loose or soft when dry. Therefore, agricultural implements can be used on these soils within a large range of moisture conditions from wet through to dry (e.g. Manawatu soils, Coulter soils).

Clay soils become sticky and plastic when wet and hard or extremely hard when dry. These soil conditions are not suitable for cultivation. Therefore, clay soils have a very limited soil moisture range for cultivation.

Soils that are sticky, very sticky, plastic and very plastic when wet; firm, very firm and extremely firm when moist and hard, very hard, and extremely hard when dry conditions are not suitable for cultivation. Under these conditions more power is needed to cultivate land and damage to soil structure is likely.

## 21. Soil Physical Properties

These are properties that can be sensed by sight and feel, but can also be substantiated in the laboratory.

### 21.1 Bulk Density (BD)

Bulk density is a method of expressing soil weight for a given volume of soil. In Section 9.10 "Soil Components" it was explained that soils are composed of solids and pore spaces. Bulk density is measured in tonnes per cubic metre ( $t\ m^{-3}$ ) or grams per cubic centimetre ( $g\ cm^{-3}$ ). Bulk density is a measure of how compact or dense a soil is.

It is also an indirect measure of pore spaces within a soil. Soils having more pore spaces have low bulk density whereas soils having fewer pore spaces have high bulk density (Figure..9).

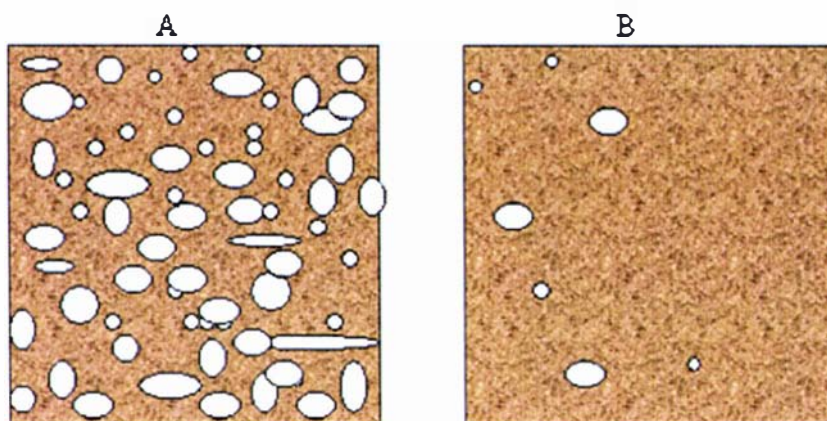


Figure.9 Soils with low bulk density and high porosity (A) and soils with high bulk density and low porosity (B). The white shapes are pores.

If a soil is compacted, the amount of pore space is reduced, the weight of a given volume of soil is increased and its bulk density also increases. Some soils have naturally compacted layers (pans) that may have a high bulk density. Such densities restrict root penetration and water movement. In other cases, heavy tractors and machinery may cause compaction which limits plant growth. Soils developed from volcanic ash have very low bulk densities, because these soils are very porous.

Soils formed from parent materials mixed with volcanic ash (e.g. Coulter and Dannevirke silt loams) have low bulk densities ( $0.9 \text{ g/cm}^3$ ), because the soils have high porosity. The ratings for bulk density are:

<b>Bulk density <math>\text{t/m}^3</math></b>	<b>Rating</b>
<0.2	very low
0.2 – 0.8	low
0.8 – 1.3	medium
1.3 – 1.8	high.

## 21.2 Porosity

The percentage of pore space in soil is called porosity (see Figure..9). As the parent material of soil becomes weathered, loosened and mixed during soil formation, pore spaces develop, providing a place for air and water to be held. Both the amount of pore space and the size of the pores are important. Small pores (micropores) retain water very well, while from large pores (macropores) water drains out and air moves in. Therefore, it is desirable to have both large and small pores in a soil.

Soils with good structure have a high porosity between and within aggregates, but soils with large structural units may not have large pores within the large clods and therefore, may not be adequately aerated. Soils having granular or nutty structure have a high porosity whereas soils with massive or columnar structures have low porosity. Sandy soils contain a number of large pores. Therefore, sandy soils are well drained and well aerated except where the water table rises within the profile. Clay soils are highly porous, but the pores are small and do not drain readily. Clay soils have a tendency to poor drainage and aeration. The ratings for porosity are:

<b>Total pores %</b>	<b>Large pores %</b>	<b>Rating</b>
<35	<5	low
35-45	5-10	moderately low
45-55	10-15	moderate
55-65	15-20	moderately high
>65	>20	high.

## 21.3 Soil Water

Plants take up water stored in soils, but not all water held in soils is accessible to plants. If a soil can store more plant available water, crops and pastures will survive on those soils for a longer period in the absence of rain or irrigation. Otherwise crops and pastures may suffer from moisture stress, particularly during dry summers. Therefore, the amount of water that a soil can store, known as soil moisture storage capacity, is important in agriculture.

To understand the moisture storage capacity for a soil we need to know the meaning of the following terms.

### ***Saturation:***

Soils receive water either from rainfall or irrigation. After heavy rains or a continuous supply of irrigation water, soils begin to soak. As the water enters the soil, air within soil pores is displaced and the pores will be filled with water. At this stage the soil is said to be at saturation (Figure.10, A).

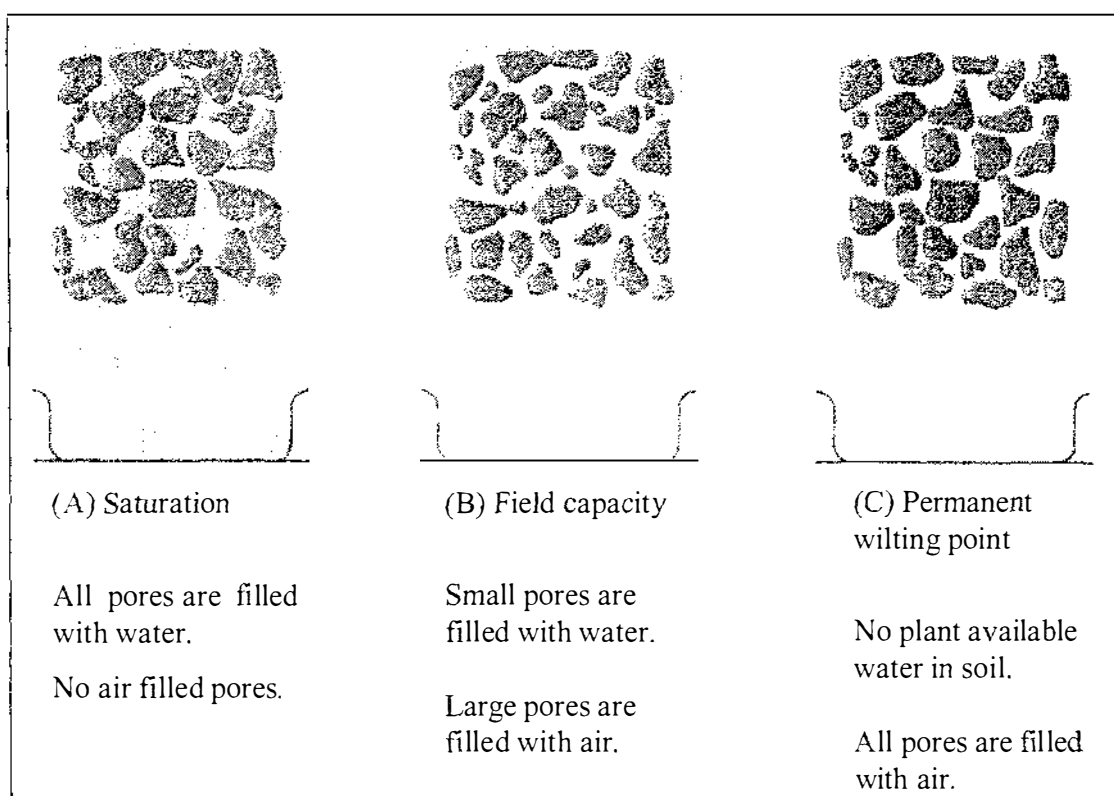


Figure.10 Soils at (A) saturation, (B) field capacity and (C) wilting point.(Source: Brady, N.C., Weil, R.R. The Nature and Properties of Soils).

***Field capacity:***

A day or so after it stops raining or irrigation water is shut off, excess water drains from the largest pores (macropores). At this stage, water is held in medium and small pores but the large pores are filled with air and the soil is said to be at its field capacity (Figure..10, B).

***Permanent wilting point:***

The water held in soils at field capacity can be lost from the soil in two ways: transpiration from crops and direct evaporation from the soil surface. This process was explained in Section .5 as evapotranspiration.

As the soil dries out plants will begin to show the effects of reduced soil moisture. During the daytime plants will tend to wilt, and will recover during nighttime. After a few more days plants will be permanently wilted. Permanent wilting point can be described as the amount of water in the soil at which plants are permanently wilted (Figure..10, C).

***Available water capacity (AWC):***

The amount of water, which a soil can store for plant growth, can be considered as the available water capacity (AWC). This is equal to the amount of water held in soil between field capacity and the permanent wilting point (Figure..11). However, not all the water within the range of field capacity and the permanent wilting point is equally available to plants. The portion of the AWC that plants can easily absorb and continue to grow is known as readily available water. Available water capacity and the readily available water capacity of soils can be determined in the laboratory. The amounts are expressed in millimetres (mm) per 50 cm of soil depth (eg. For a shallow rooted crop such as grass) or 100 cm of soil depth (eg. for a deep rooted crop such as maize).

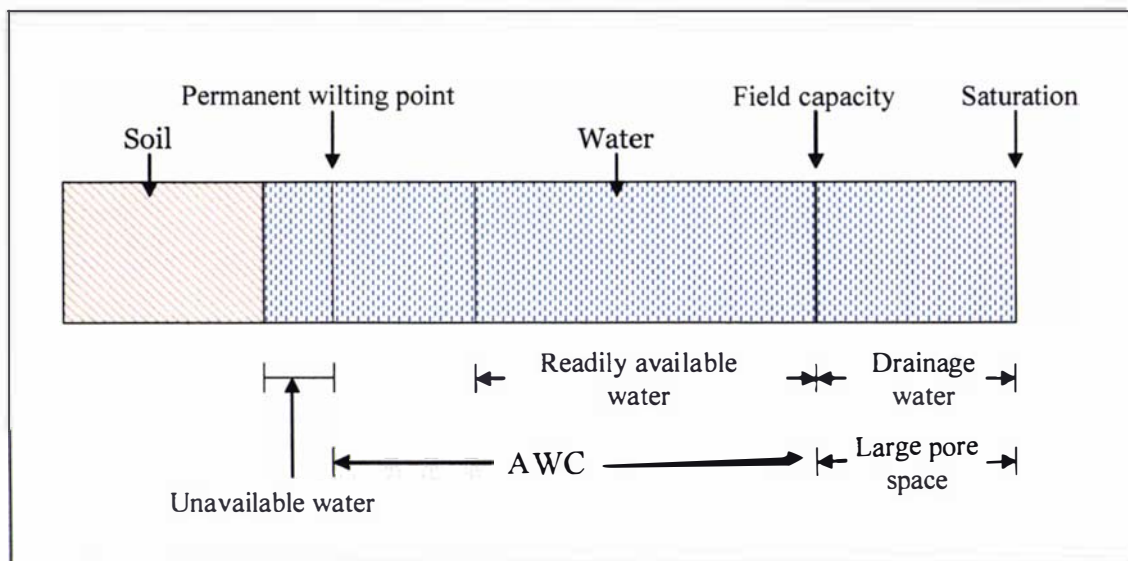


Figure.11 The amounts of water held by a soil at its saturation, field capacity and permanent wilting point.

The AWC in soils vary according to soil properties. The AWC of sandy soils is very low, whereas the AWC of silty soils is very high. For example Manawatu fine sandy loam and Manawatu silt loam<sup>20</sup> are sandy soils. Their readily available water within the 50 cm soil depth is 43 mm and 37 mm respectively. Kiwitea silt loam, which is a silty soil can store 59 mm of available water within the upper 50 cm of soil. If a soil is very stony, its AWC again is low. For example Kawhatau stony silt loam, which is a stony soil has only 35 mm of available water within the upper 50 cm of soil. If the soil is shallow, the amount of water that can be stored is also low. Therefore, crops and pastures grown on sandy soils, gravelly soils and shallow soils may suffer from moisture stress during dry seasons.

<sup>20</sup> Manawatu silt loam usually consists of a silty topsoil over a sandy subsoil

### ***The dry season in the Kiwitea District:***

The main source of soil water in the Kiwitea study area is rainfall. The water stored in the soil is lost through the process of evapotranspiration (ET). When we look at the monthly rainfall data and the monthly ET data (Table.3, Figure..12) it is clear that from March until October monthly rainfall is more than the monthly ET rates.

Table.3 Monthly rainfall (RF) data for Kiwitea and evapotranspiration (ET) data for Ohakea.

RF/ET mm	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	year
RF – Kiwitea	78	80	95	91	91	102	111	91	98	116	105	95	1152
ET - Ohakea	156	121	97	59	36	25	26	42	65	97	126	149	999

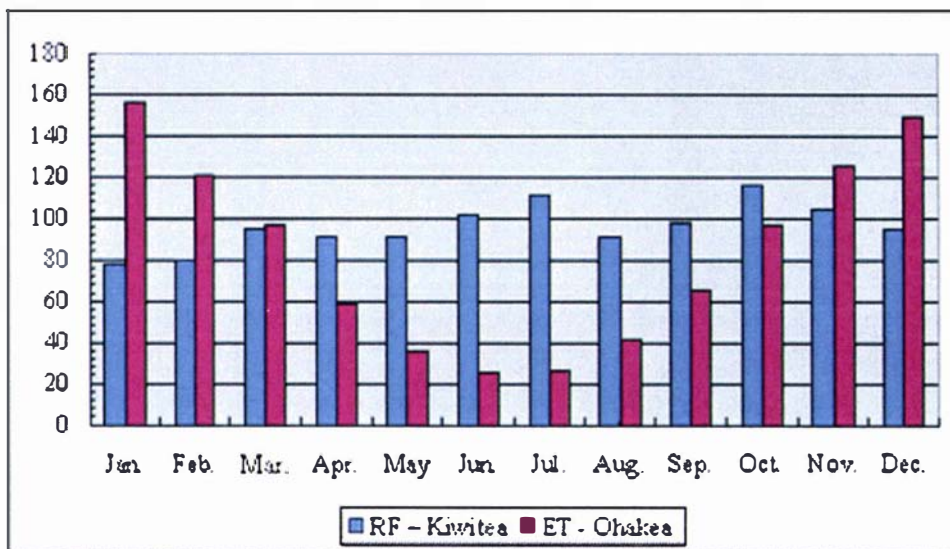


Figure.12 Relationship between monthly rainfall (RF) and monthly evapotranspiration. (ET) November to March (4 months) is normally the dry period for Kiwitea.

During this period there is no moisture stress for pastures or crops. From November onwards ET rates are higher than rainfall. During this period crops start to use moisture stored in the soil. Depending on the moisture storage capacity of the soils and the

rooting depth, crops can absorb stored soil moisture for a limited time. The higher the readily available moisture in the soil the longer the crops can survive in the dry period.

## 22. Soil Chemical Properties

We cannot see or feel chemical soil properties and need to measure them in the laboratory. Most soil chemical properties are associated with soil colloids. Therefore, we need to know about soil colloids and their functions in soils.

### 22.1 Soil Colloids and their Functions

Very tiny clay and humus particles in soils are known as soil colloids. These particles are so tiny that it would take 100,000 of these particles, side by side, to extend one centimetre. Colloidal particles carry negative (-) charges on their surface. Some plant nutrients are positively charged cations ( e.g.  $K^+$ ,  $Ca^{++}$ ,  $Mg^{++}$  etc.). Opposite charges attract each other, therefore positively charged cations in soils are attracted by these negatively charged soil colloids and are loosely held so that plant nutrients are not readily lost from the soil and beyond the root zone by leaching. Plant roots can absorb nutrients whenever they need them.

The number of negative charges carried on a colloidal particle depends upon the type of colloid. Humus particles carry more negative charges compared to clay particles (e.g. if a clay particle can carry 30 negative charges, a humus particle will carry 300). Therefore, humus can retain more nutrients than clay minerals and organic matter rich soils can retain more plant nutrients than soils which are poor in organic matter (Figure.13).

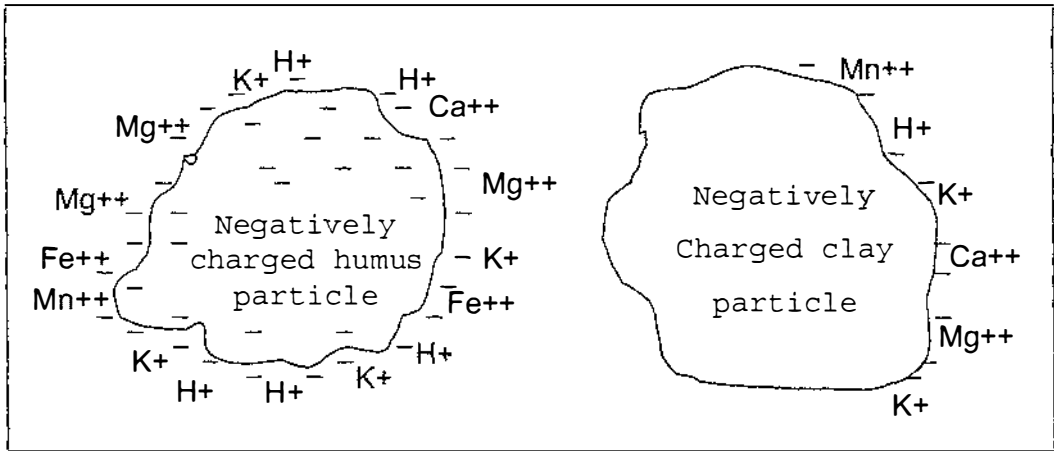


Figure.13 Colloidal humus can retain more plant nutrients than can clay.

There are colloidal particles in soil other than humus and clay minerals. They are the oxides of iron and aluminium, most commonly allophane. They can carry either negative (-) or positive (+) charges. When soil pH is acidic (less than 6) their surface carries more positive charges and when soil pH is alkaline (more than 8 ) their surface carries more negative charges. When soil pH is neutral (pH 6-8) the negative and positive charges on the colloid becomes equal (Figure.14). Positively charged soil colloids have beneficial effects by retaining negatively charged plant nutrients such as phosphate ( $HPO_4^{--}$  and  $H_2PO_4^{-}$ ), sulphate ( $SO_4^{--}$ ) and nitrates ( $NO_3^{-}$ ).

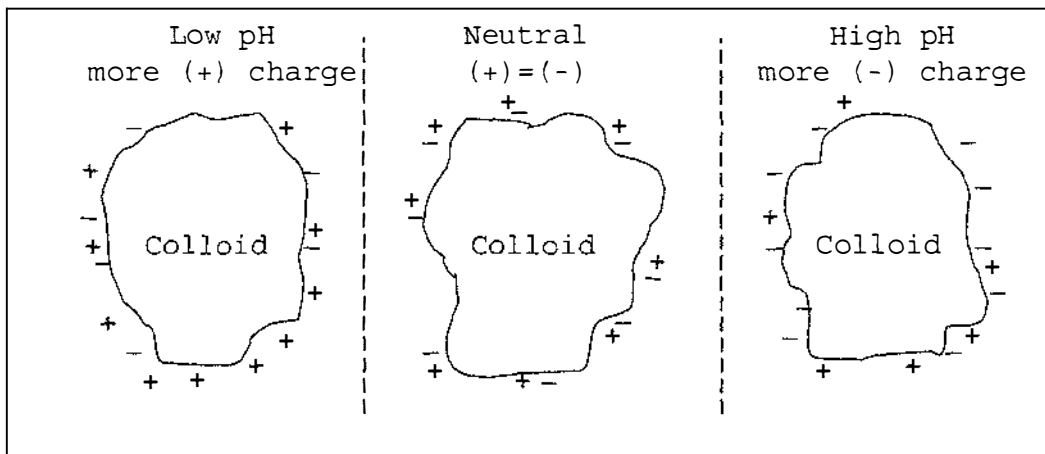


Figure.14 Some colloidal particles carry more positively charges at low soil pH and more negative charges at high soil pH. Both positive and negative charges are equal at neutral pH.

## 22.2 Soil Reaction (soil pH)

Soil pH is important in crop production and is an indicator of the acidity or alkalinity of the soil. Soil acidity is associated with hydrogen ions ( $H^+$ ). When negatively charged soil colloidal particles are surrounded by more  $H^+$  ions the soil becomes acidic. Some soils are rich in aluminium (Al), and  $Al^{+++}$  ions also indirectly cause soil acidity. If the colloidal particles are surrounded by other cations such as  $Ca^{++}$ ,  $Mg^{++}$ , and  $K^+$  soils become less acidic (Figure..15).

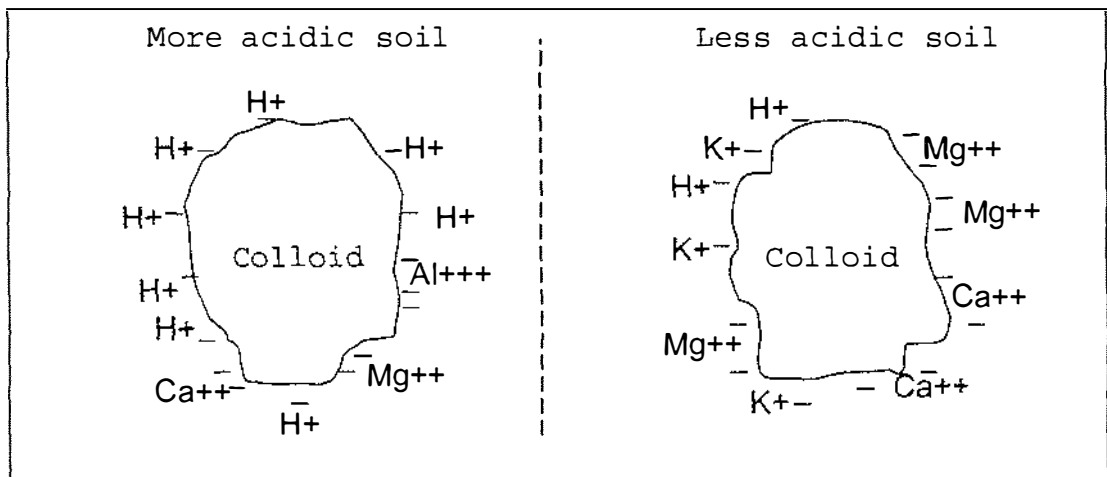


Figure.15 Soil colloids in more acid soils are surrounded by  $H^+$  and  $Al^{+++}$  than other cations.

The pH scale ranges from 1 to 14. pH 7 is considered as neutral. The ranges of pH values used in measuring soil pH are as follows:

pH range	Rating
Less than 4.5	extremely acid
4.5 – 5.2	strongly acid
5.3 – 5.9	moderately acid
6.0 – 6.5	slightly acid
6.6 – 7.0	near neutral
7.1 – 7.5	slightly alkaline
7.6 – 8.3	moderately alkaline

8.4 – 9.0                   strongly alkaline  
 more than 9.0             extremely alkaline

This important soil property affects the availability of plant nutrients. It is clear from Figure.15 that more acidic soils have fewer plant nutrients such as  $K^+$ ,  $Ca^{++}$  and  $Mg^{++}$ .

In strongly acidic soils (less than pH 5) activities of soil microorganisms (eg. bacteria and actinomycetes) become very low. Nitrogen (N), calcium (Ca), magnesium (Mg), phosphorus (P), potassium (K) also becomes less available to plants. On the other hand the availability of micro nutrients except for molybdenum (Mo) become high (Figure.16)

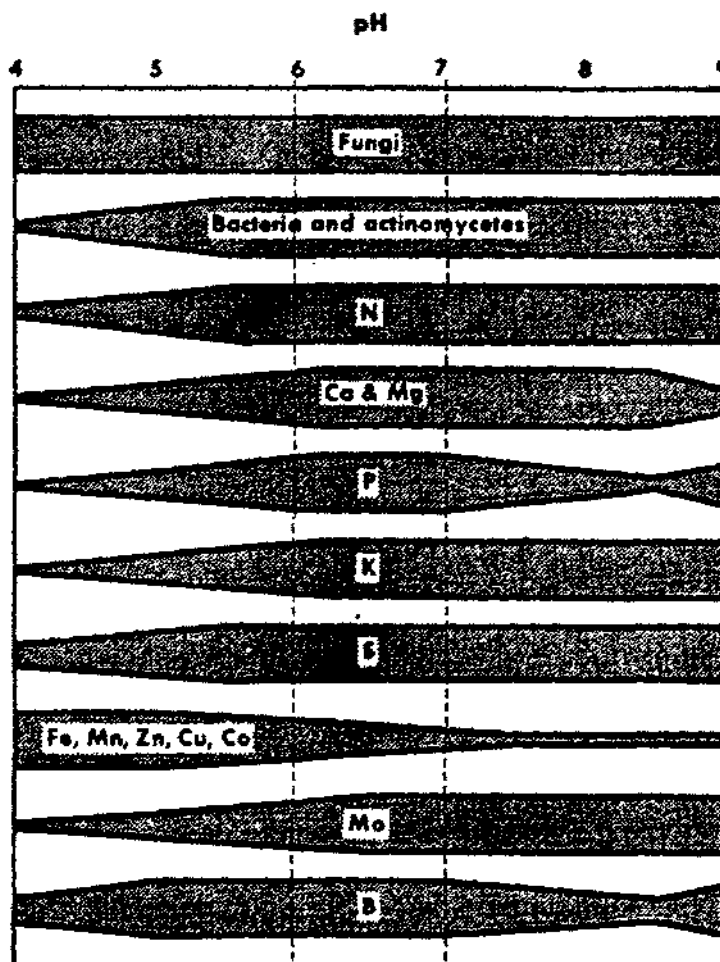


Figure.16 The relationships existing in soils between pH and

the activity of microorganisms and between pH and the availability of plant nutrients. The width of the bands indicate the zones of greatest microbial activity and the mostly readily availability of plant nutrients. (Source: Buckman, H.O., Brady, N.C., *The Nature and Properties of Soils*)

A pH range of approximately 6 to 7 seems to promote the ready availability of most essential plant nutrients. If soil pH is suitably adjusted for maximum availability of phosphorus, other plant nutrients, if present, will be satisfactorily available to plants in most cases.

### **22.3 Organic Carbon (O.C)**

Compost, green manure and farmyard manure are very common terms to farmers. Decomposed animal and plant residues are generally known as organic matter. The organic matter level in soils is measured in laboratories in terms of organic carbon. The organic matter content is equivalent to 1.7 times the organic carbon in a soil.

Animal and plant residues in soils are decomposed by micro-organisms. They feed on organic matter to obtain nutrients. When organic matter is decomposed a number of plant nutrients are released into the soil. Highly decomposed organic material called humus is resistant to further decomposition. Humus is dark brown or black, therefore, organic matter rich soils are dark coloured. Usually topsoil rich in humus is darker than the subsoil.

Organic matter plays a number of important roles in soils.

- Organic matter functions as a binding material or granulator of the mineral particles, being largely responsible for the development of soil structure.
- Organic matter is also responsible for loose, friable and porous conditions of productive soils.
- It is a source of some plant nutrients. Nitrogen (N), phosphorus (P), potassium (K), sulphur (S), calcium (Ca), magnesium (Mg) and micro nutrients such as zinc (Zn), manganese (Mn) and boron (Bo) are the most common ones.

- Organic matter increases plant available water holding capacity.
- It is the main source of food for soil microorganisms, which are responsible for a number of activities in soils such as decomposition of plant and animal residues, nitrogen fixation, nitrification etc.
- Organic matter is largely responsible for soil physical and chemical fertility.
- It can retain more plant nutrients attached to its surface as explained in Section 9.22.1 “Soil Colloids”, and increase soil fertility.

Organic matter content decreases when soils are cultivated for crops. This can result in the break down of soil structure and poor soil physical and chemical properties. Therefore, maintenance of soil organic matter is a very important soil management practice. The ratings for Organic Carbon are:

<b>Rating</b>	<b>Organic carbon (%)</b>
Very high	more than 20
High	10 – 20
Medium	4 – 10
Low	2 – 4
Very low	less than 2

## **22.4 Cation Exchange Capacity (CEC):**

Negatively charged humus and clay colloids in soil attract positively charged cationic plant nutrients in the soil solution. The process was explained in Section.22.1 "Soil colloids". The attracted cations can be replaced by some other cations. For instance, when we apply lime into acid soils, the  $H^+$  ions attracted to colloids are replaced or exchanged with  $Ca^{++}$  in the liming material (Figure 17). When colloidal particles are surrounded by  $Ca^{++}$  ions the soil becomes less acidic. An another example is that when we apply potassium fertilizer to soils,  $H^+$  ions attracted by colloids are replaced by potassium ions ( $K^+$ ). The replacement of one cation by another cation from soil colloids is known as cation exchange.

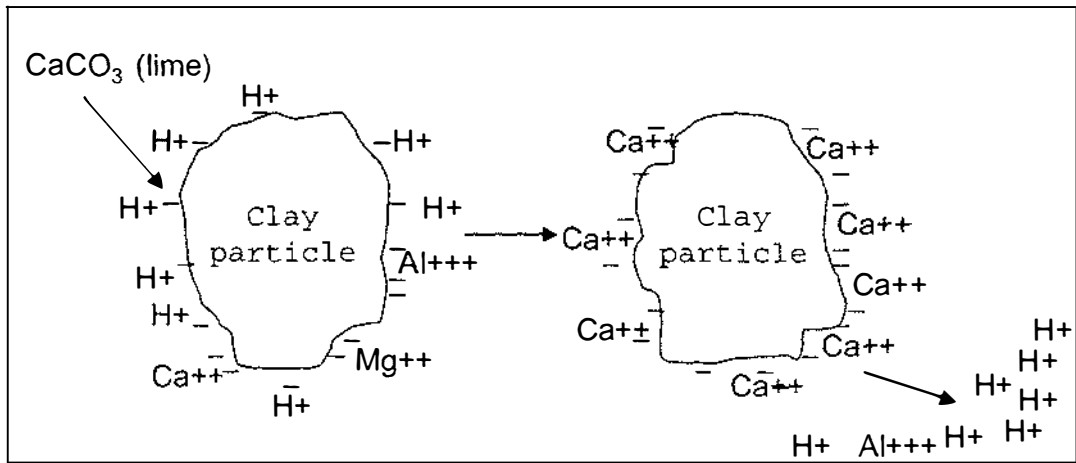


Figure.17 Diagram showing the cation exchange process.  $H^+$  associated with soil colloidal particles in acidic soils can be replaced by  $Ca^{++}$  in lime material.

As explained in the previous section, humus particles have more capacity to attract cations than clay particles. This means that the cation exchange capacity of humus is more than that of clay. It is clear that if soil or humus particles carry more negative charges on their surface they could attract more cations and the cation exchange capacity (CEC) is also greater. When CEC is high, a soil can retain more plant nutrients. The CEC of the soil gives a strong indication of the ability of a soil to retain and release plant nutrients. Organic matter rich topsoils usually have high CEC values compared to the subsoil, because humus has high CEC values.

The CEC is expressed in terms of positive charge adsorbed per unit mass. The CEC of soils commonly varies from 0.03 to 0.5 mole of positive charge per kilogram of soil. To express the CEC in whole numbers, the charge is usually indicated in centimoles per kilogram of soil ( $cmol_c\ kg^{-1}$ ). Since there are 100 centimoles in 1 mole, the preceding range of CEC of soils is 3 to 50  $cmol_c\ kg^{-1}$ . For example the CEC of the topsoil of Manawatu fine sandy loam is 10  $cmol_c\ kg^{-1}$ . This means 1 kg of Manawatu fine sandy loam soil can adsorb 10  $cmol_c$  of positive charges (+). When we apply potassium fertilizer to Manawatu fine sandy loam soil, 1 kg of this soil can retain 10  $cmol_c$  of potassium ions ( $K^+$ ). Since the  $K^+$  ion is singly charged, the mass of  $K^+$  needed to provide 1 mole of charge is the gram atomic weight of potassium (39 g). The weight providing 1 centimole of charge is 1/100 of this amount or 0.39 g. The weight providing

10 centimoles of charge is 3.9 g. Therefore, 1 kg of Manawatu fine sandy loam soil can hold 3.9 g of K when potassium fertilizer is applied. The ratings for CEC are:

<b>Rating</b>	<b>cmol<sub>c</sub> kg<sup>-1</sup></b>
Very high	more than 40
High	25 – 40
Medium	12 – 25
Low	6 – 12
Very low	less than 6.

## 22.5 Total Exchangeable Bases (TEB)

The cations attracted to the negatively charged colloids except for H<sup>+</sup> and Al<sup>+++</sup> are known as basic cations, because when these cations are attached to negatively charged clay and humus particles, soils become less acidic. Basic cations such as Ca<sup>++</sup>, Mg<sup>++</sup> and K<sup>+</sup> are important plant nutrients and are also known as exchangeable bases. The total exchangeable bases in a soil give an indication of soil fertility status. The higher the TEB value in a soil, with a few exceptions, the better the soil fertility. The ratings for TEB are:

<b>Rating</b>	<b>cmol<sub>c</sub> kg<sup>-1</sup></b>
Very high	more than 25
High	15 – 25
Medium	7 – 15
Low	3 – 7
Very low	less than 3

## 22.6 Base Saturation (B.S)

The proportion of CEC occupied by the exchangeable bases is referred to as percentage base saturation. As an example, on the colloidal clay particle in Figure 9.18 there are 20 cations, 10 of which are basic. Therefore, the percent base saturation is  $10/20 * 100 = 50\%$ .

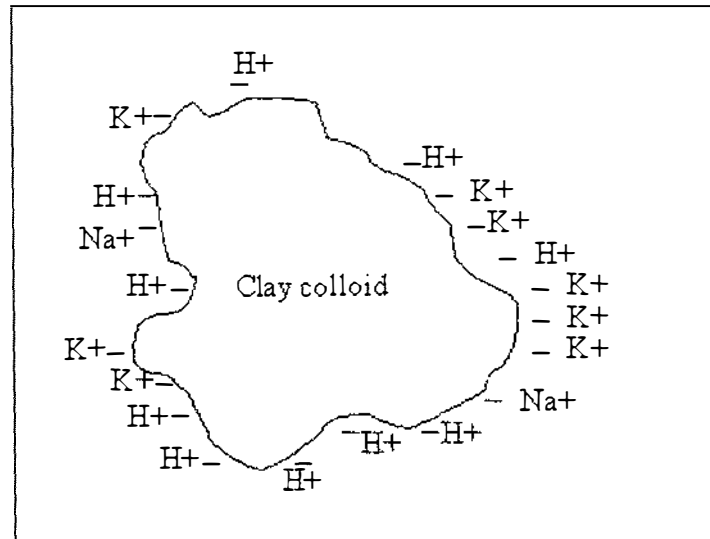


Figure.18· Negatively charged colloidal particle surrounded by acidic and basic Cations.

The ratings for base saturation are:

Rating	B.S (%)
Very high	80 – 100
High	60 – 80
Medium	40 – 60
Low	20 – 40
Very low	less than 20.

Base saturation gives an indication of the status of plant nutrients in soils. High base saturation means a relatively high amount of plant nutrients, but it is sometimes misleading. As an example, the two soils shown in Figure..19 have 50 % base saturation, but in soil 1, TEB is 30 whereas in soil 2, TEB is 15. The plant nutrient level

in soil 1 (TEB=30) is more than in soil 2 (TEB = 15), but both soils have the same base saturation. Therefore, when we talk about BS, we have to consider the CEC of the soil too.

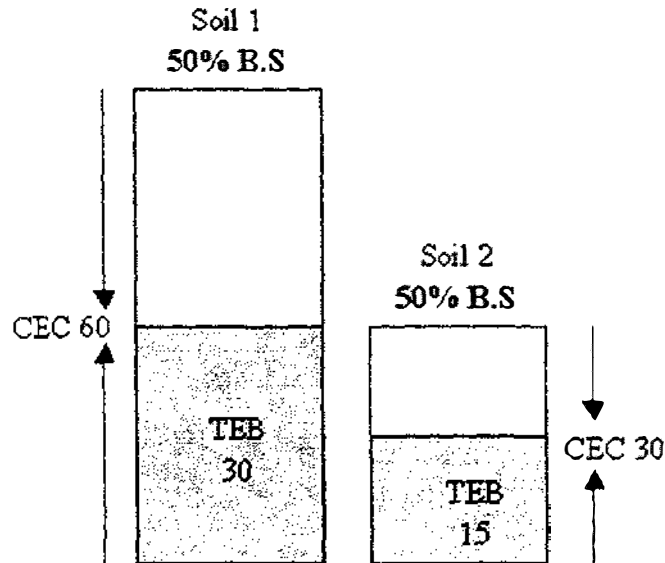


Figure.19 Two soils having the same base saturation, but different plant nutrient status (TEB).

## 22.7 P-retention

Most phosphate fertilizer applied to soil is readily soluble in water and plant roots can easily absorb it. Unfortunately, in many soils, a large proportion of the added phosphate reacts with the soil in ways which makes the phosphate less soluble and less available to plants. The alteration from water-soluble and plant available phosphate to less plant available forms is known as phosphate fixation. When phosphate is fixed into soils, plants cannot absorb the phosphate at least in the short-term (unlike cation exchange). Therefore, plants do not grow to their potential and may start to show phosphate deficiency.

Certain clay minerals present in soils are responsible for phosphate fixation. Under acid conditions (low pH) fixation is mainly as a result of colloidal iron (Fe) and aluminum (Al) compounds, whereas above pH 7.0 fixation is mainly as calcium (Ca) or magnesium (Mg) phosphate. Soils which have allophane clay minerals contain a large

amount of iron and aluminum compounds. Therefore, allophone rich soils fix a lot of phosphate compared to other soils.

The ability of a soil to fix phosphate is determined in laboratories. This laboratory test is known as the phosphate retention test. Soils having high P retention values can fix more phosphate, whereas soils having low P retention values, fix less phosphate. The P retention results are given as percentages.

When we apply P fertilizer into a soil having high P retention, more of the phosphate ions are fixed onto soil colloids and less phosphate is released into the soil solution in a plant available form (Figure..20). Therefore, more phosphate fertilizer needs to be applied to soils having high P retention in order to increase the plant available soil solution P. If the same amount of P fertilizer is applied to a soil having low P retention, less P is fixed onto soil colloids (Figure..20) and more phosphate is released into the soil solution in a plant available form. Sometimes P in soil solution can exceed the plant requirement. Then the excess P goes to waste and also pollutes ground water and local waterways. Therefore, soils with low P-retention have to be treated with less P fertilizer. The ratings for P-retention are:

Coulter and Dannevirke silt loam soils in the study area have high to very high P retention capacity, because these soils contain allophone in their colloidal clay fraction. In contrast Manawatu soils have low P-retention capacity because these soils contain no allophone in their clay fraction.

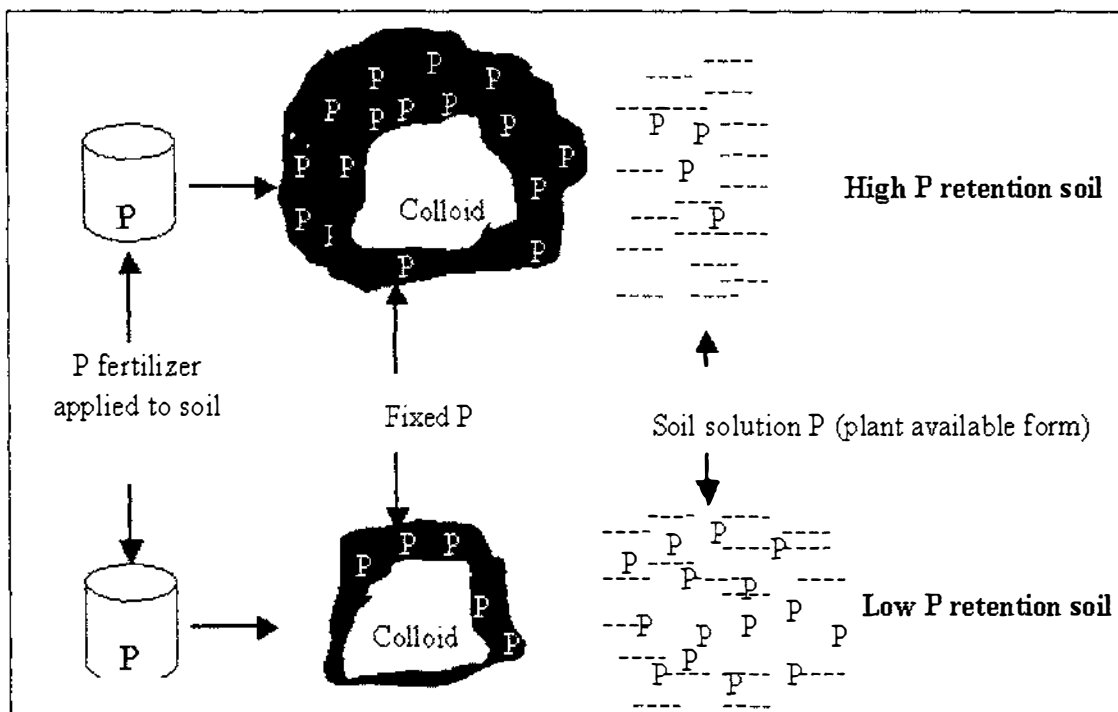


Figure.20 Soils having high P retention capacity fix more phosphate on to soil colloids and release less phosphate to soil solution. Soils having low P retention capacity fix less phosphate on to soil colloids and release more phosphate into soil solution.

The ratings for P-retention are:

Rating	P-retention (%)
Very low	0 - 10%
Low	10 - 30%
Medium	30 - 60%
High	60 - 90%
Very high	90 - 100 %.

## **23. Soils of Kiwitea District and Their Properties**

### **23.1 Introduction**

The soils of the Kiwitea study area are mapped at 1:25, 000 scale and are grouped into 16 different soil map units (Map.2). The individual soil map units are described in this section of the bulletin under the following format.

#### ***Distribution:***

The distribution of the soil map unit in relation to the other map units are shown in a Figure. The landscape features and the total area covered in hectares and as a percentage are also given.

#### ***Inclusions:***

Small areas of other soil units are also included within a soil map unit due to practical limitations of the soil mapping scale. The map unit is given the name of the major soil included within the map unit. The other soils included within the map unit are given as inclusions.

#### ***Parent material:***

A short description of the parent material from which the soil is developed is given.

#### ***Profile characteristics:***

The photograph of the soil profile showing the topsoil, upper subsoil and the lower subsoil is given. The topsoil can be easily identified due to its dark colours. The upper subsoil is separated from the lower subsoil considering the differences of soil properties such as soil texture, structure, presence of gleying or mottling, pH, CEC etc. Soil colour, texture, structure and consistency for the topsoil, upper subsoil and the lower subsoil are given. The profile photograph and the physical properties are helpful to identify the soil in the field.

***Physical properties:***

Soil properties such as soil depth, drainage, bulk density, porosity and water retention properties for the major soil are given. The terms used to describe bulk density, porosity and available water (e.g. high, medium, low) refer back to relevant sections in the text or the soil properties given in the table provided

***Chemical properties:***

Important soil chemical properties related to soil fertility such as soil pH, organic carbon levels, CEC, TEB, BS, and P-retention status for the major soil are given. The terms used to describe these properties such as moderate, strong, low, medium, high etc. are described in relevant sections in the text.

***Present land use:***

How the land is presently being used is described under this heading.

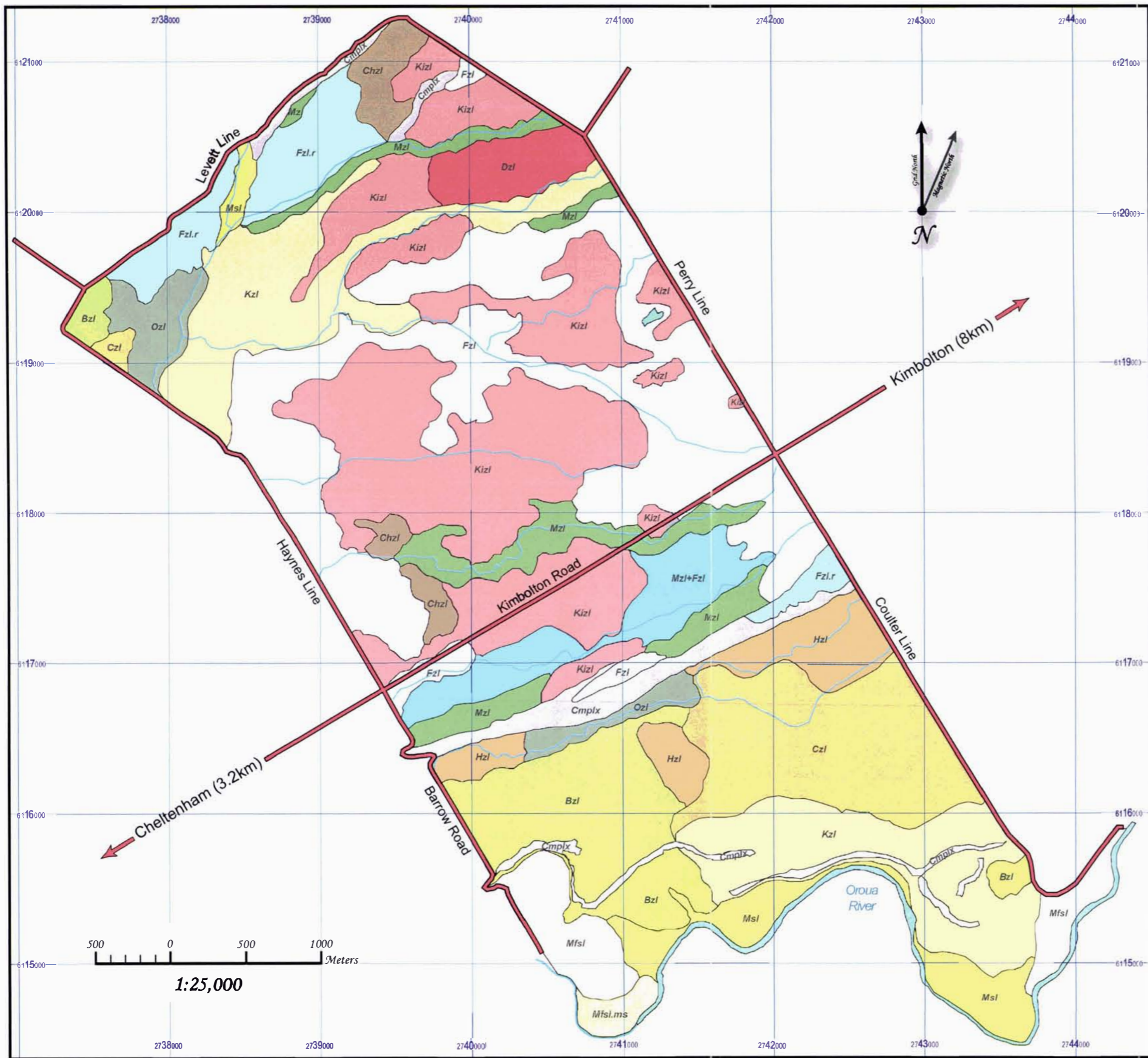
***Limitations and management:***

Limitations of soils for agriculture and the strategies for overcoming these limitations are discussed.

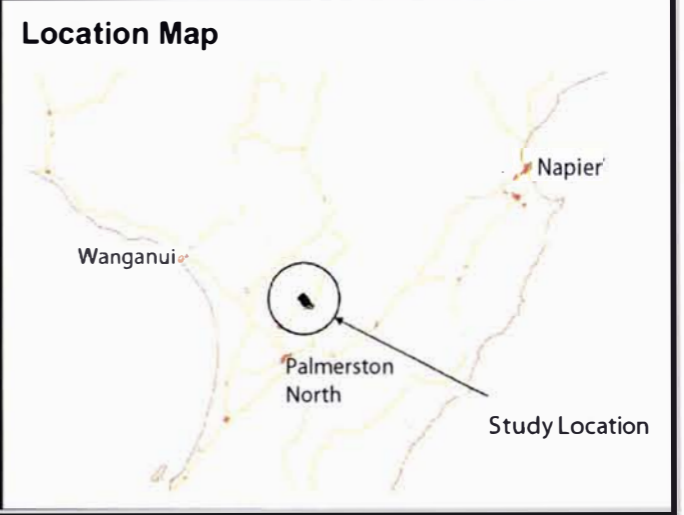
***Laboratory analytical results:***

Laboratory analytical results for physical and chemical properties of the major soil is given as a table.

# SOIL MAP 2 Of Kiwitea Study Area



- Soils of the Lower Terrace**
- Mfs1 Manawatu fine sandy loam
  - Mfs1.ms Manawatu fine sandy loam - moderately shallow
  - Msl Manawatu silt loam
- Soils of the Intermediate Terrace**
- Kz1 Kawhatau stony silt loam
  - Cz1 Coulter silt loam
  - Hz1 Horoeke silt loam
  - Bz1 Barrow silt loam
  - Oz1 Ohakea silt loam
- Soils of the Upper Terrace**
- Dz1 Dannevirke silt loam
  - Kiz1 Kiwitea silt loam
  - Chz1 Cheltenham silt loam
  - Fz1 Feilding silt loam
  - Fz1.r Feilding silt loam - rolling phase
  - Mz1 Marton silt loam
  - Mz1+Fz1 Marton and Feilding complex
- Soils of the Terrace Risers**
- Cmplx Steep slope complex
- Miscellaneous features**
- Water bodies
  - Streams
  - Roads
- Asoka Senarath 2002*



## 23.2 Manawatu fine sandy loam (*Mfs1*)

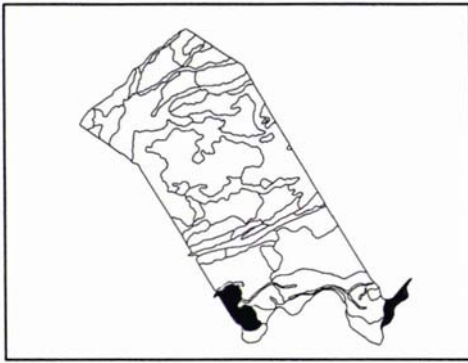


Figure 21 Distribution of Manawatu fine sandy loam.

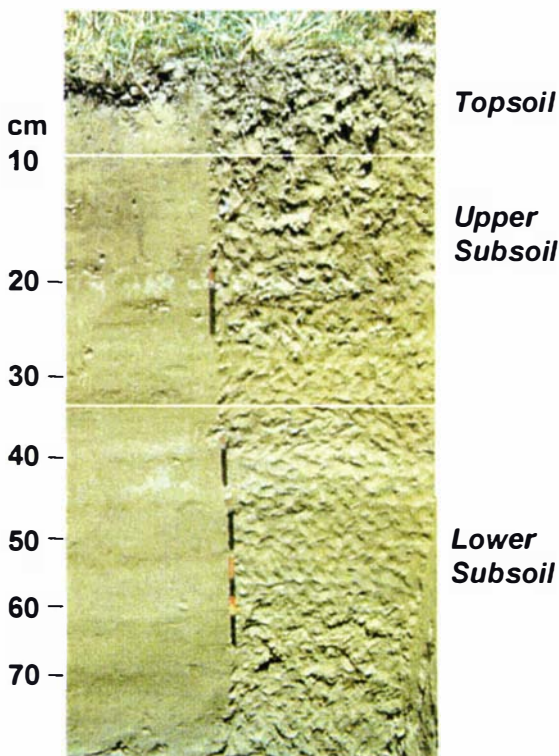


Plate 3 Soil profile of Manawatu fine sandy loam.

### Distribution (Figure .21):

Almost flat landscape of the lower terrace. The total land area covered is 65 ha (3%).

### Inclusions:

Small areas of Manawatu sandy loam and Manawatu fine sandy loam moderately shallow soils are included with this soil.

### Parent material:

Recent sandy alluvial material derived from the greywacke-argillite Ruahine Ranges and foothills of soft marine sediments, laid down by the Oroua River.

### Profile characteristics (Plate .3):

#### Topsoil (10 cm):

Dark greyish brown, very fine sandy loam with moderately developed coarse nut structure breaking to strongly developed fine nuts and non-sticky and non-plastic consistence when wet.

#### Upper subsoil (23 cm):

Dark brown, silt loam with moderately developed medium nut structure breaking to weakly developed very fine nuts and non-sticky and slightly plastic consistence when wet.

**Lower subsoil (69 cm):**

Dark greyish brown, loamy fine sand and sand with single grain structure and non-sticky and non-plastic consistence when wet.

**Physical properties (Table .4):**

Deep (>90 cm), well drained soils with medium bulk density, moderate to high macroporosity and low readily available water.

**Chemical properties (Table .4):**

The soil pH is moderately acid, but the upper subsoil is strongly acid. Organic carbon is low to very low. CEC is medium in the topsoil and low in the subsoil. TEB is medium in the subsoil and low in the subsoil. Base saturation is very high in the topsoil, and medium to high in the subsoil. P retention is low.

**Present land use:**

Dairying, fattening sheep and cattle, market gardens.

**Limitations and management:**

Manawatu fine sandy loam is well drained. Plant available water in the soil is low in the soil due to its sandy texture. Crops may suffer from water stress in dry summers, but the soil is suitable for irrigation.

Soil consistence allows ploughing operations within large range of field moisture levels, from dry to wet. Stock grazing in wet seasons can cause damage to soils because soil structures are weak in these youthful soils. Organic matter levels are low. The soils are slightly acid and have few readily available plant nutrients but reserves, in particular K, are higher.

Manawatu soils are prone to occasional floods, which is a risk when using the soils for crops.

Manawatu fine sandy loam soils have very good physical properties. Chemical properties can easily be improved. This is a versatile soil that is suitable for a variety of purposes.

Table .4 Laboratory analytical results for Manawatu fine sandy loam.  
(Source: Landcare Research National Soil Data Base. Lab No. SB 10034).

Soil properties of Manawatu fine sandy loam			
	Topsoil	Subsoil	
		Upper	Lower
Bulk density ( $Mg\ m^{-3}$ )	1.1 - 1.2	1.3 - 1.4	1.2 - 1.3
Macro porosity (%)	10 - 11	10 - 11	20 - 25
Readily available water		.....43 mm	
50 cm depth		.....87 mm	
100 cm depth			
PH	5.4	5.1	5.5 - 5.8
Organic Carbon ( $g\ Kg^{-1}$ )	3.5	1.8	0.9 - 0.5
CEC ( $cmol_c\ kg^{-1}$ )	15.5	10	5 - 7
TEB ( $cmol_c\ kg^{-1}$ )	12.6	5.5	4.3 - 4.0
Base saturation (%)	81	55	62 - 77
P-retention (%)	21	22	15 - 8

**23.3 Manawatu fine sandy loam, moderately shallow phase (*Mfsl.ms*)**

**Distribution (Figure .22):**

Almost flat landscape of the lower terrace. The total land area covered is 13 ha (0.7 %).

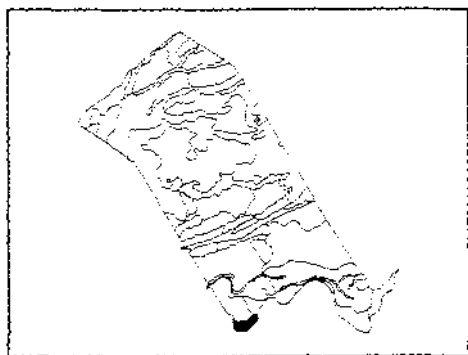


Figure .22 Distribution of Manawatu fine sandy loam, shallow phase.

**Inclusions:**

Small areas of Manawatu sandy loam shallow soils are included with this soil.

**Parent material:**

Recent sandy alluvial material derived from the greywacke-argillite Ruahine Ranges and foothills of soft marine sediments, laid down by the Oroua River.

**Soil Properties:**

These soils are excessively drained and moderately shallow (30-60 cm). The thickness of topsoil overlying river gravels is not more than 30 cm. Otherwise the properties of this soil are similar to that of Manawatu fine sandy loam

**Present land use:**

Dairying, fattening sheep and cattle.

**Limitations and management:**

The major limitation of this soil is the depth. Soils are not capable of

storing large quantities of water and plant nutrients.

Plant available water in the soil is low due to sandy texture and shallow depth to gravels. Crops may suffer from moisture stress in dry summers. Frequent irrigation is needed in dry seasons. The soils offer safe grazing for heavy stock in winter and spring except for the possibility of flooding.

Fertilizer and other management practices are similar to that of Manawatu fine sandy loam soils.

## 23.4 Manawatu silt loam

(*Ms1*)



Figure 23 Distribution of Manawatu silt loam.

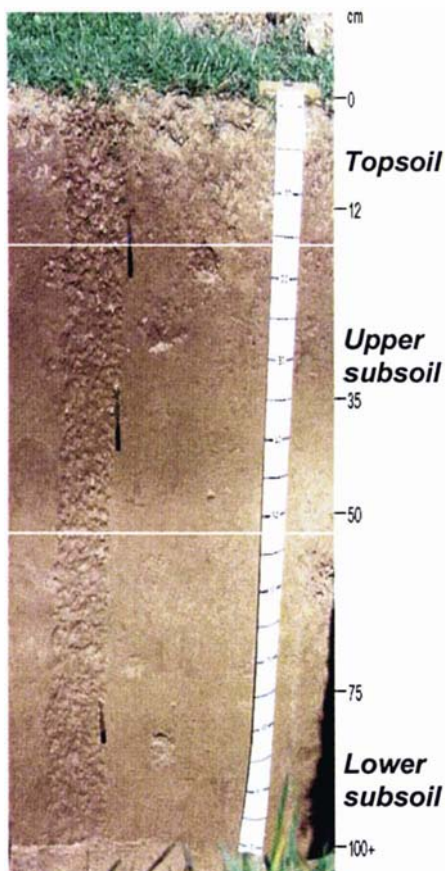


Plate 4 Soil profile of Manawatu silt loam.

### Distribution (Figure 23):

Almost flat landscape of the lower terrace. The total land area covered is 67 ha (3.3%).

### Inclusions:

Small areas of Manawatu sandy loam and Manawatu fine sandy loam soils are included with this soil.

### Parent material:

Recent sandy alluvial material derived from the greywacke-argillite Ruahine Ranges and foothills of soft marine sediments, laid down by the Oroua River.

### Profile characteristics (Plate .4):

#### Topsoil (15 cm):

Very dark greyish brown, silt loam with moderately developed coarse nut structure breaking to strongly developed fine nuts and non-sticky and slightly plastic consistence when wet.

#### Upper subsoils (37 cm):

Dark brown to dark greyish brown, very fine sandy loam with moderately developed coarse nut structure breaking to strongly developed fine nuts and non sticky and non plastic consistence when wet.

**Lower subsoil (45 cm):**

Olive grey, fine sand, with single grain structure and non-sticky and non-plastic consistence when wet.

**Physical properties (Table .5):**

Deep (>90 cm), well-drained soils with medium bulk density, medium to high macroporosity and low moisture storage capacity in the topsoil.

**Chemical properties (Table .5):**

The topsoil pH is moderately acid, but the upper subsoil is strongly acid. Organic carbon is low to very low. CEC is medium in the topsoil and low in the subsoil. TEB is medium to high in the topsoil, but is medium to low in the subsoil. Base saturation is very high in the topsoil, and medium to high in the subsoil. P retention is low.

**Present land use:**

Dairying, fattening sheep and cattle.

**Limitations and management:**

Plant available water in the soil is low in the soil due to its sandy texture, and crops may suffer from moisture stress in dry summers. Frequent irrigation is needed in dry seasons.

Plant nutrient levels are higher than for Manawatu fine sandy loams. Applications of phosphate and potassium fertilizer improve soil fertility. Lime is necessary to raise the soil pH, improve the availability of plant nutrients and the activity of nitrogen fixing bacteria in soils and clover.

Cultivated paddocks are prone to wind erosion, but this can be avoided by ploughing when soils are moist, or direct drilling. The soils are relatively safe for winter and spring grazing.

These soils have good physical properties and easily improved chemical properties. They are suitable for a variety of purposes.

Table .5 Laboratory analytical results for Manawatu silt loam.  
 (Source: Landcare Research National Soil Data Base. Lab No. SB 10036).

properties of Manawatu silt loam			
	Topsoil	Subsoil	
		Upper	Lower
Bulk density ( $\text{Mg m}^{-3}$ )	1.1 - 1.2	1.3 - 1.4	1.2 - 1.3
Macro porosity (%)	53 - 56	10 - 15	25 - 35
Readily available water 50 cm depth	.....37 mm		
PH	6.2 - 5.1	5.4 - 5.7	5.8 - 5.9
Organic Carbon ( $\text{g Kg}^{-1}$ )	3.3 - 2.1	1.2 - 1.3	0.5
CEC ( $\text{cmol}_c \text{kg}^{-1}$ )	13 - 15	10 - 11	6
TEB ( $\text{cmol}_c \text{kg}^{-1}$ )	18.7 - 8.7	6.1 - 7.5	4.4 - 4.2
Base saturation (%)	100 - 66	61 - 69	67 - 73
P-retention (%)	22 - 23	22	12 - 13

## 23.5 Kawhatau stony silt loam (Kz1)



Figure. 24 Distribution of Kawhatau stony silt loam.

### Distribution (Figure .24):

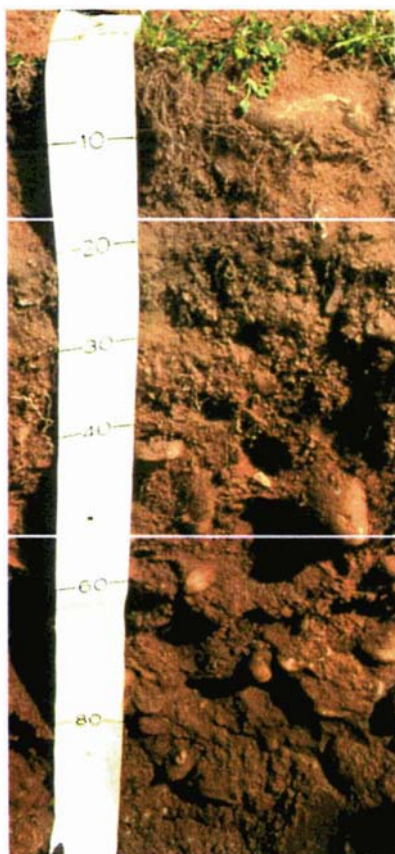
The edge of the intermediate terrace and on small terraces descending to the lower terrace, covering 250 ha (12.5%).of the total survey area.

### Inclusions:

Small areas of Coulter silt loam, Horoeoka silt loams and Barrow silt loams are included within the map unit.

### Parent material:

Moderately weathered alluvial deposits rich in greywacke gravel and rock particles intermixed with volcanic ash.



**Topsoil**

### Profile characteristics (Plate .5):

#### Topsoil (17 cm):

**Upper subsoil** Very dark greyish brown, stony silt loam with moderate fine nuts and granular structure and slightly plastic consistence when wet.

#### Upper subsoil (35 cm):

**Lower subsoil** Very dark yellowish brown and strong brown, stony silt loam soils with moderate fine nut and granular structure and slightly plastic consistence, when wet

#### Lower subsoil (23 cm):

Yellowish brown, stony silt loam soils with moderate medium nut structure breaking to moderate fine nuts and slightly plastic consistence, when wet.

Plate .5 Soil profile of Kawhatau stony silt loam.

**Physical properties (Table .6):**

A deep (>90 cm), but very stony soil with excessive drainage and low soil moisture storage.

**Chemical properties (Table 6):**

The pH is slightly to strongly acid in the topsoil and is moderately to strongly acid in the subsoil. Organic carbon in the topsoil is medium, but is low to very low in the subsoil. CEC is high in the topsoil but medium to low in the subsoil. TEB is very high to high in the topsoil and low to very low in the subsoil. Base saturation is medium to high in the topsoil, but low to very low in the subsoil. P retention is medium in the topsoil and high to very high in the subsoil.

**Present land use:**

Dairying, fattening sheep and cattle.

**Limitations and management:**

Stoniness is the major disadvantage of this soil for cultivation and cropping but is not a limitation for perennial horticulture. Plant available water holding capacity is also low, 35 mm per 50 cm of soil depth. Pastures and crops may be affected by moisture stress during dry seasons.

The soil is leached, and has a moderate to high P retention. Therefore lime, phosphate, sulphur and potassium based fertilizers are needed.

The soils can be successfully used for fattening stock, intensive sheep farming and dairying. They are especially valuable for safely wintering heavy stock. Perennial horticulture is a possibility.

Table 6 Laboratory analytical results for Kawhatau stony silt loam.  
(Source: Landcare Research National Soil Data Base. Lab No. SB 09943).

Soil properties of Kawhatau stony silt loam			
	Topsoil	Subsoil	
		Upper	Lower
Bulk density ( $\text{Mg m}^{-3}$ )	1.6	1.6 - 1.5	NA
Macro porosity (%)	NA	5 - 13	NA
Readily available water 50 cm depth	.....35 mm		
PH	6.0 - 5.2	5.4 - 5.3	5.1 - 5.2
Organic Carbon ( $\text{g Kg}^{-1}$ )	9.5 - 7.0	3.7 - 2.1	1.0 - 0.9
CEC ( $\text{cmol}_c \text{kg}^{-1}$ )	41 - 28	17 - 12	11 - 8
TEB ( $\text{cmol}_c \text{kg}^{-1}$ )	32 - 14.7	3.8 - 1.1	0.6 - 0.9
Base saturation (%)	77 - 51	21 - 9	5 - 12
P-retention (%)	54 - 55	80 - 90	85 - 62

## 23.6 Coulter silt loam (Cz1)

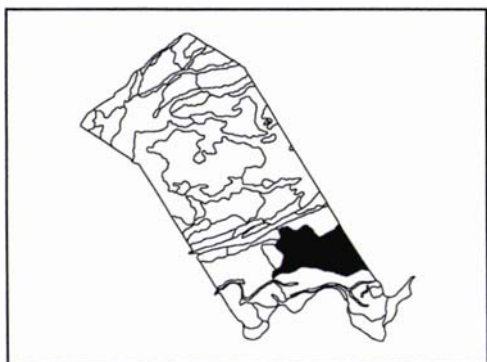


Figure 25 Distribution of Coulter silt loam.

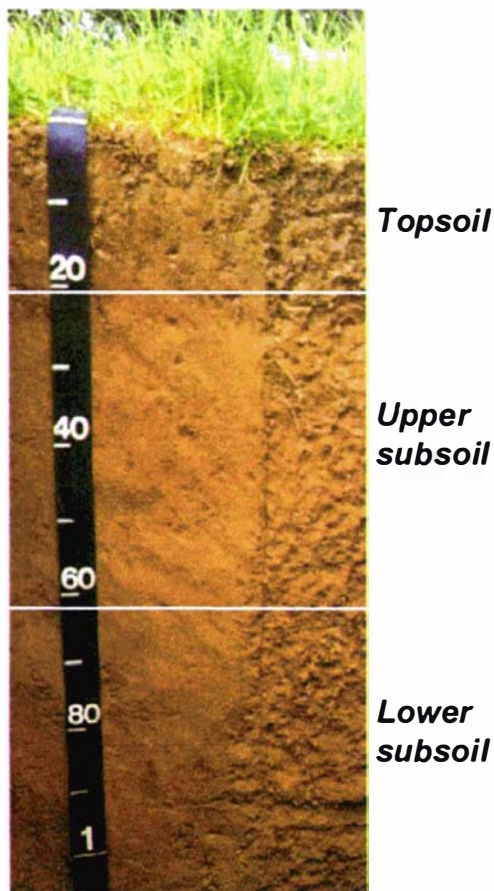


Plate 6 Soil profile of Coulter silt loam.

### Distribution (Figure 25):

The flat to gently sloping landscape of the intermediate terrace, covering 155 ha (7.8%) of the total survey area.

### Inclusions:

Small areas of Horoeke silt loams and Barrow silt loams are also included within the map unit.

### Parent material:

A mixture of alluvium, colluvium, loess and volcanic ash.

### Profile features (Plate 6):

#### Topsoil (20 cm):

Dark brown, silt loam soils with moderate fine to medium nutty structure; friable, when moist, and non-sticky and non-plastic consistence, when wet.

#### Upper subsoil (45 cm):

Dark yellowish brown, silt loam soils with moderate fine to medium nutty structure; friable, when moist, and non-sticky and non-plastic consistence, when wet.

#### Lower subsoil (60 cm):

Dark yellowish brown, silt loam and clay loam soils with moderate fine to medium and medium to coarse nutty structures; friable, when moist, and non-sticky and non plastic consistence, when wet.

**Physical properties (Table .7):**

A deep (>90 cm), well drained soil with medium bulk density and high plant available water content.

**Chemical properties (Table 7):**

The soil pH is slightly acid in the topsoil and moderately acid in the lower subsoil. Organic carbon and CEC are medium in the topsoil, but very low in both the upper and lower subsoil because of the gravelly nature of the subsoil. Base saturation and TEB are medium in the topsoil and medium to low in the subsoil. P retention is high.

**Present land use:**

Dairying, fattening sheep and cattle, deer farming, cut flowers and bulbs, maize and carrots.

**Limitations and management:**

Coulter soils have excellent physical properties. They provide good aeration and a good rooting medium to crops and pastures. Plant available water in the soil is high.

The soils are naturally acidic and low in plant nutrients, but applications of phosphate and

potassium fertilizer improve soil fertility.

Application of lime improves the soil pH, availability of plant nutrients, and activity of nitrogen fixing bacteria in soils and clover.

The soils are friable and form a good seedbed under cultivation but are equally suited to direct drilling because wind erosion on continuously cultivated paddocks is a concern. Careful stock grazing in wet seasons causes minimal damage to soils.

Coulter soils have very good physical properties and are suitable for a variety of annual and perennial crops as well as pasture-based enterprises

Table 7 Laboratory analytical results for Coulter silt loam.  
(Data obtained from the present study).

Soil property	Topsoil	Subsoil	
		Upper	Lower
Bulk density ( $\text{Mg m}^{-3}$ )	0.9	0.9	0.9 - 1.3
Macro porosity (%)	6 - 7	11	5 - 8
Readily av. water			
50 cm depth	..... 60 mm		
100 cm depth	.....113 mm		
PH	6.0 - 6.1	6.5	5.3 - 6.0
Organic Carbon ( $\text{g Kg}^{-1}$ )	6.6 - 5.5	1.5	0.9 - 0.3
CEC ( $\text{cmol}_c \text{kg}^{-1}$ )	25 - 21	13	10 - 12
TEB ( $\text{cmol}_c \text{kg}^{-1}$ )	12.8 - 9.8	5.9	3.5 - 4.5
Base saturation (%)	51 - 46	45	35 - 37
P-retention (%)	86 - 87	90	87 - 33

### 23.7 Horoeke silt loam (Hz1)

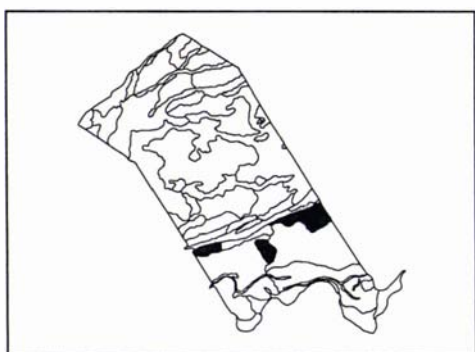


Figure 26 Distribution of Horoeke silt loam.

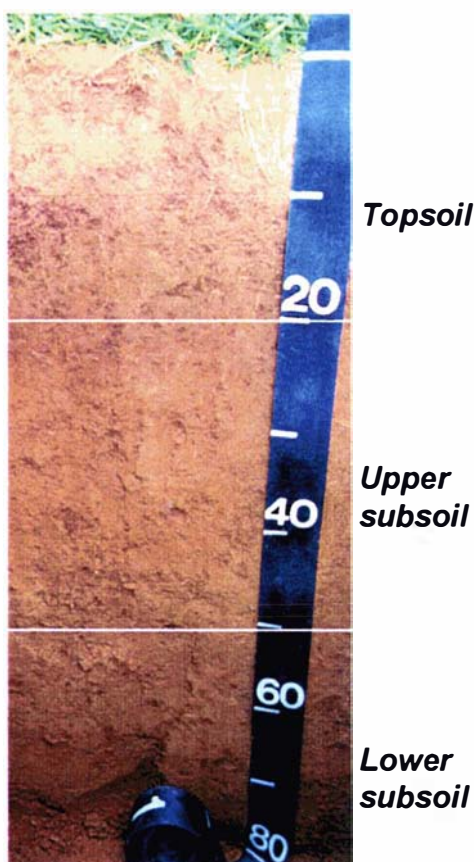


Plate .7 Soil profile of Horoeke silt loam.

#### Distribution (Figure 26):

The flat to gently sloping landscape of the intermediate terrace, covering 70 ha (3.5%) of the total survey area.

#### Inclusions:

Areas of Coulter silt loams, small areas of Barrow silt loams and Ohakea silt loams are also included within the map unit.

#### Parent material:

A mixture of alluvium, colluvium, loess and volcanic ash.

#### Profile characteristics (Plate .7):

##### Topsoil (20 cm):

Dark brown, silt loam with moderate medium nutty structure breaking to fine nutty structure, friable when moist, and slightly-sticky and slightly-plastic consistence, when wet.

##### Upper subsoil (30 cm):

Dark yellowish brown, silt loam soils with moderate fine to medium nutty structure, friable when moist, and non-sticky and non plastic consistence, when wet.

##### Lower subsoil (30 cm):

Olive coloured with strong brown mottles and silt loam textures. Moderate medium to coarse nutty structure, friable when moist, and non-sticky and non plastic consistence, when wet.

**Physical properties :**

No analysis is available but the topsoil and upper subsoil is expected to have similar properties to Coulter silt loam. However, the mottled nature of the lower subsoil indicates that the drainage is somewhat impeded.

**Chemical properties:**

Laboratory analytical results are not available for this soil. However, chemical soil properties of the topsoil and upper subsoil are expected to be similar to Coulter silt loam soils. P-retention ranges from medium to high.

**Present land use:**

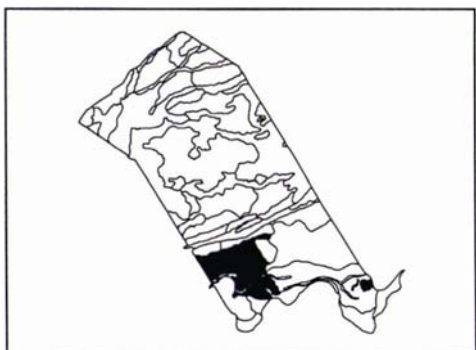
Dairying, fattening sheep and cattle, deer farming, cut flowers and bulbs, Maize and carrots.

**Limitations and management:**

Horoeka soils are very similar to Coulter soils except are moderately well drained rather than well drained. They are thus more suited for shallow rooted crops such as grass, potatoes, and brascicas rather than the deep-rooted crops that are possible on Coulter soils.

Fertilizer and other management practices are similar to that of Coulter soils except P-retention is not high and thus less P based fertilizer is need.

## 23.8 Barrow silt loam



(Bz1)

Figure 27 Distribution of Barrow silt loam.

### Distribution (Figure 27):

The flat to gently sloping landscape of the intermediate terrace, covering 148 ha (7.4 %) of the total survey area.

### Inclusions:

Small areas of Horoeka and Ohakea silt loams are included within the map unit.

### Parent material:

A mixture of alluvium, colluvium, loess and volcanic ash.

### Profile characteristics (Plate 8):

#### Topsoil (21 cm):

Very dark greyish brown, silt loam with strong fine to medium nut structure; friable when moist and slightly sticky and slightly plastic consistence when wet.

#### Upper subsoil (44 cm):

Olive and light olive grey, silty clay loam - fine sandy clay loam with strong brown mottles. Strong fine medium and coarse nut structure, firm to friable when moist and slightly sticky and plastic consistence when wet.

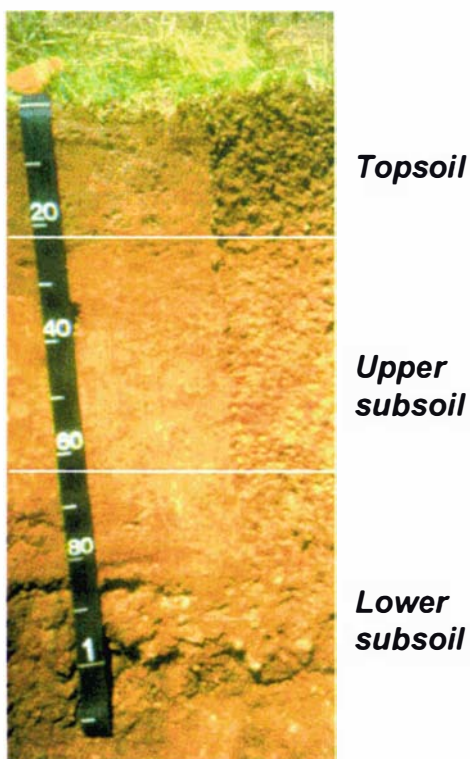


Plate 8 Soil profile of Barrow silt loam.

**Lower subsoil (30 cm):**

Olive grey, clay loam and coarse loamy sand with yellowish brown mottles, moderate medium to coarse sub angular blocky and massive structure, friable when moist, and sticky and plastic consistence when wet.

**Physical properties (Table 8):**

A moderately deep-to-deep (60-90 and >90 cm) soil with imperfect drainage. The dry bulk density is moderate in the topsoil and upper subsoil but higher in the lower subsoil and mirrors a decline in macroporosity in mottled subsoil horizons. Readily available water is moderate.

**Chemical properties (Table .8):**

The topsoil pH is moderately acid and the subsoil pH is slightly acid. Organic carbon in the topsoil is low, but is very low in the subsoil. CEC is medium. TEB is medium and medium to low in the lower subsoil. Base saturation is medium, but medium to high in the lower

subsoil. P retention is medium in the topsoil, medium to high in the upper subsoil and low in the lower subsoil.

**Present landuse:**

Dairying, fattening sheep and cattle.

**Limitations and management**

Barrow silt loam has imperfect natural drainage, therefore, on undrained paddocks topsoils pug badly in wet seasons under heavy stock. Imperfect drainage conditions limit the use of the soils for cropping or vegetables. Drainage can be improved with mole and plastic pipe drains.

Soils are naturally acidic and low in plant nutrients. Applications of phosphate and potassium fertilizer are needed to improve soil fertility.

Table 8 Laboratory analytical results for Barrow silt loam.  
(Data obtained from the present study).

Soil properties of Barrow silt loam			
	Topsoil	Subsoil	
		Upper	Lower
Bulk density ( $\text{Mg m}^{-3}$ )	1.04 - 1.12	1.1 - 1.0	1.35
Macro porosity (%)	4 - 8	12 - 9	3
Readily available water 50 cm depth	.....44 mm		
PH	5.6 - 5.7	6.0 - 6.3	6.2 - 6.0
Organic Carbon ( $\text{g Kg}^{-1}$ )	3.5 - 4.0	1.0 - 0.5	0.2 - 0.3
CEC ( $\text{cmol}_c \text{kg}^{-1}$ )	15 - 16	15	12 - 14
TEB ( $\text{cmol}_c \text{kg}^{-1}$ )	7.8 - 8.7	8.6 - 8.8	8.8 - 5.6
Base saturation (%)	52 - 54	57 - 59	65 - 47
P-retention (%)	50	79 - 41	25 - 30

### 23.9 Ohakea silt loam (Oz1)

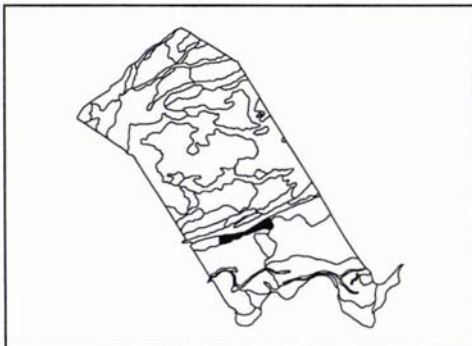
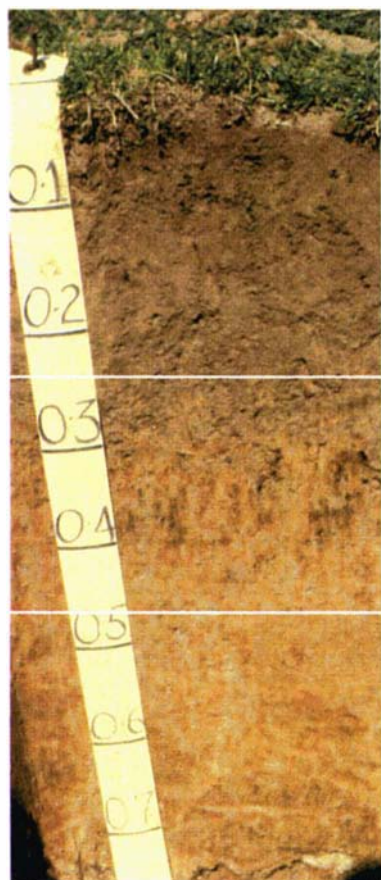


Figure 28 Distribution of Ohakea silt loam.



**Topsoil**

**Upper subsoil**

**Lower subsoil**

#### **Distribution (Figure .28):**

The flat to gently sloping landscape of the intermediate terrace, covering 50 ha (2.5 %) of the total survey area.

#### **Inclusions:**

Small areas of Barrow silt loam are included within the map unit.

#### **Parent material:**

A mixture of alluvium, colluvium, loess and tephra.

#### **Profile characteristics (Plate .9):**

##### **Topsoil (25 cm):**

Very dark brown, silt loam with strong fine nutty and blocky structure and slightly sticky and moderately plastic consistence when wet.

##### **Upper subsoil (23 cm):**

Pale olive and pale yellow, clay loam to clay with faint mottles, weak coarse nut and moderate fine to medium blocky structure and slightly sticky and moderately plastic consistence when wet.

Plate 9 Soil profile of Ohakea silt loam.

**Lower subsoil (18 cm):**

Light olive grey, clay with moderate medium block structure and moderately sticky and moderately plastic consistence when wet.

**Physical properties (Table .9):**

Moderately deep to deep (60-90 and >90 cm), poorly drained soils. Dry bulk densities throughout are high and macroporosity is low. Soils are slowly permeable with low plant available water.

**Chemical properties (Table .9):**

The topsoil is strongly acid and the subsoil is moderately to slightly acid. Organic carbon in the topsoil is medium, but is low to very low in the subsoil. CEC is medium in the topsoil and medium to low in the subsoil. TEB ranges from medium to low. Base saturation is high except for the upper subsoil. P retention is medium to low.

**Present landuse:**

Dairying, fattening sheep and cattle.

**Limitations and management:**

Ohakea silt loam has poor natural drainage, and on undrained paddocks

topsoils pug badly in winter under heavy stock. Pastures are infested with moisture tolerant grasses and weeds. Variations in soil depth and texture make drainage with mole drains rather unsatisfactory, but plastic pipe drains work well.

The soils are naturally acidic and low in plant nutrients, but respond to applications of phosphate and potassium fertilizer. Application of lime raises the soil pH, improves the availability of plant nutrients and the activity of nitrogen fixing bacteria in soils and clover.

With adequate drainage and fertilizers, good ryegrass and white clover can be established and maintained.

Adequately drained lands can be used for fattening sheep and cattle and dairying, provided stocks are removed from the soils when wet.

Table .9 Laboratory analytical results for Ohakea silt loam.  
( Source:Landcare Research National Soil Data Base. Lab No. SB 08683).

Soil properties of Ohakea silt loam			
	Topsoil	Subsoil	
		Upper	Lower
Bulk density ( $\text{Mg m}^{-3}$ )	NA	NA	NA
Macro porosity (%)	NA	NA	NA
PH	5.2	5.6 - 6.1	6.3
Organic Carbon ( $\text{g Kg}^{-1}$ )	5.6	2.9 - 0.9	0.3 - 0.2
CEC ( $\text{cmol}_c \text{ kg}^{-1}$ )	22	14 - 10	11
TEB ( $\text{cmol}_c \text{ kg}^{-1}$ )	14 - 4.4	3. - 6.9	8.3
Base saturation (%)	61	31 - 32	63 - 73
P-retention (%)	34	54 - 29	17 - 21

### 23.10 Dannevirke silt loam (Dz1)

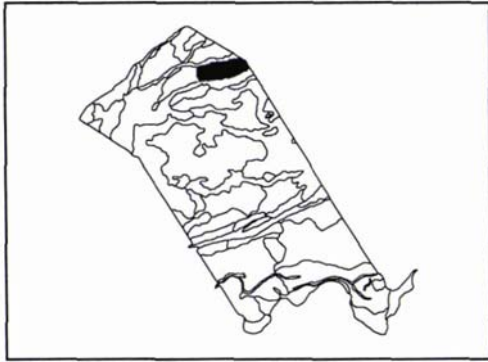


Figure 29 Distribution of Dannevirke silt loam.

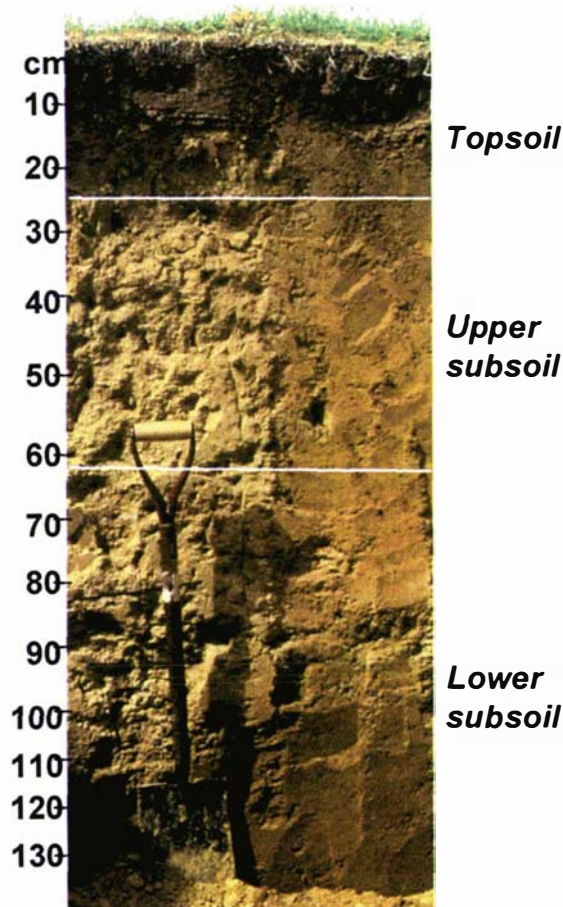


Plate .10 Soil profile of Dannevirke silt loam.

#### Distribution (Figure .29):

Flat to gently sloping landscape of the upper terrace, covering 40 ha (2 %) of the total survey area.

#### Inclusions:

Small areas of Kiwitea silt loams, are also included within the map unit.

#### Parent material:

A mixture of loess and volcanic ash.

#### Profile characteristics (Plate .10):

##### Topsoil (23 cm):

Dark brown, fine sandy loam with moderately developed fine to medium nutty structure, friable consistence when moist and slightly sticky and slightly plastic consistence when wet.

##### Upper subsoil (39 cm):

Dark yellowish brown and yellowish brown, fine sandy loam with weakly developed coarse nutty and blocky structure, friable consistence when moist and slightly sticky and slightly plastic consistence when wet.

##### Lower subsoil (88 cm):

Yellowish brown and light yellowish brown silt loam and fine sandy loam with weakly developed coarse nutty and medium blocky structure, friable consistence when moist and slightly

sticky and slightly plastic consistence when wet.

**Physical properties (Table 10):**

A deep (>90 cm) well drained soil with low dry bulk densities and high macroporosity in the topsoil and the upper subsoil. Dry bulk density can increase slightly and macroporosity decreases in lower subsoil horizons. Soil moisture storage is moderate.

**Chemical properties (Table 10):**

The soil pH is strongly acid in the topsoil but near neutral to slightly alkaline in the subsoil. Organic carbon in the topsoil is high, but is medium in the upper subsoil and very low in the lower subsoil. CEC is high in the topsoil, medium in the upper subsoil and low in the lower subsoil. TEB is high in the topsoil and ranges from high to low in the subsoil. Base saturation is medium in the topsoil and medium to high in the subsoil. P retention is very high in Dannevirke silt loam.

**Present landuse:**

Dairying, fattening sheep and cattle, potatoes and maize.

**Limitations and management:**

Dannevirke soils have very good physical properties providing a good rooting medium for crops and pastures.

The topsoil needs to be limed to raise pH. The high P retention means that for intensive crops, the application rate of phosphate based fertilizer needs to be high. The additional cost is easily made up for in increased production, ease of management and the diverse uses that the soil is suitable for.

Continued cultivation may break down topsoil structure and increases the likelihood of wind and rill erosion. The soils are not prone to pugging in wet weather, but bulls and deer can cause damage to the topsoil.

Dannevirke soils are versatile soils suited to a wide range of uses including both annual and perennial crops.

Table .10 Laboratory analytical results for Dannevirke silt loam.

(Source: Landcare Research National Soil Data Base. Lab No.SB 09846).

Soil properties of Dannevirke silt loam			
	Topsoil	Subsoil	
		Upper	Lower
Bulk density ( $\text{Mg m}^{-3}$ )	0.67 - 0.71	0.67 - 0.86	0.82 - 1.08
Macro porosity (%)	18	15 - 20	5 - 15
Readily av. water			
50 cm depth		.....35 mm	
100 cm depth		.....64 mm	
PH	5.2	6.5 - 7.0	7.1 - 7.2
Organic Carbon ( $\text{g Kg}^{-1}$ )	10.4	5.0 - 2.4	1.2 - 1.4
CEC ( $\text{cmol}_c \text{ kg}^{-1}$ )	38	15 - 24	9 - 11
TEB ( $\text{cmol}_c \text{ kg}^{-1}$ )	19.3	17.3 - 11.8	7.7 - 6.2
Base saturation (%)	50	71 - 76	59 - 69
P-retention (%)	94	97 - 95	94 - 99

### 23.11 Kiwitea silt loam (Kiz1)

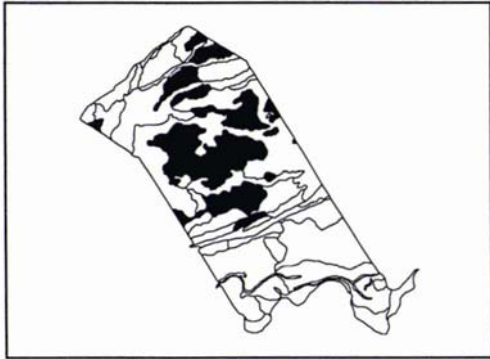


Figure .30 Distribution of Kiwitea silt loam.

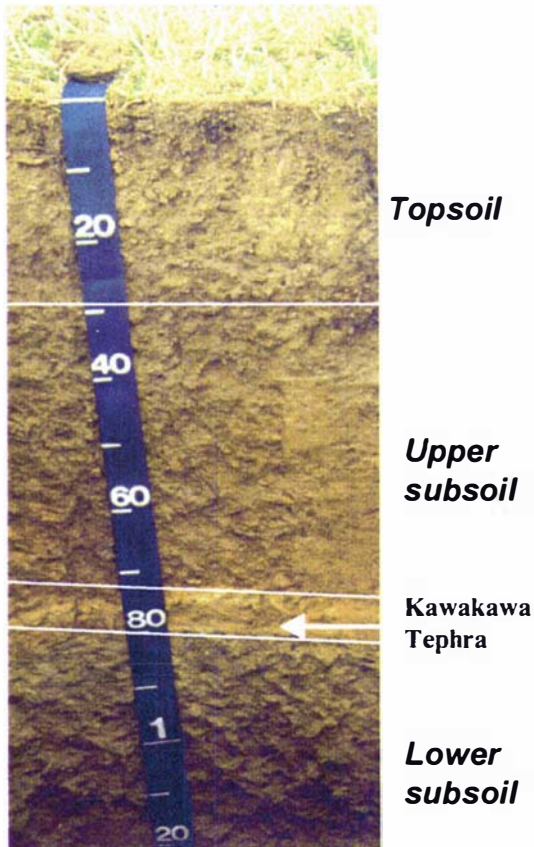


Plate .11 Soil profile of Kiwitea silt loam. The pale layer at 80 cm depth is the 24,000 year old Kawakawa Tephra, a volcanic ash erupted from Lake Taupo.

#### Distribution (Figure .30):

The flat to undulating landscape of the upper terrace, covering 420 ha (21 %) of the total survey area.

#### Inclusions:

Small areas of Dannevirke silt loam, Cheltenham silt loam and Feilding silt loam, are included within the map unit.

#### Parent material:

A mixture of loess and volcanic ash.

#### Profile features (Plate .11):

##### Topsoil (25 cm):

Dark brown, silt loam soils with strong fine to medium nutty structure, friable when moist and slightly sticky and slightly plastic consistence when wet.

##### Upper subsoil (45 cm):

Dark yellowish brown, silty clay loam, with strong, fine, medium and coarse nutty structure, friable when moist and sticky and plastic consistence when wet.

##### Lower subsoil (50 cm):

Yellowish brown and dark yellowish brown, coarse sandy loam to silty clay loam with moderate fine to medium nutty structure, friable when moist and sticky and plastic consistence when wet.

**Physical properties (Table .11):**

Deep (>90 cm), well drained soils with moderate bulk density that rises in the lower subsoil. Readily available moisture is high.

**Chemical properties (Table .11):**

The soil pH is moderately acid in the topsoil, slightly acid in the upper subsoil and near neutral in the lower subsoil. CEC and exchangeable cations are medium. Base saturation is high. P retention is medium in KIWITEA silt loam.

**Present landuse:**

Dairying, fattening sheep and cattle, deer farming, potatoes, swedes and maize.

**Limitations and management:**

Physical and chemical properties of KIWITEA silt loams are quite favourable for a range of crops and other uses, having good aeration and providing a good rooting medium for crops and pastures. Available water in these soils is also higher than that of DANNEVIRKE soils.

Liming topsoils raises soil pH and phosphate fertilizers improve the soil fertility.

Continued cultivation may break down topsoil structure and increase the likelihood of wind and rill erosion. The soils are not prone to pugging in wet weather, but bulls and deer can cause damage.

These soils have very good physical properties and chemical properties can be improved. They are suitable for a variety of annual and perennial crops, pastures and other uses.

Table . 11      Laboratory Analytical results for Kiwitea silt loam.  
 ( Data obtained from the present study).

Soil properties of Kiwitea silt loam			
	Topsoil	Subsoil	
		Upper	Lower
Bulk density ( $Mg\ m^{-3}$ )	1.12	1.12 - 1.18	0.83 - 1.33
Macro porosity (%)	NA	9	14
Readily av. water			
50 cm depth		.....59 mm	
100 cm depth		.....126 mm	
PH	5.6	6.1 - 6.4	6.6
Organic Carbon ( $g\ Kg^{-1}$ )	NA	NA	NA
CEC ( $cmol_c\ kg^{-1}$ )	20	16 - 18	12 - 13
TEB ( $cmol_c\ kg^{-1}$ )	12.8	11.9 - 14.1	8.4 - 10.7
Base saturation (%)	64	74 - 78	70 - 83
P-retention (%)	41	49 - 55	59 - 26

### 23.12 Cheltenham silt loam (Chz1)

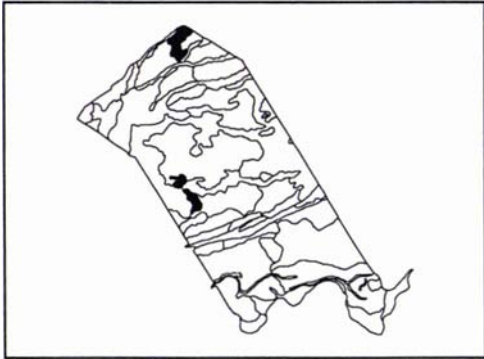


Figure 31 Distribution of Cheltenham silt loam.

#### Distribution (Figure .31):

Flat to undulating landscape of the upper terrace, covering 40 ha (2 %) of the total survey area.

#### Inclusions:

Small areas of Kiwitea silt loams, and Feilding silt loams are also included within the map unit.

#### Parent material:

A mixture of loess and volcanic ash.

#### Profile features (Plate .12):

##### Topsoil (20 cm):

Very dark greyish brown, silt loam with strong fine nutty structure, friable when moist and slightly sticky and slightly plastic consistence when wet.

##### Upper subsoil (40 cm):

Brown and dark yellowish brown, silt loam and silty clay loam with moderate to strong fine to medium nutty structures, friable when moist and sticky and plastic consistence when wet.

##### Lower subsoil (70 cm):

Dark olive, yellowish brown and brown soils with strong brown mottles and clay loam to silt loam textures, moderate medium to fine blocky structure breaking to fine sub angular

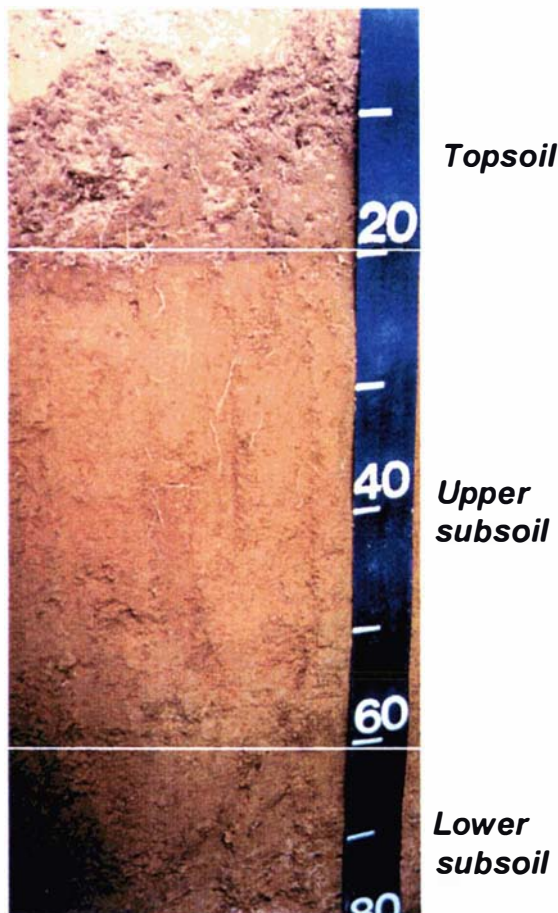


Plate .12 Soil profile of Cheltenham silt loam.

blocks, with firm to friable moist consistence and sticky and plastic consistence when wet.

**Physical and chemical properties:**

No analyses are available for this soil, however the topsoil and upper subsoil should have properties similar to those of Kīwitea soils, while in the lower subsoil drainage is impeded and may be more similar to fielding and Marton soils.

**Present landuse:**

Dairying, fattening sheep and cattle, deer farming, potatoes, swedes and maize.

**Limitations and management:**

Cheltenham soils are very suited to pastoral uses and for that use there are few limitations. They can also be used for shallow rooted crops such as potatoes and brassicas, but are not recommended for deep-rooted perennial crops such as apples or kiwifruit because of slow drainage in the lower subsoil.

### 23.13 Feilding silt loam (Fz1)

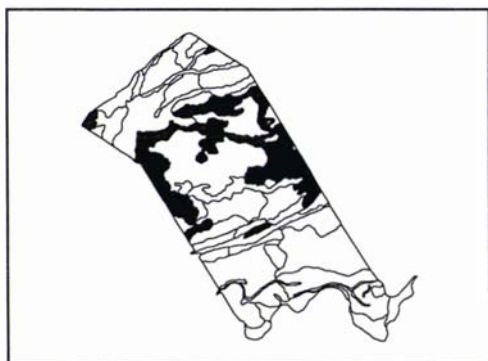


Figure .32 Distribution of Feilding silt loam.

#### Distribution (Figure .32):

Flat to undulating landscape of the upper terrace, covering 364 ha (18.3 %) of the total survey area.

#### Inclusions:

Small areas of Kiwitea silt loam, Cheltenham silt loam and Marton silt loam are also included within the map unit.

#### Parent material:

A mixture of loess and volcanic ash.

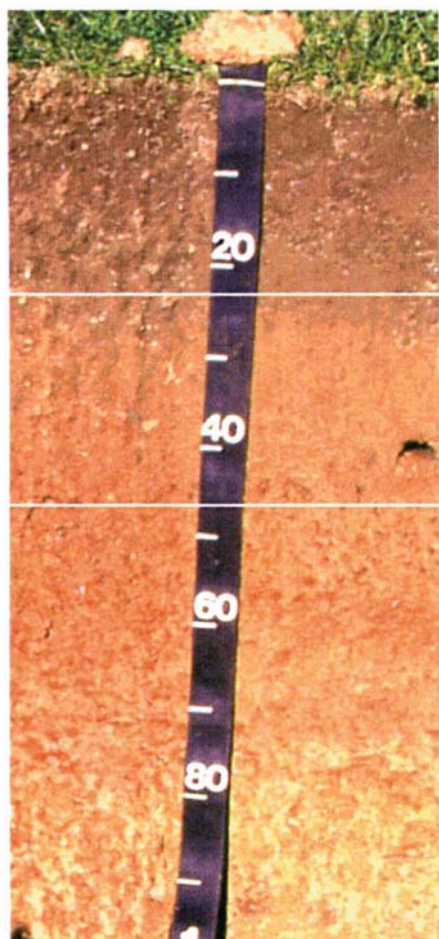
#### Profile characteristics (Plate .13):

##### Topsoil (23 cm):

Very dark greyish brown, silt loam with strong fine crumb structure, friable when moist, slightly sticky and slightly plastic consistence when wet.

##### Upper subsoil (24 cm):

Dark greyish brown and light olive brown with strong brown mottles, silt loam textures, strong fine to medium nutty and sub angular blocky structures, and friable when moist and sticky and plastic consistence when wet.



**Topsoil**

**Upper subsoil**

**Lower subsoil**

Plate .13 Soil profile of Feilding silt loam.

**Lower subsoil (53 cm):**

Grey with strong brown mottles, silt loam and sandy loam textures, strong to moderate fine to medium sub angular blocky and very coarse to coarse blocky structures, very firm when moist and slightly sticky and slightly plastic consistence when wet.

**Physical properties (Table 9.12):**

A deep (>90 cm), imperfectly drained soil with moderate topsoil dry bulk density increasing to moderately high values in the subsoil and mirrored by a steady decline in aeration (macroporosity). Moisture storage in the upper 50 cm is high.

**Chemical properties (Table 9.12):**

The soil pH is moderately acid in the topsoil and slightly acid in the subsoil. CEC and TEB are medium. Base saturation increases down the profile from medium values to high in the lower subsoil. P retention is medium.

**Present land use:**

Dairying, fattening sheep and cattle, deer farming, wheat and barley.

**Limitations and management:**

One of the limitations in this soil is its natural drainage. Feilding silt loam soils are imperfectly drained. Therefore, on undrained paddocks topsoil pug badly in wet winter and spring seasons with heavy stocking. Subsurface drainage can be improved with mole, plastic pipe, or tile drains. Natural drainage conditions limits use of the soils for crops such as root crops, potatoes and maize. However, wheat and barley can be grown successfully.

Table .12 Laboratory analytical results for Feilding silt loam.  
(Data obtained from the present study).

Soil properties of Feilding silt loam			
	Topsoil	Subsoil	
		Upper	Lower
Bulk density ( $\text{Mg m}^{-3}$ )	0.92 - 1.05	1.12 - 1.33	1.12 - 1.46
Macro porosity (%)	14	12 - 7	9
Readily available water (mm) 50 cm depth	.....55 mm		
PH	5.6 - 5.7	6.0 - 6.2	6.3 - 6.4
Organic Carbon ( $\text{g Kg}^{-1}$ )	NA	NA	NA
CEC ( $\text{cmol}_c \text{kg}^{-1}$ )	18 - 17	15 - 14	13 - 17
TEB ( $\text{cmol}_c \text{kg}^{-1}$ )	9.5 - 8.6	7.9 - 9.3	13.7 - 9.3
Base saturation (%)	53 - 51	53 - 66	71 - 81
P-retention (%)	38	36 - 34	23 - 44

### 23.14 Feilding silt loam rolling phase (Fz1.r)

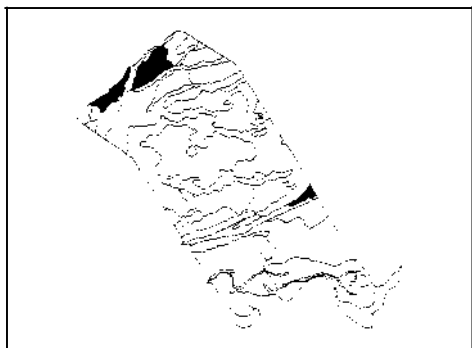


Figure 33 Distribution of Feilding silt loam rolling phase.

#### **Distribution (Figure .33):**

The undulating to rolling landscape (slopes more than 8 degrees) of the upper terrace, covering 80 ha (4 %) of the total survey area.

#### **Inclusions:**

Small areas of Kiwitea silt loam, Marton silt loam and Cheltenham silt loam are also included within the map unit.

#### **Parent material:**

**A mixture of loess and volcanic ash**

#### **Present land use:**

Dairying, fattening sheep and cattle.

#### **Physical and chemical properties:**

Physical and chemical properties of the soils are similar to that of Feilding silt

loams except for the slopes, and more variable thickness of soil horizons.

#### **Limitations and management:**

Similar to that of Feilding silt loams except for the added limitations of slope.

### 23.15 Marton silt loam (Mz1)

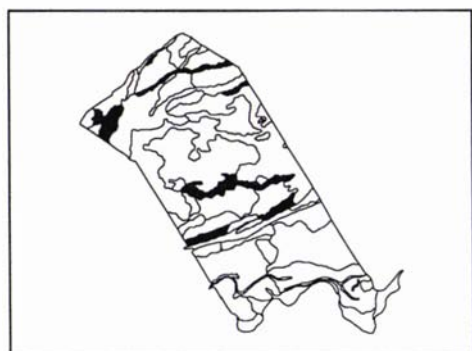


Figure 34 Distribution of Marton silt loam soils.

#### Distribution (Figure .34):

Flat to undulating landscape of the upper terrace, covering 100 ha (5 %) of the total survey area.

#### Inclusions:

Small areas of Feilding silt loam, are included within the map unit.

#### Parent material:

A mixture of loess and volcanic ash.

#### Profile characteristics (Plate .14):

##### Topsoil (20 cm):

Very dark greyish brown, silt loam with weak fine nut and granular structure, friable when moist and slightly sticky and slightly plastic consistence when wet.

##### Upper subsoil (31 cm):

Greyish brown to light olive brown with strong brown mottles and silty clay loam to clay loam textures, moderate fine to medium blocky structures, firm consistence when moist and moderately sticky and moderately plastic consistence when wet.

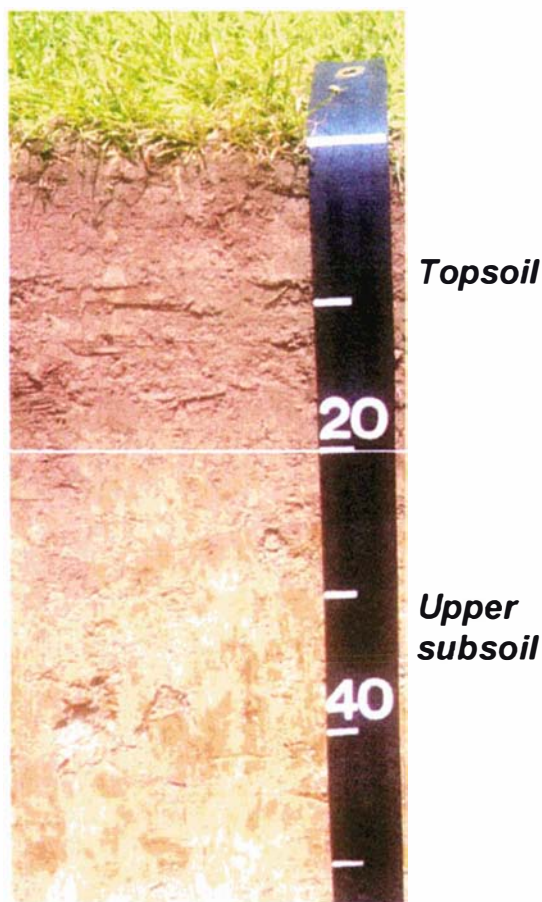


Plate .14 Soil profile of Marton silt loam.

**Lower subsoil (113 cm):**

Light brownish grey to yellowish brown, with strong brown, and olive grey mottles, sandy clay loam, silt loam or clay textures, massive and moderate coarse prismatic structures, moderately sticky and moderately plastic consistence when wet.

**Physical properties:**

A deep (>90 cm), poorly drained soil with moderate to high bulk density and poor aeration. Plant available moisture storage is low to moderate.

**Chemical properties (Table 13):**

The pH in the topsoil is slightly acid and is moderate to strongly acid in the upper subsoil. However, it ranges from moderately acid to moderately alkaline in the lower subsoil. Organic carbon in the topsoil is low and is very low in both the upper and lower subsoil. CEC is medium. TEB is medium in the topsoil and medium to high in the lower subsoil. Base saturation is high to very high. P retention ranges from low to medium.

**Present landuse:**

Dairying, fattening sheep and cattle, deer farming, wheat and barley.

**Limitations and management:**

Natural drainage of this soil is poor and pugging by cattle in wet seasons can be severe. Mole drainage has long lasting effects and has been used successfully in conjunction with plastic pipes or tiles. When the soil dries out in summer artificial drainage will reduce the effect of drought because root development is better and deeper.

Soil physical properties are not favourable for crops, because of poor drainage. Artificially drained soils are suitable for fattening of stock, sheep breeding, wheat and barley crops. The soil is not suitable for dairying.

Natural soil fertility levels are medium. However, application of potassium and phosphate fertilizers are recommended for better soil productivity. Soils are naturally acidic and application of lime decreases soil acidity and also increases availability of plant nutrients and activity of nitrogen fixing bacteria.

Table .13 Laboratory analytical results for Marton silt loam.  
(Source: Landcare Research National Soil Data Base. Lab No. SB 09369).

Soil properties of Marton silt loam			
	Topsoil	Subsoil	
		Upper	Lower
Bulk density ( $Mg\ m^{-3}$ )	NA	NA	NA
Macro porosity (%)	NA	NA	NA
PH	5.0	6.0 - 5.8	5.9 - 7.1
Organic Carbon ( $g\ Kg^{-1}$ )	2.8	0.8 - 0.4	0.3 - 0.1
CEC ( $cmol_c\ kg^{-1}$ )	14	12 - 14	12 - 18
TEB ( $cmol_c\ kg^{-1}$ )	11.1	9.8 - 11.6	11.3 - 17.6
Base saturation (%)	79	84	80 - 97
P-retention (%)	27	32 - 31	34 - 14

### 23.16 Marton and Feilding silt loam complex (Mz1+Fz1)

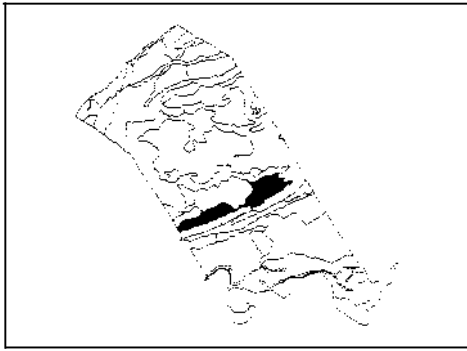


Figure .35 Distribution of Marton and Feilding silt loam complex.

#### **Distribution (Figure..35):**

This soil is found on the gently sloping to undulating landscape of the upper terrace, covering 72 ha (3.5 %) of the total survey area.

#### **Parent material:**

A mixture of loess, colluvium and volcanic ash.

#### **Properties of soils:**

These two soils are present on the landscape in a very complex way that cannot be separated at the scale of soil mapping. Soil properties are similar to the properties of Feilding and Marton silt loams.

#### **Present landuse:**

Dairying, fattening sheep and cattle, deer farming, growing wheat and barley.

#### **Limitations and management:**

Natural drainage of these soils range from imperfect to poor, and pugging by grazing stock in wet seasons can be severe.

Management practices are similar to that of Feilding and Marton silt loams.

### 23.17 Steep slope soil complex (Cmplx)

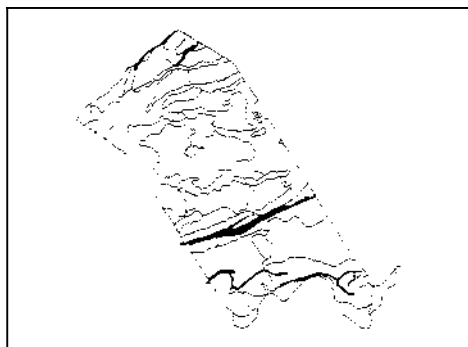


Figure .36 Distribution of steep slope soils.

#### **Distribution (Figure .36):**

This soil is found on the steep slopes of the terrace risers., covering 70 ha (3.5 %) of the total survey area.

#### **Parent material:**

A mixture of loess, alluvium, colluvium and volcanic ash, terrace gravels and underlying sandstones and mudstones.

#### **Physical soil properties:**

This is a very complex soil and includes various soils with variable colours, textures, structures and drainage properties.

#### **Present landuse:**

A source of metal for farm road construction. Growing pine trees and natural forest reserves, and rough grazing.

#### **Limitations and management:**

Land is steep and has a range of soil properties. A good source of metal for the construction of farm roads. Deep soils are suitable for forest plantations.

### **23.18 Conclusions:**

This soil survey report presents a 1:25,000 scale soil map of a 2000 ha window of terraced land in northern Manawatu. The soil pattern is shown to be complex, and quite unlike existing small scale maps. In this survey, particular account has been taken of soil drainage because drainage influences many other soil properties, and has a telling affect on suitable land uses. New soil series have been introduced to reflect the drainage capacity of the soil. It is also recognized that the upper and intermediate terrace soils are developed in different parent materials. New series names have been introduced to reflect the differences.

It is hoped that this soil map and report will lead to better investment, land use and management decisions in the district. In the past the entire area has been referred to as well drained “Kiwitea Soils” by real estate agents and advisors. However, the area does contain a high proportion of versatile soils. It is important to delineate these for wise investment. The map is at a scale sufficient to see the broad pattern of soils in the district. Farmers, growers and investors are advised to seek detailed mapping at 1:10,000 scale because soil properties important to farm management are changing at paddock scale.