# Spatial variability of drainage and phosphate retention and their inter-relationship, in soils on the river terraces of the northern Manawatu Region, New Zealand

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## Abstract

Spatial variability of drainage, phosphate retention and their inter-relationship was investigated in soils developed from mixed quartzo-feldspathic and tephric parent material on river terraces in northern Manawatu. A series of drainage class maps at 1:25,000, 1:10,000 and 1:5000 scales were produced for selected window areas. The optimal soil mapping scale for capturing soil drainage variability and the usefulness of the soil maps for identifying spatial variability of phosphate-retention was investigated. Soil drainage varies from well drained through moderately well drained to imperfectly drained and poorly drained within a paddock scale (2-3 ha). In this study, soil drainage had no topographic control which makes soil mapping extremely difficult. The reason for the short distance variability in drainage is attributed to slight textural variations of the original alluvial parent material. This gives rise to the formation of different soil structures, which in turn influences the hydraulic conductivity of the soil and results in variable drainage properties which influence the clay mineralogy. There is a close relationship between soil drainage, P-retention and clay mineralogy. Well drained soils have high P-retention and the clay fraction contains 12-13% allophane. Poorly drained soils have low P-retention and the clay fraction has no allophane and contains mainly kandite. The relationship between soil drainage and P-retention can be used to identify different P-retention areas on soil maps. In addition, 1:10,000 is the most suitable soil mapping scale for practical farm planning in the Manawatu Region.

## Keywords

Soil survey, large scale soil maps, P-fertilizer, pastoral farming, alluvium, river gravels.

## Introduction

A detailed soil survey carried out at 1:25,000 scale in an area covering 2000 ha of terraced land near Kiwitea village in northern Manawatu Region reveals that the soil drainage varies over the landscape at paddock scale (2-3 ha.) having no topographic control (Senarath,2003). Soil drainage dictates suitability for cropping and intensive grazing and sensitivity of land to a number of management practices so, soil drainage class maps will be helpful in land use planning and management practices. Furthermore previous studies have shown that phosphate retention (P-retention) is related to soil drainage; and in particular Parfitt *et al* (1984) have shown that soil drainage influences clay mineralogy and hence P-retention. Phosphate retention is an important soil attribute determining the amount of P needed to be applied for plant production. Soil maps are therefore valuable tools. Small scale existing soil maps published for the area at 1:250,000 (NZ Soil Bureau, 1954) and at 1:63,360 (NZ Land Resource Inventory, 1979) are clearly incapable of showing drainage variability on soil maps (Senarath, 2003). The aim of this study is to investigate the best scale to map soil drainage classes to aid land management decisions and the ability of soil drainage classes to predict P-retention values.

## Overview of the study area

The study area, is located near Kiwitea village in the northern Manawatu district which is situated towards the south-western part of the North Island. The landform of the area is characterized by suites of river terraces at different elevations. Three major terraces can be identified within the area; the river flats (180 m above msl) covered with recent alluvium (1000-2000 years BP) having flat to gently sloping topography, the intermediate terrace (200-240 m above msl) covered with a mixture of old alluvium, colluvium, loess and tephra (<15,000 years BP) having flat to gently sloping topography and the upper terrace (240-300 m above msl ) covered with a mixture of loess and tephra (15,000-25,000 years BP) having flat to rolling topography. The annual rainfall ranges from 900-1200 mm having dry summers and wet winters. The mean annual temperature in the area ranges from 12-13.5 ° C (New Zealand Meteorological Service, 1983).

### Soil sampling methodology

A window area (2000 m by 300 m) (Figure 1 and 2) was selected from the intermediate terrace of the study area mapped at a scale of 1:25,000 (Senarath, 2003). The window area was chosen on the basis that it had both reasonably large areas with similar drainage, but also rapid change from one drainage class to another. The window area, on the 1:25,000 scale map, has three different soil drainage classes; well drained, moderately well drained and imperfectly drained. The drainage classes were used to define new soil series. No artificial drainage has been installed by the farmers. On each map unit a 300 m by 250 m small window area (Blocks A, B and C) was established and sampling points were selected on a 50 m grid (Figure 2). Soil sampling methods for drainage class mapping and P-retention are discussed below.

### Drainage class mapping

Soil drainage properties were examined by making auger observations to a depth of 110 cm where possible on the established grid, giving 42 observation points in 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). In the soil survey, soils with gley profile form are considered poorly drained; soils with mottled profile form are considered imperfectly drained; soils containing a redox-mottled horizon below 60 cm are considered moderately well drained; while soils containing no reductimorphic horizon or redox-mottled horizon within 90 cm are considered well drained. These criteria follow the drainage class separation criteria used in New Zealand soil surveys (Milne *et al,* 1995).

### Phosphate retention

Soil samples were collected from 0-7.5 cm surface soils, on the grid patterns shown in Figure 2. Three soil samples were taken within 30 cm diameter of each observation point using a core sampler and were combined to form a composite sample to determine P-retention. This is the methodology used in New Zealand as part of a fertiliser recommendation for pastures.

P-retention of soils was determined according to the method given by Saunders (1965) and the results are expressed as percentage values. Eight quality control samples with known P-retention values were incorporated within each 100-sample batch to monitor the possible variations that might arise among different batches. The same P-retention solution and vanado-molybdate solutions were used throughout the analysis of the samples for a fair comparison of results.

### Preparation of maps

Drainage class maps were generated by the “Surfer” programme (version 5.0) based on the point drainage class data. The drainage class maps (Figure 3A, 3B and 3C) are contour maps generated by the “Surfer” programme based on the point drainage data. The programme generates values between the points automatically by kriging (Senarath *et.al.*, 2001). To generate maps, drainage classes were given numerical values of 100, 90, 60 and 30 for well drained, moderately well drained, imperfectly drained and poorly drained drainage classes respectively (Milne, 1995). When generating the contour pattern, the programme always generates a sequential drainage pattern according to this order. That is if a well drained soil was found by augering to occur adjacent to a poorly drained soil, the programme automatically interpolates moderately well drained and imperfectly drained soil units between the two.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.

### Bulk density

Bulk density measurements were made on core samples (with known volume) taken from each soil horizon. Soil samples were oven dried at 105° C until the weight became constant.

### Saturated hydraulic conductivity (Ksat)

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) according to the method of Klute (1986).

### Mineralogical analysis

Mineralogical properties of soil samples were determined according to methods described by Whitton and Churchman (1987). Allophane present in soils was determined according to the method of Parfitt (1986) and Parfitt and Wilson (1985). Acid-oxalate extractable Si was determined according to the method of Blakemore *et.al.*, 1987.

## Results and Discussion

### *Soil drainage variability*

The 1:250,000 scale soil map (NZ Soil Bureau, 1954), of the study area portrays the 2000 m by 300 m window area as well drained, Kawhatau silt loam (Table 1). A subsequent land resource map at 1:63,360 scale (NZ Land Resource Inventory, 1979) shows the area to be well drained, Kiwitea loam. Senarath (2003) has explained why neither series name is appropriate for the soils on the Intermediate terrace, and introduced new series.

**Table 1 Classification of soil types according to the New Zealand soil classification system and the USDA Soil Taxonomy.**

| Soil type | New Zealand Classification (Hewitt, 1992) | USDA Soil Taxonomy (Soil Survey Staff, 1999) |
|---|---|---|
| Kawhatau silt loam | Acidic Allophanic Brown Soil | Andic Eutrudepts |
| Kiwitea loam | Typic Orthic Melanic Soil | Eutrudepts |
| Coulter silt loam | Typic Orthic Allophanic Soil | Dystrudepts |
| Horoeka silt loam | Typic Orthic Melanic Soil | Andic Eutrudepts |
| Barrow silt loam | Mottled Immature Pallic Soil | Aqualfs |

When the authors mapped the area at 1:25,000 scale it appears to encompass three different soil drainage classes; well drained, Coulter silt loam, moderately well drained, Horoeka silt loam and imperfectly drained, Barrow silt loam (Figure 1). When selected window areas (blocks A, B and C) are mapped at 1:10,000 scale it becomes apparent that the relatively simple soil drainage pattern represented in the 1:25,000 scale map (Figure 1) is much more complex (Figure 3A, 3B, and 3C). Instead of a gradation of drainage status from well drained to imperfectly drained soils (Figure 1), there is a mixture of well, moderately well and imperfectly or poorly drained soils present in each block within close proximity. At least three different soil drainage classes are identified in each of the 300 m by 250 m blocks when mapped at 1:10,000 scale. Each of these blocks comprises only one soil drainage class when mapped at 1:25,000 scale.

When blocks A, B and C are mapped at 1:5000 scale, no new drainage classes are found in any areas except for block B (Figure 4B), but the drainage class boundaries could be shown more accurately and it is apparent that the distribution of drainage classes is more complex even than that revealed at 1:10,000 scale (Figure, 4A, 4B and 4C). It is evident that when ground observation intensity is increased a more and more variable soil drainage pattern can be observed.

**Figure 1 Soil drainage class map for the 2000 m by 300 m window area (60 ha) when mapped at 1:25,000 scale.**

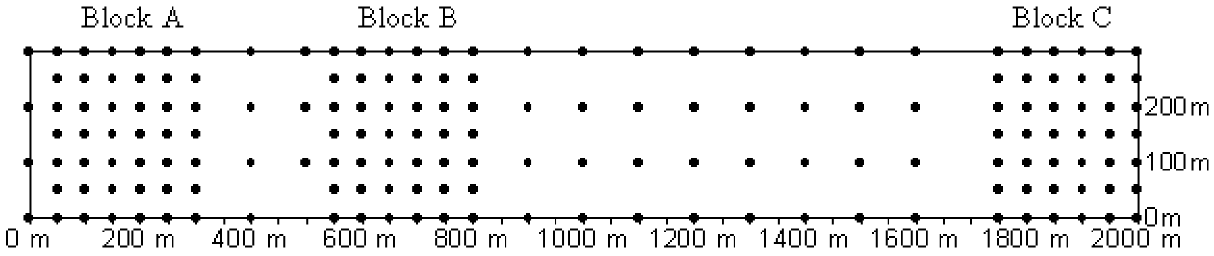

**Figure 2 Grid sampling design (50 m by 50 m) within blocks A, B and C established within the 2000 m by 300 m large window area on imperfect, moderately well and well drained soil units respectively mapped at 1:25,000 scale.**

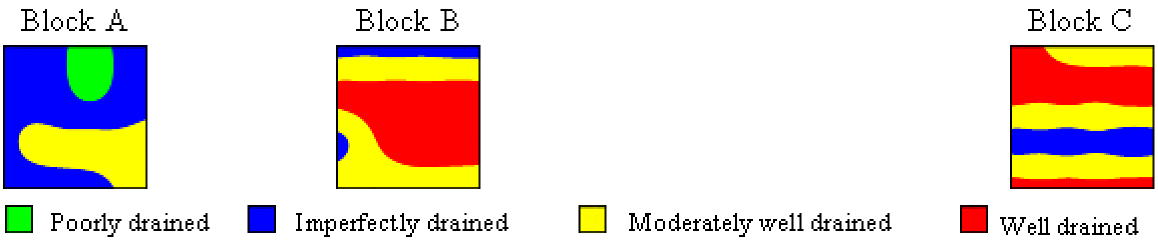

**Figure 3 .Soil drainage class maps for the 300m by 250m window (7.5 ha) areas when mapped at 1:10,000 scale.**

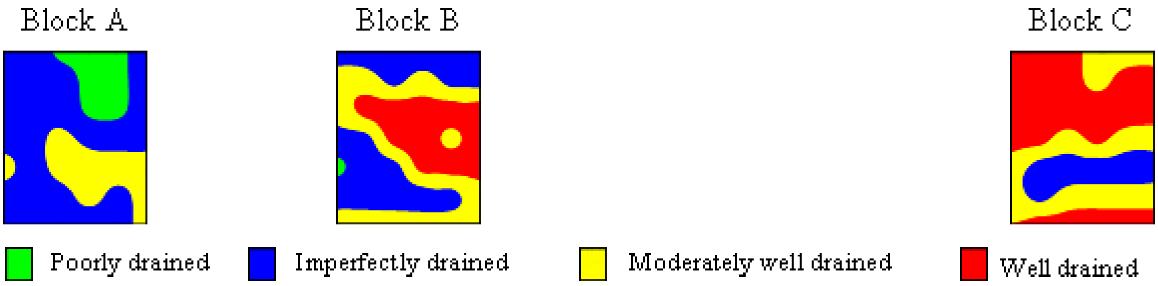

**Figure 4 Soil drainage class maps for the 300 m by 250m blocks (7.5 ha) when mapped at 1:5,000 scale.**

*Soil-landscape relationship*
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 (Senarath 2003). The land is essentially flat to gently undulating, with a gentle tilt to the west. There are some instances where soils in local depressions, areas close to water bodies or streams are imperfectly or poorly drained, but that cannot be accepted as a general rule for the entire area.

*Phosphate retention (P-retention)*
The relationship between soil drainage and P-retention was investigated in detail using soil drainage information collected from blocks A, B and C on a 50 m interval grid (Figure 2). The comparison between soil drainage and the P-retention at each observation point 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 (Table 2).

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 paddocks can be attributed to the variability of soil drainage. The relationship has been suspected but never before demonstrated for New Zealand soils.

**Table 2. The relationship between soil drainage classes and P-retention classes. 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 0 - 30% | MP-ret 31 – 60% | HP-ret 61 – 100% | LP-ret 0 -30% | MP-ret 31 – 60% | HP-ret 61 – 100% |
| Poorly drained | 9 | 0 | 0 | 100 | 0 | 0 |
| Imperfectly drained | 4 | 34 | 11 | 82 | 69.4 | 22.4 |
| Moderately well drained | 0 | 5 | 29 | 0 | 14.7 | 85.3 |
| Well drained | 0 | 0 | 34 | 0 | 0 | 100 |

*Soil drainage, phosphate retention and clay mineralogy*

The sand fractions of both the well drained and imperfectly drained soils on the intermediate terrace contain volcanic glass. 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 3).

As mentioned in the introduction, Parfitt *et al.* (1984) showed that clay mineralogy is related to soil drainage. It is well known in New Zealand that topsoils dominated by allophane have high P-retention while those dominated by kandite have low P-retention. These results show that the average P-retention of the topsoil is also influenced by the drainage of the whole profile.

**Table 3. The relationship between soil drainage, P-retention and clay mineralogy of the topsoil of two of the soils (Senarath, 2003).**

| Soil Type | | Sand fraction | | | Clay fraction | | |
|---|---|---|---|---|---|---|---|
| | | Quartz% | Feldspar% | Volcanic.glass% | Kandite % | Allophane % | P-Ret.% |
| Coulter silt loam | Well drained | 41 | 32 | 13 | 16 | 10 | 86 |
| Barrow silt loam | Imperfectly drained | 54 | 29 | 8 | 31 | 0 | 50 |

*Soil mapping scale and variability of P-retention*

The P-retention values of the topsoil samples collected from the study area range from 15% to 86% (Senarath, 2003). These values indicate that there is considerable variability in P-retention within the soils, ranging from low to high (Saunders, 1965). When the area is mapped at 1:25,000 scale, the ranges of P-retention within the imperfectly, moderately well and well drained map units have not reduced significantly (Table 4) compared to the total range of P-retention (15 – 86%).

When the mapping scale is increased from 1:25,000 to 1:10,000 a new poorly drained map unit (Ohakea silt loam) with less variable P-retention values (22 – 44%) is added to the soil map (Table 4). The range of P-retention values in the Barrow and Horoeka map units changed only slightly. However, there is a considerable change of range in P-retention within the Coulter map unit (Table 4)). The co-efficient of variation (CV) indicates that Barrow and Horoeka 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 and Horoeka silt loams whereas CV considerably reduced in Coulter silt loams (Table 4).

When the mapping scale increased from 1:10,000 to 1:5,000, the variability of P-retention very slightly decreased in Ohakea, Barrow, Horoeka and Coulter silt loam map units (Table 4). Therefore map units at all scales have a considerable range in P-retention, but their mean P-retention values increase in an orderly manner with improving drainage.

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 added cost of producing the maps at the larger scale is taken into account.

**Table 4 The variability of P-retention within the soil map units when mapped at three different scales. (Senarath, 2003).**
**STD = standard deviation; CV% = coefficient of variation; PD = poorly drained; ImD = imperfectly drained; MWD = moderately well drained; WD = well drained**

| Map unit | Phosphate Retention | | | |
|---|---|---|---|---|
| | Range | Mean | STD | CV% |
| Mapping scale 1:25,000 | | | | |
| Ohakea silt loam (PD) | No mapping unit at 1:25,000 scale | | | |
| Barrow silt loam (ImD) | 15 - 72 | 44.1 | 14.4 | 32.6 |
| Horoeka silt loam (MWD) | 23 - 86 | 65.1 | 14.2 | 21.8 |
| Coulter silt loam (WD) | 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 | 22.3 |
| 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 |

*Genesis of soil drainage conditions*

Soil texture is a property that is initially inherited from its parent material, so variations in soil texture are presumed to reflect variations in initial deposition overprinted by changes due to weathering. The slight textural variations in the parent material probably effected slight variations in soil structural development. In the soils of the study area, 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 5 and 6).

**Table 5 The physical properties of a representative profile of well drained Coulter silt loam related to water movement in soil (Senarath, 2003).**

| Horizon | Depth (cm) | Field -texture | Structure | Macro-Porosity (%) | Ksat (mm hr $^{-1}$) |
|---|---|---|---|---|---|
| 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 |

It is hypothesised that the differences in soil structure largely caused the differences in drainage status. The hydraulic conductivity of a soil is directly related to its porosity, more importantly the macro porosity. The shape and the size of the soil structural units has a noticeable affect on the space between them (Griffiths, 1985; Griffiths *et al.*, 1999) Blocky structure is more closely fitting than nutty structure hence water can move more readily along structural faces of soils having nutty structure.

Saturated hydraulic conductivity (Ksat) values in the Bg1 and Bg3 horizons (0.9 and 0.8 mm/hr) are very slow in the imperfectly drained Barrow soils (Table 6). This impedes drainage in the whole profile. K sat values for the other two horizons are approximately same as that of the Coulter soil (Table 5). Ksat values range from moderately slow to very slow in soils having blocky structures (Griffiths, 1985) Although macro porosity is more or less similar to that of Coulter soils (Table 5), 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 Barrow soils, creating imperfect drainage conditions.

**Table 6 The physical properties of a representative profile of imperfectly drained Barrow silt loam related to water movement in soil (Senarath, 2003).**

| Horizon depth (cm) | Field-texture | Structure | Macro-porosity (%) | Ksat (mm hr $^{-1}$) |
|---|---|---|---|---|
| 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 |

The soil textures of Coulter soils are silt loam and the structures are nutty. The structural units are not closely packed 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. These subtle changes in texture have been subsequently masked by weathering including clay formation and changes in clay mineralogy.

Soil drainage conditions influence clay mineralogy (Parfitt *et al.* (1984). 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 Si not being leached from the profile, and kandite minerals (kaolinite + halloysite) form instead.

The variability in P-retention within a paddock should have a significant influence on the amount of phosphate fertilizer applied by farmers. If fertilised at a rate suited to the low P-retention soil, then the high P-retention soils in the paddock will be deficient in P and will have suboptimal productivity. If land is fertilised according to the high P-retention soil, then surplus P will be applied to the low P-retention soil which is uneconomic and may increase the rate of loss of P to waterways. Thus it is clear from both an economic and an environmental point of view that soils within different P-retention classes should be treated differently. Therefore, identification of low, medium and high P-retention areas in the landscape and managing them accordingly is important. Variable rate of application of phosphate fertiliser through precision agriculture is an obvious solution, if the areas of low, intermediate and high P-retention in a paddock can be identified. This is most cheaply and efficiently achieved by soil survey recognising drainage class.

## Conclusions

- Soil drainage properties in the study area vary from well drained through moderately well drained to imperfectly drained and poorly drained with in the paddock scale.
- The poor relationship between soil drainage and the topography of the landscape poses difficulties for conventional soil survey.
- Short distance drainage variability has a relationship to the textural variations of the original alluvial parent material which gives rise to the formation of different soil structures and different pathways of weathering. This in turn influences the hydraulic conductivity of the soil and results in variable drainage conditions and different P-retention values.
- There is a strong relationship between soil drainage, phosphate retention and clay mineralogy in soils developed from tephra mixed parent materials. Well drained soils have high P-retention and the clay fraction contains allophane whereas poorly drained soils have low P-retention and the clay fraction contains no allophane but mainly kandite.
- The positive relationship between soil drainage and P-retention can be used to identify different P-retention areas on soil maps.
- 1:10,000 is the optimal soil mapping scale for practical farm planning in this area.

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