Soil Survey to Predict Soil Characteristics Relevant to Land Management

(Naivasha, Kenya)

BY

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This thesis is submitted in partial fulfilment for the degree of Master of Science in Geoinformation Science and Earth Observation with specialisation in Land Degradation Conservation and Rehabilitation (LDCR) at the International Institute for Aerospace Survey and Earth Sciences (ITC), Enschede, The Netherlands.

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Disclaimer

Abstract

It is generally known that management practices such as tillage, fertilisation, insecticides, herbicides applications, etc. may result in changes in the physical and chemical properties of the soil. For example, soil compaction, problems of soil aeration, decline in soil fertility and the effect on soil ecosystem. The results of the different types of management are called “phenoforms” whereas the genetically defined soil types are “genoforms”.

The purpose this study was to distinguish and characterise the different phenoforms formed by different types of management in the area of lake Naivasha, Kenya. Genoforms were defined by standard soil survey and classification systems and phenoforms by statistical analysis and classification methods such as the FAO proposed topsoil characterisation (1998) including USDA (1998) and World Reference Base (1998).

Twenty-nine observation points with a total of 74 horizons were sampled. Eleven of them were paired (managed vs unmanaged). The observation points that were made in pairs were chosen based on site observation, close to each other, with the same genoform and differing only in management practices. Soil properties including infiltration (I), bulk density (Bd), soil structure, organic mater content, coarse fragments, pH, EC, and penetration resistance (r) were determined. Results and conclusions were made using statistical methods and by inference from principles of soil science.

The main soil types of the area are Areni-Vitric Andosols (Eutri) and Sodi-Fluvic Cambisols (Skeletic, Eutric). There is significant difference between managed and unmanaged in two properties: in soil infiltration rate during the first 8 minutes and r of the 2^{nd} horizon. Though not significantly different, suggestive results in soil pH and Bd were found. These both increased with depth. Soils in the volcanic plain have significantly higher Bd and significantly lower pH than those in the lacustrine plain. Organic mater content increases due to management in the volcanic plain soils and decreases in the lacustrine plain. Soil structure can not be a diagnostic criterion in these gravely sandy soils, derived from volcanic ash, due to its weak development.

The proposed FAO topsoil classification highlights most of the soil properties useful for management, for example the low nutrient retention, natric, and altaric properties of these soils. On the other hand, production limitations such as excessively drained properties, problems of nematodes, some toxicities, potic nature, and soil capping were not recognised and could be added to improve the usefulness of the classification system.

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1. Introduction

The main aim of soil survey is to determine the pattern of soil cover, characterise it, and present it in understandable and interpretable form to various users.

Depending on the demand of the consumers, special or general-purpose soil survey could be conducted. The first kind of soil survey is more rapid, and can be done with less skilled mappers. The later kind of survey is conducted when multipurpose map/survey is required. The problem with this kind of survey is that it is not ideal for any one purpose. Therefore, to increase the usefulness or interpretability of general-purpose surveys, different soil classification systems have emerged and are being used. For example, the USDA, Canadian, French, and FAO systems.

It is generally known that management practice such as tillage, fertilisation, pesticide, and insecticide application result in a change in the physical and chemical properties of the soil. For example, soil compaction, organic matter depletion, salinity build-up, structure degradation, and change in the hydraulic characteristics of the soil.

Due to this, some researches have shown that differences in management within the same family, in the USDA system of classification for example, could result in different soil properties that are relevant for management. This led Bouma, (1994) to propose the concept of genoform (the genetically defined soil types e.g. Fine, mixed, mesic, Typic Fluvaquent and phenoform, for the differences brought by management with in a genoform. That is to say, the genetically defined families would be a genoform, while results of different types of management would represent various phenoforms. But, so far sufficient researches were not done to support this.

A detailed study was conducted in Kenya in the south and south east part of lake Naivasha where differences in soil management and degradation problems are discovered. Due to the fresh water nature of the lake there are a lot of investment activities in the area. Most of them are high-tech managed commercial agricultural farms. These farms demand soil information for their proper land management. Moreover, these farms have different management units or landuse. For example, greenhouses for flowers, open vegetable fields, organic farm plots, open unmanaged sites and forested areas. These different landuses could give an idea of how management practices alter the genetic makeup of the soil and ultimately result in a different phenoform.

Most classification systems are mainly based on the subsoil and do not pay much attention to the topsoil, which is the most important part of the soil for food production, for soil management, and for degradation control. Fertility capability classification (FCC) and topsoil classification (FAO, 1998) are some of the very few systems, which attempt to bridge the gap between the soil classification and soil fertility constraints. Therefore, this research was designed to determine the different phenoforms occurring within a genoform and analyse their relationship or significance with respect to management and classification. Moreover, to verify the proposed FAO (1998) topsoil characterisation, for its practicability in the field.

1.1. Objectives

- To determine the different phenoforms, resulting from different management practices and that are relevant for land management, within genoforms.
- To determine the relationships between phenoforms and genoforms.
- To study the significance of the phenoforms relevant for land management.
- To carry out soil (genoforms) survey in the area and study its relationship with the geo-pedologic units. Special emphases being given to soil characteristics which are relevant to soil management.
- To add to the usefulness of a soil classification system for land management.

1.2. Research Questions

- What are the geo-pedologic units, the different phenoforms and genoforms in the study area?
- Is the phenoform concept meaningful? What properties should be used to define them?
- Can the taxonomic classification segregate variability caused by management?
- Is there a big difference in nutrient management?
- Can phenoforms be mapped at a reasonable scale?
- Is the new proposed FAO topsoil characterisation practical? Is it useful to define phenoforms?
- Relation between phenoforms and phase concept?

1.3. Hypothesis

- There are significant differences between phenoforms within a given genoform.
- Differences between phenoforms are important for land management.
- Differences between phenoforms result from different land management.
- The phenoform concept is more precise and narrower in scope than the phase concept.

2. Literature Review

2.1. Soil survey

The main aim of soil survey is to determine the pattern of soil cover, characterise it, and present it in understandable and interpretable form to various consumers.

According to the USDA soil survey manual (1993) “a soil survey describes the characteristics of the soils in a given area, classifies the soils according to a standard system of classification, plots the boundaries of the soils on a map, and makes predictions about the behaviour of soils. The different uses of the soils and how the response of management affects them are considered (in designing and carrying out the survey). The information collected in a soil survey helps in the development of land-use plans and evaluates and predicts the effects of land use on the environment.”

We know from the Jenny equation that soil is a product of interaction of different pedogenetic factors. (S= *f* (Parent material, climate, Organism, Relief, and Time)). “These soil-forming factors vary continuously over the landscape, so do the soils that are there by formed. We can map these soils directly with the continuous model of spatial variation, or we can try to divide the continuum with the discrete model of spatial variation” (Rossiter, 2000b).

Zinck (1988/89) developed an approach to systematically integrate geomorphology and pedology using geomorphology as a tool so that to improve and speed up the soil survey. He named this as Geopedologic approach. This depends on the truth of two hypotheses: boundaries drown by landscape analysis separate most of the variation in the soils, and sample areas are representative; their soil pattern can be reliably extrapolated to unvisited map units.

“Moreover, the approach has advantages in legend construction and structuring. On the other hand, since all the delineations are not actually visited, the sampling is biased towards ‘typical’ landscape positions, so only crude estimates of internal variabilities are shown” (Rossiter, 2000b).

2.2. Fertility Capability Classification (FCC)

“The fertility capability classification system is one of the very few systems, which attempts to bridge the gap between soil classification and soil fertility constraints. The system emphasises on the topsoil properties because of their relation to fertility and management” (Buol et al., 1973). It first appeared in soil management in tropical America (Christopher, 1989)

The FCC groups soils according to their fertility constraints in a quantitative manner. It consists of three categorical levels: type (topsoil texture 0-20cm), substrata type (subsoil texture 20-60cm), and 15 modifiers. Class designations form the three categorical levels are combined to form an FCC unit.
The topsoil characterisation and classification system is based on this system but expands the number of topsoil influencing features, e.g. organic matter status, land use and erosion/land degradation, to make it even more practical and widely (FAO, 1998).

2.3. Topsoil classification

Topsoil is a part of the soil that is strongly influenced by soil-forming factors, both externally and internally. They are very variable in space and time which makes it difficult to classify them. Due to this, pedologists base themselves more on the subsoil than on topsoil. For example, "A common criticism of soil taxonomic classification is that they are mainly based on subsoil and do not pay much attention to the topsoil which is the most important part of the soil for food production, for soil management and for degradation control" (FAO, 1998).

"Soil classification tends to ignore or down play the diversity of topsoil characteristics, mainly because they can change fairly rapidly under human influence. However, the topsoil determines to a large extent soil-related land qualities, especially for infiltration, erosion, crusting and other surface processes. To fill this gap, a draft proposal has been developed by ISRIC and FAO. This is an important development, and soil scientists working with surface processes should test the classification to see if it is a useful stratification for their purposes" (Rossiter, 2000a).

According to FAO (1998) for classification purposes, the topsoil lower limit is set at 30-cm depth, or at a root growth-inhibiting layer whichever is shallower. They are grouped by texture and the following dominant features: Organic material, organic matter status, physical, chemical and biological features, drainage features, land use, erosion or degradation, external physical conditions, and slope class.

Moreover, the following factors have to be taken into account to characterise topsoil. These are climate, vegetation and organic matter, topography and physiography, mineralogical soil constituents, surface processes, biological, and human activity.

For example, under surface processes they distinguished two types of surface processes: climate-related and soil-related. Climate-related surface processes induce water and wind erosion and soil heating. Soil-related surface processes comprise sealing, crusting, hardening, cracking and self-mulching.

The topsoil characterisation is proposed to be used in the identification of fertility and management related soil characteristics. For example, a soil could be characterised as **Eutri-grumic Vertisol**/with a Natric, clayey, Crusting and Self-mulching topsoil (**Cnr1v1**), this being the code given to the limiting factors by the FAO topsoil classification. The management requirements are given per interpreted topsoil property or group of properties. A complete listing of all possible combinations is not given because only limited number of combinations of topsoil properties will be found in any area under consideration. At large scale, however, interpretation of the topsoil properties in relation to farming systems, local expertise or crops could be a valuable extension tool.

2.4. Human activity

Man makes use of land for a variety of purposes. One of the most important and widespread uses is agriculture. A replacement of a natural or semi-natural ecosystem by an agricultural, less diverse, agro-ecosystem entails changes in physical and chemical topsoil properties.

Human activities like removal of vegetation, organic matter management, land levelling, liming, fertiliser application, use of pesticides, Long-term irrigation practices affect the properties of topsoil greatly.

2.5. Soil Survey vs Management

Bouma and Droogers (1999) investigated soil moisture supply capacity (MSC) of three different 'phenoforms within a given genoform'. In the opinion of Bouma (1994) the genetically defined soil series would be a genoform, while results of different types of management would represent various phenoforms. These two terms are closely related to the well-known genotype and phenotype as used in genetics.

Calculations were made for a prime agricultural soil in the Netherlands, a fine, mixed, mesic Typic Fluvaquent (genoform). Three phenoforms, defined by long-duration management, were distinguished: BIO (biodynamic), CONV (conventional, High-tech) and PERM (permanent grassland).

They found out that the three phenoforms being characterised show significantly different values to the MSC. They concluded that, linking MSC directly with taxonomic genoforms should be avoided because much error is introduced because of variations caused by soil management. Moreover, they illustrated the need to distinguish phenoforms, rather than only genoforms, when reporting basic physical data for soil series. That is soil series reflect the effects of soil genesis, but not of management.

According to these authors different management leads to the formation of different phenoforms. Common soil properties such as bulk density, porosity, moisture retention and hydraulic conductivity reflect the effects of short-range management. Tillage or soil traffic under wet conditions in a given year may lead to compaction, puddling and structure degradation which may not occur in the same soil where soil traffic is avoided.

Therefore, for the purpose of long-range effects of management, it is important to focus on soil properties that are not significantly influenced by short-range management practices. For example, they explained that organic matter content shows long-range management effects.

2.6. Soil Properties

Soil Compaction: according to USDA (1996), soil compaction occurs when soil particles are pressed together, reducing the pore space between them. This increases the weight of solids per unit volume of soil (bulk density). Soil compaction occurs in response to pressure (weight per unit area) exerted by field machinery or animals. The risk for compaction is greatest when soils are wet.

Compacted soils are a major problem in agriculture world-wide; they restrict root growth and seedling emergence, increase the energy costs of tillage, and impose restrictions on the soil management regimes that can be used (Bengough et al., 2001). The soil compaction or strength can be measured using penetrometer. Penetration resistance is expressed as penetration force per unit cross-sectional area of the cone base. Penetrometer resistance measurements are used widely, are relatively quick and easy to make, and can provide data that are valuable if interpreted carefully. Penetration resistance depends on many factors, but the dry bulk density, stones or gravel and water content of the soil are important especially Bengough etal. (2001) and CBR instrument (model 244) manual.

The CBR instrument is used for rapidly measuring resistance to penetration in depth. An easily read dial at the top of the instrument automatically indicates the force required in terms of the equivalent insitu C.B.R. (California Bearing Ratio) value. The range of the instrument is from 0-15% C.B.R. Moreover, the instrument is important to make comparative tests.

Soil organic matter promotes aggregation of soil particles. This increases porosity and reduces bulk density (i.e. Compaction). It also increases permeability and may increase plant available water. Addition of manure, compost, or other organic materials including newspaper, wood-chips, and municipal sludge can improve soil structure, helping to resist compaction.

Infiltration: According to Jury etal. (1991) "Infiltration refers to the entry of water into a soil profile from the boundary. Generally, it refers to vertical infiltration, where water moves downward from the soil surface. Since infiltration causes the soil to become wetter with time, water at the leading edge of the wetting pattern advances into the drier soil region ahead of the front under the influence of matric potential gradients as well as gravity (infiltration is vertical)". There are many vertical infiltration models in use, the majority of which have been derived empirically from field data. These models all share the common feature that the infiltration rate is highest when water first enters the soil and decreases with time as the wetting front moves away from the surface.

The easiest way to observe ponded infiltration in the field is simply to watch the rate that water disappears from a surface puddle. However, two factors control infiltration from a pond, capillary and gravity. In order to eliminate the perimeter effects of capillarity, buffered rings have been used so that the flow in the inner ring is due only to gravity. By this arrangement, it is hoped that the steady flux from the inner ring might be the saturated hydraulic conductivity, since capillary effects would be quenched by flow from the buffer ring (Clothier, 2001).

Organic material: The volume of organic material in a soil determines the amount of water retained in a soil (FAO, 1988a). At low tensions it is much greater for organic soils than only mineral soils. For example, the total pore space in fibric organic topsoil is high which allows a high rate of water movement because of the large pores usually present. These collapse on progressive decomposition and total pore space also decreases. On drainage the porosity of organic soils changes drastically.

Bulk density (Db): is the density of a soil volume including pore space (mineral +organic matter). That is oven dry soil weight divided by soil volume in g/cm^3. It is an indicator of porosity (texture + structure); Natural compaction; Artificial compaction (traffic pan by men, animals & equipment, plow pan); Nature of special material such as volcanic material (<0.85g/cc), organic matter e.g. decomposed peat Db 0.5-0.6g/cc, biogenic lacustrine materials (diatoms and calcareous shell fragments) Db 0.6-0.9: weathering isovolumetric alteration of igneous or metamorphic rocks (differential weathering) Db: 2.7-2.2-2.0 g/cc (Zinck, 1986/87).

2.7. Soil Boundaries (Fuzziness and Uncertainity)

According to Lagacherie (1996), uncertainty corresponds to lack of knowledge about an object or a fact. And, fuzziness occurs when the considered object or fact itself can not be precisely defined. Natural fuzziness and uncertainty can occur simultaneously and they are positively correlated. Two adjacent soil units often merge gradually at their boundary and this boundary is mostly fuzzy. Fuzziness must always referred to a given scale of observation, because a boundary which was considered as fuzzy in the detailed survey of an agricultural field may become abrupt for users dealing with the whole region.

Table 1 Examples of unit boundaries (adapted from (Rossiter, 2000b), page 89)

		Fuzziness	
		High	Low
Uncertainty	High	**Gradual** variation of the stoniness of an intermediate soil layer with **no observable surface** features	**Undetectable but abrupt** variation in the soil structure in deep soil layers
	Low	**Gradual** variation of soil layers thickness, delineated by **marked changes** in vegetation/ landuse	**Abrupt** variation of the whole soil profile (geological change) **detectable** by a break in slope and a variation in surface features

According to Rossiter (2000b), "a major challenge to traditional free-survey based on airphotos and soil-landscape analysis are so called areas of law predictability, were important soil properties (typically in the subsoil) have no surface expression, neither in the vegetation or present landuse, nor in their landscape position. Yet, the soils must be mapped accurately to predict the success of new uses, which would rely on some of the subsoil properties".

2.8. The Phase Concept

According to USDA soil survey manual (1993), if a property of a taxon has too wide a range for the interpretations needed or if some feature outside the soil itself is significant for use and management, these are bases for defining phases.

"In any soil classification system, there will be soil characteristics that are not considered at any level. Also, in any area to be mapped there will be non-soil land characteristics that are important to land use, that can be mapped with the same methods and at the same time as the purely soil characteristics. These are the two motivations for the concept of phases of any higher taxon" (Rossiter, 2000b).

Because of these, he grouped the phases in to four kinds:

1. Soil characteristics of the **surface layer** that have been explicitly excluded from Soil Taxonomy or local classification systems. Example: texture, coarse fragments, and amount of erosion or truncation. A good example is surface stoniness: the number, size, type and pattern can have a major influence on erosion hazard, heating and drying, tillage, etc.
2. **Internal** soil characteristics not included in the definition of the soil Series, because they are deeper than the Series control section, they must be taken into account in phases. These are substrata phases.
3. For maps of higher **categorical level** than soil Series, any internal soil characteristics not used at higher levels of taxonomy. Many of these could be used to define Series. Example: 'Typic Ustorthents, fine-loamy, mixed, mesic, subactive; moderately deep' for soils that are between 50-

100cm to a root-limiting layer. The 'Lithic' subgroup is defined for soils <50 cm; for deeper soils there is no difference in classification at family level.

4. **Non-soil** land characteristics. Soil surveyors map these because the surveyor sees them and infers their importance for land use or behaviour. In many cases the soil surveyor is the only person who maps the relatively permanent land characteristics, so not just soil but also physiography etc. Example: site slope, physiographic position (e.g. Terrace level to infer flood hazard)

Furthermore, Soil water behaviour (e.g. Surface ponding); salinity; sodicity; other chemical characteristics not included in the series definition; external climate; flooding hazard; degree of exploitation (e.g. Organic soils, drained soils), etc could be described as phases.

2.9. Statistical Analysis

Before conducting any statistical tests the quality of the data should be checked thus appropriate statistical method would be chosen.

Various descriptive statistics have been devised to aid in understanding the population, including mean, variance, median, range, histogram, etc. Descriptive statistics may be used to infer information about the population by hypothesis testing, for example does the mean of population 1 equal the mean of population 2, or are the means different in some way. Unfortunately, some information is required about the population distribution of the random variable being tested, in order to test an inference about a sample description (e.g. mean). In practice this has led to a fairly limited set of commonly used statistical tests, which are based upon a particular population distribution. For example, the "mean" is used as a measure of central tendency in a data set, but the use of the mean requires an underlying assumption that the data set has an almost symmetrical distribution (Skidmore, 2000).

Parametric methods in statistics are based on specific assumptions in the model of the population, for example that the population has a normal distribution. When the parametric model of the population does not match the true shape of the population, the assumption of the parametric test is broken, and the parametric test should not be used. In contrast, non-parametric statistics replace specific distribution functions with very general assumptions about the sample population.

Tests for Normality: There are three types of goodness-of-fit test: an ECDF (empirical cumulative distribution function) based test, a correlation based test, and a chi-square based test. In this study, for data analysis, Anderson-Darling test was used. Therefore, it will be discussed in brief

Anderson-Darling test is an empirical cumulative distribution function, which generates a normal probability plot and performs a hypothesis test to examine whether or not the observations follow a normal distribution. For the normality test, the hypotheses are,

H0: the data follow a normal distribution vs.
H1: the data do not follow a normal distribution

On the plot, the vertical axis has a probability scale; the horizontal axis, a data scale. A least-squares line is fit to the plotted points and drawn on the plot for reference. The line forms an estimate of the cumulative distribution function for the population from which data are drawn. Numerical estimates of the population parameters, μ and σ, are also displayed with the plot.

The Mann-Whitney U test is a two-sample non-parametric test, substituting for the parametric t-test. This allows the analyst to infer whether there is a statistically significant difference between two samples, typically drawn from a treatment population and a control population. The assumptions of the test are that the two populations have similar shapes, and that the measurements are on a continuous scale. (Skidmore, 2000)

It is possible to do Mann-Whitney test using Minitab statistical software. The software describes the method as follows: That is, one can perform a two-sample rank test (also called the Mann-Whitney test, or the two-sample Wilcoxon rank sum test) of the equality of two population medians, and calculate the corresponding point estimate and confidence interval. The hypotheses are

H0: h1 = h2 vs H1: h1 $\neq$ h2 where h is the population median.

"An assumption for the Mann-Whitney test is that the data are independent random samples from two populations that have the same shape (hence the same variance) and a scale that is continuous or ordinal (possesses natural ordering) if discrete. The two-sample rank test is slightly less powerful (the confidence interval is wider on the average) than the two-sample test with pooled sample variance when the populations are normal, and considerably more powerful (confidence interval is narrower, on the average) for many other populations. If the populations have different shapes or different standard deviations, a 2-Sample t without pooling variances may be more appropriate".

Application of Geostatistics: Soils vary both in space and time. Knowledge about the soil spatial variability is a crucial element to quantify the pedogenic concepts and better understand the causal factors of soil distribution patterns and landscape evolution (Wilding and Drees, 1983).

Several techniques have been used to quantify/ estimate spatial variability. But, there is no theoretical answer to which estimator is best. One has to check against the validation. "Geostatistics is basically a technology for estimating the values at unsampled places of properties that vary in space, whether in one, two or three dimensions, from more or less sparse sample data" (Webster and Oliver, 1990).

"The semi-variogram is the basic geostatistical tool for visualising, modelling and exploiting the spatial autocorrelation of a regionalised variable. As the name implies, the semi-variance is a measure of variance. A straight forward way of measuring how a variable z changes in value between site x and a site (x+h) a distance h apart is the following relation" (Meer, 1999).

$$\gamma^*(h) = \sum\{z(x)-z(x+h)\}^2/2n$$

Where $\gamma(h)$ is the semivariance for distance h.

There are different methods of estimating values at unvisited site. For example, Nearest point, Moving average, Trend surface and Kriging. At its simplest a kriged estimate is still a linear sum of the data but one in which the data carry different weights according to their positions both in relation to the unknown point and to the another (Webster and Oliver, 1990).

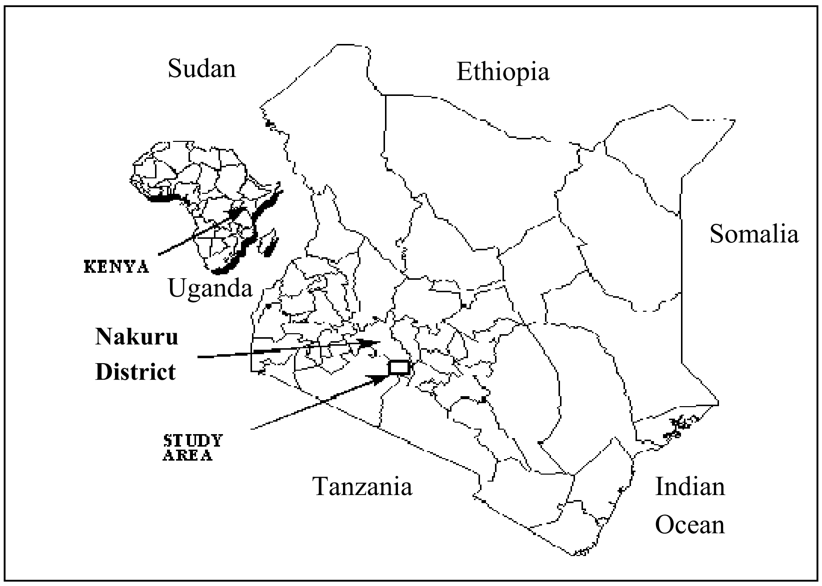
If the source data is normally distributed then ordinary Kriging could be used. Otherwise, non-parametric Kriging has to be used. The non-parametric Kriging was termed as Indicator Kriging. It descretizes the histogram of the grades in several classes and carries out interpolation separately for every class. The principal difference between ordinary kriging and indicator kriging is that indicator kriging works on transformed data (0.1) according to several cut-off grades. Therefore, the final result of indicator kriging is a cumulative probability distribution for every bloc (or panel) that gives the probability that the bloc or panel exceeds a specific cut-off grade (Meer, 1999).

3. Description of The Study Area

3.1. Location

Naivasha town is located in the southern part of the Nakuru district, itself located 100 km north-west of Nairobi, the capital of east African country, Kenya. Figure 1 shows the position of the study area.

Figure 1 The position of the study area (Data source: Kenya Bureau of Statistics/Cartographic Section, 1989, Kenya population census District maps, 1989)



The study area is located with in UTM zone 37 and lies between the following co-ordinates
East-West: 0214,000-0194,000 (36°25’37”-36 ° 15’04”E)
South-North: 9,904,000-9,914,000 (00 °52’16”-00°46’29”S)

3.2. Lake Naivasha

Lake Naivasha is the only fresh water lake in the district. It has a surface area of approximately 127 km^2, which is derived from a 1995 Landsat TM image. The Depth averaged 7 m in the period of 1963-1993 (Verschuren, 1996). However depth measurements made during the field visit resulted in an average depth of 4 m (Trottman, 1998). In October 1997 the lake storage was 403 million m^3.

The drainage basin is topographically closed, but the lake itself is hydrologically open, with groundwater flowing into the lake from the north, east and west, and out-flowing mainly in the south-Southeast (Gaudet and Malack, 1981). This inflow and outflow of water keeps the lake waters fresh. Conductivity measurements taken during the site visit in October 1997 averaged 500 µS/cm (Trottman, 1998).

The lake serves different purposes like fishing, drinking water, irrigation, tourism and recreation. Fishing in the lake is one source of income and employment generation. It provides an alternative source of animal protein. Lake Naivasha's fish production fluctuates year after year depending on the prevailing climatic conditions. The main species of fishes in the lake are *Tilapia zilii, Barbus amphigramma Gigr* and *Louisiana Red* (swamp) Crayfish (*Procambarus clarkii* (Girard)) (Harper et al., 1990).

3.3. Hydrology

The main rivers in the study area are the Marmonet River on the West Side of the lake draining the Mau Escarpment, and to N-NE of the lake, the Gilgil, Malewa and Karati rivers. The Karati River is perennial, and contributes very little inflow to the lake. The Gilgil and Malewa rivers collect runoff from the Aberdare mountains and their foothills to the NE of the lake, and discharge into the papyrus swamp forming part of the northern lake shore (Darling et al., 1990). The Marmonet River, although it flows towards the lake, fails to reach it.

Other sources of water inputs into the lake include rainfall that occurs directly over the lake and through underground water movement. The lake has a catchment area of 1730 km^2. The lake catchment has an internal drainage system. It has underground water inflows and outflows.

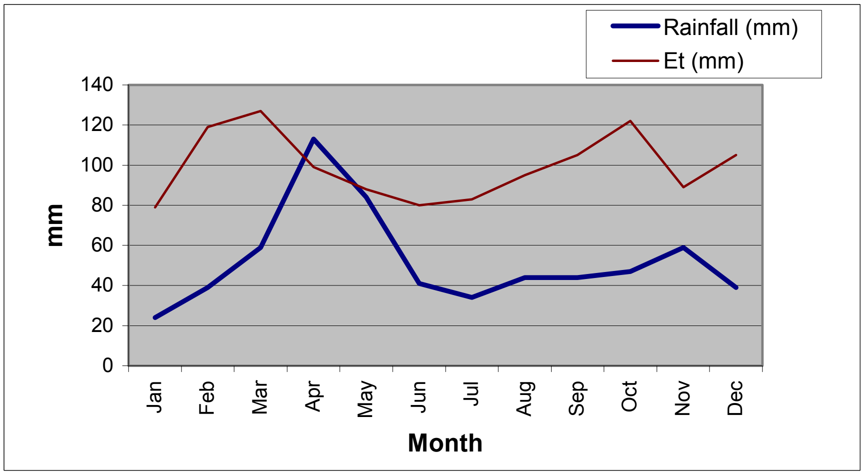
3.4. Climate

The area has semi-arid type of climate, with an average annual precipitation of 450-900mm/yr. The mean annual temperature for the area ranges from 16- 18.3°C. The maximum is 27.3°C, while the minimum is 7.9°C. The mean annual, mean, max and min are 16.9°C, 24.9°C and 9°C respectively (Kamoni, 1988). Figure 2 shows that annual average rainfall, for the period of 1966-80, is less than the potential Evapo-transpiration through out the months except in April. Therefore, supplementary irrigation is required to compensate the deficits during the other months.

Table 2 The monthly rainfall and temperatures for National Animal Husbandry Station-Naivasha, W.D.D (90360281), Altitude: 1900m a.s.l. (Kamoni, 1988)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	sum/avg
Rainfall (mm)	24	39	59	113	84	41	34	44	44	47	59	39	627
Mean Temp. °c	18	18	18	18	17.1	16	16	16	16.2	17	17	17	16.93
Max Temp.°c	27	27	27	25	23.6	23	22	23	24.5	26	25	26	24.90
Min Temp. °c	7.9	8.1	9.4	11	10.6	9.2	8.6	8.6	7.9	8.9	9.1	8.3	8.97
Eo (Pan "A' type) (mm)	118	178	190	149	132	120	125	142	158	183	134	158	148.92
Et (2/3*Eo) (mm)	79	119	127	99	88	80	83	95	105	122	89	105	99.25

Figure 2 Rainfall vs evapo-transpiration



3.5. Population and Communication

The population of Naivasha area is about 250,000 (LNORA, 1995). Due to the fact that most recently the area has become industrially significant as a consequence of development of flower production, horticultural production and tourist industries and other human activities, around the shore of the lake there is continuous increase in population.

Flower and horticulture production employs more than 20,000 people directly and many others indirectly, while the number of tourists visited Hells Gate National Park which is near the lake Naivasha increased by more than 600% between 1985 and 1992 (LNORA, 1995).

The area is well accessible by a network of tracks and roads, both unpaved and tarmac roads. A major tarmac road and railway line connecting Nairobi and Kisumu passes through Naivasha town. Moreover, in the area there are many small airstrips.

3.6. Geology

In general, the study area is dominated by two types of quaternary deposits, one lacustrine and the other volcanic in origin (Thompson and Dodson, 1963). The oldest rocks found in situ in Naivasha area have been described as belonging to the Tertiary era. Geological report and map of the area (at 1:100,000 and 1:250,000 scale) is available (Clarke et al., 1990). The sub-map of it is shown in Figure 3.

On the basis of surface outcrops the main products of volcanism within the Olkaria Volcanic Complex (termed the Olkaria Volcanic Group) have been alkali rhyolite (comendite) lava and pyroclastic rocks. Trachyte and basalt-hawaiite lava have been minor products, but widespread trachytic pyroclastics to the north-west, west and south-west of the complex are believed to have been erupted from vents within the complex (Clarke et al., 1990).

On the other hand, the Longonot Volcano constitute the Longonot Volcanic Group which incorporates seven formations. The major events in its history are:

1. Building of an early shield: Represented by the longonot Volcanic Formation-poorly exposed pyroclastics and lavas in boreholes.
2. Caldera formation: Represented by the (dominently ignimbritic) Kedong Valley Tuff Formation.
3. Building of a pyroclastic and lava cone: Represented by the Akira (often plinian) pumice Formation. This comprises six members, the early one including surge beds, the-later-ashfalls.
   Later stages of cone building are dominated by lava-the Longonot trachyte Formation. The Longonot Mixed Lava Formation was erupted on the northern lower flanks at this time also.
4. Formation of a summit crater: Preceded or accompanied by the Longonot Ash Formation.
5. Flank and craterfloor lava eruption: Represented by the Upper Trachyte Member (flanks) and Upper Mixed Lava Member (crater).

Pyroclastics-ashes, agglomerates and tuffs make up a considerable proportion in the area, this covers the whole volcanic plain, Easterly winds during the eruption caused the heaviest accumulations of ejected ashes, form Longonot volcano, to occur in around the study area and reported that recent pyroclastics are more acid in composition. The ashes are usually inter-bedded with other volcanics (Thompson and Dodson, 1963).

3.7. Geomorphology

The geomorphological history of the study area is characterised by Rift Valley development and the occurrence of volcanism together with modification by climate and the lake. According to geo-pedological approach three main landscapes have been identified these are Hilland (Hi), Volcanic plain (Pv) and Lacustrine plain (Pl.).

Geomorphologically Thompson (1963) has identified three major types of landscapes in Naivasha area, the Kinganop plateau, the Mau escarpment and the Rift floor. The study area is categorised under the Rift floor landscape unit.

3.8. Soils

Different soil scientists with various levels of intensity have carried researches particularly on the soil in the area. Sombroek (1980) indicated that the distribution of the soils in Lake Naivasha area is complex and influenced by intensive variation in relief, climate, volcanic activities and underlying rocks.

The soils of the study area can be grouped in to soils developed on the lacustrine plain, soils developed on volcanic plain and, soils developed in the hilland area, considering the geo-pedologic landscape units. The soils of the volcanic plain are formed mainly from weathered volcanic and pyroclastics. The soils of the lacustrine plain are the result of reworked volcanic and pyroclastic deposits.

According to Kwacha (1998), the types of soils found in the study area are Haplic Luvisols, Eutric Cambisols, Haplic Fluvisols dominating on the lacustrine plain, and Haplic Andosols dominating on the volcanic plain according to FAO (1988b). In addition, according to Gatahi (1986) Lithic Regosols and Ando-calcaric Regosols dominate on the volcanic plain, and Calcaric Fluvisols on the lacustrine plain.

In general, soils developed on the volcanic plain are well drained, moderately deep to very deep, dark brown to pale brown, with non-calcareous to moderately calcareous topsoil, and moderately to strongly calcareous deep subsoil. On the other hand, soils developed on lacustrine deposits are moderately well drained to well drained, very deep, very dark greyish brown to pale brown, silty clay to clay loam. In some places volcanic ashes and volcanic glasses are observable, and soils are very porous and contain pumiceous gravel (Kwacha, 1998). Previous studies classified these soils also as " well drained, very deep, strongly calcareous, very friable, loam or sandy loam" (Gatahi, 1986).

3.9. Landuse and Vegetation

3.9.1. Agriculture

In the 18th century the area was occupied by pastoralists (Massai tribe). They used the land for grazing their cattle and the lake for watering their livestock (Harper et al., 1990). With the arrival of (European) settlers, considerable changes in land use occurred: they introduced beef and dairy farming, irrigated agriculture and later the introduction of horticultural crops and flower cultivation. This pattern continued and intensified following independence form Great Britain in 1964. Flower production and horticulture production are the activities that dominate the shores of Lake Naivasha (Kwacha, 1998).

3.9.2. Vegetation

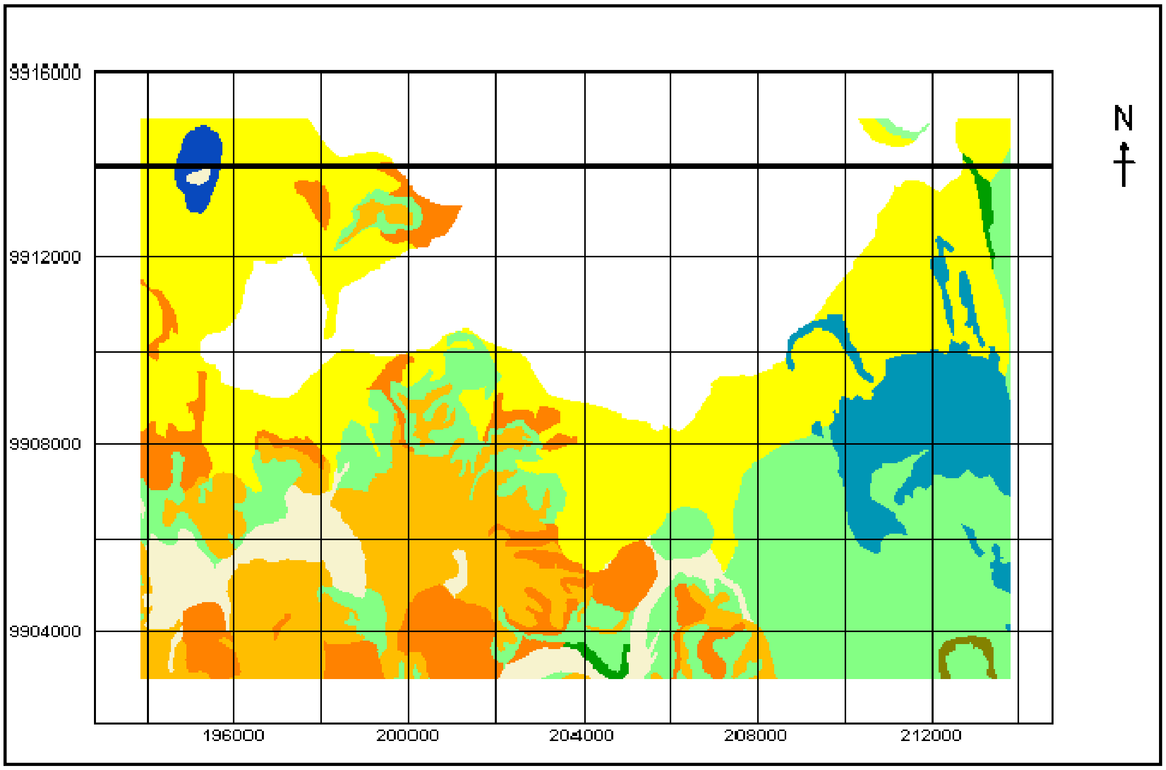
A large part of the natural vegetation has been cut and replaced by agriculture and pasture. The remaining vegetation has been partly disturbed by clearing except for some areas that are conserved as National parks.

The main vegetation types of the survey area are Papyrus mixed with grassland, Acacia trees and wooded grassland. The papyrus vegetation occurs in the riparian zone- wet lands, on map unit Pl611. Acacia trees mostly occur in the low lacustrine plain and some conserved forests -forming dense forest. The third type comprises scattered shrubs mixed with short grasses-occurs mostly in the volcanic plain. Livestock and wildlife mainly graze this type of vegetation.

3.9.3. Wildlife

In the Naivasha area a number of Game parks and Game reserves are located for example, Hells Gate National Park that is located to the south of Sulmac farm. In these parks, a large variety of animals can be seen such as buffaloes, warthogs, giraffe, hippos (near the shore), impala, and zebra.

Figure 3 Geological map of the study area (sub-mapped from Clarke (1990).



Legend

a	Alluvial Deposits
kbt	Surtseyan tuff cones
ls	Lacustrine sediments
n	Ndabibi comendite lava flows, domes and pyroclastic
lpa	Akira pumice
op	Olkaria comendite; pyroclastics
p	Pantellerite lava flows
or	Olkaria comendite, lava flows and domes
lpk	Kedong Valley tuff; Trachytic ignimbrites and associated fall deposits
lp8	
lpa+lp8	Akira pumice, Longonot Ash
lmx1	Lower Longonot mixed basalt/trachyte lava flows, and pyroclastic cones
lt3	
lpt	
lake naivasha	Upper Longonot trachyte; lava flows and pyroclastic cones

3.10. Commercial Farms

There are a number of big commercial farms around the lake including Sulmac, Oserian, Sher-Agency, Longonot Horticulture, Longonot, and Kijabe farms. These farms produce mainly flowers and horticultural crops.

Because of the availability of water, from the lake Naivasha, the crops are grown through out the year. They use different irrigation methods to irrigate their farms, mainly drip and sprinkler.

The land around the lake, the volcanic and lacustrine plain, appears to be well suited for irrigated agriculture mainly due to the topography and drainage. With better management practices like proper application of fertilisers, insecticides, and irrigation water better yields are obtained.

4. Materials and Methods

The whole study or research work was sub-divided in to three phases, namely: pre-fieldwork, field-work and post-fieldwork. Accordingly, the materials and methods will be discussed. A generalised schematic workflow is shown in appendix G.

4.1. Pre-Field Work

Proposal Writing: Proposal writing comprised literature review and collection of general site information.

Preparatory Phase: The task included literature search, collection of available site information/data such as soil, geology, and climate, etc, and listing of materials and equipment required for fieldwork. These are listed below:

- Topographic map of the area (1:50,000) Year 1975 (BKS Surveys Ltd., 1975)
- Exploratory soil map of Kenya (1:1M) year 1980 (Sombroek et al., 1980)
- Geological Map of the study area (1:50,000) Year 1988 (Ledgard, 1988)
- Aerial photographs at a scale of 1:50,000 year (1972), 1:12,500 (year, 1984) and, 1:10,000 (year, 1990)
- Satellite imagery (Landsat TM) May 2000 and January 1995.

The lists of photographs and photo index map (which was made in ILWIS) are shown in appendix D. Data used for the GPS instrument were co-ordinate system: UTM/UPS; Map datum: ARC 1960; off-set, +03:00 Hours; and country, Kenya.

Aerial photo interpretation: Before going out to the field, aerial photo interpretation, using the 1:12,500 photos) was made on the southern and south-east portion of the lake. The geo-pedological approach (Zinck, 1988/89) was used for a preliminary interpretation the photos.

Digital Topomap: Digital topomap was created for the purpose checking the accuracy of GPS observation points and orthophoto mosaic. At first, it was scanned with TIF format and later georeferenced. For georeferencing, Georeference tiepoints (affine transformation) and Co-ordinate system NAIV were used. Secondly, fifty-three metric co-ordinates were digitised onscreen. The final sigma (transformation accuracy) value obtained was 1.47 pixels with a pixel size of 3.83m. This means the accuracy of the georeferencing the topomap was 5.63 m.

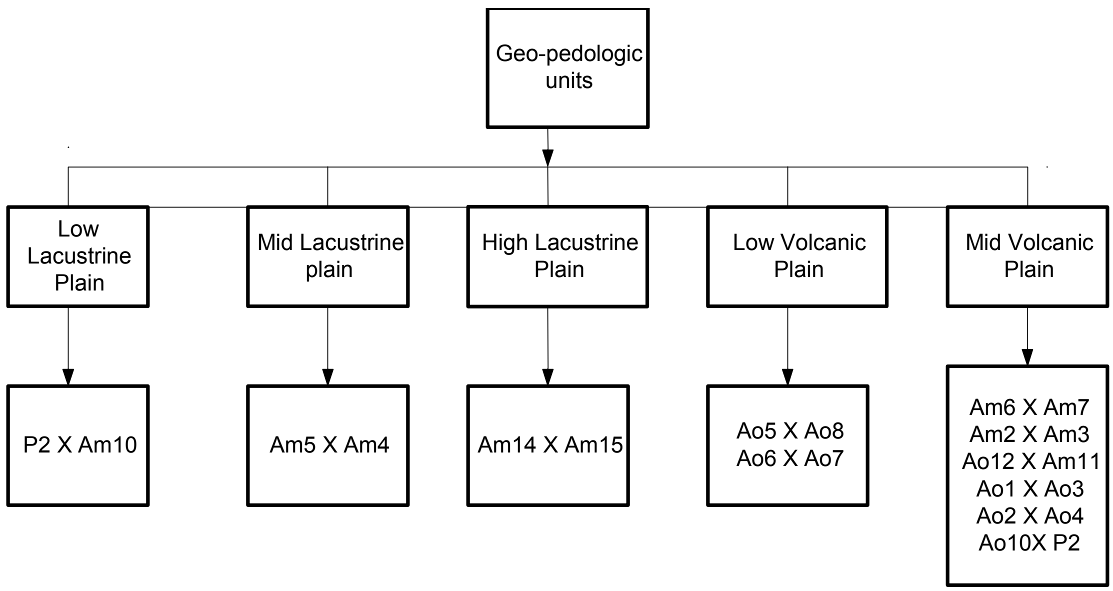
4.2. Field Work

Field observations consisted of opening of standard/reference soil pits, mini-pits and shovel holes. Two reference pits were dug, pit1 on the mid volcanic plain and pit2 on the low lacustrine plain for detailed soil description and laboratory analysis. In addition, 15 mini-pits (Am1-Am7, Am9-Am16) were dug for the purpose of soil mapping, phenoform determination and, topsoil classification purpose. Moreover, 12 shovel holes (Ao1-Ao12) were opened for the purpose of topsoil classification and phenoform determination.

Most of the survey was concentrated in three farms namely Sulmac, Oserian and Kijabe. The mapping focused on agriculturally important geo-pedologic units. That is on low, mid, and high Lacustrine and volcanic plain.

Phenoform survey: For the purpose of phenoform study, within a genoform, paired (twin) observations were made. These pairs are listed in Appendix F and in Figure 4. The paired comparison points were chosen based on site/field observation, one on a natural (unmanaged) and the other on a managed site. In addition they should be close enough –to minimise variability. Moreover, from the same genotype or same soil taxonomic units. As much as possible field observations were supported by field interviews.

Figure 4 The paired observation points



Shovel holes, labelled Ao, were dug for the purpose of topsoil classification. Without following the normal procedure of horizon description, soil samples from the depth of ~20cm were taken (with ±5cm). The shovelling was made to 30cm from the top. These sites were selected to be also useful for the phenoform classification. That is, one from managed and the other from natural (unmanaged) area.

For the purpose of soil mapping, Am1-Am16, pit1 and pit2 were considered. Because the shovel holes were taken only up to 30cms of depth, they are not considered for soil classification. Figure 6 shows geopedologic and observation point map of the study area.

The geo-pedologic units: The geo-pedologic map, which was produced during preparatory phase, was verified in the field. Some modifications were made after making field observation and checks. Specifically, some units like swale in between the volcanic and lacustrine plain, third unit coded Pl111, in between the mid and low volcanic plain in the Longonot part of Sulmac farm, and some swales observed around Kijabe farm, were omitted. The main reason was due to the quality of the 1:12,500 scale photographs. For example, the slope around sulmac farm, on 1:12,500 scaled photographs, appear steeper than they really are-vertical exaggeration. On the other hand, units like footslope in Sulmac's Naivasha part of the farm was added. Moreover, the area was extended further to the west side to include the research plot of the Oserian farm.

Auger holes in transect were made to determine boundaries especially between the volcanic and the lacustrine plain. Determining these boundaries was difficult due to the different processes occurring in the area. The unit boundaries mostly were gradual and not obvious. In appendix F the uncertain boundaries of the study area are. Broken lines represent the uncertain boundary whereas solid lines show more or less sharp boundaries. Hilland areas were not surveyed because of lack of time and less importance in terms of management for agriculture. In addition, they are mostly lava flows (rocks).

Some farms were difficult to access requiring permissions and personnel to follow up of what is being surveyed. Therefore, major surveys concentrated on farms, which were not difficult to access.

Site Description: At each sampling point, description of soils was done according to the 3rd edition (revised) FAO-ISRIC (1990) soil description guidelines for soil mapping. And, for topsoil characterisation, the proposed FAO (1998) Topsoil Characterisation book was used.

Infiltration: Infiltration was measured using a double-ring infiltrometer (outer ring: 53-cm in diameter by 25 cm high; inner ring: 28.5 cm in diameter by 25 cm high). It was pressed 10 cm in to the soil. The rate of fall of water was measured every 30 seconds for the first five minutes and every one-minute for the second five minutes. Starting after 10 minutes, measurements were taken every 5 minutes for about one to two hours depending on the steady state. Most of the observations reach steady state before 50 minutes.

The head of the outer ring water was maintained at an equal height as the inner ring to keep only vertical penetration of water. Keeping time constant, the head of the water was maintained to fluctuate within 2cm of height. The water level was normally ~7-9cm from the ground

All the infiltration observation points are near the observations points (pits, mini-pits, and shovel holes) in a distance range of less than 5 meters. After finishing the measurement, the depth at which the water has reached was observed by augering. The observation points are shown in Appendix F.

Bulk density: Undisturbed soil samples, using core sampler of volume 90 cm^3, were taken from the field. They were all analysed, in Sulmac laboratory, by the researcher. They were weighed before placing them in an oven that is adjusted at 105^oC, and re-weighed after drying them for about 72 hours.

Penetration Resistance: Penetration resistance assessment was conducted using C.B.R (California Bearing Ratio) value and a small standard hand penetrometer. Using the C.B.R instrument, readings on the dial were taken at depth interval of 7.5cm starting form the topsoil downwards. Six readings at different points near the test pit were taken to obtain good estimate of the probable mean value. With this instrument, it was possible to record only to a maximum C.B.R. value of 13. Beyond that it requires some force.

On the other hand, three hand penetrometer readings of each horizon were averaged to obtain reasonable compaction value. The maximum limit of this instrument is 4.5 kg/cm^2, soils that are more compacted beyond 4.5 kg/cm^2 could not be differentiated.

Soil pH and EC: Both soil pH and EC were at first measured in Sulmac using standard Sulmac lab procedures. Using 1:5 soil to water ratio (5gm of sieved soil and 25ml of distilled water). Distilled water was used rather than de-ionised water because of inavailability. Some samples were selected and measured in ISRIC laboratory for comparison.

GPS Points: A total of one hundred thirty five GPS points were acquired from the field. Almost all points contributed for the process of geo-referencing scanned aerial photographs. Thus, to make an Orthophoto mosaic which is corrected for tilt and relief displacement. Due to the presence of enough satellites in the area, the accuracy of the GPS points when compared with a scanned and later geo-referenced topo-map (1:50,000) were in the range of 3-8m (~6m average), which was considered good for the study. Replicated measurements at one spot showed insignificant differences at almost the same time. Only one point (P2) showed much error, which was reacquired on another day. The reason for this is due to lack of enough satellites during acquiring.

Interviews: Some interviews, for the purpose of phenoform evaluation, were made with farm managers. Focus was given to the paired comparison observation sites, aiming to know about the history of the farms. Data on the management units and practices was collected. The interview form is attached in appendix H.

4.3. Post Field Work

Creating an Orthophoto Mosaic: Aerial photo interpretation was made to produce geo-pedologic map of the area to map soils, phenoforms and topsoil of the area. Segment lines of photo interpretation units are not geometrically correct because of tilt, radial and relief distortions. In order to get a geometrically correct map and to overlay of different maps, combine information and function as a database in geographic information system (GIS), an Orthophoto mosaic was created.

In ILWIS it was possible to create photo mosaic (see Appendix D). The aerial photographs used to produce the mosaic are also shown in the appendix (typed in bold). A Digital Terrain Model (DTM) named NAIVDEM2 and a co-ordinate system (NAIV, a common geo-reference) which was produced by ITC-WRES department in 1999 was used to produce the Orthophoto mosaic.

Co-ordinate system NAIV has the following parameters (The same datum as on the topographic map)

- Minimum X, Y (166,000, 9,889,400),
- Maximum X, Y (221,750, 9,972,350)
- Projection: UTM zone 37, South of the equator
- Datum: Arc 1960
- Datum Area: Mean
- Ellipsoid: Clarke 1880

To check the accuracy of the Orthophoto creation, digital topo-map was required. Therefore, the topo-map (BKS Surveys Ltd., 1975) which was scanned and geo-referenced during the pre-field phase was used.

The photos were scanned (300 dpi) and imported to ILWIS. The result of the scanned aerial photograph is a raster file with rows and columns. Thus, each photo has to be geo-referenced by creating new geo-reference, using geo-reference Orthophoto, and the available DTM.

In the geo-reference editor, principal distance (152mm), 4 centre fiducial marks
(-116,0) left, (0, -116) bottom, (116,0) right, and (0,116) top for the 10,000 scale photos and; (-106,106) upper left, (-106, -106) lower left, (106, -106) lower right, and (106,106) upper right, for the 12,500 scale photos were entered. Because corner fiducial marks were not visible on the 10,000 scale photos, the centre fiducial marks were used. After this, the metric co-ordinates were transferred/digitised, from the scanned topographic map and GPS points that were collected form field. The result was a geo-referenced photo. The transformation accuracy of each photograph is shown in Appendix D.

After geo-referencing, the photos were re-sampled to a pixel size of 5m to increase speed of work. Some of them were sub-mapped to screen out unwanted borders. Beginning from one photo at the north east corner near the Crescent Island, glueing of the photos was made. Finally, the photo mosaic was sub-mapped to obtain clean boundaries.

A segment map of roads and known features was created from the photomosaic to compare it with the geo-referenced topo-map and satellite image. Distortion/displacement along the road, near Kijabe, Oserian, and Sulmac farms were minimum (<10 m). Hilly areas between the junction of Sulmac and Oserian farms were displaced in the range of 10-20 m. The main reason for this is due to lack of sufficient GPS points collected from the field in these photos.

A segment map of API lines were digitised on screen, visually following interpreted lines from the stereo photo interpretation, setting the Orthophoto mosaic as a background map.

Geo-pedologic map preparation: After the fieldwork, another examination of all photographs was made to change the originally interpreted boundaries where necessary according to the acquired field knowledge. The modified API units were transferred to GIS software (ILWIS 2.23) after Orthophoto making by onscreen digitising on top of the displayed photomosaic. Due to lack of complete coverage of aerial photographs of the same year, combination between the 1984 (1:12,500) and 1990 (1:10,100) was made to produce the API units of the study area. It is possible in GIS to merge the two products.

Data Base Development: The soil database (relational) was developed in Microsoft Access software for ease of entering, retrieving and manipulation of the research data. Initially the data was entered in Microsoft Excel software to make calculations and graphics easy. But, later on they were transferred to MS-Access. The MS-Access structure and relationship of the tables is shown in Figure 5

Land cover map: Land cover map of Sulmac farm, the Longonot branch, was made by digitising the plot boundaries on the aerial photo-mosaic. The land cover units exactly follow the plot/block boundaries of the farm like vegetable plot, greenhouses (planted with Hypericum flowers) and uncultivated area. The units or the plot numbers were recorded from the field.

Topsoil mapping: Topsoil mapping was performed by applying the concept of geo-statistics and the proposed topsoil mapping (FAO, 1998). The main purpose of doing it is to see if there is a trend in the selected properties between the managed and unmanaged plots giving little focus to the soil types differences. Secondary data, which was collected from Sulmac soil lab for soil pH and EC, was used in the mapping (continuous) of the Longonot site, Sulmac. The original and interpolated values are shown in Appendix I.

The soil EC data were not initially normally distributed. Therefore, transformation was necessary. Transformation using indicator kriging. Three cut-off limits the first quartile (454), the second quartile (592), and third quartile (736) values were set. Using the quartile cut-offs three semi-variogram models were generated and the data was interpolated. The interpolated output values are probability values. Therefore, they were transformed to real values in MS-excel. By the following formulae

$g = \sum\{(\text{probability of falling in a class})*\text{mean of the class}\}$

The converted data was mapped in ILWIS for a better visualisation. Moreover, managed vs unmanaged plots were statistically analysed using the original EC values.

The pH data were normally distributed and therefore transformation was not necessary. Ordinary kriging was used for this purpose.

In addition, using the proposed FAO topsoil characterisation method the topsoil of the area was characterised.

Soil Sample Preparation: Coarse fragments of size greater than 2 mm were weighed and sieved out in ITC lab- to prepare them for laboratory analysis in ISRIC. The type and number of samples that were analysed in ISRIC lab are shown in appendix B.

Software: In addition to MS-Access, MS-Excel, and MS-Word softwares; Endnote-4, Minitab-12, and Flow4 were used. Endnote was used for proper and consistent bibliography and citation making. "NumberedAllAuthors" style, with some modification on the citation and bibliography template, was used. Minitab and flow4 for statistical analysis and flow chart making respectively were used.

Statistical analysis: Statistical analyses were performed on all the available soil properties using Minitab software. Samples were grouped according to depth management (managed vs unmanaged) and geopedologic landscape units. The descriptive statistics data is shown for every property analysed.

Before proceeding with the statistical test, the data was checked for normality. When they are normal and the sample size is relatively higher (>10 pairs), standard t-test was followed. But, when the sample size was relatively higher and the data is not normally distributed, log transformation was used. And when the sample size is lower and is not normally distributed the data was analysed using Mann-Whitney test. The idea of paired t-test is to see if the mean soil properties between the high-tech managed sites and the unmanaged sites are different. With the hypothesis:

$H1 = \mu_1 \neq \mu_2$
$Ho = \mu_1 = \mu_2$
$\alpha = 5\%$

Analysis of variance was used to test whether a classification is justified, by comparing the variance within classes to the variance between classes. One way of analysis of variance was performed with the fundamental assumption about the nature of the parent population that each parent population is normally distributed.

Ho: $\mu = \mu_2 = \mu_3 = \mu_4$
H1: at least one mean is different
$\alpha = 5\%$
The question to be answered here is

Is there significant difference in soil properties between the two geopedologic units (lacustrine and the volcanic plain)?

Figure 5 Data relationships in MS-Access (all enforced for referential integrity)

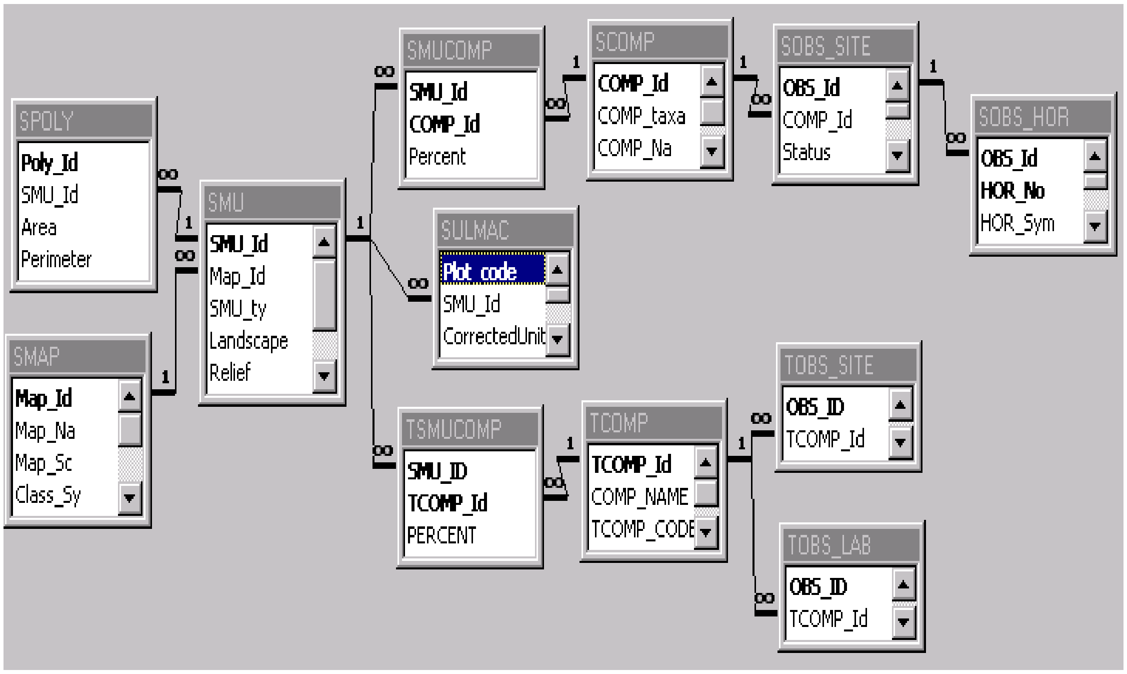


Table 3 Lists of the tables in MS-Access

Table Name	Purpose	Key (lookup table)
DELINEATION	Information about a single Geo-pedologic polygon	--
SMU	Soil mapping unit table.	--
SMUCOMP	Linking table between SMU and Soil Type	--
SCOMP	List of type of soils	--
SOBS_SITE	List of site information	Lut_Site, lut_KST1, lut_KST2, Lut_FAO
SOBS_HOR	List of field and laboratory observation results at a horizon level	Lut_HOR, lut_color
SULMAC	Sulmac Data (Previously made)	--
TSMUCOMP	Linking table between SMU and topsoil type	--
TCOMP	List of topsoil types	--
TOBS_SITE	Site (Field) information on the topsoil observation point	K_topcla
TOBS_LAB	Laboratory data on the topsoil	--

5. Results and Discussion

5.1. Geopedologic Map of the Study Area

There are three major landscape units in the area. Namely, the lacustrine plain, the volcanic plain, and hilland.

The lacustrine plain occurs around the lake and ranges between an altitude of approximately 1880-1910 m.a.s.l. Several auger holes were made to determine the boundary between the volcanic and the lacustrine plain. But, it was difficult to put a clear Geopedologic boundary in between. Such kinds of units according to Lagacherie (1996) are classified as highly fuzzy and highly uncertain boundaries. By looking at the surface, one can not put the boundaries possibly in the range of 50-200m's.

The lake level changes and the different episodes of the volcanic ash eruptions complicated the boundary between the two landscape units. For example, the maximum height the lake has reached was 1940 m.a.s.l. (Clarke et al., 1990). This reworked the volcanic materials found under it. After some years, the lake level has lowered and it was followed by another Longonot volcanic eruptions. The eruption covered the lacustrine reworked and/or deposited materials.

Though the lacustrine plain doesn't have sharp boundaries with the volcanic plain, its surface features and topography to some degree can identify it. Generally, it has strait, flat, gently sloping topography and less sandy in texture.

This landscape unit has three major relief types namely high, mid and low lacustrine plain. They are modified terraces or relief types of high water lines. That is to say, the riser and tread units cannot be separated. The tread tapers out to the lower lacustrine landform unit. It is probably smoothened by the wave and lake water level fluctuations. In fact, on few places, the tread and riser could be separated. Similar to the boundary between the volcanic and lacustrine plain, the relief units don't have sharp boundaries between them. But, they could be separated by gray tone, vegetation and texture (see Table 4)

By the same token, **the volcanic plain** has also three different relief or moulding types the low, mid and high volcanic plain. It is underlain by layers of different episodes of volcanic materials erupted from Longonot and Olkaria complex, the most recent 2000 years ago (Thompson and Dodson, 1963). This unit, for example around Longonot branch (Sulmac farm), shows hummocky surfaces that are sand than the lacustrine plain. They are most probably transported and shaped by wind, sand dunes. Moreover, on some places fresh lava flows are evident on the surface. The different units of this volcanic plain are described in Table 5

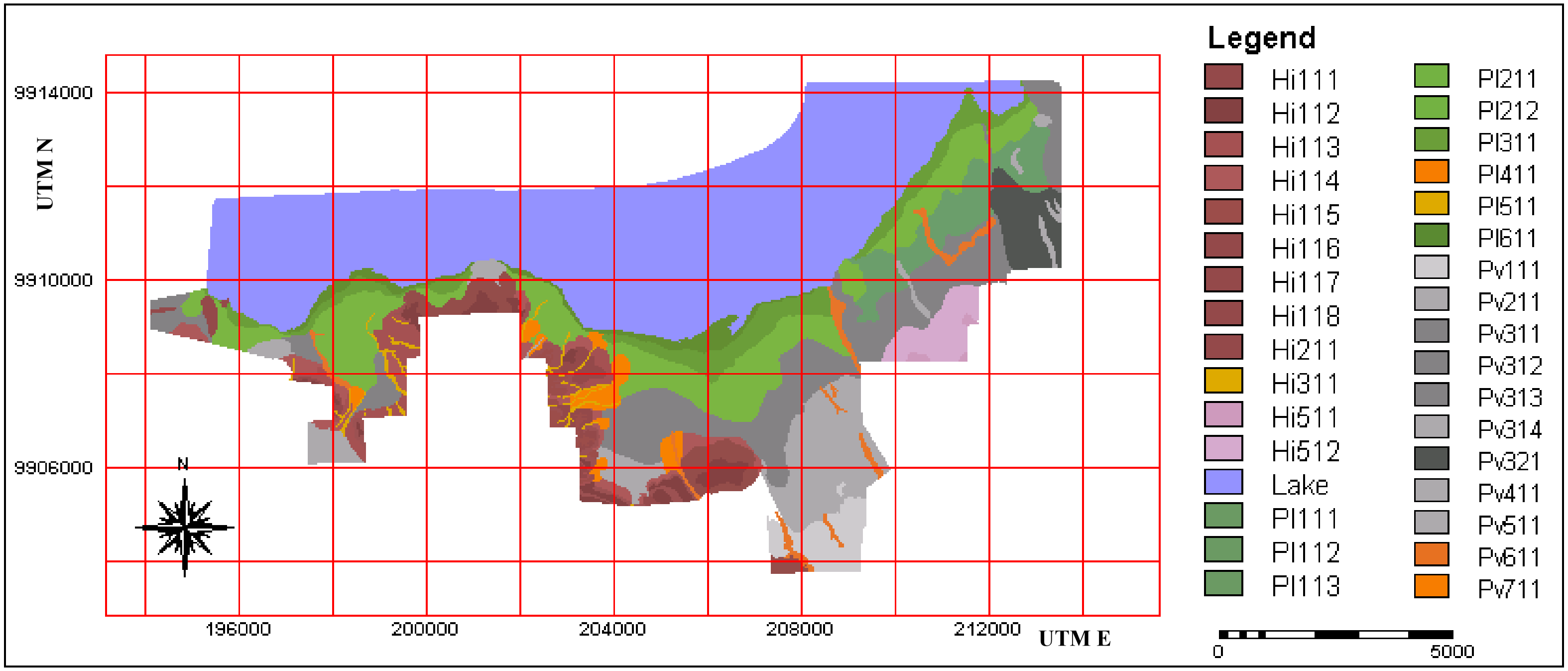
Table 4 Description of the lacustrine relief/molding units

	Riparian	Low lacustrine plain	Mid lacustrine plain	High lacustrine plain
Topography	-Almost flat	-Almost flat to gently undulating	-Almost flat to gently undulating	-Gently undulating
Slope:				
▪ Gradient/grade	-0-2%	-1-3%	-1-4%	-2-5%
▪ Shape/type	-Straight	-Straight	-Straight	-Straight
▪ Size/length	-60-100m average	-200-300m average	-600-700 average	-400-500 average
▪ Regularity	-Regular	-Regular	-Regular	-Regular
▪ Site	-The most close to the lake	-Next to the riparian	-Close to the volcanic plain	-Close to the volcanic plain
Erosion				
▪ Type	-Water	-Water	-Water and wind	-Wind
▪ Degree	-Moderate	-Slight	-Slight	-Slight
Drainage	-Somewhat poorly drained	-Moderately well drained	-Moderately well drained	-Moderately well drained to well drained
Aerial photo:				
▪ Gray tone	-Darker	-Lighter in tone	-Grayish/Whitish tone	-Grayish/Whitish tone
▪ Texture	-Coarser due to vegetation	-Relatively fine	-Medium between fine and coarse	-Medium between fine and coarse
▪ Mottling	-Little/no mottling	-White/Gray mottles	-Very few whitish mottles	-White/Gray mottles
▪ Natural vegetation	-Papyrus	-Few Acacia trees and grasses	-Relative to the other units Acacia trees are dominant	-Very few, scattered undifferentiated tree species
Remark	-This is the youngest in terms of development, therefore, the soils that are developed on these unit are also younger than the others -Darkness in tone is due to moisture and vegetation	-In terms of development this is the second youngest. -Most agricultural activities concentrate on this. There are some natural vegetation (trees)	-Similar to the volcanic plain -Most housings and road constructions concentrate on this unit	-More diatomite -Higher in elevation -Located near Kijabe farm

Table 5 Description of the volcanic plain relief/molding units

	Low volcanic plain	Mid volcanic plain	High volcanic plain
Topography	-Gently undulating	-Gently undulating	-Gently undulating to undulating
Slope:			
▪ Gradient/grade	-2-5%	-2-5%	-3-7%
▪ Shape/type	-Straight	-Straight & irregular	-Straight & Irregular
▪ Size/length	-700-1000m average	-1300-1500m average	-1500-2000m average
▪ Regularity	-Regular	-Somewhat irregular	-Irregular
▪ Site	-Close to the lacustrine plain	-In between low and high volcanic plain	-Higher in elevation
Erosion			
▪ Type	-Wind erosion & deposition	-Wind erosion and deposition	-Wind erosion and deposition
▪ Degree	-Moderate	-Moderate to severe	-Moderate to severe
Drainage	-Moderately well drained	-Well drained to somewhat excessively drained	-Well drained to somewhat excessively drained
Aerial photo:			
▪ Gray tone	-Dark gray	-Moderate gray toned	-Relatively lighter in gray tone
▪ Texture	-Relatively Fine textured	-Generally Fine textured	-Fine textured
▪ Mottling	-Relatively no mottling	-White mottling on some spots	-White mottling on some spots
▪ Natural vegetation	-No vegetation	-small, very few bushes on the upper parts	-Little, few bushes
Remark	-This unit was under the lake influence. Later it was covered again by new volcanic ashes or deposits	-Small Part of this unit was under the effect of the lake -The irregular topography of this unit is due to the sand dunes-formed by erosion. The dunes are somewhat stable -The white spots are indicatives of wind erosion	-No past lake influence on this unit -On some areas the texture is coarser due to the bushes -There are white spots, indicatives of wind erosion.

Figure 6 Geopedologic map (South and south east of lake Naivasha)



NB: For the legend full description see Table 6

Table 6 Geopedologic map legend

Landscape	Relief	Lithology	Land form	
Hilland (Hi)	High Hills	Olkaria Comendite; lavaflows and in some parts covered with Longonot Ash	Hi111	Slope facet complex
			Hi112	Summit/shoulder complex
			Hi113	Backslope/footslope complex
			Hi114	Foot slope
			Hi115	Scarp
			Hi116	Talus
			Hi117	Dissected Summit
			Hi118	Backslope
	Low Hills	<<Same>>	Hi211	Slope facet complex
	Vale	Alluvium	Hi311	Bottom side complex
	Obsidian Ridge	Lower Longonot (mixed basalt/ trachyte lava flows)	Hi511	Summit
			Hi512	Riser
Volcanic plain (Pv)	High Volcanic Plain	Longonot ash and Akira Pumice	Pv111	Tread/riser complex
	Mid Volcanic Plain		Pv211	Tread/riser complex
	Low Volcanic Plain	Volcanic Ash & Akira pumice	Pv311	Tread/riser complex
			Pv312	Tread
			Pv313	Riser
			Pv314	Talus
		Lava flow	Pv321	Tread/riser complex
	Ridge	Longonot mixed basalt/ Trachyte lava flows	Pv411	Slope facet complex
	Vale	Alluvium	Pv511	Bottom side complex
	Swale	Alluvium	Pv611	Bottom side complex
	Fan	Alluvium	Pv711	Distal/proximal complex
Lacustrine Plain (Pl)	High Lacustrine Plain	Lacustrine sediments and re-worked volcanic materials	Pl111	Tread/riser complex
			Pl112	Tread
			Pl113	Riser
	Mid Lacustrine Plain		Pl211	Tread/riser complex
			Pl212	Tread
	Low Lacustrine Plain		Pl311	Tread/riser complex
	Fan	Alluvium/colluvium	Pl411	Distal/proximal complex
	Swale	Alluvium/colluvium	Pl511	Bottom side complex
	Riparian	Lacustrine sediments	Pl611	Undifferentiated

5.2. Topsoil Mapping

5.2.1. Geostatistical Method

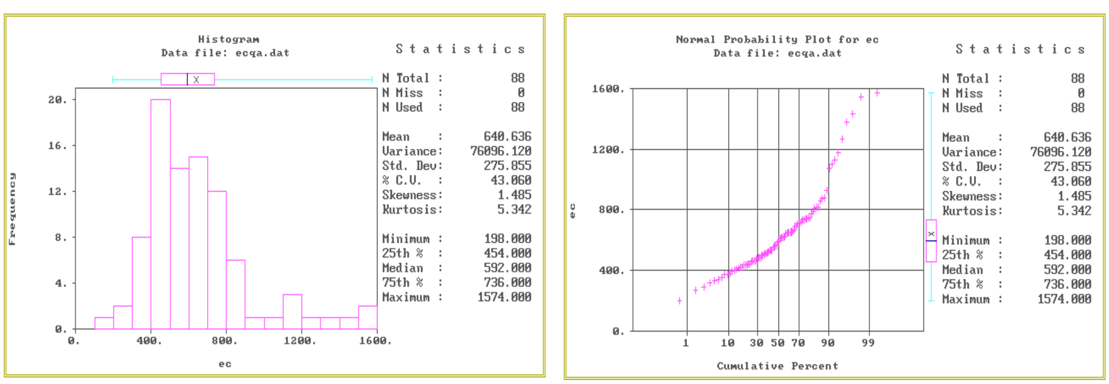
5.2.1.1. Electric Conductivity (EC)

Geo-statistical analysis was applied to determine the nature of spatial variability of the EC (μS/cm) value of the Longonot branch, Sulmac farm. The total number of samples used for this analysis is 92. All the data was measured and analysed by the Sulmac soil lab during the month of August 2000. They were taken form the first 5-20cm depth by bulking from a plot size of 100m x 300m. In ILWIS, a point map was created by taking the centers of the farm plots. For this purpose the photo mosaic (see appendix D) was used as a background.

The distribution of variable EC is not normal even after removing few outliers considering class width of 100 units. The mean (640.6 μS/cm) is not the same as the median (592 μS/cm). In addition, the probability plot is not straight confirming that it is not normal, there are *outliers also* especially in the upper tail. Therefore, transformation, using non-parametric geo-statistics (indicator kriging), is necessary. Because, it is known that to conduct ordinary kriging the data should be normally distributed.

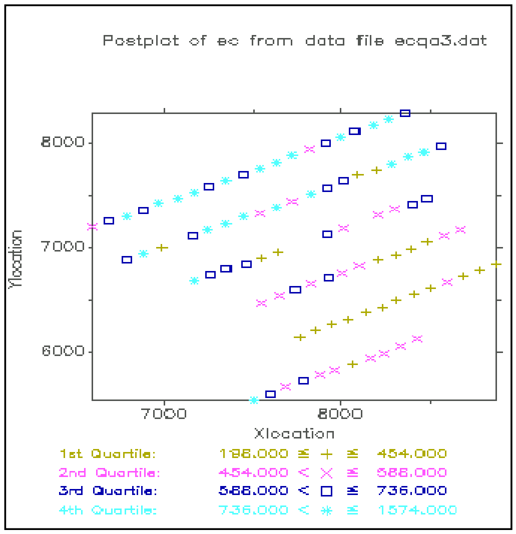
After removing extreme outliers the data was analysed. From Figure 8 just by looking at the quartile values one can conclude that those areas which are under management have higher EC than the non managed plots, it can be compared with Figure 10. The second step made was to see anisotropic condition. From the variogram surface we can see that there is an anisotropic condition at 15^{o} clockwise from the y-axis. This anisotropic condition was visible at limiting distance of 300 m (see Figure 11). The grid distance between the blocks and the plots was not equal and the number of sample (88) is few to detect pure anisotrophy. Therefore, for this purpose the anisotropic condition was not considered.

Figure 7 Histogram and probability distribution for EC



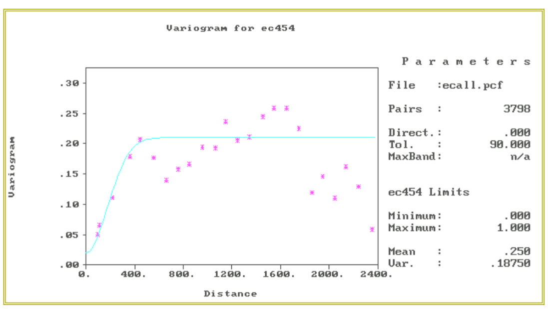
Three cut-off limits, using the quartile range values, were determined and the data was transformed. These are 454 μS/cm (first), 592 μS/cm (second) and 736 μS/cm (third) quartile range. The data was prepared using Prevar command and 3828 number of pairs were generated later to be fitted with an appropriate semivariogram model. Figure 9 shows the fitted semivariogram curves for the different cut-off limits.

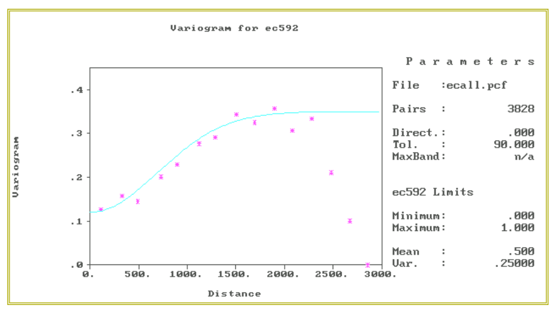
Figure 8 Location of the samples points using post plot (in Geoeas)

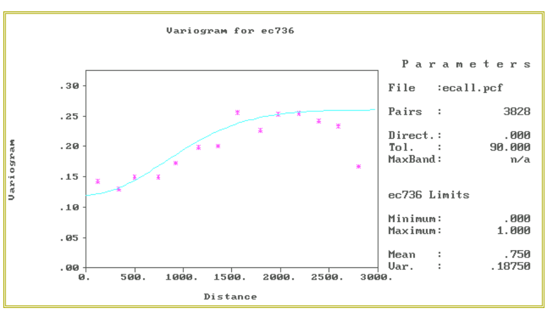


NB: For ease of manipulating the metric co-ordinates, in Geoeas, they were shortened to four digits; x-axis should be read as, for example, 207000 m and Y-axis as 9906000 m.

Figure 9 EC Variogram models for cut-off limits of 454, 592, and 736.



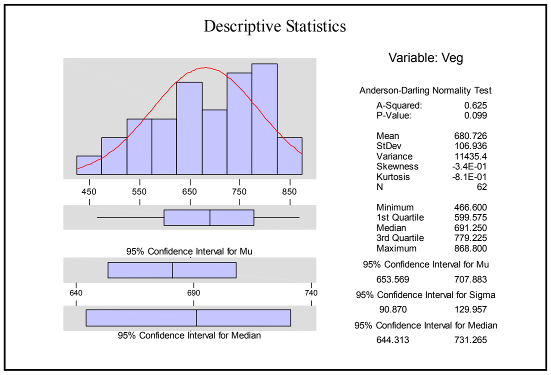


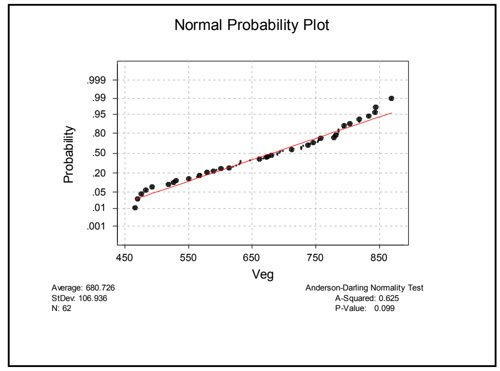


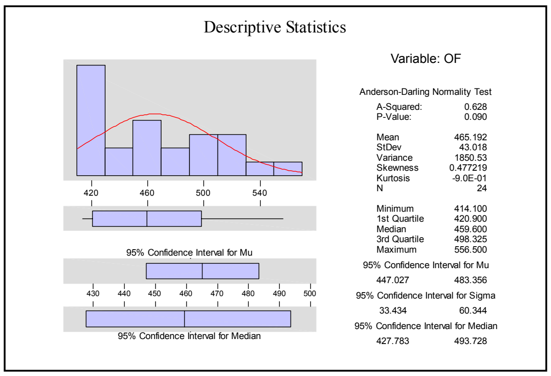
Cut-off	Model	Nugget	Sill	Range
454	Spherical	0.02	0.19	430
592	Gaussian	0.12	0.23	1700
736	Gaussian	0.12	0.14	2000

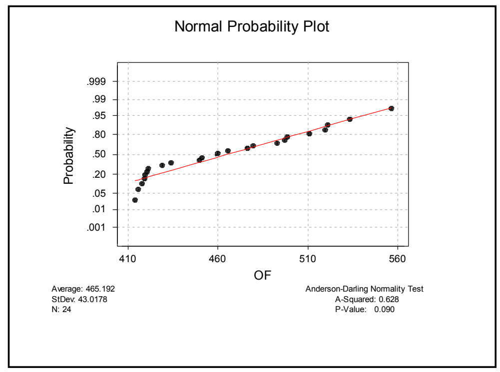
The variogram models show that there is long range dependence at high EC values.

Descriptive statistics and normal probability plot of EC values









The result of the two sample t-test for EC shows that there is highly significant difference between the vegetable plots and the open filed plots at a confidence interval of 95 % (p = o). This can also be seen from the box plot.

	N	Mean	StDev	SE Mean	p-value
OF	24	465.2	43.0	8.8	0.0
Veg	62	681	107	14	

Where OF: open field and
Veg: vegetable field

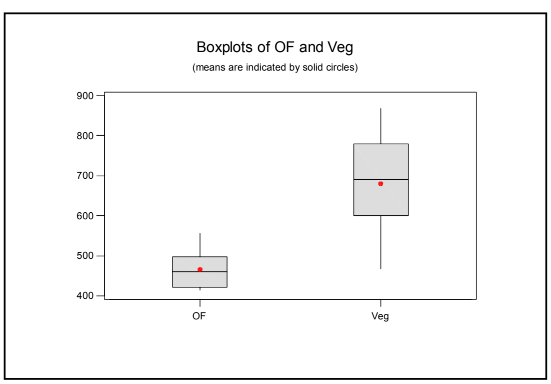
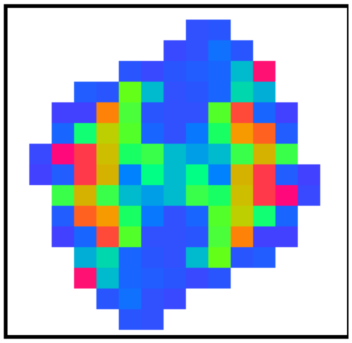


Figure 10 Topsoil map using Indicator Kriging

Figure 11 Variogram surface



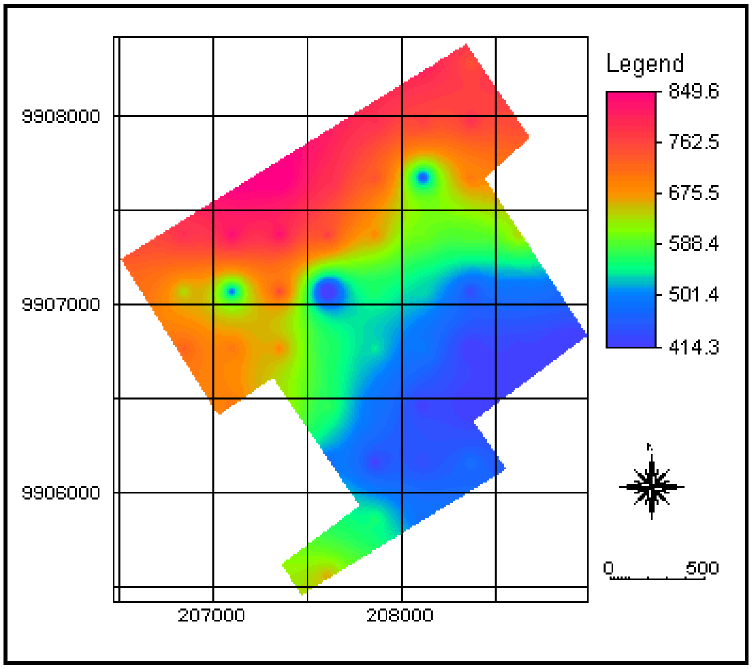
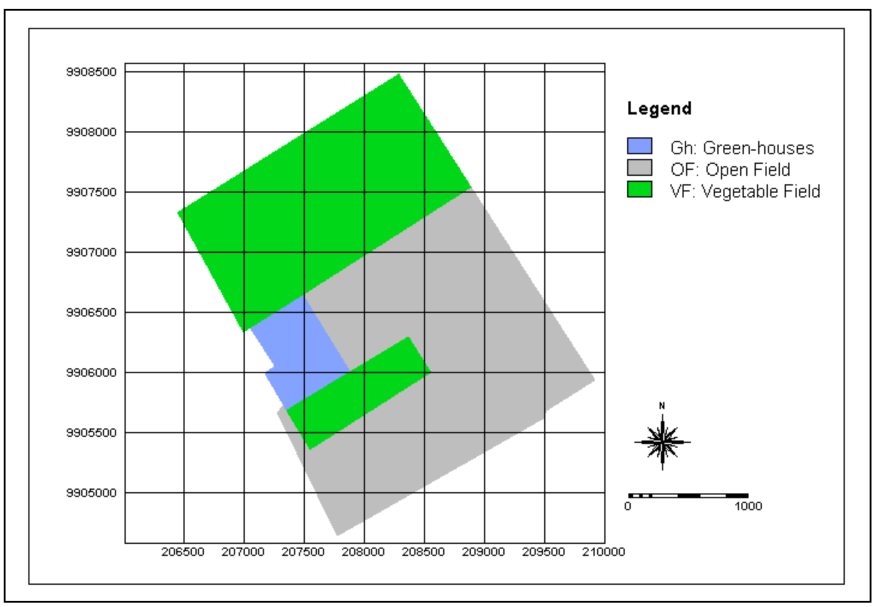


Figure 12 The land cover map of Sulmac farm (Longonot site)



5.2.1.2. Soil pH

Similar to the soil EC, soil pH map of Sulmac farm, Longonot area was produced using geo-statistical methods. But, in this case the data is normally distributed at 95 % confidence interval. The mean (7.65) and median (7.7) values are more or less similar with few outliers. Since the data is normally distributed, transformation is not necessary. From the variogram surface model one can see that there is no Anisotropy.

Figure 13 Descriptive statistics and normal probability plot for soil pH

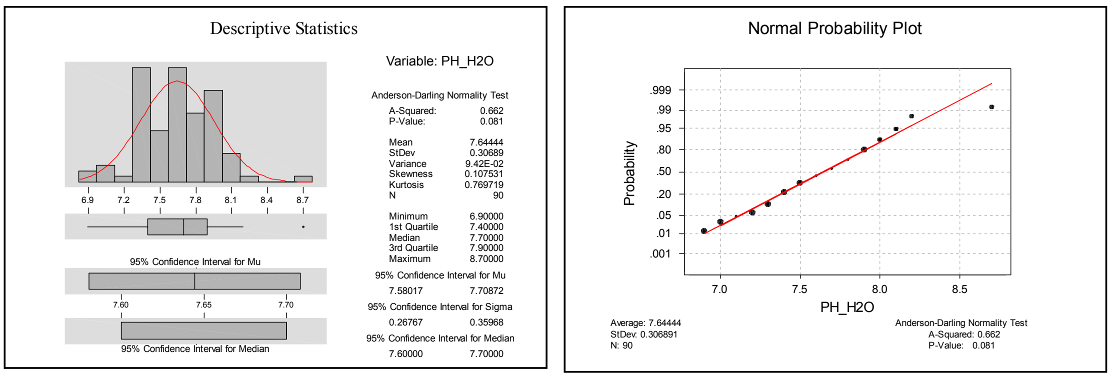


Figure 14 Post plot of soil pH quartile value

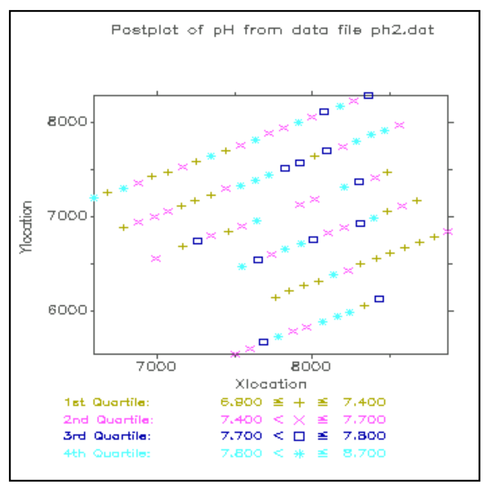
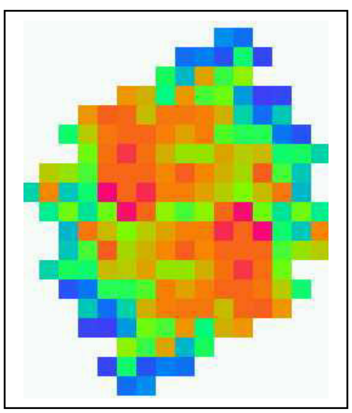
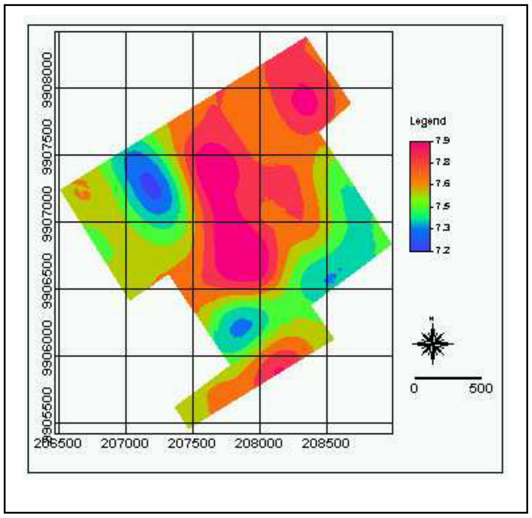


Figure 15 Variogram surface for soil pH

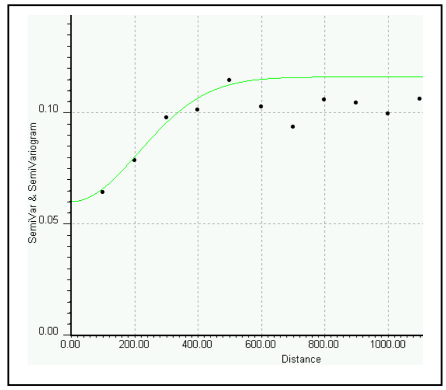


Kriging method (in ILWIS) was used to interpolate the values at the unvisited points. Similar to the soil EC map, it can be concluded that managed plots have relatively higher soil pH than the unmanaged ones Figure 16 but statistically they are not significant. The blue colour represents low values and red represents high pH values.

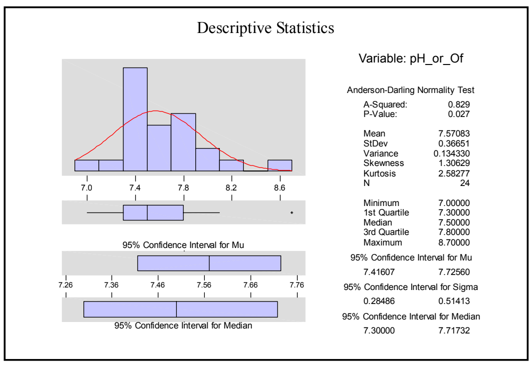
Figure 16 Soil pH map of Sulmac farm, the Longonot area

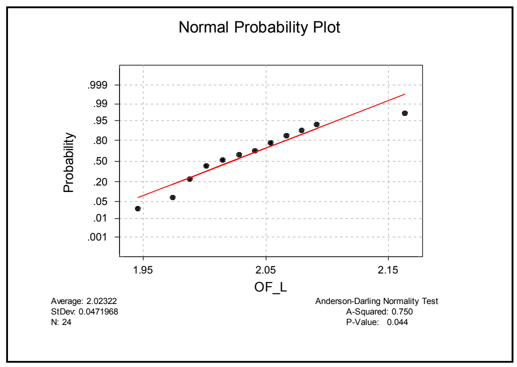


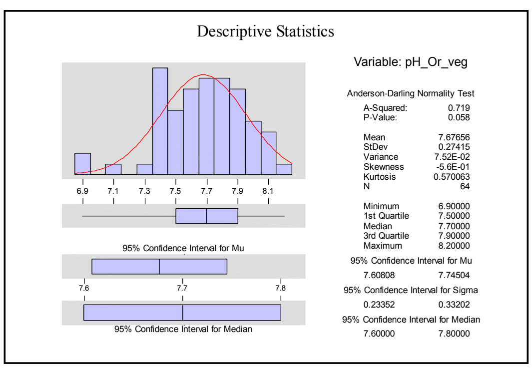
	Model	Nugget	Sill	Range
pH	Gaussian	0.06	0.116	300

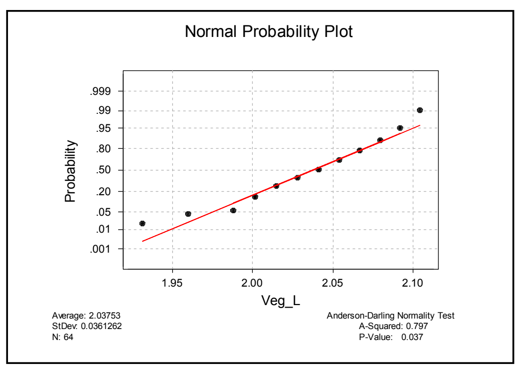


Descriptive statistics of the pH data values vs management units







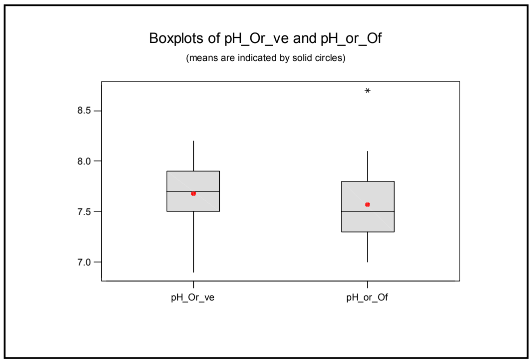


Two sample T for vegetable plots vs open field

	N	Mean	StDev	SE Mean	p-value
pH_Or_ve	64	7.677	0.274	0.034	0.21
pH_or_Of	24	7.571	0.367	0.075	

The t-test results of the analysis of pH shows that there is no significant difference (p = 0.21) between open field and vegetable plots at a confidence level of 95 %. This result agrees with the result of the paired comparison points.

Figure 17 Boxplot of pH for vegetable vs open field plots



5.2.2. Proposed FAO Method

As described in the methodology part, the proposed FAO topsoil characterisation system was followed to classify the topsoils of the study area. It is generally known that topsoils are very variable in space and time. Topsoil is the part of the soil profile which is in direct contact with external factors like with climate (rainfall, sunshine, wind, temperature, etc.) and human activities mainly cultivation. It is also part of the soil which is the most important in terms of agricultural use.

The study area is mainly dominated by flower and vegetable cultivation. Flowers include roses, carnations, hypericum, and statice, and vegetables include cabbage, and beans. These crops are shallow rooted, their roots are concentrated in the upper most 50 cm of the soil. Because of this, most agricultural activities like ploughing, cultivation, application of chemicals and fertilisers are concentrated on the topsoil. In addition, because of its importance most chemical and physical laboratory analysis is made on the topsoil. For example, for soil laboratory analysis, mostly samples are taken form the first 5-20 cm’s depth. This indicates that understanding and classifying the topsoils of the study area gives users meaningful results for use.

In terms of topsoil characterisation, the newly proposed system has several options to give topsoils meaningful interpretation for use, which is mostly not detected by general-purpose classification systems. For example, USDA (1998) has 8 surface diagnostic horizons namely, mollic, umbric, plaggen, anthropic, melanic, histic, ochric and folistic epipedos. And, WRB (1998) has mollic, umbric, chernic, antraquic, irragric, hortic, plaggic, terric, melanic, fulvic, histic, folic and ochric surface diagnostic horizons. By contrast, the proposed topsoil characterisation has a very large number of possible combinations specific to the topsoil.

To mention some, the proposed system characterises or recognises the following properties, which are important in the study area

1. *Low nutrient retention properties:* From the interviews made, most of the unmanaged volcanic plain soils have low nutrient retention properties. They have to be fertilised almost every day to obtain reasonable yields. This is mainly because of their sandy nature

and having low cation exchange capacity. This property of the soils was detected by the proposed topsoil classification system.

2. *Natric properties:* According to USDA (1998), for a soil to be classified as having natric epipedon, it should fulfil the requirements of the (USDA) argillic horizon. The WRB (1998) needs similar requirements but with more detailed description than the USDA system. But, this natric property of the soils, as classified by the new FAO topsoil characterisation, is a useful soil property especially in the low lacustrine plain, even in the absence of argillic horizons at depth.

3. *Altaric properties:* This consists of mixture of former surface and subsurface soil materials caused by, for example, deep ploughing, subsoiling and intensive fertilisation. This effect is not very pronounced when it comes to classify according to USDA and WRB systems. Also it should meet more or less the requirements of mollic epipedon/horizon to be described as anthropic epipedon or hortic horizon in USDA system and WRB respectively.

4. *Gravel:* gravel percentages are classified as 1, 2 and 3 having ranges of 15-35, 35-80 and > 80. This characterisation is relatively better when compared to the general-purpose surveys. For example, a soil is considered skeletic when it has 40-90 % gravel in WRB. Lower than 40% are neglected.

Some important soil properties, which were not detected by the proposed topsoil characterisation system in the area and that are important for management, are listed as below

1. *Problems of nematodes*: nematode infestation is one of the production-limiting factors in the area. Because of this, some chemicals/fumigants are applied to the soil to destroy and or reduce the infestation. Also leading to higher levels of chemicals

2. *Toxicity:* some toxicity including copper is also reported to be a production-limiting factor. The system accounts for toxicities due to Aluminium, but not for Cu^{++} and other micronutrients.

3. *Nutrient imbalances* due to the potic nature, i.e. excess of K inhibiting uptake of other cations. The 'k' modifier is provided for low K reserves, but there is no provision for excessive K. The 'd6' modifer for chemically-degraded soils could conceivable apply, although the definition is not very close; also the soils in the study are not degraded as such but seem to have naturally excessive K, inherited from the parent ash.

4. *Physical features*: The soils of the volcanic plain, in general, when ploughed they change to powdery masses. During or after irrigation they develop thin surface crusts (capping) that causes problem of infiltration and soil aeration. From the interviews made the surface crusts should be broken once a week to promote good aeration and infiltration. This does not seem to be included in the FAO's concept of 'sealing' (code r1) topsoils, which is based on fairly large quantities of silt in the topsoil.

5. *Drainage*: there are some excessively drained soils in the area, which have a high infiltration rate. These soils are also needing separate management practices and therefore to be considered in the classification. In part this is implied by the S (Sandy) type, but this is beyond the central concept of 'Sandy'. The system includes 'drainage features' but only relating to imperfect drainage. These soils behave somewhat like 'gravelly'soils but can not be included there, since the actual amount of gravel never exceeds 10%.

6. *Water repellancy:* this property is also recognised in the Areni-Vitric Andosols which is important leading to difficulties in beginning an irrigation treatment.

Management requirements

Sandy topsoil: most of the soils of the study area are dominated by sandy topsoil. The sandy topsoil properties of the soils have an effect on the water holding capacity and nutrient retention capacity of the soils. Taking in to account the climatic conditions of the area (higher ETo) and the texture of the topsoil, proper irrigation scheduling is required.

Natric property: this property of the soils is an indicative of high sodium levels which requires special management practices including use of gypsum amendments and drainage practices. Common mineral amendments which could be used are: gypsum, phosphogypsum, calcite and other acid-forming salts like iron and aluminium sulphates, lime-sulphur and pyrites.

Low nutrient retention property: some of the soils of the study area are very sandy having low nutrient retention property. These soils need appropriate fertilisation and irrigation scheduling. Nutrients should preferably be provided in split. Furthermore, leaching may cause big nutrient losses.

Wind-eroded property: wind erosion is prevalent in the volcanic plain. It is more severe in the high and mid volcanic plain. Therefore, windbreaks are preferably planted at the farm boundaries to reduce its impact. It will also have physical impact on the crops.

Table 7 Topsoil classification of the observation points

Obs_Id	P1	P2	Am1	Am2	Am3
Texture	Sandy topsoils (S)	Loamy (L)	Sandy topsoil (S)	Sandy topsoil (S)	Sandy topsoil (S)
Organic material	-----				
Org. mater status		melanic (m2)			
Physical features					
Chemical features	-Low nutrient retention (e)	natric (n)	low nutrient retention (e)	Low nutrient retention (e)	Low nutrient retention (e)
Biological features					
Drainage					
Landuse					
Erosion or degradation			wind eroded (d5)	Wind eroded (d5)	Wind eroded (d5)
External physical condition			arid properties (t2)	Arid properties (t2)	Arid properties (t2)
Slope class	Level to gently undulating (a)	Level to gently undulating (a)	Level to gently undulating (a)	Level to gently undulating (a)	Level to gently undulating (a)
Soil classification	Areni-Vitric Andosol (Eutric)	Sodi-Fluvic Cambisol (Skeletic, Eutric)	Tephric Arenosol	Areni-Vitric Andosol (Eutric)	Areni-Vitric Andosol (Eutric)
Topsoil code	**S e**	**L n m2**	**S e d5 t2**	**S e d5 t2**	**S e d5 t2**

P1 **Areni-Vitric Andosol (Eutric)** with Sandy, low nutrient retaining topsoil **S e**
P2 **Sodi-Fluvic Cambisol (Skeletic, Eutric)** with Loamy, natric, melanic topsoil **L n m2**
Am1 **Tephric Arenosol** with Sandy, low nutrient retention property, wind eroded, arid topsoil **S e d5 t2**
Am2 **Areni-Vitric Andosol (Eutric)** with Sandy, low nutrient retention, wind eroded, arid topsoil **S e d5 t2**
Am3 **Areni-Vitric Andosol (Eutric)** with Sandy, low nutrient retention, wind eroded, arid topsoil **S e d5 t2**

Table continued

Obs_Id	Am4	Am5	Am6	Am7	Am9
Texture	Sandy (S)	Loamy top soil (L)	Sandy topsoil (S)	Sandy topsoil (S)	Sandy topsoil (S)
Organic material					
Org. mater status	melanic (m2)	melanic (m2)	melanic (m2)		
Physical features					
Chemical features				low nutrient retention (e)	
Biological features					
Drainage					
Landuse	altaric (a5)				altaric (a5)
Erosion or degradation			wind-eroded (d5)	wind-eroded (d5)	wind eroded (d5)
External physical condition					
Slope class	Level to gently undulating (a)	Level to gently undulating (a)	Level to gently undulating (a)	Level to gently undulating (a)	Level to gently undulating (a)
Soil classification	Areni-Vitric Andosol (Eutric)	Areni-Vitric Andosol (Eutric)	Areni-Vitric Andosol (Eutric)	Areni-Vitric Andosol (Eutric)	Areni-Vitric Andosol (Eutric)
Topsoil code	**S m2 a5**	**S m2**	**S m2 d5**	**S e d5**	**S a5 d5**

Am4 **Areni-Vitric Andosol (Eutric)** with Sandy, melanic, altaric topsoil **S m2 a5**
Am5 **Areni-Vitric Andosol (Eutric)** with Sandy, melanic topsoil **S m2**
Am6 **Areni-Vitric Andosol (Eutric)** with Sandy, melanic, wind eroded topsoil **S m2 d5**
Am7 **Areni-Vitric Andosol (Eutric)** with Sandy, low nutrient retention, wind eroded topsoil **S e d5**
Am9 **Areni-Vitric Andosol (Eutric)** with Sandy, altaric, wind eroded topsoil **S a5 d5**

Table continued

Obs_Id	Am10	Am11	Am12	Am13	Am14
Texture	Sandy topsoil (S)	Loamy topsoil (L)	Loamy topsoil (L)	Sandy topsoil (S)	Loamy topsoil (L)
Organic material					
Org. mater status	melanic (m2)	melanic (m2)	melanic (m2)		
Physical features			compacted (p2)		
Chemical features	natric (n)		natric (n)	Low nutrient retention (e)	Calcic (b)
Biological features					
Drainage					
Landuse	altaric (a5)				
Erosion or degrada-tion					
External physical condition					
Slope class	Level to gently undulating (a)	Level to gently undulating (a)	Level to gently undulating (a)	Level to gently undulating (a)	Level to gently undulating (a)
Soil classification	Sodi-Fluvic Cambisol (Skeletic, Eutric)	Areni-Vitric Andosol (Eutric)	Fluvic Cambisol	Arenic Fluvisol	Orthicalcic Calcisol
Topsoil code	**S m2 n a5**	**L m2**	**L m2 p2 n**	**S e**	**L b**

Am10 **Sodi-Fluvic Cambisol (Skeletic, Eutric)** with Sandy, melanic, natric, altaric topsoil **S m2 a3**
Am11 **Areni-Vitric Andosol (Eutric)** with Loamy, melanic topsoil **L m2**
Am12 **Fluvic Cambisol** with loamy, melanic, compacted, natric topsoil **L m2 p2 n**
Am13 **Arenic Fluvisol** with sandy, low nutrient retaining topsoil **S e**
Am14 **Orthicalcic Calcisol** with loamy, calcic topsoil **L b**

Table continued

Obs_Id	Am15	Am16	Ao1 & Ao2	Ao3 & Ao4, Ao7 & Ao8	Ao5, Ao6, Ao9-Ao11	Ao12
Texture	Loamy topsoil (L)	Sandy topsoil (S)	Sandy topsoil (S)	Sandy topsoil (S)	Loamy topsoil (L)	Sandy topsoil (S)
Organic material						
Org. mater status	Melanic (m2)		Melanic (m2)		Melanic (m2)	Melanic (m2)
Physical features						
Chemical features	Calcic (b) natric (n)	Low nutrient retention (e)	Low nutrient retention (e)	Low nutrient retention (e)		
Biological features						
Drainage						
Landuse	Altaric (a5)		Altaric (a5)		Altaric (a5)	Altaric (a5)
Erosion or degrada-tion		Wind-eroded (d5)		Wind eroded (d5)		
External physical condition		Arid (t2)				
Slope class	Level to gently undulating (a)	Level to gently undulating (a)	Level to gently undulating (a)	Level to gently undulating (a)	Level to gently undulating (a)	Level to gently undulating (a)
Soil classification	Orthicalcic Calcisol	Areni-Vitric Andosol	Areni-Vitric Andosol	Areni-Vitric Andosol	Areni-Vitric Andosol	Areni-Vitric Andosol
Topsoil code	**L m2 b n a5**	**S e t2 d5**	**S m2 e a5**	**S e d5**	**L m2 a5**	**S m2 a5**

Am15	**Orthicalcic Calcisol** with loamy, melanic, calcic, natric, altaric topsoil	**L m2 b n a5**
Am16	**Areni-Vitric Andosol** with sandy, low nutrient retention, wind-eroded, aridic topsoil	**S e t2 d5**
Ao1 & Ao2	**Areni-Vitric Andosol** with sandy, melanic, low nutrient retention, altaric topsoils	**S m2 e a5**
Ao3, Ao4, Ao7, Ao8	**Areni-Vitric Andosol** with sandy, low nutrient retention, wind-eroded topsoils	**S e d5**
Ao5, Ao6, Ao9-Ao11	**Areni-Vitric Andosol** with loamy, melanic, natric, altaric topsoil	**L m2 a5**
Ao12	**Areni-Vitric Andosol** with sandy, melanic, altaric topsoils	**S m2 a5**

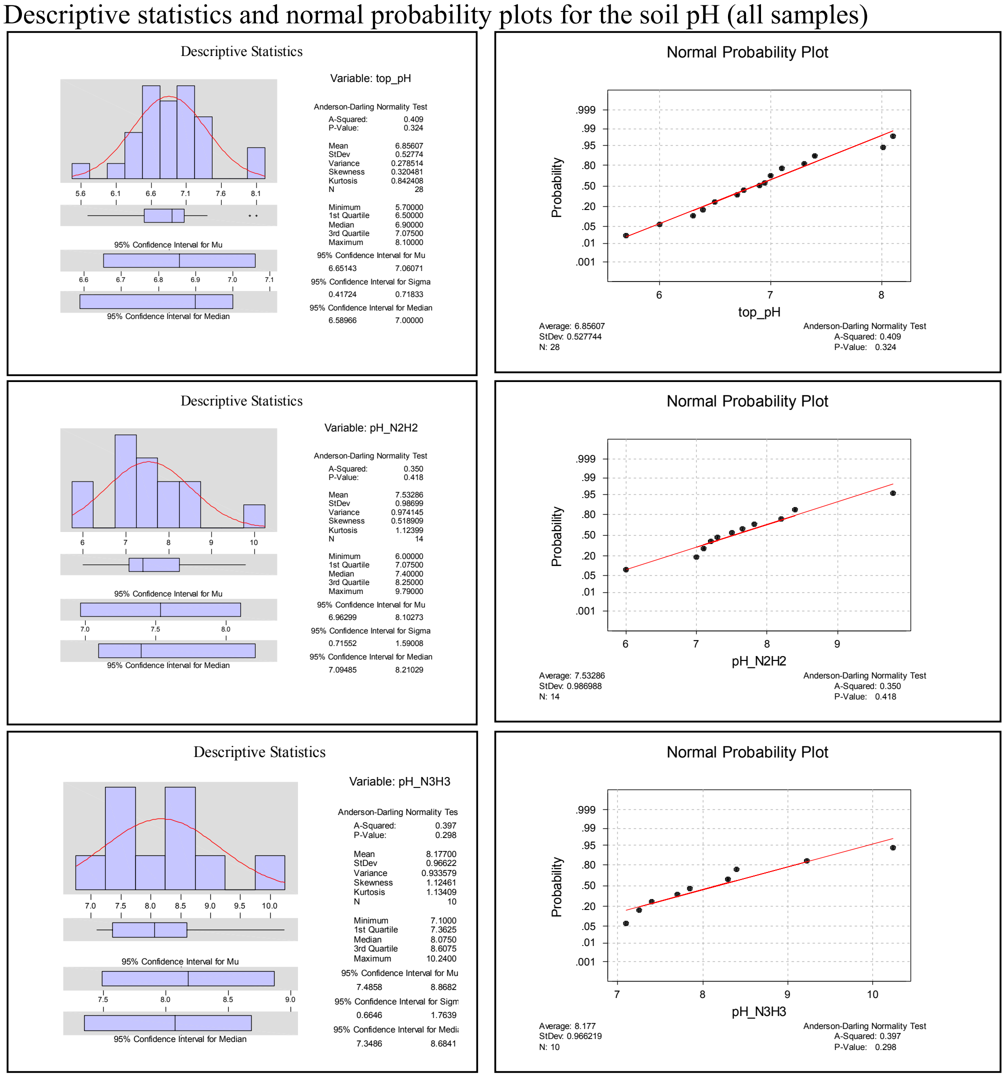
5.3. Data Analysis

5.3.1. Soil pH

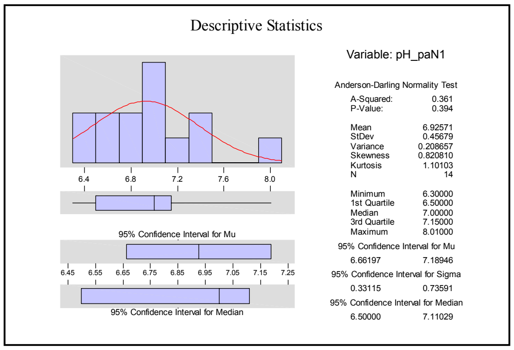
In this section, the data that were measured, by the author, in Sulmac laboratory are analysed. The raw data (see appendix B) was arranged to ease comparisons between the paired sample points, the managed and unmanaged points. Three of the horizons, the 1st, 2nd and 3rd, did not show evidence for the soil pH differences between the managed and non-managed paired observation points. From the interviews made high-tech managed plots are mostly kept to range between pH of 6 to 7 for proper flower cultivation. Most unmanaged happen to have already an optimal range for the selected crops. When the soil pH on the managed plots was higher, nitric and phosphoric acids are added to lower it. On the other hand, lime is added when the soil pH is low. Generally, in all of the cases, the pH of the soil gets higher with depth.

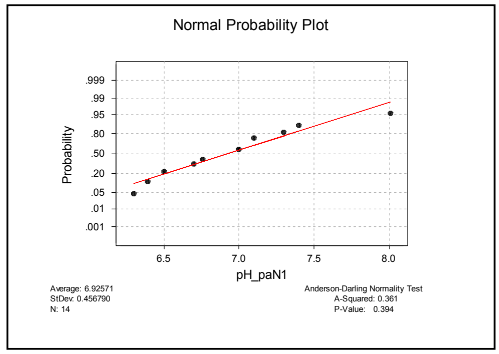
Figure 18 Descriptive statistics and normal probability plots

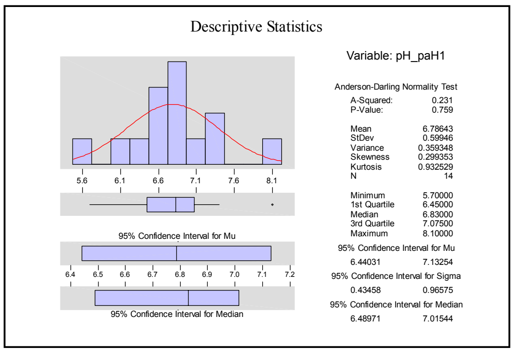
Descriptive statistics and normal probability plots for the soil pH (all samples)

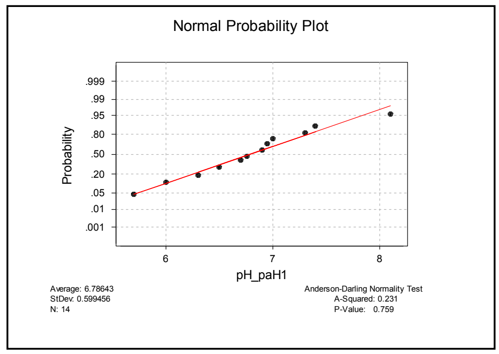


Descriptive statistics and normality plots for the paired comparison points (top horizon)

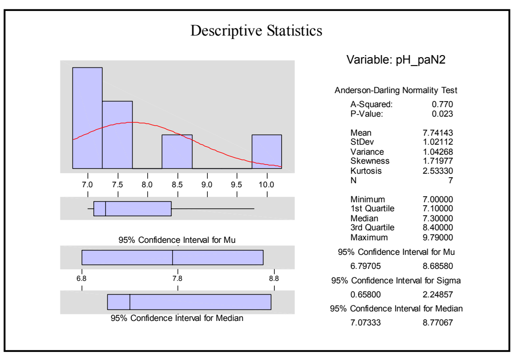


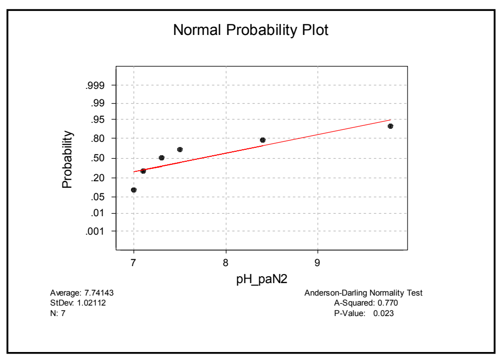


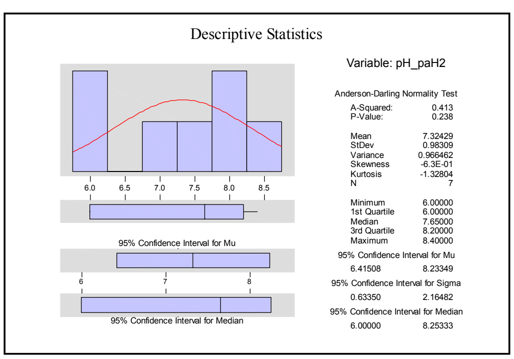


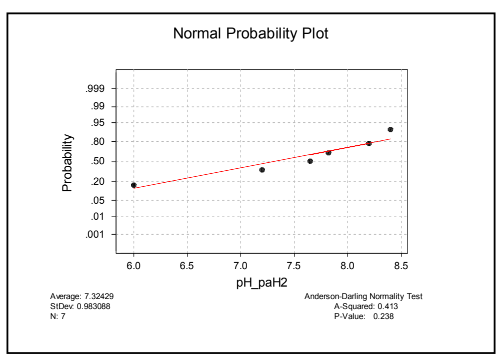


Descriptive statistics and normality plots for the paired comparison points (2nd horizon)

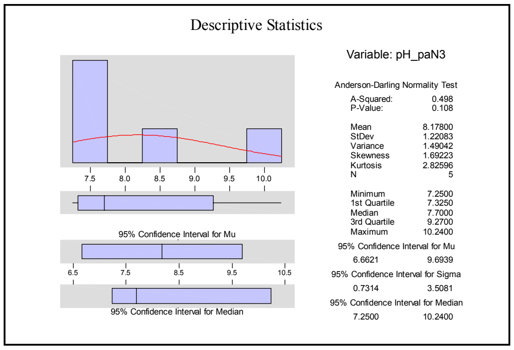


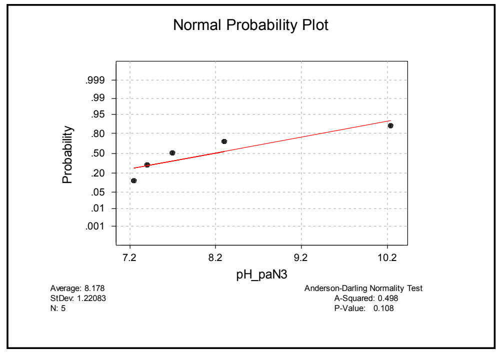


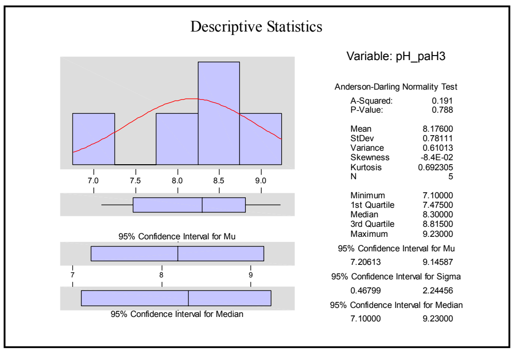


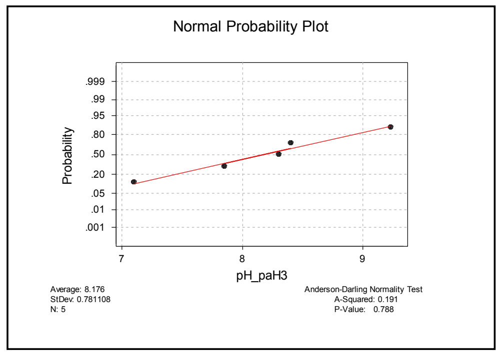


Descriptive statistics and normality plots of pH for the paired comparison points (3rd horizon)









Correlation (Pearson)

	PH_paN1	pH_paH1	pH_paN2	pH_paH2	pH_paN3
pH_paH1	0.030				
	0.918				
pH_paN2	-0.018	0.907			
	0.969	0.005			
pH_paH2	0.260	0.414	0.599		
	0.573	0.356	0.155		
pH_paN3	-0.311	0.805	0.973	0.818	
	0.611	0.101	0.005	0.091	
pH_paH3	-0.180	0.517	0.798	0.964	0.860
	0.772	0.372	0.106	0.008	0.061

```
The values at the top are:    Correlation
        At the bottom are:    P-Value
```

The analysis shows that there is positive correlation only between high-tech managed horizon 1 and unmanaged horizon 2; unmanaged horizon 2 and unmanaged 3; high-tech managed horizon 2 and high-tech managed horizon 3 at 95 % confidence interval (they are underlined above). The correlation between the high-tech managed horizon 1 vs unmanaged 2 could be by chance. But, there is good correlation between the 2nd and the 3rd horizon pH of the unmanaged horizons also between the 2nd and the 3rd horizons of the managed plots. The poor correlation result with their respective first horizons could be due to the variable nature of the surface horizons in general.

Table 8 Analysis of soil pH test results at $\alpha = 0.05$

Management	Hor	# of samp.	Median	Mean	SE of mean	Anderson-Darling Normality test		Statistical method used	Difference			
							p-value		Mean difference	SE of mean difference	ETA1-ETA2	**p-value**
All	1	28	6.9	6.85	0.1	N	0.324					
Not managed	1	14	7	6.93	0.122	N	0.394	T-test	0.139	0.198		0.495
Managed	1	14	6.83	6.79	0.16	N	0.759					
All	2	14	7.4	7.5	0.264	N	0.418					
Not managed	2	7	7.3	7.74	0.39	NN	0.023	MW			0.1	0.94
Managed	2	7	7.65	7.3	0.14	N	0.238					
All	3	10	8.08	8.17	0.31	N	0.298					
Not managed	3	5	7.7	8.18	0.55	N	0.108	MW			-0.15	0.75
Managed	3	5	8.3	8.17	0.35	N	0.788					

Where N = Normally distributed
NN = Not normally distributed
MW = Mann-Whitney test (non parametric test)
ETA1-ETA2 = Point estimate

Table 9 Analysis of log transformed soil EC (mS/cm) test results at $\alpha = 0.05$

Management	Hor	# of samp.	Median	Mean	SE of mean	Anderson-Darling Normality test		Statistical method used	Difference			
							p-value		Mean difference	SE of mean difference	ETA1-ETA2	**p-value**
All	1	28	-1.571	-1.39	0.2	NN	0.014					
Not managed	1	14	-1.942	-1.528	0.281	N	0.146	T-test	-0.281	0.389		0.482
Managed	1	14	-1.477	1.247	0.283	N	0.142					
All	2	14	-1.729	-1.52	0.29	N	0.305					
Not managed	2	7	-1.47	-1.43	0.47	N	0.723	MW			0.154	0.74
Managed	2	7	-1.99	-1.614	0.38	N	0.328					
All	3	10	-1.716	-1.52	0.39	N	0.401					
Not managed	3	5	-1.542	-1.43	0.51	N	0.813	MW			0.208	0.753
Managed	3	5	-1.89	-1.612	0.65	N	0.407					

5.3.2. Electrical Conductivity (EC)

This data, similar to the pH data, were analysed in Sulmac laboratory by the author. All the original EC data values are not normally distributed. Because of this, log transformation was found necessary. Except one (see Table 9), all showed normality after they were log transformed. Therefore, analysis was made on the transformed values. On the other hand, since the number of sample pairs for the 2nd and the 3rd horizons is few, non-parametric test, Mann-Whitney test was used. F-test was made only for the first horizon.

The result of the three of the horizons, the 1st, 2nd and 3rd, did not show evidence for the soil differences between the managed and unmanaged paired observation points. This can also be reasoned out like the soil pH values. Management has a great influence on the adjustment of both EC and pH conditions of the soil for proper cultivation.

Correlations (Pearson)

	EC_N1L	EC_H1L	EC_N2L	EC_H2L	EC_N3L
EC_H1L	0.047				
	0.873				
EC_N2L	0.903	0.062			
	0.005	0.895			
EC_H2L	0.387	0.585	0.600		
	0.391	0.168	0.154		
EC_N3L	0.593	0.251	0.897	0.712	
	0.292	0.684	0.039	0.177	
EC_H3L	0.681	0.182	0.941	0.707	0.985
	0.206	0.770	0.017	0.182	0.002

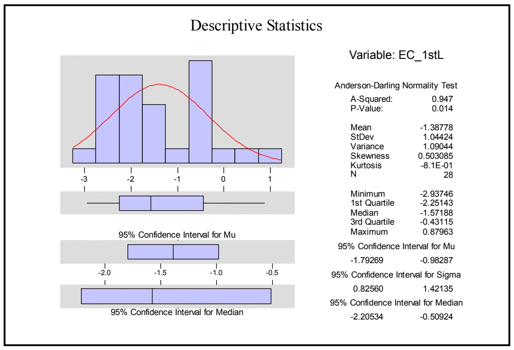
The values at the top are: Correlation
At the bottom : P-Value

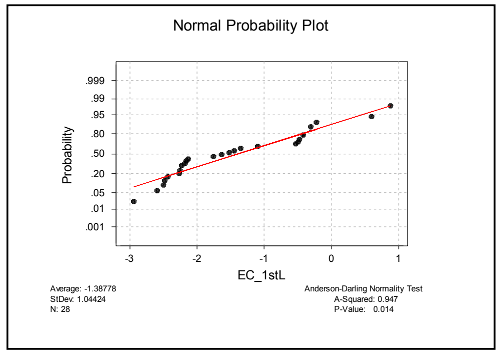
The correlation analysis above shows that there is significant positive correlation between unmanaged horizon 1 and unmanaged horizon 2; unmanaged horizon 2 vs unmanaged horizon 3 and high-tech managed horizon 3; and unmanaged horizon 3 and high-tech managed horizon 3 at 95 % confidence interval (they are underlined above).

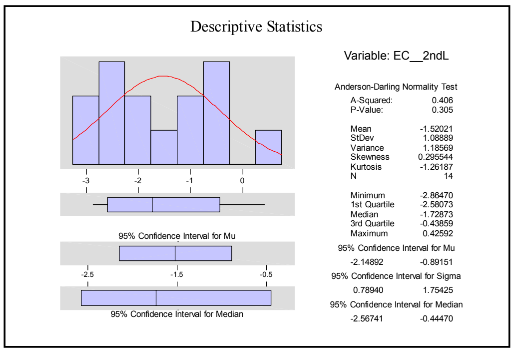
As depth increases we can see that the unmanaged horizons show good correlation. But, the high-tech managed ones do not show good correlation as depth increases. This could mainly because of variabilities in management practices at every observation points.

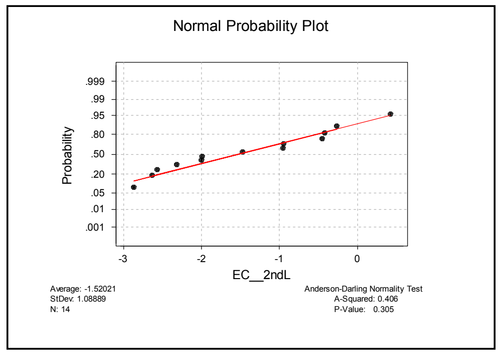
Figure 19 Descriptive statistics and normal probability plot of EC

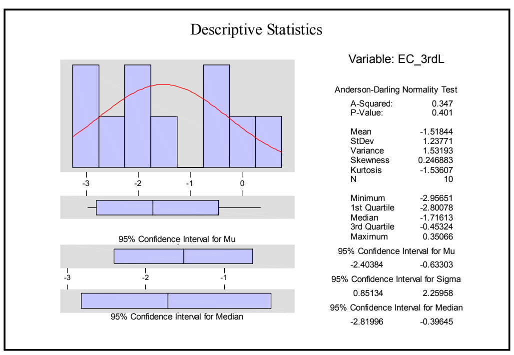
Descriptive statistics and normal probability plot of EC (all samples)

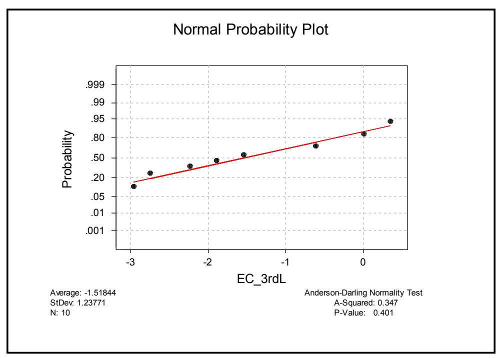




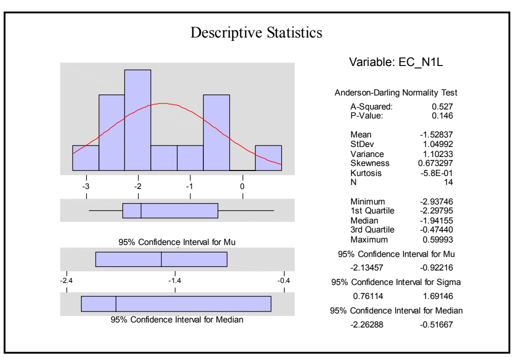


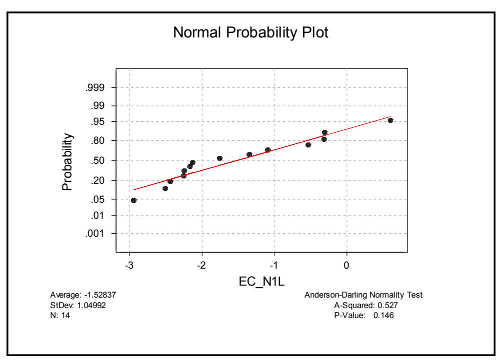


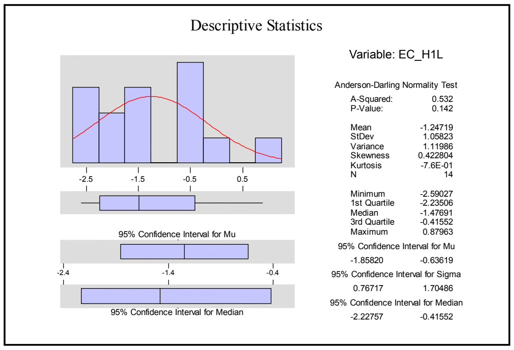


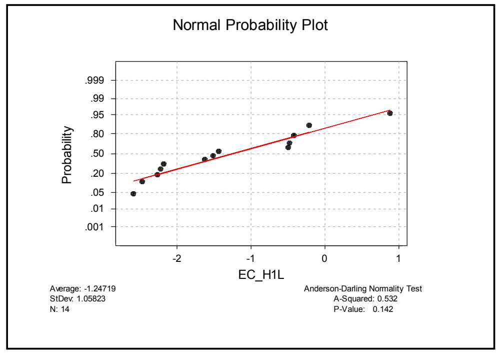


Descriptive statistics and normal probability plot of EC (top horizon pairs)

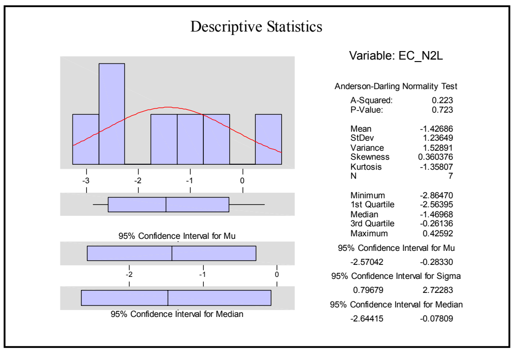


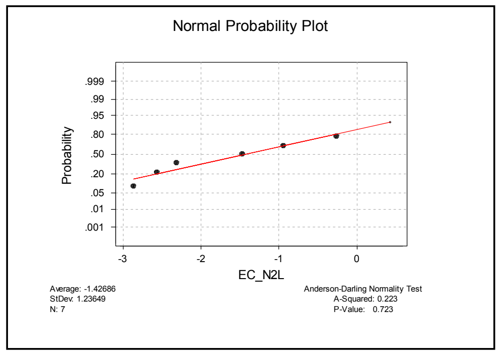


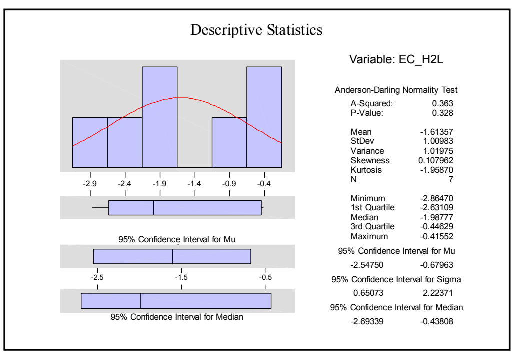


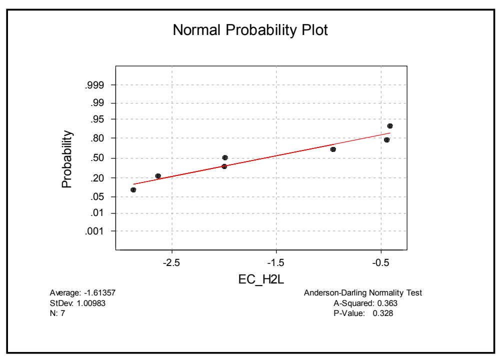


Descriptive statistics and normal probability plot of EC (2nd horizon pairs)

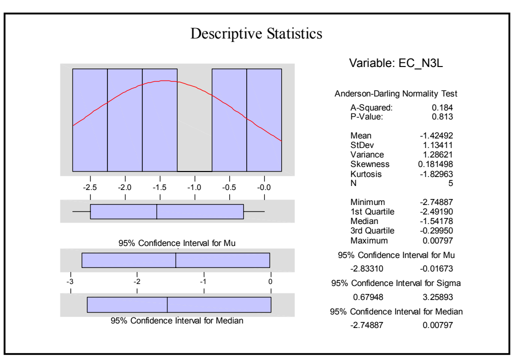


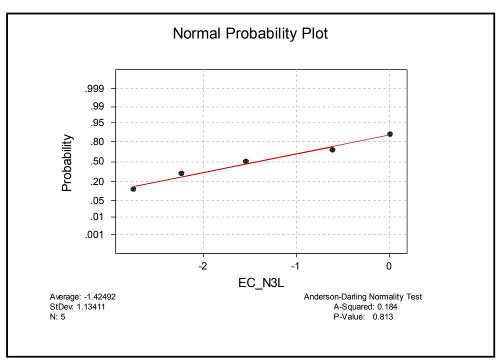


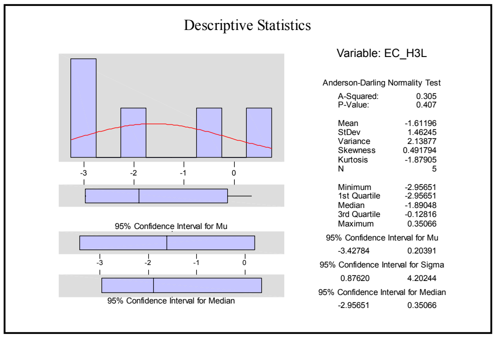


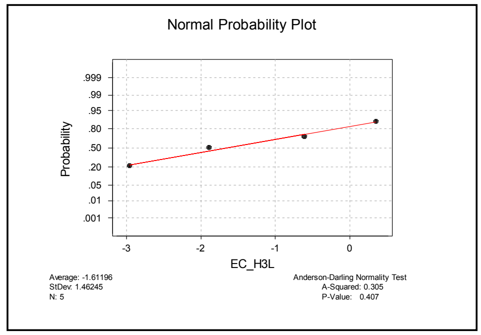


Descriptive statistics and normal probability plot of EC (3rd horizon pairs)






Descriptive Statistics
Variable: EC_H3L
Anderson-Darling Normality Test
A-Squared: 0.305
P-Value: 0.407
Mean -1.61196
StDev 1.46245
Variance 2.13877
Skewness 0.491794
Kurtosis -1.87905
N 5
Minimum -2.95651
1st Quartile -2.95651
Median -1.89048
3rd Quartile -0.12816
Maximum 0.35066
95% Confidence Interval for Mu
-3.42784 0.20391
95% Confidence Interval for Sigma
0.87620 4.20244
95% Confidence Interval for Median
-2.95651 0.35066
95% Confidence Interval for Mu
95% Confidence Interval for Median


Normal Probability Plot
Probability
EC_H3L
Average: -1.61196
StDev: 1.46245
N: 5
Anderson-Darling Normality Test
A-Squared: 0.305
P-Value: 0.407

5.3.3. Bulk Density (Bd)

Similar to soil pH and EC, laboratory tests of bulk density soil samples were made by the author in Sulmac laboratory. For analysis purpose all the data was log transformed. Similar to the EC values only the first horizons Bd of the whole population was not normally distributed even after transformation. But, the remaining paired samples are normally distributed after transformation. Further analysis was made on the transformed data.

The method chosen to analyse the samples either parametric or non-parametric depends on the number of samples or number of paired observation results. The second and the third horizons have lower number of paired points than the top horizon. Due to this, F-test was made for the first horizon and Mann-Whitney test for the 2^{nd} and the 3^{rd} horizons.

The result of the three of the horizons, the 1^{st}, 2^{nd} and 3^{rd}, did not show evidence of soil bulk density differences between the managed and non-managed paired observation points. Both the high-tech managed and the unmanaged plots have a wide range of bulk density. In some small event even though the samples taken had similar moisture levels before they were put in an oven, soil moisture conditions of the bulk density samples may contribute in some small extent for the variability.

Correlations (Pearson)

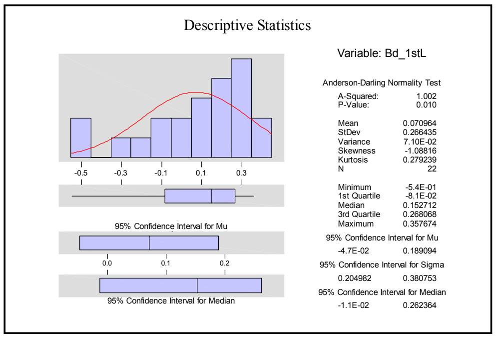
	Bd_N1L	Bd_H1L	Bd_N2L	Bd_H2L	Bd_N3L
Bd_H1L	0.202				
	0.552				
Bd_N2L	0.670	0.688			
	0.216	0.199			
Bd_H2L	0.377	0.974	0.767		
	0.531	0.005	0.130		
Bd_N3L	0.234	0.900	0.754	0.970	
	0.704	0.037	0.141	0.006	
Bd_H3L	0.317	0.926	0.692	0.977	0.973
	0.603	0.024	0.195	0.004	0.005

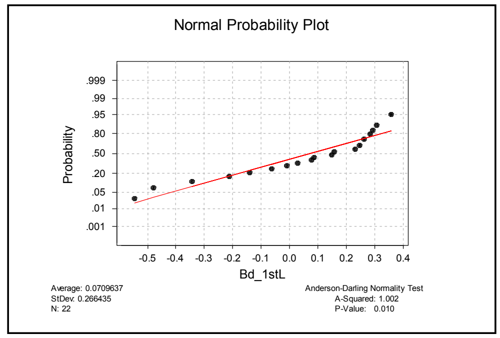
The values at the top are: Correlation
At the bottom: P-Value

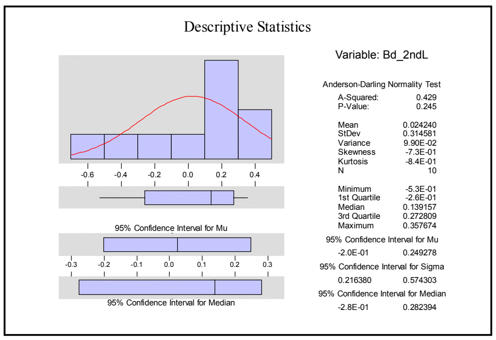
From the correlations above we can see that there is highly significant correlation between the lower horizons of the high-tech managed and unmanaged plots. That is between high-tech managed horizon 2 vs unmanaged and high-tech managed horizon 3; unmanaged horizon 3 vs high-tech managed horizon 3 at 95 % confidence interval (they are underlined above).

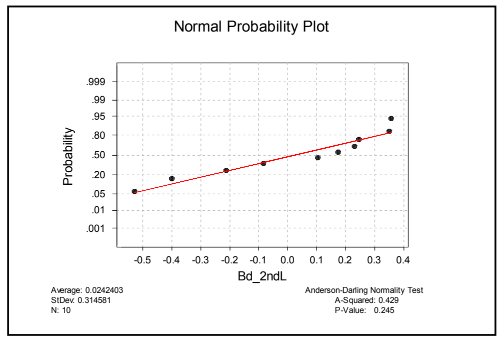
One can see that the high-tech managed horizons show good correlation. But, the unmanaged observations didn't show good correlation as depth increases.

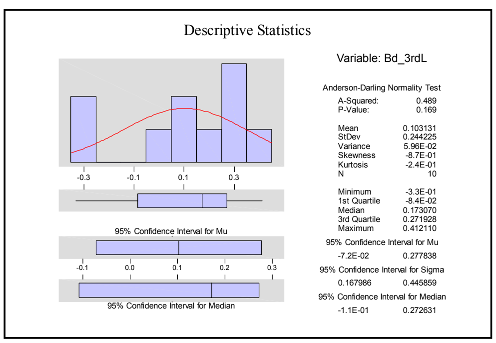
Descriptive statistics and normal probability plot of Bd (all samples, gm/cm^3)

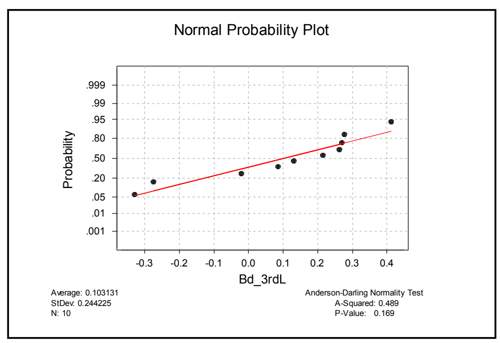




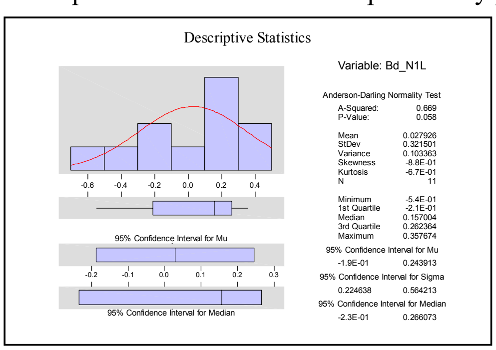


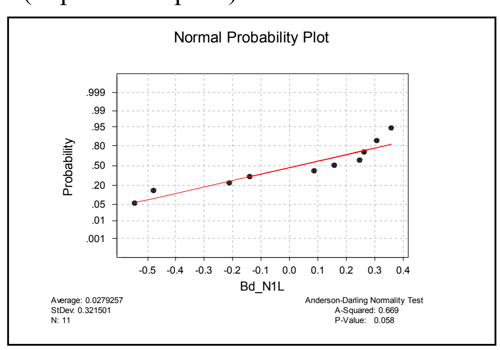


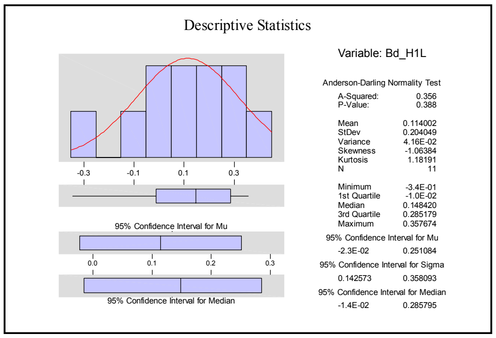


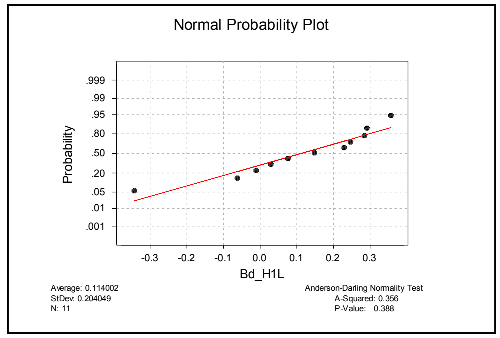


Descriptive statistics and normal probability plot of Bd (top-horizon pairs)

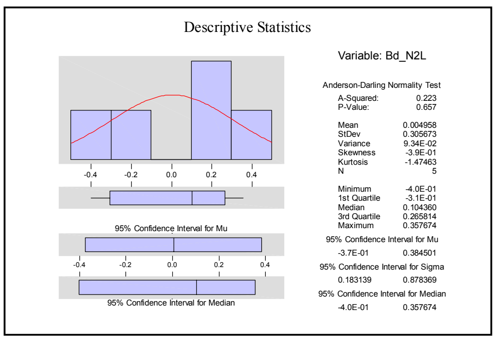


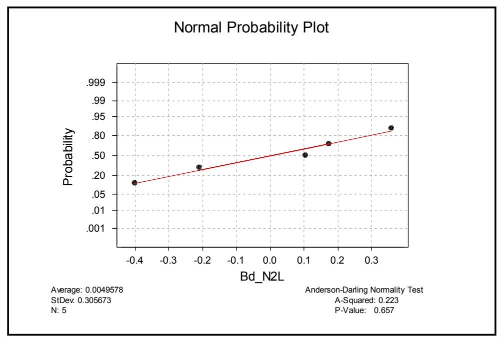


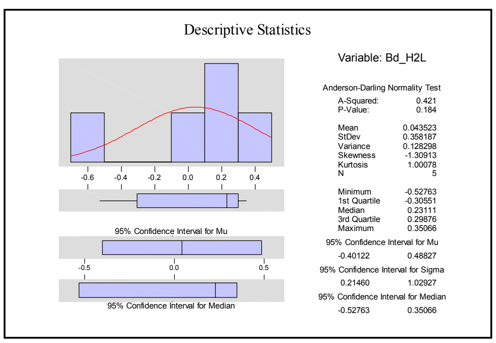


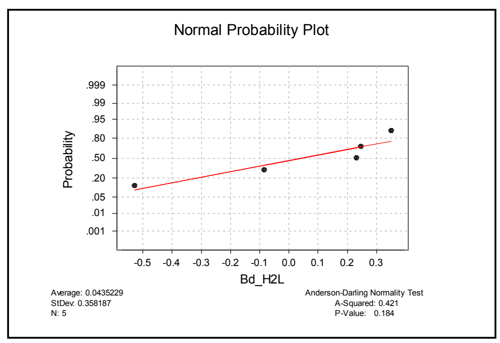


Descriptive statistics and normal probability plot of Bd (2nd horizon pairs)

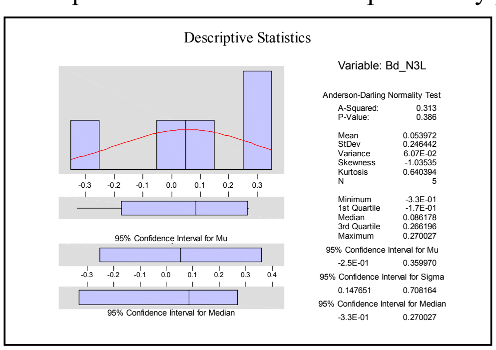


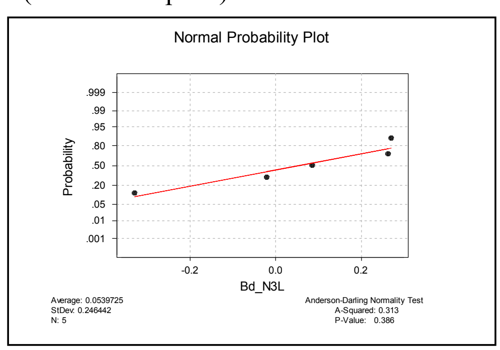


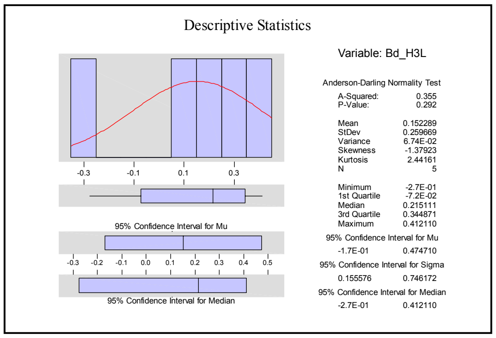




Descriptive statistics and normal probability plot of Bd (3rd horizon pairs)






Descriptive Statistics
Variable: Bd_H3L
-0.3
-0.1
0.1
0.3
95% Confidence Interval for Mu
-0.3 -0.2 -0.1 0.0 0.1 0.2 0.3 0.4 0.5
95% Confidence Interval for Median
Anderson-Darling Normality Test
A-Squared: 0.355
P-Value: 0.292
Mean 0.152289
StDev 0.259669
Variance 6.74E-02
Skewness -1.37923
Kurtosis 2.44161
N 5
Minimum -2.7E-01
1st Quartile -7.2E-02
Median 0.215111
3rd Quartile 0.344871
Maximum 0.412110
95% Confidence Interval for Mu
-1.7E-01 0.474710
95% Confidence Interval for Sigma
0.155576 0.746172
95% Confidence Interval for Median
-2.7E-01 0.412110

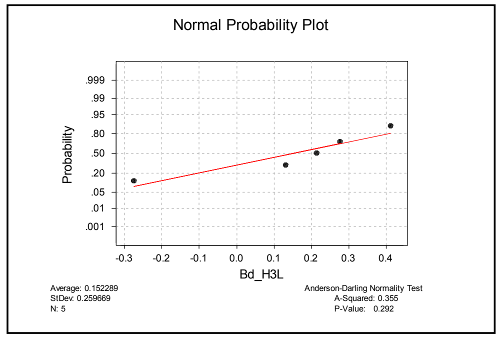

Normal Probability Plot
Probability
.999
.99
.95
.80
.50
.20
.05
.01
.001
-0.3 -0.2 -0.1 0.0 0.1 0.2 0.3 0.4
Bd_H3L
Average: 0.152289
StDev: 0.259669
N: 5
Anderson-Darling Normality Test
A-Squared: 0.355
P-Value: 0.292

Table 10 Analysis of log transformed soil bulk density (Bd) test results at $\alpha = 0.05$

Management	Hor	# of samp.	Median	Mean	SE of mean	Anderson-Darling Normality test		Statistical method used	Difference			
							p-value		Mean difference	SE of mean difference	ETA1-ETA2	**p-value**
All	1	22	0.153	0.07	0.06	NN	0.01					
Not managed	1	11	0.16	0.027	0.01	N	0.06	T-test	-0.086	0.104		0.426
Managed	1	11	0.148	0.114	0.062	N	0.388					
All	2	10	0.139	0.024	0.1	N	0.245					
Not managed	2	5	0.104	0.005	0.137	N	0.657	MW			-0.073	0.835
Managed	2	5	0.231	0.04	0.16	N	0.184					
All	3	10	0.173	0.103	0.08	N	0.169					
Not managed	3	5	0.086	0.054	0.11	N	0.386	MW			-0.129	0.403
Managed	3	5	0.215	0.152	0.12	N	0.292					

Where N = Normally distributed
NN = Not normally distributed
MW = Mann-Whitney test (non parametric test)
ETA1-ETA2 = Point estimate

Table 11 Analysis of log transformed coarse fragments (%CF) in a soil at $\alpha = 0.05$

Management	Hor	# of samp.	Median	Mean	SE of mean	Anderson-Darling Normality test		Statistical method used	Difference			
							p-value		Mean difference	SE of mean difference	ETA1-ETA2	**p-value**
All	1	22	2.14	1.827	0.22	NN	0.021					
Not managed	1	11	2.03	1.833	0.254	N	0.325	MW			0.02	0.974
Managed	1	11	2.13	1.677	0.359	NN	0.006					
All	2	10	6.46	7.727	2.23	N	0.341					
Not managed	2	5	2.07	1.688	0.42	N	0.164	MW			-0.025	1
Managed	2	5	1.60	-0.34	2.27	NN	0.032					

5.3.4. Percentage of Coarse Fragments (%CF)

The percentage by weight of coarse fragments of soil samples was determined for comparison purpose if at all management brings about differences in %CF. Before analysing the samples, log transformation was attempted, because the untransformed distributions are far from normal. In this case, the high-tech managed %CF results are not normally distributed even after transformation. On the other hand, after transformation, the unmanaged results were normally distributed.

The method chosen to analyse the %CF of the paired samples is Mann-Whitney test. This is because of the few number of sample size for the 2nd horizon and non-normal distribution of the high-tech managed observation of the first horizon. From Table 11 one can conclude that the differences in %CF between the high-tech and unmanaged observation points is purely by chance.

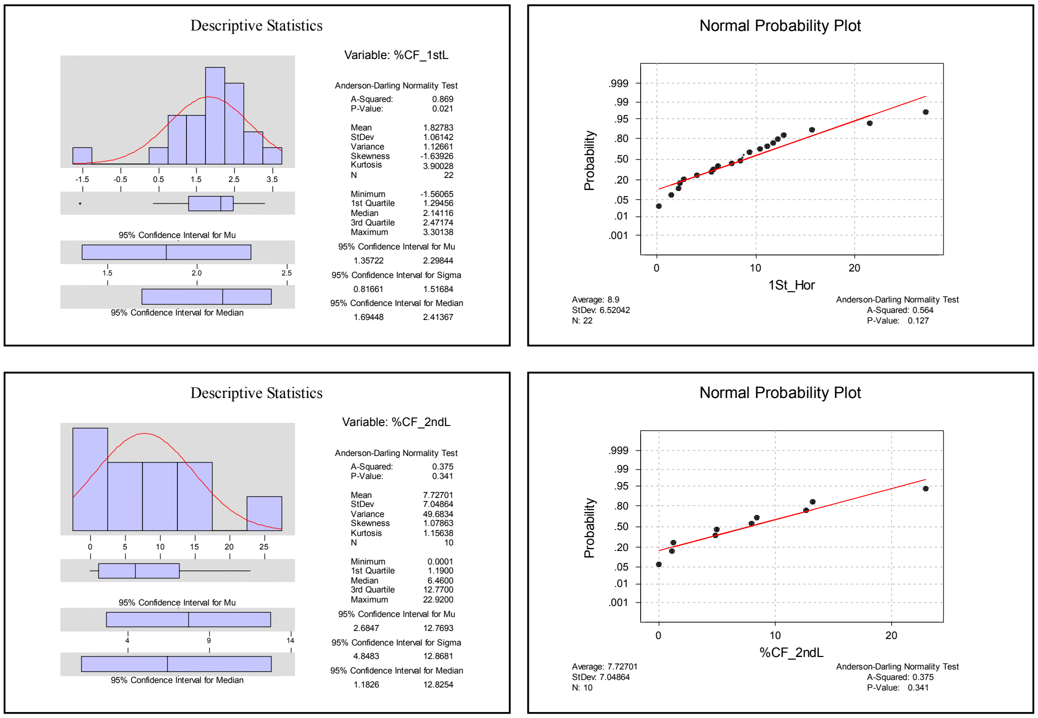
Correlations (Pearson)

```
        %CF_N1L  %CF_H1L  %CF_N2L
%CF_H1L   0.305
          0.361
%CF_N2L   0.798    0.299
          0.106    0.625
%CF_H2L   0.646    0.986    0.234
          0.239    0.002    0.705
The values at the top are: Correlation
        At the bottom are: P-Value
```

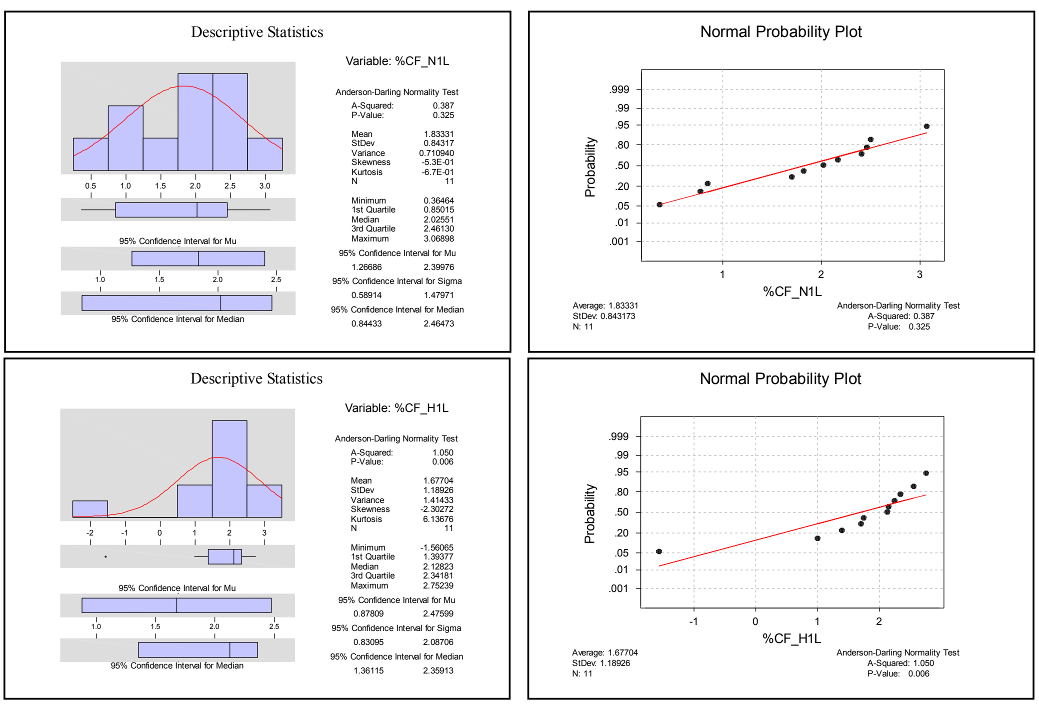
From the correlations above one can see that there is highly significant correlation only between the high-tech managed horizon 1 and 2. With the rest there is no correlation at 95 % confidence interval

Figure 20 Descriptive statistics and normal probability plot of coarse fragments

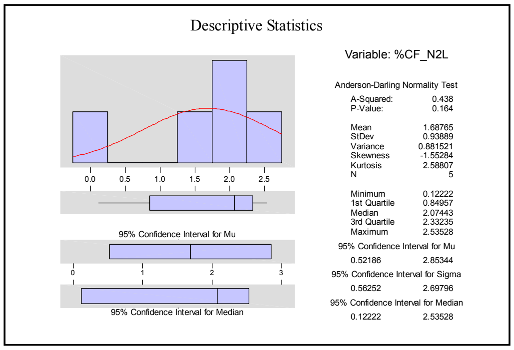
Descriptive statistics and normal probability plot of %CF (all samples)

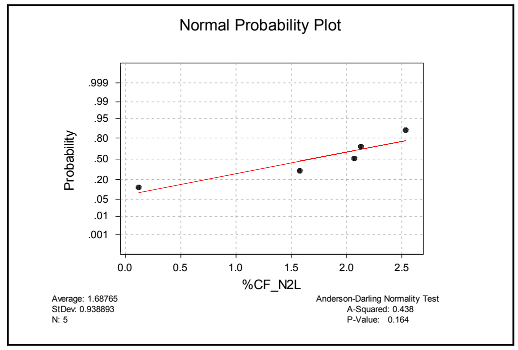


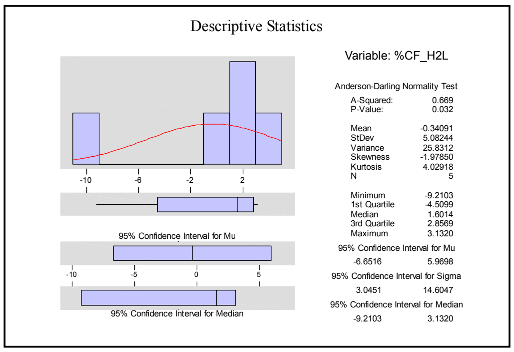
Descriptive statistics and normal probability plot of %CF (top horizon)

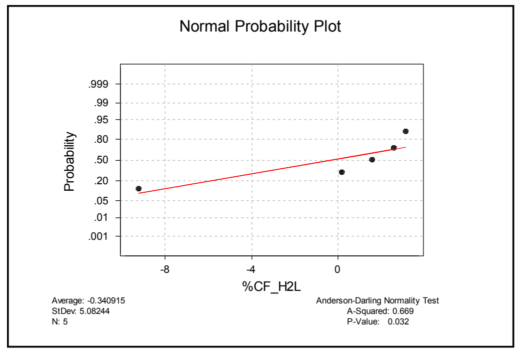


Descriptive statistics and normal probability plot of %CF (3rd horizon)



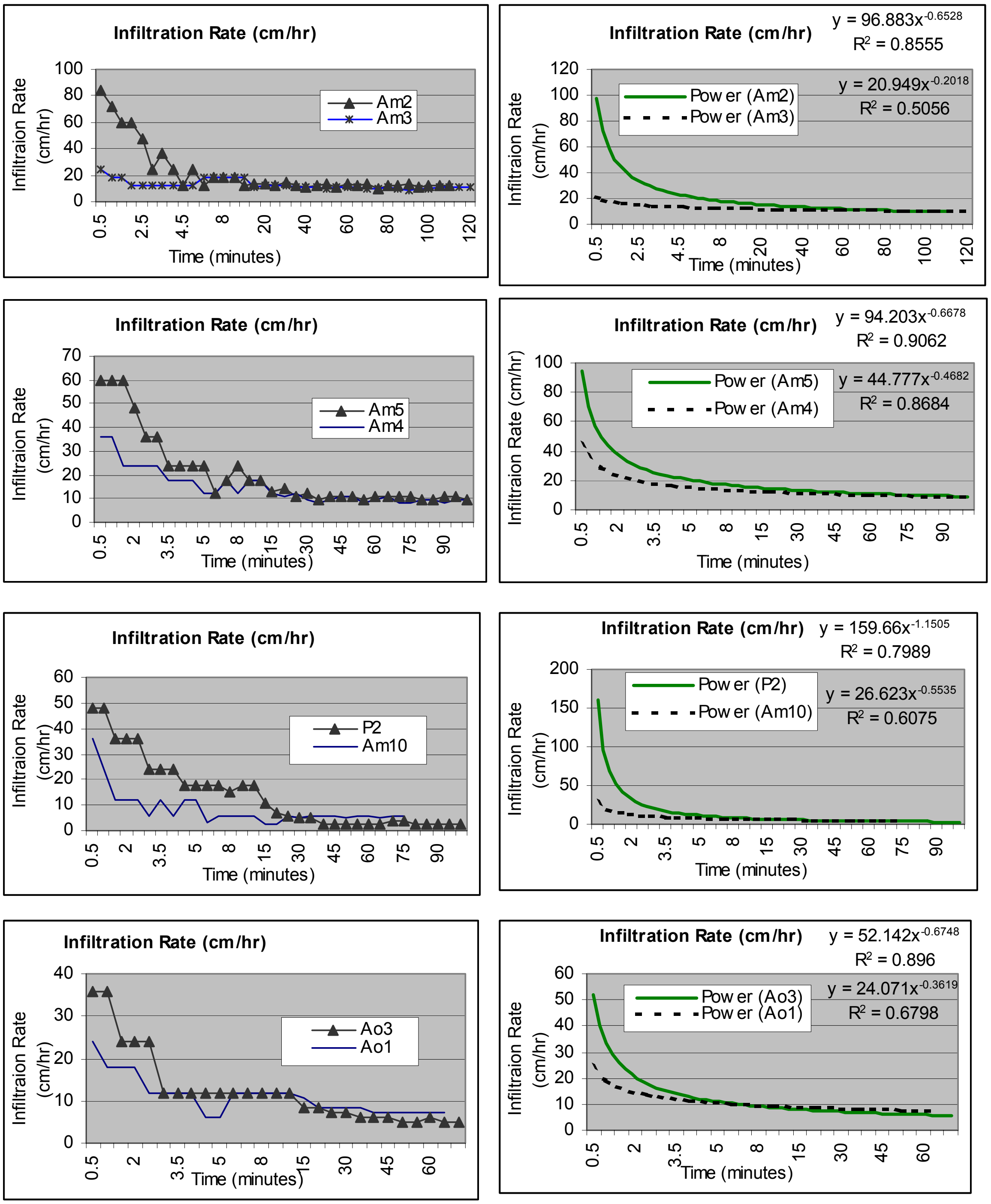


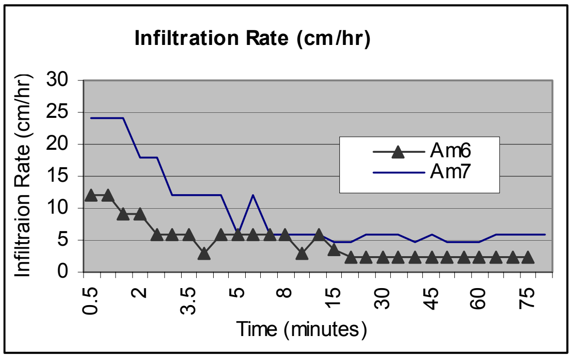




5.3.5. Infiltration

Figure 21 Infiltration rates between the paired comparison points





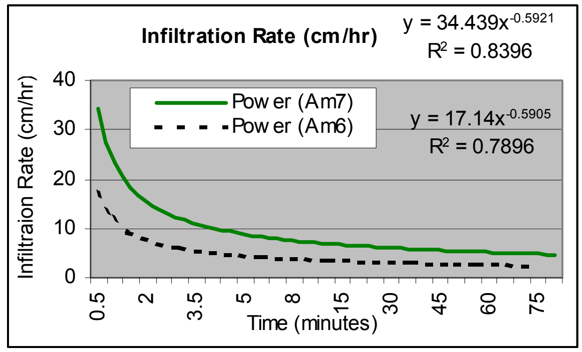


Table 12 Infiltration rate (cm/hr) of the paired comparison observation points

Unmanaged Sites				Managed Sites			
Obs_Id	Infiltration Rate (cm/hr)			Obs_Id	Infiltration Rate (cm/hr)		
	Initial (1st minute)	Final (steady state)	Depth of wetting (cm)		Initial (1st minute)	Final (steady state)	Depth of wetting (cm)
Am2	72	12.0	69	Am3	18	10.8	56
Am5	60	9.6	57	Am4	36	9.6	62
Am7	24	6.0	25	Am6	12	2.4	23
Ao3	36	4.8	36	Ao1	18	7.2	30
P2	48	2.4	50	Am10	24	6	60

Six options were considered for the analysis of infiltration test results. These are, at minute one, steady state and depth at which the infiltration water has reached down the profile using the raw infiltration data, and at minute one, 1st hour and 2nd hour using the power fit model.

The results of the analysis using Mann-Whitney test show that (see Table 13 and Table 14) there is significant difference at the first minute (during the initial water uptake) for both the raw data and the power fit models between the paired comparison observation points. On the other hand, there is no significant difference at the steady state, 1st hour, and 2nd hour of infiltration tests between the paired comparison points. The output data from the power fit model was log transformed to obtain better distribution before conducting analysis.

The difference in the infiltration rate results could also be seen from the charts. In all of the cases the initial infiltration rate of the unmanaged sites are considerably higher than the managed sites. This effect is seen for the first 5-8 minutes thereafter the fitted curves are almost identical. One comparison is an exception Am6 vs Am7 by looking at the fitted graphs.

Table 13 Analysis of infiltration test results at $\alpha = 0.05$

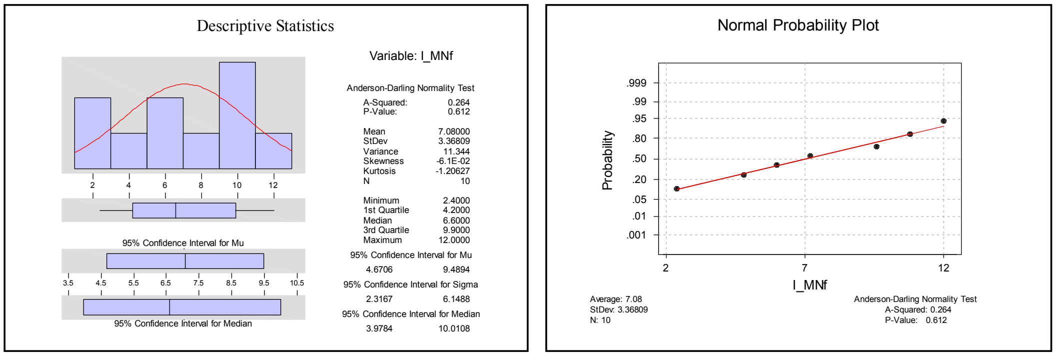
Management	Condition	# of samp.	Median	Mean	SE of mean	Anderson-Darling Normality test		Statistical method used	Difference	
							p-value		ETA1-ETA2	**p-value**
All	1. Initial infiltration rate (at the first minute)	10	30	34.8	6.25	N	0.292			
Not managed		5	48	48	8.48	N	0.92	MW	24	**0.037***
Managed		5	18	21.6	4.07	N	0.353			
All	2. Final (Steady state) infiltration	10	6.6	7.08	1.07	N	0.612			
Not managed		5	6	6.96	1.71	N	0.792	MW	0.00	0.917
Managed		5	7.2	7.2	1.47	N	0.784			
All	3. Depth at which the water has reached (percolated)	10	53	46.8	5.31	N	0.208			
Not managed		5	50	47.4	7.74	N	0.894	MW	1	1
Managed		5	56	46.2	8.18	N	0.119			

Where N = Normally distributed; NN = Not normally distributed; MW = Mann-Whitney test (non parametric test); ETA1-ETA2 = Point estimate; * = significant at 95%

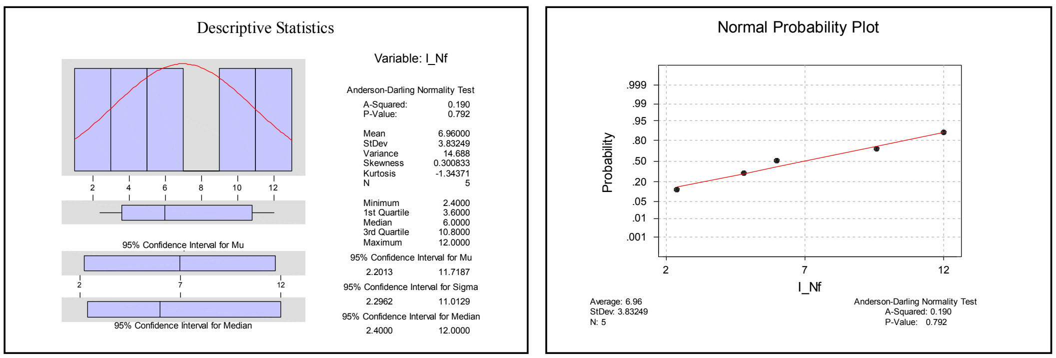
Table 14 Analysis, based on infiltration power fit model results

Management	Condition	# of samp.	Median	Mean	SE of mean	Anderson-Darling Normality test		Statistical method used	Difference	
							p-value		ETA1-ETA2	**p-value**
All	1. At minute 1	10	3.67	3.78	0.24	N	0.552			
Not managed		5	4.55	4.34	0.27	N	0.64	MW	1.264	**0.0216***
Managed		5	3.18	3.23	0.16	N	0.504			
All	2. At one hour	10	1.45	1.36	0.202	N	0.324			
Not managed		5	1.19	1.28	0.28	N	0.46	MW	-0.072	0.8345
Managed		5	1.7	1.45	0.32	N	0.599			
All	3. Two hours	10	1.04	0.95	0.24	N	0.455			
Not managed		5	0.722	0.759	0.34	N	0.265	MW	-0.441	0.4647
Managed		5	1.45	1.15	0.36	N	0.608			

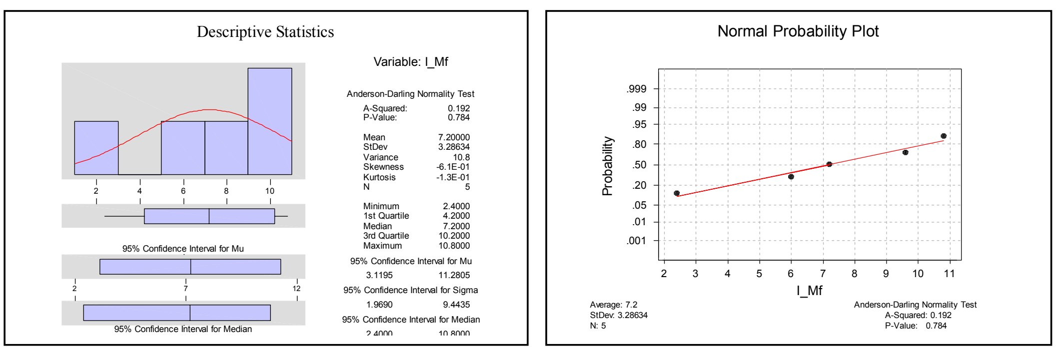
Figure 22 Descriptive statistics and normal probability plot of infiltration (all samples)



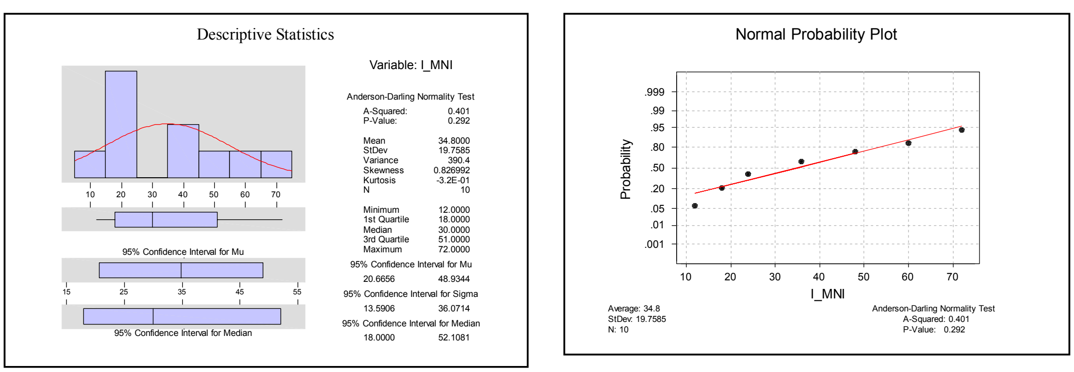
Descriptive statistics and normal probability plot of infiltration (unmanaged, steady state)



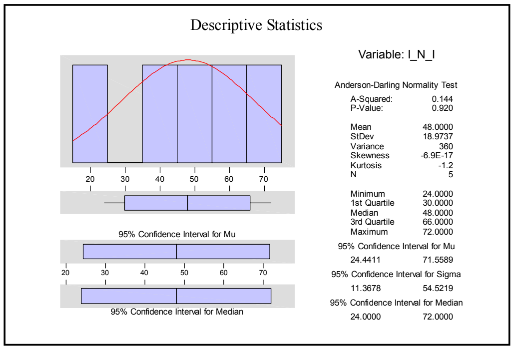
Descriptive statistics and normal probability plot of infiltration (managed, steady state)

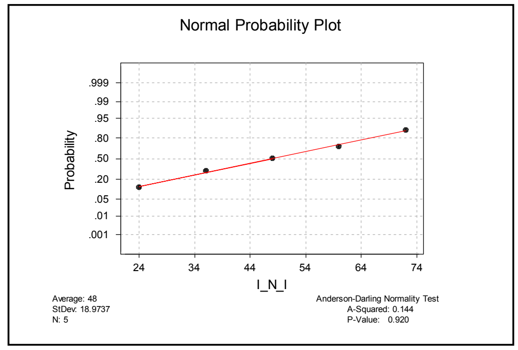


Descriptive statistics and normal probability plot of infiltration (all samples, 1st minute)

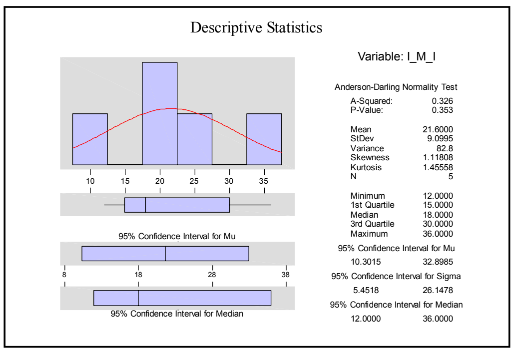


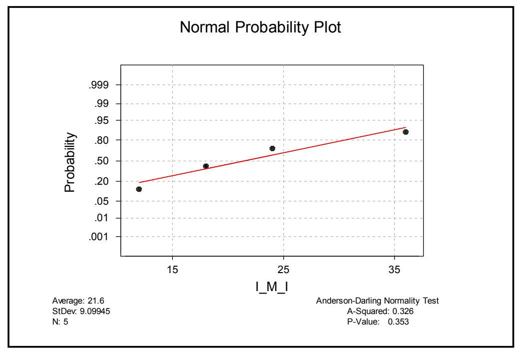
Descriptive statistics and normal probability plot of infiltration (unmanaged, 1st minute)



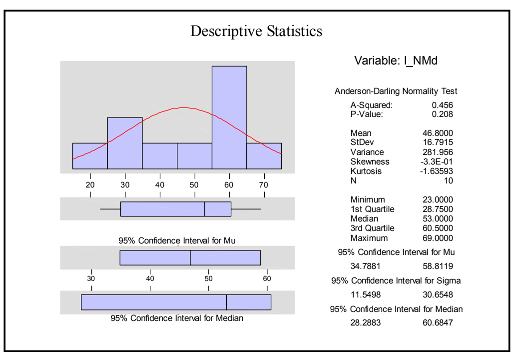


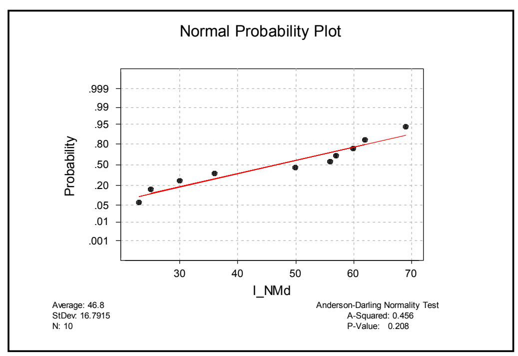
Descriptive statistics and normal probability plot of infiltration (managed, 1st minute)





Descriptive statistics and normal probability plot of depth of wetting (all samples, 1st minute)



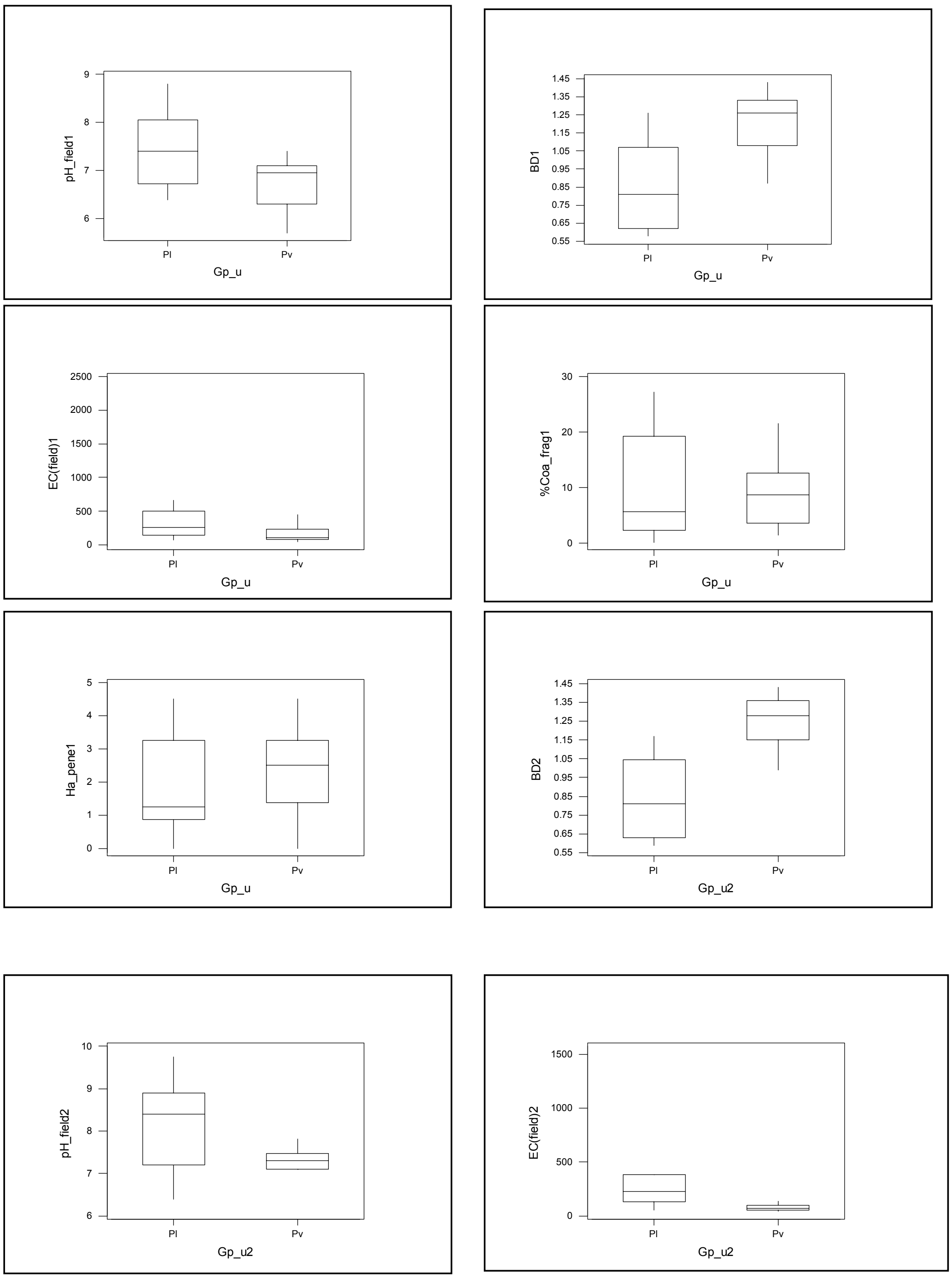


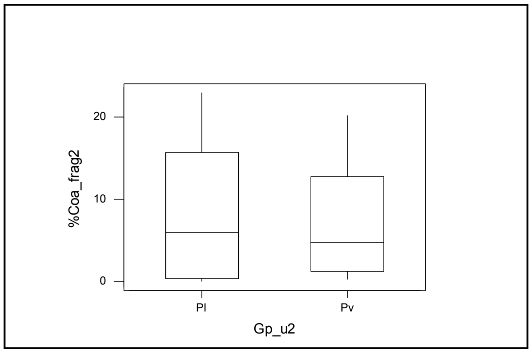
5.3.6. The Volcanic and the Lacustrine Plain

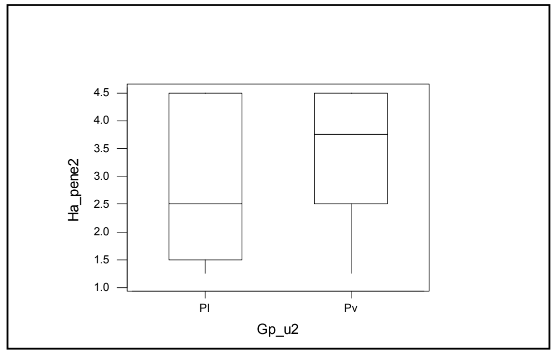
An obvious question is weather the geopedologic landscape units, the volcanic and the lacustrine plain, form a useful stratification the soil properties studied.

Figure 23 Box plot to compare the two geopedologic units (lacustrine and volcanic plain)

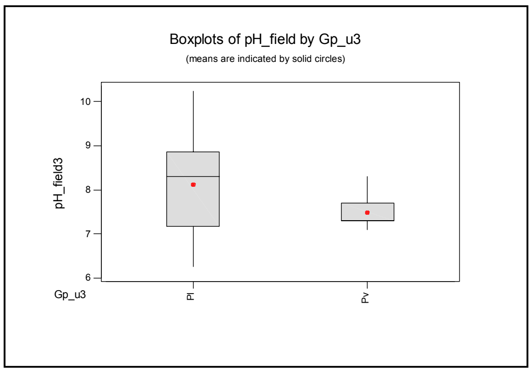
Box plot to compare the two Geopedologic units (1st and 2nd horizons)

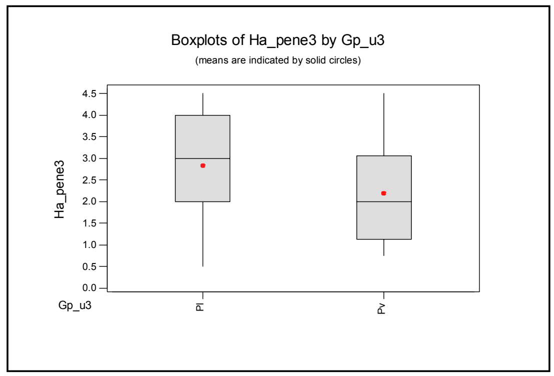


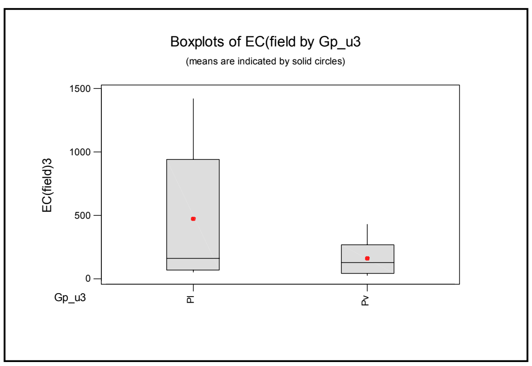


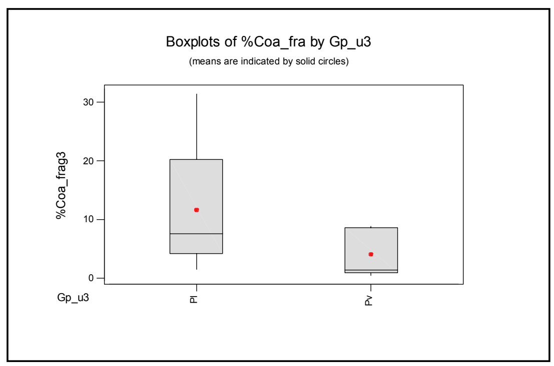


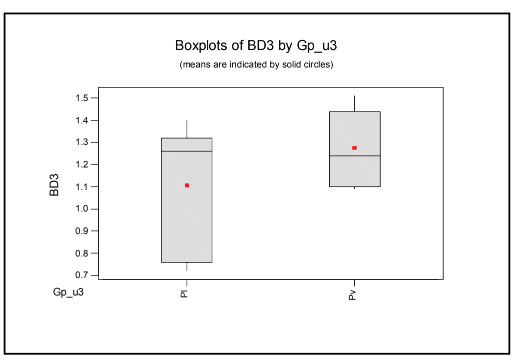
Box plot to compare the two Geopedologic units (lacustrine and volcanic plain, 3rd horizon)











One-way Analysis of Variance of Geopedologic units

Top-horizon pH

Analysis of Variance for pH_field1 (topsoil pH)

Source	DF	SS	MS	F	P
Gp_u	1	2.036	2.036	5.78	0.024
Error	26	9.162	0.352		
Total	27	11.198			

```
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level        N      Mean     StDev  ----+---------+---------+---------+--
Pl           9    7.3800    0.7929               (-----------*----------)
Pv          19    6.8026    0.4791  (-------*-------)
                                    ----+---------+---------+---------+--
Pooled StDev =    0.5936              6.65      7.00      7.35      7.70
```

Top-horizon Bd

Analysis of Variance for BD1 (bulk density)

Source	DF	SS	MS	F	P
Gp_u	1	0.5655	0.5655	16.25	0.000
Error	24	0.8353	0.0348		
Total	25	1.4007			

```
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level        N      Mean     StDev  -----+---------+---------+---------+-
Pl           7    0.8686    0.2561  (--------*--------)
Pv          19    1.2011    0.1567                           (----*-----)
                                    -----+---------+---------+---------+-
Pooled StDev =    0.1866               0.80      0.96      1.12      1.28
```

Top-horizon hand penetration test

Analysis of Variance for Ha_pene1 (topsoil hand penetration test)

Source	DF	SS	MS	F	P
Gp_u	1	1.32	1.32	0.75	0.395
Error	27	47.69	1.77		
Total	28	49.01			

```
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level        N      Mean     StDev  ----+---------+---------+---------+--
Pl           9     1.889     1.587  (--------------*---------------)
Pv          20     2.350     1.204              (---------*---------)
                                    ----+---------+---------+---------+--
Pooled StDev =     1.329              1.20      1.80      2.40      3.00
```

Top horizon EC

Analysis of Variance for EC(field1)

Source	DF	SS	MS	F	P
Gp_u	1	116304	116304	0.39	0.535
Error	26	7667306	294896		
Total	27	7783610			

```
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev

Level       N      Mean     StDev  ---------+---------+---------+-------
Pl          9     440.0     545.5    (--------------*-------------)
Pv         19     302.0     542.0   (---------*---------)
                                   ---------+---------+---------+-------
Pooled StDev =    543.0                   250       500       750
```

Top horizon % coarse fragments

Analysis of Variance for %Coa_fra

Source	DF	SS	MS	F	P
Gp_u	1	5.7	5.7	0.10	0.752
Error	27	1517.1	56.2		
Total	28	1522.8			

```
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N      Mean     StDev  ---+---------+---------+---------+---
Pl          9    10.308    10.071  (----------------*----------------)
Pv         20     9.348     6.094     (----------*-----------)
                                   ---+---------+---------+---------+---
Pooled StDev =    7.496              6.0       9.0      12.0      15.0
```

As shown above the analysis of variance (ANOVA) for the **top horizon** soil properties between the two Geopedologic units (the lacustrine and volcanic plain) shows that there is highly significant difference in bulk density and significant difference in soil pH. The bulk density of the volcanic plain was higher than the lacustrine plain. The pH of the volcanic plain top horizon was lower than the lacustrine plain.

On the other hand, there is no difference in the hand penetration test, electric conductivity and coarse fragment percentage between the two Geopedologic units at 95% confidence level.

Moreover, the lacustrine top horizon soils show wider range in hand penetration test, electric conductivity, and percentage of coarse fragments as compare to the volcanic soils. The volcanic plain soils show very narrow ranges in soil pH and bulk density.

Second horizon soil pH

Analysis of Variance for pH_field

Source	DF	SS	MS	F	P
Gp_u2	1	2.910	2.910	5.27	0.038
Error	14	7.729	0.552		
Total	15	10.639			

```
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level        N      Mean     StDev  -------+---------+---------+---------
Pl           7    8.1786    1.0962               (---------*---------)
Pv           9    7.3189    0.2549  (--------*--------)
                                    -------+---------+---------+---------
Pooled StDev =    0.7430                 7.20      7.80      8.40
```

Second horizon soil Bd

Analysis of Variance for BD2

Source	DF	SS	MS	F	P
Gp_u2	1	0.5676	0.5676	18.69	0.001
Error	12	0.3644	0.0304		
Total	13	0.9320			

```
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level        N      Mean     StDev  -------+---------+---------+---------
Pl           5    0.8320    0.2276  (--------*-------)
Pv           9    1.2522    0.1402                         (------*-----)
                                    -------+---------+---------+---------
Pooled StDev =    0.1743                 0.80      1.00      1.20
```

Second horizon soil hand penetration test

Analysis of Variance for Ha_pene2

Source	DF	SS	MS	F	P
Gp_u2	1	0.92	0.92	0.50	0.489
Error	15	27.24	1.82		
Total	16	28.15			

```
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level        N      Mean     StDev  ----+---------+---------+---------+--
Pl           7     2.929     1.519  (---------------*--------------)
Pv          10     3.400     1.220            (------------*------------)
                                    ----+---------+---------+---------+--
Pooled StDev =     1.348              2.10      2.80      3.50      4.20
```

Second horizon EC test

Analysis of Variance for EC(field)

Source	DF	SS	MS	F	P
Gp_u2	1	430280	430280	3.88	0.069
Error	14	1553932	110995		
Total	15	1984212			

```
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level        N      Mean     StDev  -------+---------+---------+---------
Pl           7     408.6     507.8               (---------*----------)
Pv           9      78.0      29.2   (--------*---------)
                                    -------+---------+---------+---------
Pooled StDev =     333.2                    0       250       500
```

Second horizon % coarse fragments

Analysis of Variance for %Coa_fra

Source	DF	SS	MS	F	P
Gp_u2	1	9.3	9.3	0.17	0.684
Error	15	812.4	54.2		
Total	16	821.8			

```
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N      Mean     StDev  -----+---------+---------+---------+-
Pl          7     8.306     8.354    (----------------*----------------)
Pv         10     6.799     6.614  (-------------*--------------)
                                   -----+---------+---------+---------+-
Pooled StDev =    7.359                3.5       7.0      10.5      14.0
```

The analysis of variance (ANOVA) for the **second horizon** soil properties between the two Geopedologic units (the lacustrine and volcanic plain) shows that there is highly significant difference in bulk density and significant difference in soil pH at 95% confidence level. This result is the same as the first horizon. The bulk density of the volcanic plain was higher than the lacustrine plain. And, the pH of the volcanic plain top horizon was lower than the lacustrine plain. Moreover, there are differences between the volcanic and lacustrine plain at a confidence level of 93% for soil EC. The lacustrine plain soils had the highest EC values.

On the other hand, there is no difference in the hand penetration test and coarse fragment percentage between the two Geopedologic units at 95% confidence level.

Moreover, both the lacustrine and the volcanic (second horizon) soils show wide range of values in hand penetration test and percentage of coarse fragments. The volcanic plain soils show narrow ranges of values of bulk density as compared to the other soil properties.

Third horizon soil pH

Analysis of Variance for pH_field

Source	DF	SS	MS	F	P
Gp_u3	1	1.612	1.612	1.84	0.197
Error	14	12.280	0.877		
Total	15	13.892			

```
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N      Mean     StDev  --------+---------+---------+--------
Pl          9    8.1256    1.1891              (----------*-----------)
Pv          7    7.4857    0.4018  (------------*-----------)
                                   --------+---------+---------+--------
Pooled StDev =   0.9366                  7.20      7.80      8.40
```

Third horizon soil bulk density

Analysis of Variance for BD3

Source	DF	SS	MS	F	P
Gp_u3	1	0.0995	0.0995	1.89	0.194
Error	12	0.6299	0.0525		
Total	13	0.7294			

```
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N      Mean     StDev  ---------+---------+---------+-------
Pl          7    1.1057    0.2823  (------------*-----------)
Pv          7    1.2743    0.1590             (------------*------------)
                                   ---------+---------+---------+-------
Pooled StDev =   0.2291                   1.05      1.20      1.35
```

Third horizon hand penetrometer test

Analysis of Variance for Ha_pene3

Source	DF	SS	MS	F	P
Gp_u3	1	1.77	1.77	1.12	0.306
Error	15	23.59	1.57		
Total	16	25.36			

```
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N      Mean     StDev  ---+---------+---------+---------+---
Pl          9     2.833     1.275             (-----------*------------)
Pv          8     2.188     1.230   (------------*-------------)
                                   ---+---------+---------+---------+---
Pooled StDev =    1.254             1.40      2.10      2.80      3.50
```

Third horizon soil EC test

Analysis of Variance for EC(field)

Source	DF	SS	MS	F	P
Gp_u3	1	256706	256706	2.08	0.171
Error	14	1727506	123393		
Total	15	1984212			

```
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N      Mean     StDev  ---------+---------+---------+-------
Pl          9     334.3     463.8              (---------*---------)
Pv          7      79.0      33.7   (----------*-----------)
                                   ---------+---------+---------+-------
Pooled StDev =    351.3                     0       250       500
```

Third horizon % coarse fragment

Analysis of Variance for %Coa_fra

Source	DF	SS	MS	F	P
Gp_u3	1	155.0	155.0	2.08	0.183
Error	9	671.7	74.6		
Total	10	826.7			

```
                                  Individual 95% CIs For Mean
                                  Based on Pooled StDev
Level       N      Mean     StDev -------+---------+---------+---------
Pl          6    11.598    10.987             (-----------*----------)
Pv          5     4.060     4.125 (------------*-----------)
                                  -------+---------+---------+---------
Pooled StDev =    8.639                0.0       7.0      14.0
```

The analysis of variance (ANOVA) for the **third horizon** soil properties between the two Geopedologic units (the lacustrine and volcanic plain) shows that there no significant difference. Most of the properties are significant at 80% confidence interval. Relatively, by looking at their means, soil pH, EC, hand penetrometer test and % of coarse fragments, lacustrine soils for the third horizon have higher values. On the other hand, values of bulk density are higher in the volcanic plain.

5.3.7. Penetration Resistance

*Using **C.B.R.** instrument:* Visual comparative interpretation in penetration resistance between the paired sample points (unmanaged and the managed sites) was made. It is known that penetration resistance test using C.B.R. or other similar instruments is affected by the moisture, bulk density (Bd), and gravel content of the soil (see section 2.6 and 4.2). During the field survey, there were variabilities in soil moisture content of the soil. Though differences due to Bd and gravel contents of the paired comparison points are not as such significantly different.

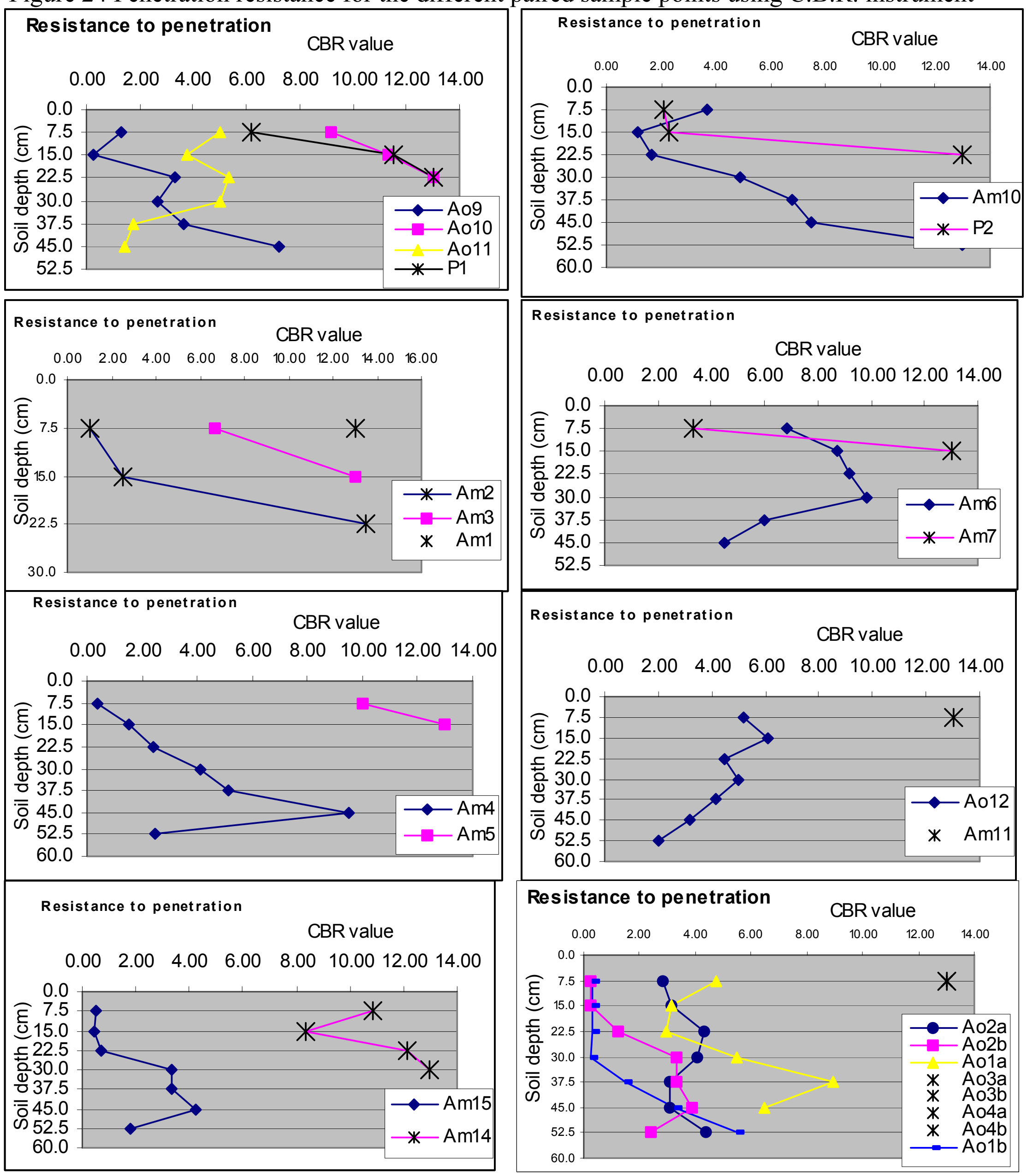
For sites having similar soil moisture, bulk density, and gravel contents it can be noticed, from the graph, that penetration resistance for unmanaged sites is higher near the surface than the managed sites, for example, P2 vs Am10 and Am2 vs Am3. This is mainly because of ploughing. Ploughing pulverised the top 0-30-cm, therefore resulting in low penetration resistance. Most of the managed sites start to be more compacted from 20-30-cm downwards. Depending on the ash and gravely layers in the soil profile, the penetration resistance reading also fluctuates. Moreover, there is a difference between the furrow and raised bed observation points (Ao5a vs Ao5b, Ao6a vs Ao6b, Ao1a vs Ao1b, Ao2a vs Ao2b). The main reason for the compactness of the furrows than the raised beds could be due to the use of light and heavy machinery, and trampling by human beings.

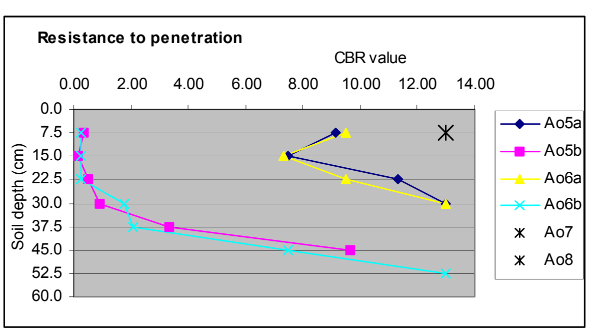
Some observation points were very compacted, beyond C.B.R value of 13, at the surface ~7-cm. Therefore, only one observation was recorded and plotted on the graph Figure 24

*Using **Hand** Penetrometer:* The Hand Penetrometer can measure only up to 4.5kg/cm^2 (see section 4.2). The data, which was collected during the fieldwork phase, is analysed in this section. Each data point, of the paired sample points, is an average from three observation readings. It was measured by pressing the hand penetrometer into the horizons sidewise (not vertically).

Similar to the C.B.R. method, this test is also affected by the soil moisture condition, bulk density (Bd), gravel and ash content of the horizons. Because of this, there is no clear difference between the unmanaged and high-tech managed observation points. Unmanaged sites Am5 and Am7 show lower values of penetration resistance at the lower horizons than the managed plots Am4 and Am6. On the other hand, Am14 vs Am15, Am2 vs Am3, P2 vs Am10 didn't show variability (see Figure 25)

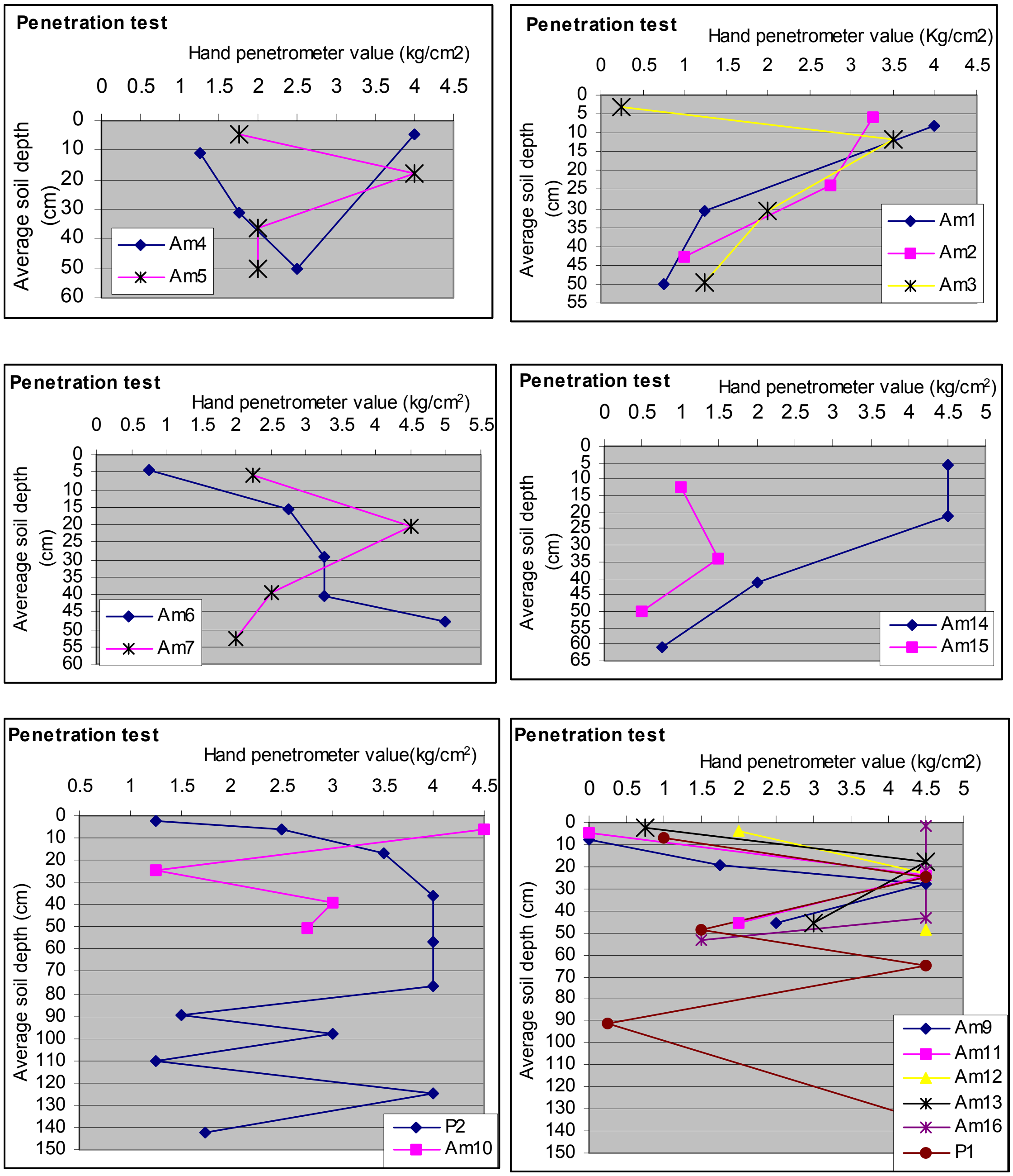
Figure 24 Penetration resistance for the different paired sample points using C.B.R. instrument





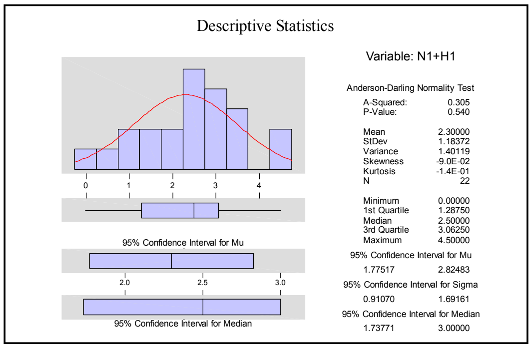
NB: code “a” stands for furrow observations and “b” for ridge (raised bed) observations

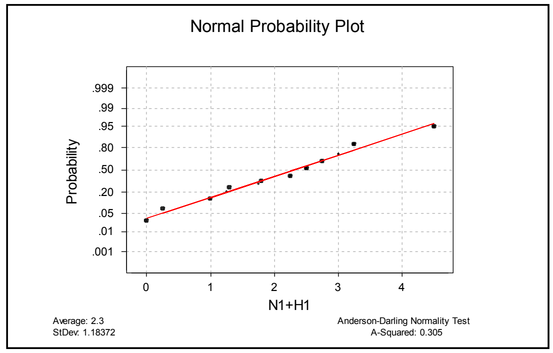
Figure 25 Penetration resistance test results using hand penetrometer for each site

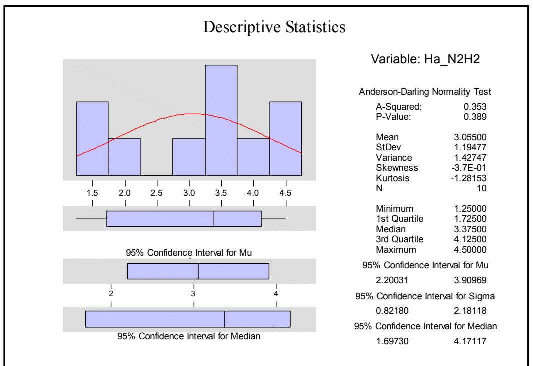


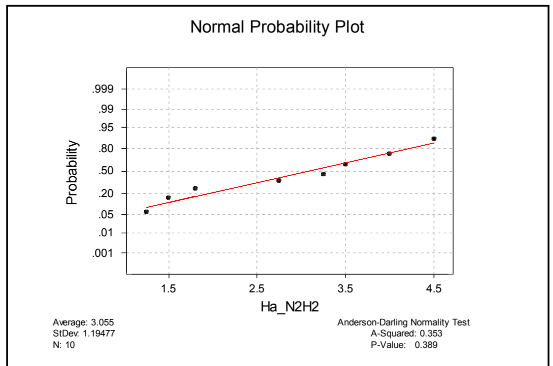
Hand penetration test results

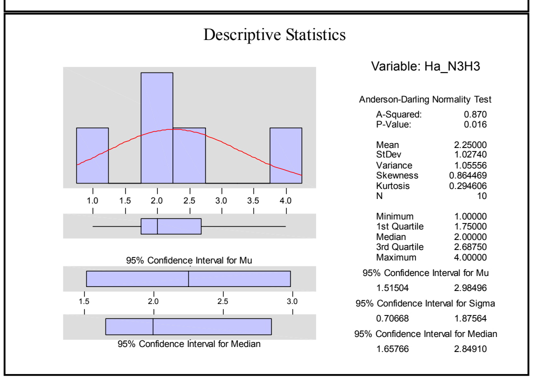
Figure 26 Normal probability plot and descriptive statistics of hand penetration test.

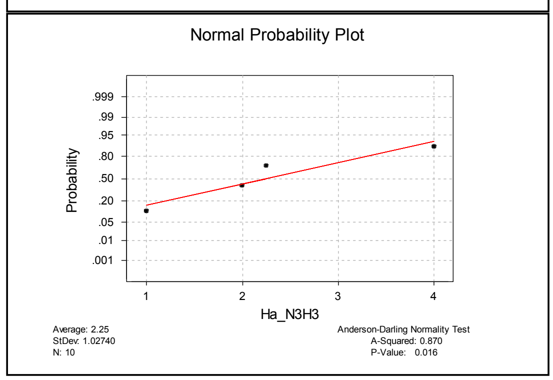




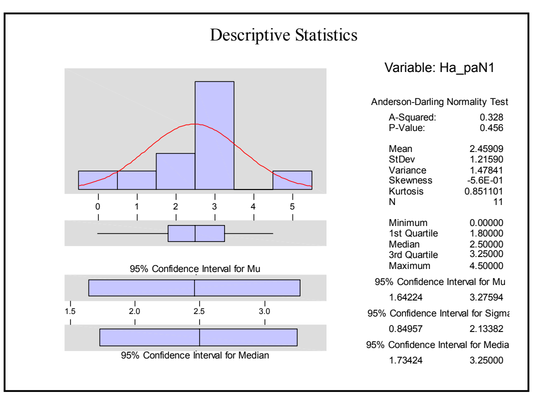


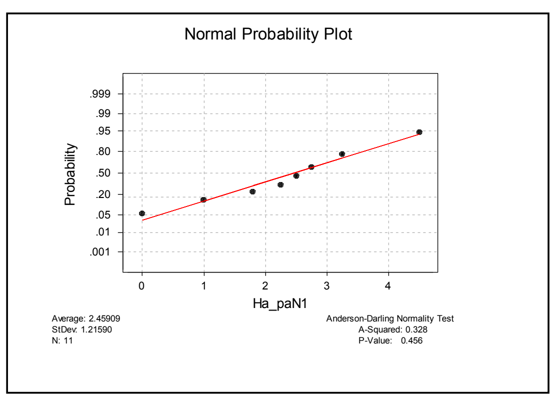


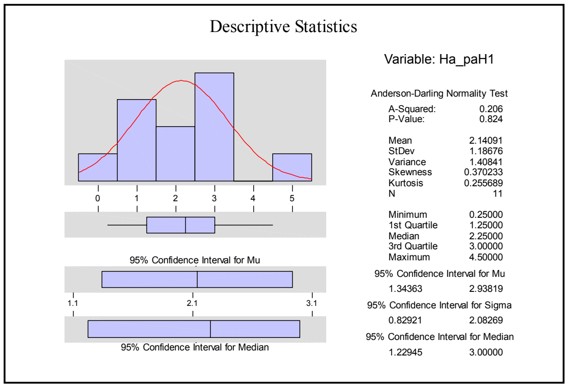


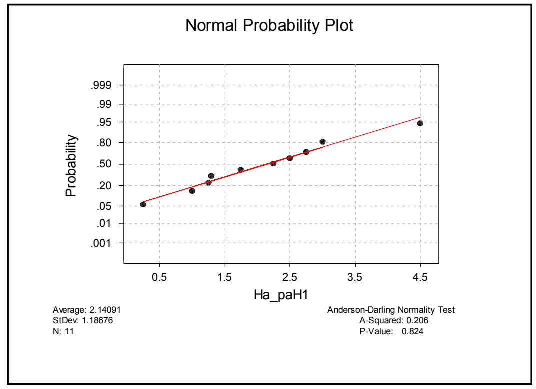


Descriptive statistics and normal probability plot of hand penetration test (1st horizon)

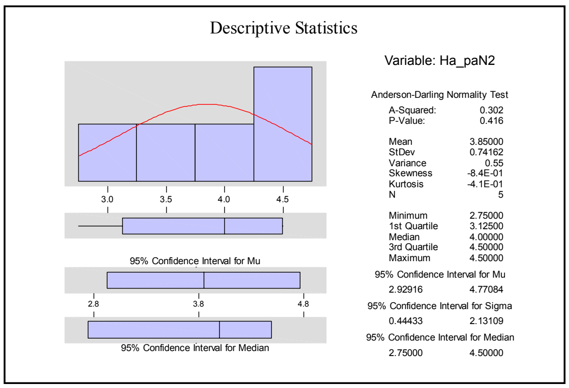


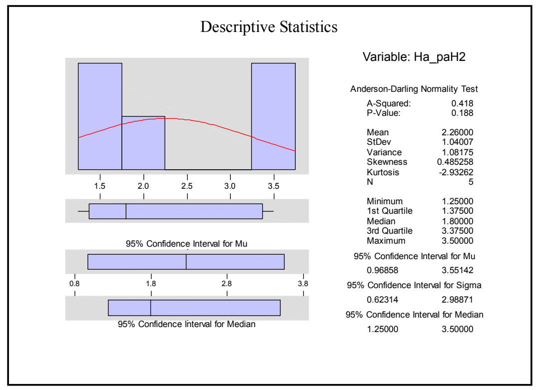




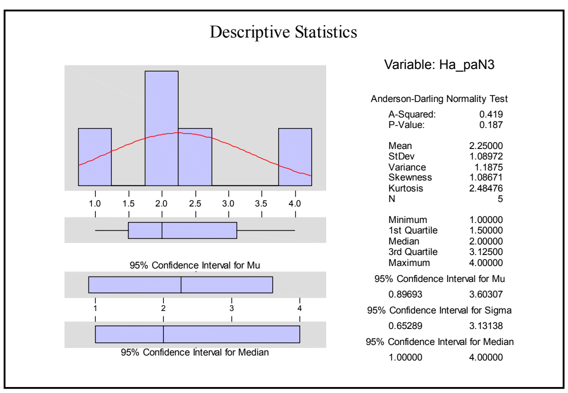


Descriptive statistics of hand penetration test (2nd horizon)





Descriptive statistics of hand penetration test (3rd horizon)



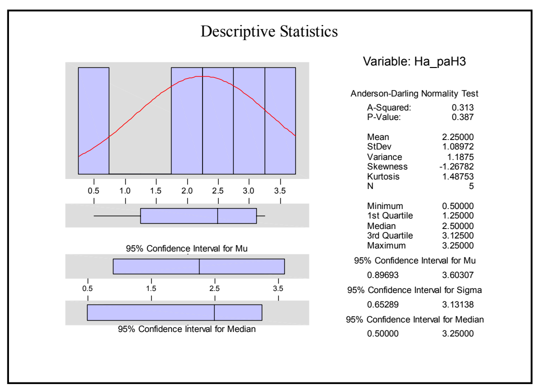


Table 15 Analysis of hand penetration test results at $\alpha = 0.05$

Management	Hor	# of samp.	Median	Mean	SE of mean	Anderson-Darling Normality test		Statistical method used	Difference			
							p-value		Mean difference	SE of mean difference	ETA1-ETA2	**p-value**
All	1	22	2.5	2.3		N	0.54					
Not managed	1	11	2.5	2.46	0.37	N	0.456	t-test	0.318	0.627		0.623
Managed	1	11	2.25	2.14	0.36	N	0.824					
All	2	10	3.375	3.06		N	0.389					
Not managed	2	5	4	3.85	0.38	N	0.416	MW			1.5	**0.046***
Managed	2	5	1.8	2.26	0.33	N	0.188					
All	3	10	2	2.25		NN	0.016					
Not managed	3	5	2	2.25	0.49	N	0.187	MW			-0.25	0.83
Managed	3	5	2.5	2.25	0.49	N	0.387					

Where N = Normally distributed
NN = Not normally distributed
* = significant at 95%

MW = Mann-Whitney test (non parametric test)
ETA1-ETA2 = Point estimate

From the analysis, it can be concluded that there is significant difference between the managed and non-managed sites for the second horizon at 95% confidence interval. But, there is no significant difference between the managed and non-managed sites for the first and the third horizons at 95% confidence interval.

Correlation (Pearson)

	Ha_N1	Ha_H1	Ha_paN2	Ha_paH2	Ha_paN3
Ha_H1	-0.412				
	0.490				
Ha_paN2	0.066	0.157			
	0.916	0.801			
Ha_paH2	-0.117	-0.409	-0.301		
	0.851	0.494	0.622		
Ha_paN3	-0.274	0.951	0.174	-0.664	
	0.655	<u>0.013</u>	0.780	0.221	
Ha_paH3	-0.893	0.631	-0.135	0.251	0.421
	<u>0.041</u>	0.253	0.828	0.684	0.480

The values at the top: Correlation
At the bottom: P-Value

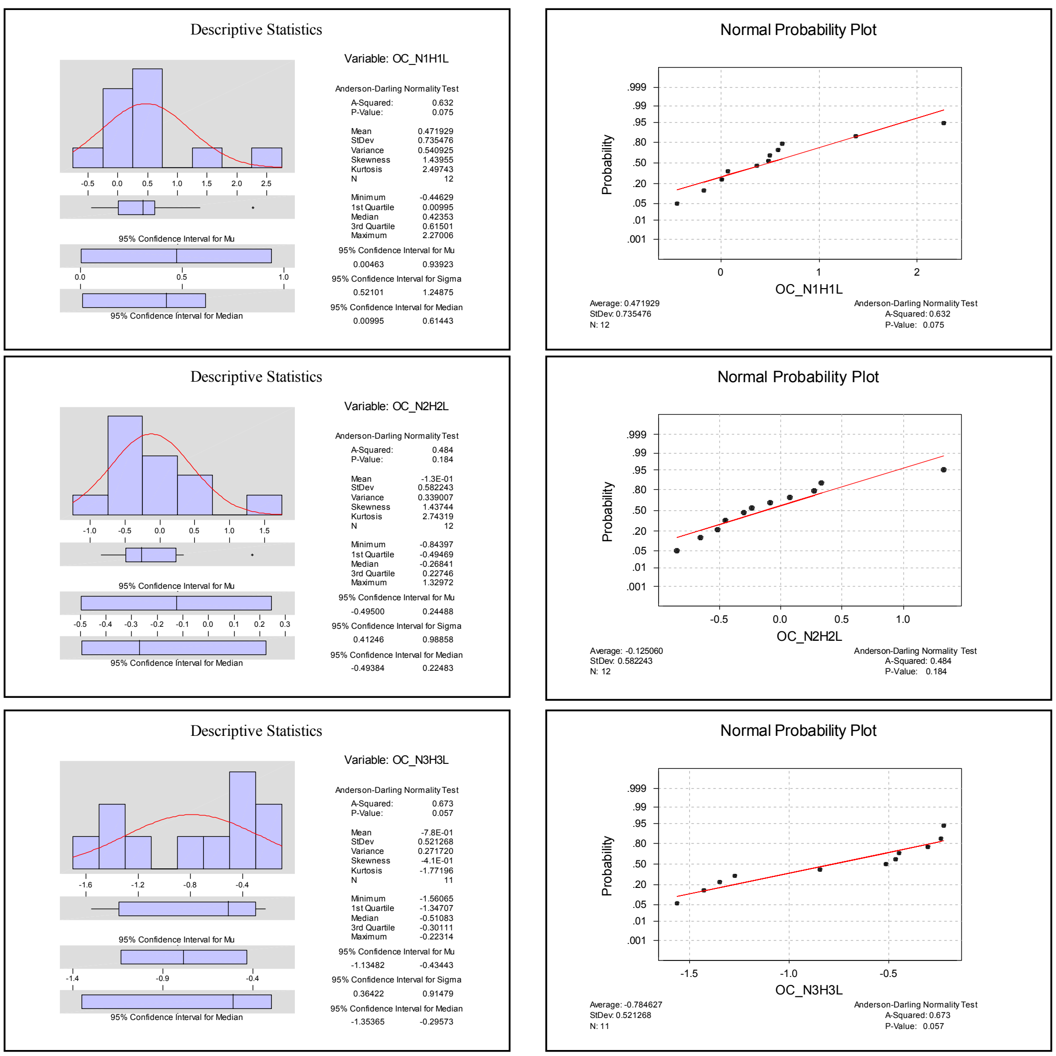
Correlation between all possible combinations of the three horizons was made. From the analysis above one can see that there is significant correlation between unmanaged horizon 1 and high-tech managed horizon 3 (negative correlation); and high-tech managed horizon 1 and unmanaged horizon 3 at 95 % confidence interval (they are underlined above).

5.3.8. Organic Matter Content

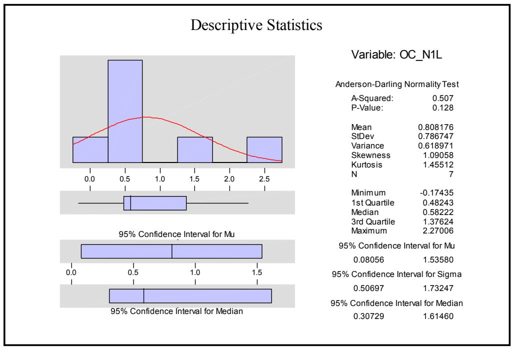
Organic matter content of 5 paired data points for the managed and unmanaged sites of the 1st, 2nd and 3rd horizons is analysed in this section. This is a very small sample, so no firm conclusions should be drown. The results of the analysis using Mann-Whitney test show that (see Table 1) there is significant difference between the managed and unmanaged pairs of the first horizon at 95% confidence interval. Most of the observation points for this analysis are from the lacustrine plain where initial OM contents are high due to thick vegetation and periodic high water tables. Upon cultivation and drainage, they become exposed and aerated. On the other hand, there is no significance difference between the 2nd and 3rd horizon also. Generally, the significant difference in the 1st horizon alone, while significant, is too small (median 0.8) does not provide strong statement to qualify it as a phenoform.

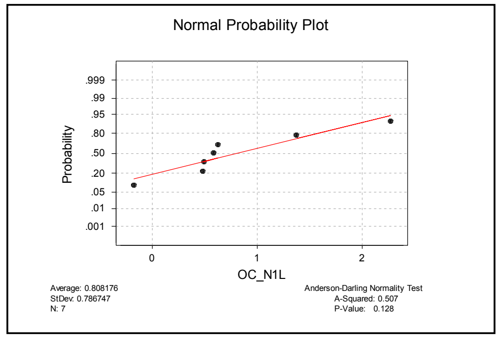
Figure 27 Descriptive statistics and normal probability plots for the soil OC

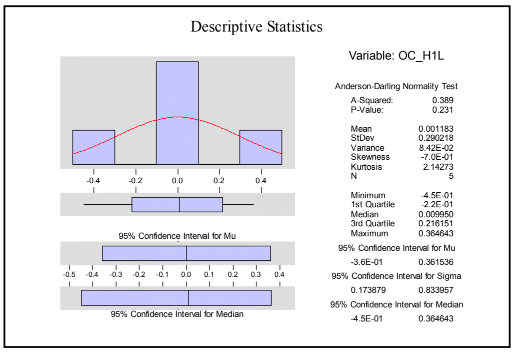
Descriptive statistics and normal probability plots for the soil OC (all horizons, log transformed)

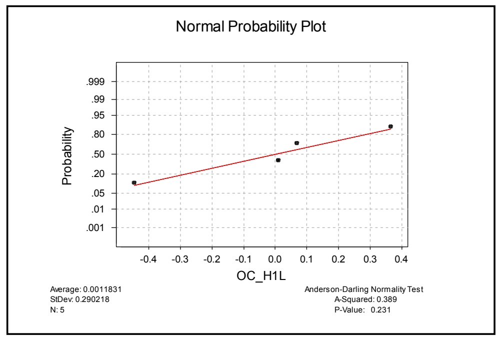


Descriptive statistics and normal probability plots for soil OC (1st horizon pairs)

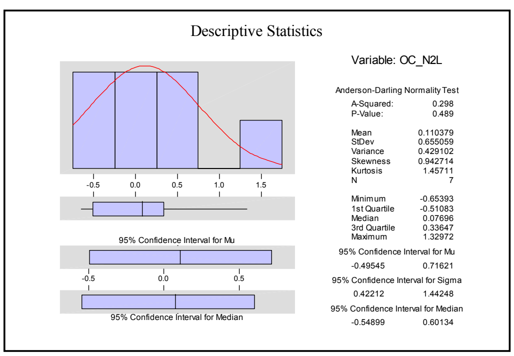


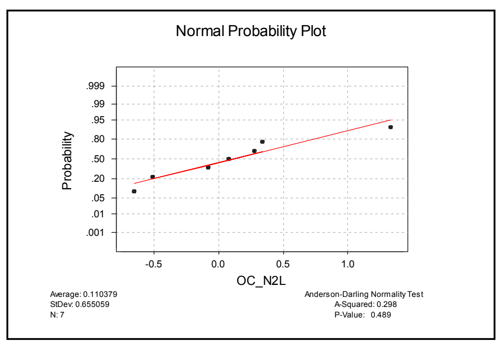


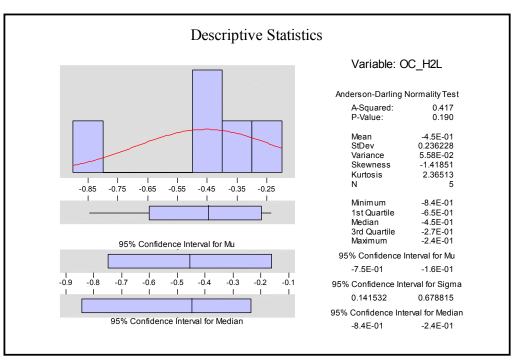


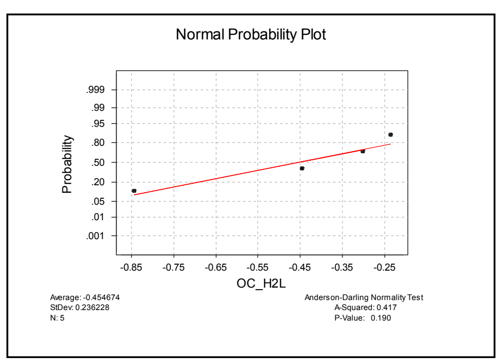


Descriptive statistics and normal probability plots for soil OC (2nd horizon pairs)

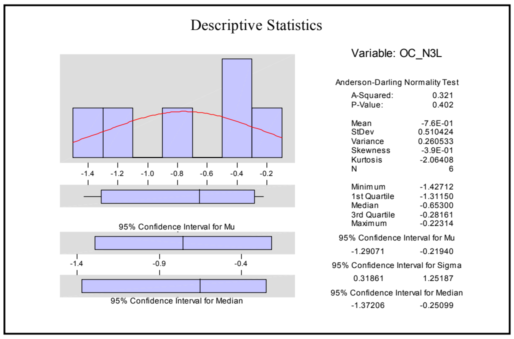


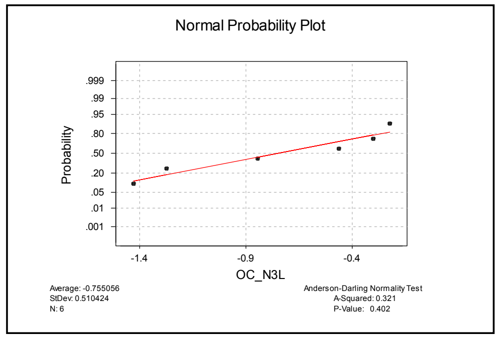


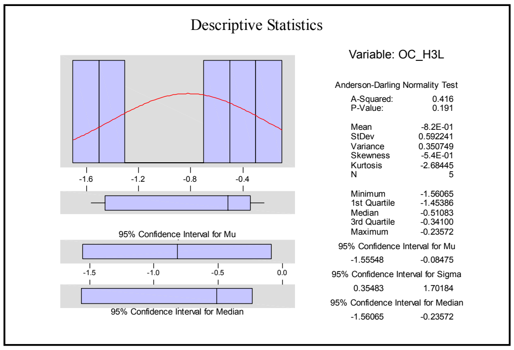


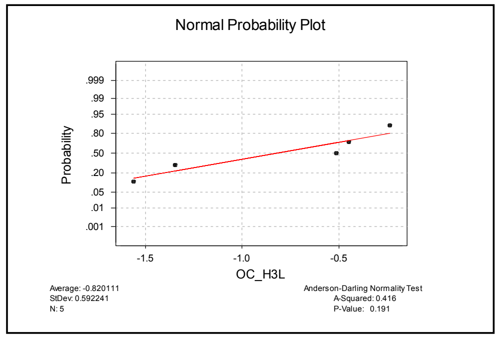


Descriptive statistics and normal probability plots for soil OC (3rd horizon pairs)









Correlation (Pearson)

	OC_N1	OC_H1	OC_N2	OC_H2	OC_N3
OC_H1	-0.822				
	0.088				
OC_N2	0.185	0.049			
	0.692	0.938			
OC_H2	-0.735	0.528	0.525		
	0.157	0.361	0.364		
OC_N3	0.452	-0.274	0.663	0.305	
	0.369	0.656	0.151	0.618	
OC_H3	-0.492	0.533	0.634	0.576	-0.189
	0.400	0.355	0.250	0.309	0.761

```
The values at the top are: Correlation
        At the bottom are: P-Value
```

The correlation result shows that the managed vs unmanaged sites do not show significant correlation. Though marginally not significant, the first horizon's organic carbon content in unmanaged sites is negatively correlated with that of the managed sites, which implies that larger initial contents are disproportionately depleted, at least in this small sample.

Table 16 Log-transformed soil OC test results at $\alpha = 0.05$

Management	Hor	# of samp.	Median	Mean	SE of mean	Anderson-Darling Normality test		Statistical method used	Difference	
							p-value		ETA1-ETA2	**p-value**
All	1	12	0.4235	0.472	0.21	N	0.085			
Not managed	1	7	0.58	0.081	0.3	N	0.128	MW	0.572	**0.035***
Managed	1	5	0.01	0.001	0.13	N	0.231			
All	2	12	-0.286	-0.13	0.17	N	0.184			
Not managed	2	7	0.08	0.11	0.25	N	0.489	MW	0.144	0.523
Managed	2	5	-0.45	-0.45	0.11	N	0.19			
All	3	11	-0.51	-0.78	0.16	N	0.06			
Not managed	3	6	-0.65	-0.76	0.21	N	0.402	MW	0.78	0.61
Managed	3	5	-0.511	-0.82	0.27	N	0.191			

Where N = Normally distributed
NN = Not normally distributed
* = significant at 95%

MW = Mann-Whitney test (non parametric test)
ETA1-ETA2 = Point estimate

5.4. The Phenoform Concept

5.4.1. Soil Properties and the Phenoform Concept

Previous studies, in particular by Bouma and Droogers, have shown that different management practices within a genoform resulted in a different phenoform that are relevant for management. Soil properties including organic matter content, bulk density, porosity, soil structure and soil moisture supply capacity were found to be important parameters to consider.

Considering these important soil properties, some comparative statements between managed and unmanaged sites of the study area could be made.

Appendix A, the dominant soil types of the study area are Areni-Vitric Andosols (Eutric) and Sodi-Fluvic Cambisols (Skeletic, Eutric) in the WRB 1998 system. These soils are generally not well developed. They have sandy loam to loamy sand soil texture, weak to very weak soil structure and their parent material is ash derived form volcanic materials. The soils of the volcanic plain mainly Areni-Vitric Andosols that have not been under cultivation have very low organic matter content as compared to the lacustrine plain soils.

Soil structure is one of the important soil properties which is often affected by management. Influence of the different management practices is evident mainly in the topsoil (0-50cm). The weak to very weak type of soil structure of these soils tend to be destroyed by plowing turning them in to powdery masses. Therefore leading to poor soil aeration, decreased infiltration, problem of capping and susceptible to wind erosion. Soil structure can not be used to diagnose phenoforms because they may vary strongly within a single growing season following tillage and or compaction, also it does not persist as in the cleyey Duch soils studied by Bouma and Droogers.

Bulk density: the soils of the study area do not have a very long history of cultivation as, for example, soils of the Netherlands. Most of them have been used for not more than 20-30 years, is mostly under rotation farming that allows soils to regain their physical and chemical fertility. Differences in bulk density between the managed and unmanaged plots were not significant. It was significant only between the two-geopedologic landscape units, the lacustrine and the volcanic plain; this is of coarse a genoform difference.

Physical features: surveys on soil compaction, crusting and sealing properties of the soils of the study area provide little information in defining phenoforms. Soil compaction was found to be a bit higher on the furrows than the ridges of dry previous carnation fields in the volcanic plain. In addition, silt cemented or compacted layer at a depth of 62-68 cm was found, but a single layer was found in one of the unmanaged sites (Am16) which is quite deep to define it as a phenoform. This silt-cemented layer is probably due to irrigation. Generally, the soils of the study area when they are put under cultivation they produce thin surface crusts that need to be broken almost every week.

Naturally, may be due to wild life trampling, these soils form compacted layer at the surface which is very difficult to penetrate (greater than 13 C.B.R.). Cultivation on these types of soils improved the surface compactness. But, turning them in to powdery masses.

Organic matter content: the soils of the volcanic plain, generally, have low organic carbon and nitrogen content. Organic matter content in the soil increases slightly upon cultivation especially when it is for a longer period of time through the leftover (crop residues) and application of irrigation water. On the other hand, organic carbon content and nitrogen in the lacustrine plain are generally high (for example >3% OC) compared to the volcanic plain (<0.6%). In the lacustrine plain, both OC and N decrease when they are put under cultivation. Kwacha (1998) noticed that OC was lower in managed plots than unmanaged plots giving little emphasis to the genoform differences. This could actually be due to clearing the natural forest to classify them as pure phenoform. The warm climate and the sandy nature of the soils could also speed up the depletion of the organic carbon content of the soil.

Porosity: the difference in soil porosity between the managed and unmanaged plots is not as such significant to be detected or to show differences. This is mainly due to the sandy nature of the soils. But, generally the macro pores in the unmanaged plots dominate than the managed plots. This property is not also strong enough to diagnose it as a phenoforms.

Infiltration: knowing the infiltration rates of these soils is very important for proper irrigation scheduling. This research has shown that there is a significant difference between the managed and unmanaged plots during the first 8 minutes of infiltration. They tend to be equal after steady state has been reached. The managed plots appear to show water repellant property during the initial state, perhaps because of poorer structure and/or organic matter coatings.

Chemical soil properties: chemical soil properties including EC and pH were not found to be significantly different. The main reason for this is because high-level management controls both EC and pH to fluctuate in an ideal crop growing range by applying chemicals such as phosphoric acid and nitric acid. By nature, the unmanaged soils have an ideal pH.

Management also regulates the macro and micronutrient levels of the soil. Because the soils cannot supply the required amounts of nutrients they have to be replenished almost every day for proper crop and or flower cultivation. But this does not cause permanent changes in soil properties.

5.4.2. Phenoforms vs the Phase Concept

The concept of the phenoform is narrower in scope than the concept of the phases. With the concept of the phenoforms, focus is only given to the impact of the management practices on soil properties. According to USDA soil survey manual (1993) if a property of a taxon has too wide a range for the interpretations needed or if some feature outside the soil itself is significant for use and management, these are the bases for defining phases. From the definition, phenoforms are included under phases.

Soil properties that are affected by management are many. The effect can be in biological, physical and or chemical property. They can vary from one type of management to the other. They can also vary depending on the type of soil under management. In addition, to detect pure phenoforms the soil should be managed for longer period of time.

The proposed FAO topsoil classification system seems to include some properties needed to describe phenoforms. For example, differences in organic carbon content between managed and unmanaged soils, if they are significantly different, can be described or highlighted.

Depending on the intensity of the management activity, a soil having a mollic or an umbric epipedon (high organic carbon content) might have its OC depleted by management and may end up in to an ochric epipedon. This brings in a change in the soil classification, for example, from Mollisol to Inceptisol.

5.4.3. Soil Management

Some of the management of activities in the study area are summarised in Table 17. The details are in appendix E.

Table 17 Summary of the management practices for the observation points

Obs_Id	Location	Crop type	Variety	Land pre-pararation	Weeding	Fertigation frequency	Source of irrigation water	Crop residue mgmt	Insecticide & Fungicides use	Previous History
Ao5 and Ao6	Roses IV Sulmac	Roses	Kwalk Kilimanjaro	At least 3 times	Manually weekly	Every day except Sunday	Lake (drip)	No	Yes	Carnation field
Ao9, Ao10 & Ao11	Hypericum project Sulmac	Hypericum	Pinky Flair	Same	Same	Same	Lake (drip)	No	Yes	Same
Am10	Sher-Agencies	Rose	Rumba	3 times	Manually	Same	Bore hole + lake (drip)	Yes	Yes	Under Gypsophillia
Am6	Oserian research plot	Statice Carnations	Perezi & others	3 time	Manually	Every day	Bore hole	Compost applied	Yes	Research plot
Am15	Kijabe	Roses	Cream prophyta	--	2 times a week	Same	Lake	Compost	Yes	Vegetables
Am4	Sulmac (30's)	Vegetables	-	At least 3 times	Weekly, manually	346 kg/ha broadcast	Lake	No	Yes	Carnations
Ao1 and Ao2	Sulmac (organics)	Squash	Raven	same	Manually	---	Lake	Use manure	No	Carnations

NB: the details are in appendix E

6. Conclusion

It is generally known that management practices such as tillage, fertilisation, insecticides, herbicides applications, etc. may result in changes in the physical and chemical properties of the soil. For example, soil compaction, problems of soil aeration, decline in soil fertility and the effect on soil ecosystem. The results of the different types of management have been called "phenoforms" whereas the genetically-defined soil types have been referred to as "genoforms". This study investigated to what extent this distinction is meaningful in the area of lake Naivasha, Kenya.

The main purpose of this study was to distinguish and characterise the different phenoforms formed by different management practices in the study area, and that are relevant for management. An additional objective was to verify the utility and practicability of the new proposed FAO topsoil classification, for making useful statements for soil management. The objectives both aim to make soil survey information directly useful for intensive soil management.

Most of the survey concentrated in three farms, namely Sulmac, Oserian, and Kijabe. The survey also focused on two agriculturally important geo-pedologic landscape units: the lacustrine and the volcanic plain.

Twenty-nine observation points with a total of 74 horizons were sampled. Eleven of them were paired (managed vs unmanaged). The paired observation points were chosen based on site observation, close to each other, with the same genoform and differing only in management practices. Soil properties including infiltration (I), bulk density (Bd), soil structure, organic mater content, coarse fragments, pH, EC, and penetration resistance (r) were determined.

The major geopedologic landscape units of the study area are hilland, volcanic plain and lacustrine plain. Both the lacustrine and the volcanic plains were subdivided in to high, mid and low relief/molding units. Generally there are no sharp boundaries between the landscape and relief units. In order to get geometrically correct geopedologic map and to overlay different maps, combine information and function as a database in geographic information system (GIS), an orthophoto mosaic was created.

Bulk density and soil pH test results show that these two units are significantly different. Soils in the volcanic plain have significantly higher Bd and significantly lower pH than those in the lacustrine plain. The parent material of both the lacustrine and volcanic plain soils is derived from volcanic material of both the Longonot volcano and Olkaria volcanic complex. The major soil types of the area are Areni-Vitric Andosols (Eutric) in the volcanic plain and Sodi-Fluvic Cambisol (Skeletic, Eutric) in the lacustrine plain. These soils are not well-developed. They have weak to very weak soil structure and sandy loam to loamy sand texture. Organic carbon content is very low in the volcanic plain as compared to the lacustrine plain. Soils on the volcanic plain are underlain by unweathered ash, sometimes loose and sometimes weakly cemented, whereas soils on the lacustrine plain are underlain by layers of reworked volcanic sediments of contrasting textures.

Flower and vegetable cultivation are the major landuse in the area. Cultivation largely depends on abstraction of water form the lake Naivasha. Very intensive management, including fertigation and heavy pesticide application, is common.

The paired (managed vs unmanaged) top three horizons did not show evidence of statistically-significant (95%) differences in soil pH, EC, Bd, and coarse fragment differences. Under high-tech management, these soil properties are regulated to fluctuate in an ideal range. Unmanaged soils happen to have already an optimal range for the selected crops. Due to this, expected differences were not observed. But, though not significant, some suggestive results in soil pH and soil EC, in the high-tech managed plots, were observed that they increase with depth, possibly due to leaching of agro-chemicals with irrigation water.

Initial (~0-8 minute) infiltration test results between the managed and unmanaged sites were significantly different. Unmanaged sites show higher initial values than the managed sites. This could mainly be because management slightly increased the water-repellent properties of these sandy soils. Water repellence manifests itself when the water content of the soil drops below a critical level, and is probably due to organic-coated sands.

Hand penetrometer test results of the second horizon showed significant difference (95%) between managed and unmanaged sites. The other two horizons didn't show significant differences. These results were highly affected by the moisture level, bulk density, the presence of an ash layer and gravel content of the soil, which were variable from one site to the other.

There was strong correlation in soil pH (considering 95% confidence interval) between the 2nd and the 3rd horizons of both unmanaged and managed sites. Weak correlation between the surface and the sub-surface horizons might have resulted due to the variable nature of the top horizon. On the other hand, there was strong correlation in soil EC between the three horizons, and weak correlation between all the horizons of the managed sites. This variability might have been caused due to differences in management activities.

There was good correlation in soil bulk density between the three horizons of the managed sites but weak with the unmanaged sites. This is mainly because deep tillage in these sandy soils mixes the different soil horizons. There was good correlation in coarse fragment contents between the first and the second horizon in the managed sites but weak between the horizons of unmanaged sites, which could also be explained similarly. Moreover, hand penetration test results showed weak correlation.

Topsoil pH and EC of the Longonot branch of the Sulmac farm were mapped using indicator kriging and ordinary kriging respectively. Generally, there was a significant difference in soil EC results between open field and vegetable plots. But, not significant for soil pH which is similar with the paired comparison test results. Even though they are significantly different the values show little management importance, because the absolute values are low.

The proposed FAO topsoil classification was found useful in highlighting most of the soil properties useful for management, for example the low nutrient retention, natric, and altaric properties of the soil. Proposed limits seemed realistic. On the other hand, other important production limitations such as excessive drainage, susceptibility to nematode infestation, some toxicities, potic properties, and soil capping were not recognized and could be added to improve the usefulness of the classification system.

The concept of the phenoform is narrower in scope than the concept of the phase. The soil properties used to define phenoforms vary from management to management and soil type to soil type. Management increased organic carbon content in the volcanic plain on the other hand, it decreased in the lacustrine plain. Thus any phenoform would have to be defined with respect to a specific genoform, and not in general.

The proposed FAO topsoil classification system seems to include some properties needed to describe phenoforms. For example, differences in organic carbon content between managed and unmanaged soils, when they are significantly different, can be described.

The phenoform concept in this landscape is less useful than found in the Netherlands, for a variety of reasons: parent material dominates soil properties, management has only short term effects, in these sandy, weakly-structured, poorly-buffered soils.

7. Recommendation

First, some recommendations on soil management in the study area, based on this study and field observations:

Soil tillage was found to destroy important soil physical properties such as soil structure. Therefore, either the property of the soil has to be improved by applying organic matter or should be done using appropriate tillage implements or one has to adjust the frequency of tillage.

Surface crusts easily form on the high-tech managed plots, they need to be broken down almost every week or else the surface soil physical property of the soils need to be improved by applying, for example, organic matter.

Soil laboratory tests are mostly conducted for the surface 0-20 cm. It is highly recommended to occasionally check subsoil properties also.

Planting windbreaks for the Longonot branch of Sulmac farm will help reduce the impact of wind erosion observed in the area.

Second, some recommendations on further work on characterising management effects on soils:

To improve the usefulness of the proposed FAO topsoil characterisation, production limitations such as excessively drained properties, problems of nematodes, some toxicities, potic nature, and soil capping could be added. A ‘potic’ modifier, indicating excessive K with respect to other cations, could be added by analogy to ‘sodic’.

Research on the concept of the phenoforms is better continued on areas that were put under management for a long period of time and where soil properties change rapidly and persist. And also on areas that are bigger in size (not patchy) to minimise the effect of genoform difference. Because the soil properties used to diagnose phenoforms are many and variable for the soil types considered, they contribute little for the general-purpose classification systems.

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Appendix A Profile Description

Soil classification of P1

WRB (1998)
The soil classifies as Areni-Vitric Andosol (Eutric). The soil shows an ochric horizon. Despite its organic carbon content (0.7 %, averaged to a depth of 25 cm) and slightly dark in colour, the diagnostic horizon has very weak soil structure to be classified as a mollic horizon. The soil has a vitric B-horizon. Because of high volcanic glass content, less clay and high bulk density, it doesn't qualify for andic horizon. The type of cementing material (probably silt in this case) and the thickness of the cemented layer does not classify it under petrocalcic, petroduric, and peterogypsic horizons. Furthermore, it has arenic qualifier due to its loamy sand texture at the upper 50 cm and eutric due to its high base saturation (>50%).

USDA (1998)
The soil classifies as Aridic Ustipsamments. Because the soil shows an ochric epipedon (surface horizon that, when mixed to a depth of 18 cm, contains 0.8% organic carbon, colour values darker then 4.5 when dry and 3.5 when moist; very weak structure, base saturation >50%). And lacks subsurface diagnostic horizon. They don't have an andic horizon because of their low phosphate retention. If their phosphate retention were high, it classifies as Typic Haplustands. More over the soil has ustic moisture regime. Because of its coarse soil texture, it qualifies for Psamments. It is also Aridic and isothermic (soil temperature regime).

Soil classification of P2

WRB (1998)
The soil classifies as Sodi-Fluvic Cambisol (Skeletic, Eutric). The soil shows an ochric horizon. Despite its OC (1.9 %, averaged to a depth of 25 cm from the surface), dark in colour (value < 3.5 when moist and dry to a depth of 25 cm), and higher base saturation (>50%) the diagnostic horizon has no (single grained) or very weak structure to be classified as mollic horizon. The soil has a cambic B-horizon. It doesn't qualify for argic horizon since it lacks an increase in clay content (clay illuviation). It has common to abundant pumice gravel content and fluvic material (from lacustrine sediments), therefore, it is skeletic and fluvic respectively. It also has high ESP >15% in the upper 30cm (sodic).

USDA (1998)
The soil classifies as Vitrandic Haplustepts. Because the soil shows ochric epipedon (surface horizon that, when mixed to a depth of 18 cm, contains 1.9 % OC, colour values darker than 4.5 when dry and 3.5 when moist; weakly developed structure, and relatively low bulk density, less than 1). It is not mollic or umbric because of its weakly developed structure. It has a cambic B-horizon, it doesn't qualify for argillic, kandic and oxic horizons because it lacks evidence of clay illuviation and clay increase with increase in depth respectively. The soil has ustic moisture regime. Due to pumice gravel (>35% by volume) it is classified as Vitrandic.

Profile P1 **Country: Kenya**

WRB (1998) : Areni-Vitric Andosol (Eutric)
USDA Soil Taxonomy (1998) : Aridic Ustipsamments
USDA Family Differentiae : Ashy, glassy, isothermic
Diagnostic Criteria WRB (1998): Ochric A, Vitric B horizon
USDA (1998) : Ochric epipedon
Soil moisture regime : Ustic

Location : Nakuru district, 13 km from Naivasha town, in Sulmac farm-farm unit73-3.
Latitude: 0^{o} 50' 48"S (9906308m UTM) Longitude : 36^{o} 22' 26"E (0207718m UTM)
Author (S) : Dr. DG Rossiter, Atkilt Girma & Paul Simfukwe
Date: September 13, 2000 Altitude : 1935 m a.s.l.

General Landform: Volcanic Plain Topography : Gently undulating
Slope gradient : 4% Form : Straight
Position of the site: middle slope Micro-topography : Low Hummocks
Surface Char. Rock outcrop : nil Stoniness : nil
Cracking : nil Slaking and crusting :
Salt : nil Alkali : nil
Soil erosion : Wind erosion and/or deposition,
Degree : Slight Activity : Active at present

Parent Material : Pyroclastic-ashes, agglomerates, & tuffs
Weathering degree : Fresh or slightly weathered

Effective soil Depth : >155 cm
Water Table : Not observed
Drainage : Somewhat excessively drained
Flooding frequency : Nil
Moisture condition of the profile: Dry

Landuse : Fallow, Under carnation flower until 4 years previously
Vegetation : At present natural grassland

Additional Remarks: P1 represents the mid and high volcanic plain. The depth of the profile is very deep. It is composed of an alternating volcanic ash layers. At depth of 62-68cm (Bm) there was a silt-cemented layer probably from past irrigation practices. Moreover, at depth 115-155 an obsidian boulder of size 9x6x2cm was found. At this layer, coarse sand mixed with glassy materials was also observed. These glassy materials are probably from obsidian glass.

Before four years it was under open field high-tech managed carnation flowers. The method of irrigation used was drip irrigation. For the purpose of reducing nematode infestation and to regain fertility it was put under rotation with the other blocks with a rotation period of four years.

PROFILE DESCRIPTION:

Very deep, Somewhat excessively drained, Olive brown loamy sand originated from volcanic ash.

Horizon Symbol	Thick-ness (cm)	**Description**
Ah	00-14	Olive brown (2.5Y 4/3 dry, 2.5Y 3/2 moist); loamy sand; very weak fine subangular blocky Structure; non-sticky, non plastic, soft; few to common, fine to very fine roots throughout; abrupt smooth boundary to
Bw1	14-35	Olive brown to dark olive brown (2.5Y 4/3 dry, 2.5Y 3/3 moist); loamy sand; very weak coarse subangular blocky structure; non-sticky, non-plastic, soft; very few channels (∅ 1-3cm) filled with gray material (ash); very few fine to very fine roots throughout; few channels; clear smooth boundary to
Bw2	35-62	Olive brown to dark olive brown (2.5Y 4/3 dry, 2.5Y 3/3 moist); loamy sand; single grained; non-sticky, non plastic, soft; very few channels (∅ 1-3cm) filled with gray material (ash); very few fine to very fine roots; abrupt smooth boundary to
Bm	62-68	Olive brown (2.5Y 4/3, dry) & light brownish gray (2.5Y 6/2, moist); loamy sand; massive structure; non-sticky, non-plastic, very hard; continuous, none structure, silt, weakly cemented; very few fine roots; abrupt smooth boundary to
C	68-115	Gray (5Y 5/1, dry) & very dark gray (5Y 3/1, moist); sand; single grained; non-sticky, non-plastic, loose; very few fine roots; abrupt wavy boundary to
2Cm	115-155+	Gray (5Y 6/1, dry) & very dark gray (5Y 3/1, moist); coarse sand; massive structure; non-sticky, non-plastic, hard; very few, fine, angular, fresh or slightly weathered pumice and obsidian rock fragments; continuous, none structure, silica, weakly cemented

Analytical Data:

Hor. no.	top	Bottom	>2mm	2000 1000	1000 500	500 250	250 100	100 50	Tot. Sand	50 20	20 2	Tot. Silt	<2 um	Disp	Bulk Dens. gm/cc
1	0	14													1.36
2	14	35													1.29
3	35	62													1.44
4	62	68													2.51
5	68	115													1.47
6	115	155													2.04

								Exch. Cat cmol(+)/kg					Exch. Ac.			
Hor. no.	top	Bott.	pH H_2O	pH KCl	Ca CO_3 %	OM C %	OM N %	Ca	Mg	K	Na	Sum	H+ Al	Al	B.Sat %	C/N
1	0	14	7	6		0.84	0.08	3.6	0.7	1.3	<0.1	5.7			>100	11
2	14	35	7.2	6.1		0.52	0.047	2.8	0.3	1.2	0.5	4.8			83.0	11
3	35	62	7.6	5.9		0.28	0.008	1.8	0.3	1.3	0.4	3.8			>100	35
4	62	68	7.6	5.5			0.004	1.6	0.3	0.5	0.2	2.6				
5	68	115	7.4	5.9			0.002	0.2	0.3	0.8	1.5	2.8				
6	115	155	7.8	5.8			0.001	0.2	15.5	13.9	3.4	33				

			CEC cmol(+)/kg						Clay Mineralogy						Ext. (Na dith		
Hor. no.	top	Bott.	soil	clay	orgC	ECEC	Al satu. %	EC mS/cm	Mica/ ILI	CHLO	KAO	MIX	GIB	GOET	Fe	Al	P-ret. (mg/kg
1	0	14	7					0.06									9
2	14	35	5.8					0.06									7
3	35	62	3.7					0.04									7
4	62	68						0.03									
5	68	115						0.03									
6	115	155						0.1									

NB: Except for bulk density, all analytical data are from ISRIC laboratory, Wageningen

Profile P2 **Country: Kenya**

WRB (1998) : Sodi-Fluvic Cambisol (Skeletic, Eutric)
USDA Soil Taxonomy (1998) : Vitrandic Haplustepts
USDA Family Differentiae : Ashy-pumiceous, mixed, isothermic
Diagnostic Criteria WRB (1998): Ochric A, Cambic B horizon
USDA (1998) : Ochric epipedon, Cambic horizon
Soil moisture regime : Ustic

Location : Nakuru district, 15 km from Naivasha town, in Sulmac farm (near the pumping station & staff lounge).
Latitude: 0^{o} 49' 35"S (9908546m UTM) Longitude : 36^{o} 20' 47"E (0204648m UTM)
Author (S) : Dr. DG Rossiter, Atkilt Girma & Paul Simfukwe
Date: September 14, 2000 Altitude : 1890 m a.s.l.

General Landform: Lacustrine Plain Topography : Gently undulating
Slope gradient : 0% Form : Straight
Position of the site: middle slope Micro-topography : surface is nearly level
Surface Char. Rock outcrop : nil Stoniness : nil
Cracking : nil Slaking and crusting : nil
Salt : nil Alkali : nil
Surface processes : lake influence (deposition), Erosion related with the lake fluctuation
Degree : Slight Activity: not active at present

Parent Material : Pyroclastic-ashes, agglomerates, tuffs, & lake sediments (reworked)
Weathering degree : Fresh and/or slightly weathered

Effective soil Depth : >152 cm
Water Table : Not observed
Drainage : Moderately well drained
Flooding frequency : Not known, but could be flooded by the lake level fluctuation
Moisture condition of the profile: Moist

Landuse : Not used not managed, Left as a nature protection
Vegetation : Savanna (Acacia), underneath grassland-cover >80%

Additional Remarks: P2 represents the mid and low lacustrine plain. The profile is very deep. It is composed of an alternating, reworked volcanic ash and lake sediment layers. At a depth of 103-118cm (4C) olive yellow, clear to sharp, distinct, fine, few to common mottles were observed. This glayic property occur below the depth at which they are mentioned in the classification. Moreover, at depth 9-67, 93-103, 118-132cm pumice gravel, which is compacted, is evident. At the fourth layer animal burrow filled material and roots 5 ∅, 40cm long was found. Further more, near the pit there are some drainage ditches dug.

PROFILE DESCRIPTION:
Very deep, Moderately well drained, dark brown loam (topsoil) originated from volcanic materials and lake sediments.

Horizon Symbol	Thick-ness (cm)	**Description**
O	00-04	Dark brown (10YR 3/3, dry); loam; single grained; loose slightly sticky, slightly plastic; very few, fine, subrounded, fresh pumice gravel's; many, fine, elongated channels (pores); many, very fine and fine roots throughout; abrupt smooth boundary to
Ah	04-09	Olive brown (2.5Y 4/3, dry) to very dark grayish brown (2.5Y 3/2 moist); loam; single grained; non-sticky, non-plastic, loose; few, fine and medium, subrounded, fresh pumice gravel; many, fine, elongated, channels (pores); many, fine and medium roots; abrupt smooth boundary to
A	09-25	Olive brown (2.5Y 4/3, moist); gravely loam; weak, fine and medium subangular blocky; slightly sticky, non-plastic, very friable; common, fine and medium subrounded gravel; pores interstitial & channels, very fine, many; few, very fine and fine roots; clear wavy boundary to
Bw1	25-47	Grayish brown (2.5Y 5/2, moist); gravely sandy loam; weak fine and medium, subangular blocky; slightly sticky, non plastic, very friable; common, fine and medium subrounded gravel; pores interstitial & channels, very fine, many; very few, very fine roots; few, infilled large burrows; clear smooth boundary to
Bw2	47-67	Grayish brown (2.5Y 5/2, moist); very gravely sandy loam; weak fine and medium, subangular blocky; non-sticky, non plastic, very friable; many, fine and medium, subrounded, fresh pumice gravel; pores interstitial & channels, very fine, many; very few, very fine roots; clear smooth boundary to
Bw3	67-86	Light olive brown (2.5Y 5/3, moist); dominant rock fragments (pumice gravel); very week, medium, subangular blocky and single grains; non-sticky non-plastic, very friable; dominant fine and medium, rounded, fresh pumice gravel; pores interstitial & channels, very fine, many; very few, very fine roots; abrupt smooth boundary to
2C	86-93	Grayish brown (2.5Y 5/2, moist); sandy loam; weak, very fine, platy structure; sticky, plastic, very friable; no gravel; many, coarse, channels; very few, very fine roots; abrupt smooth boundary to
3Bw	93-103	Grayish brown (2.5Y 5/2, moist); gravely sandy loam; weak, fine and medium, subangular blocky structure; non-sticky, non-plastic, very friable; abundant, medium, subrounded, fresh pumice gravel; very few, very fine roots; abrupt smooth boundary to
4C	103-118	Light olive brown (2.5Y 5/3, moist); sandy loam; strong, very fine, platy structure; non-sticky, non-plastic, very friable; abundant, fine subrounded, fresh pumice gravel; many, very fine, channel pores; few to common, fine, distinct, clear to sharp boundary, olive yellow (2.5Y 6/6) to dark yellowish brown (10YR 4/4) mottles; very few, medium and coarse roots; abrupt wavy boundary to
Bg1	118-132	Light olive brown (2.5Y 5/3); gravely sandy loam; weak medium subangular

		blocky structure; non-sticky, non-plastic, very friable; dominant, fine and medium, subrounded, fresh pumice gravel; many, very fine, channel pores; very few, fine roots; abrupt wavy boundary to
Bg2	132-152+	Olive brown (2.5Y 4/3, moist); sandy loam; weak, fine and medium, subangular blocky structure; non-sticky, non-plastic, very friable; common, fine and medium, subrounded, fresh pumice gravel; very few, coarse roots

Analytical Data:

Hor. no.	top	Bottom	>2mm	2000 1000	1000 500	500 250	250 100	100 50	Tot. Sand	50 20	20 2	Tot. Silt	<2 um	Disp	Bulk Dens. gm/cc
1	0	4													0.58
2	4	9													0.67
3	9	25													0.98
4	25	47													1.21
5	47	67													0.77
6	67	86													0.71
7	86	93													1.20
8	93	103													0.70
9	103	118													0.99
10	118	132													0.61
11	132	152													0.89

								Exch. Cat cmol(+)/kg					Exch. Ac.			
Hor. no.	top	Bott.	pH H_20	pH KCl	Ca Co_3 %	OM C %	OM N %	Ca	Mg	K	Na	Sum	H+ Al	Al	B.Sat %	C/N
1	0	4	6.3	5.9		3.96	1.063	41.2	15.5	13.9	3.4	74			97.0	4
2	4	9	9.3	8.1		3.78	0.226	19	6.8	16.2	20	62			>100	17
3	9	25	10.2	9.1		0.8	0.093	21	1.8	12.8	19.7	55.3			>100	9
4	25	47	10.2	8.8			0.033	9.1	1.1	13.7	20.6	44.5				
5	47	67	10.1	8.9			0.026	23.8	1.9	17	26.6	69.3				
6	67	86	10	8.7			0.038	26.6	3.7	27.5	17	74.8				
7	86	93	10.1	8.7			0.014	12.1	1.5	12.8	15.3	41.7				
8	93	103	10	8.7			0.028	25.2	3.4	19.7	37.3	85.6				
9	103	118	9.9	8.8			0.017	17.1	2.3	14.2	18.2	51.8				
10	118	132	9.9	8.7			0.017	8.4	2	14.6	13.6	38.6				
11	132	152	10	8.8			0.019	6.6	1.1	11	10.4	29.1				

			CEC cmol(+)/kg						Clay Mineralogy						Ext. (Na dithi		
Hor. no.	top	Bott.	soil	clay	orgC	ECEC	Al satu. %	EC mS/cm	Mica/ ILI	CHL O	KAO	MIX	GIB	GOET	Fe	Al	P-ret. (mg/kg
1	0	4	76.3					1.5									9
2	4	9	38.6					1.8									14.5
3	9	25	19.7					1.4									15.5
4	25	47						0.9									
5	47	67						0.9									
6	67	86						1									
7	86	93						0.6									
8	93	103						0.6									
9	103	118						0.6									
10	118	132						0.6									
11	132	152+						0.6									

NB: Except for bulk density, all analytical data are from ISRIC laboratory, Wageningen

Mini-pit Am1 **Country: Kenya**

WRB (1998) : Tephric Arenosol
USDA Soil Taxonomy (1992) : Aridic Ustipsamments
USDA Family Differentiae : Ashy, glassy, isothermic
Diagnostic Criteria WRB (1998): Ochric-A, tephric soil material
USDA (1992) : Ochric A
Soil moisture regime : Ustic

Location : Nakuru district, 17 km from Naivasha town, in Hells Gate National Park, High volcanic plain (Pv111)
Latitude: 0^{o} 52’ 03”S (9903996m UTM) Longitude : 36^{o} 22’ 45”E (0208308m UTM)
Author (S) : Dr. DG Rossiter, Atkilt Girma & Paul Simfukwe
Date: September 15, 2000 Altitude : 2005 m a.s.l.

General Landform: Volcanic Plain Topography : Gently undulating
Slope gradient : 3% Form : concave
Position of the site: middle slope Micro-topography : nil
Surface Char. Rock outcrop : nil Stoniness : nil
Cracking : nil Slaking and crusting : nil
Salt : nil Alkali : nil
Surface processes : wind erosion and deposition
Degree : moderate Activity: Active at present

Parent Material : Pyroclastic-ashes, agglomerates, & tuffs
Weathering degree : Fresh and/or slightly weathered pumice gravel

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Effective soil Depth : >1.5m
Water Table : Not observed
Drainage : well drained
Flooding frequency : nil
Moisture condition of the profile: Dry

Landuse : Wildlife management
Vegetation : No vegetation

Additional Remarks: The depth of the profile is very deep it is composed of an alternating volcanic ashes erupted from the near by volcanoes, later modified by the action of wind. The profile is not well developed. Its surface is very compact, probably due to trampling wild animals. At depth (65-70 cm) the soil was moist.

The area is part of the game park, and there was no history of cultivation. With in a distance of 10m some warthog dug holes are seen.

PROFILE DESCRIPTION:

Very deep, well drained, light olive brown (topsoil) originated from volcanic materials

Hori-zon Sym-bol	Thickness (cm)	**Description**
Ah	00-16	Light olive brown (2.5Y 5/3, dry); sandy loam; massive; non-sticky, non-plastic, slightly hard; no gravel; few, fine and very fine roots; abrupt smooth boundary to
A	16-45	Light olive brown (2.5Y 4.5/3, dry); sandy loam; single grained; non-sticky, non-plastic, loose; no gravel; very few, very fine roots; abrupt smooth boundary to
C1	45-60	Gray (2.5Y 6/1, dry), light brownish gray (2.5Y 6/2, moist); loamy sand; single grained; non-sticky, non-plastic, loose; no gravel; very few, very fine roots
C2	60-92	Light brownish gray (2.5Y 6/2, dry), gray (2.5Y 5/2, moist); loamy sand; single grained; non-sticky, non-plastic, loose; no gravel; no roots,
C3	92-105+	Light brownish gray (2.5Y 6/2, moist); loamy sand; single grained; non-sticky, non-plastic, loose; very few, fine and medium; subrounded, fresh pumice gravel; and no roots

Mini-pit Am2 Country: Kenya

WRB (1998) : Areni-Vitric Andosol
USDA Soil Taxonomy (1992) : Aridic Ustipsamments
USDA Family Differentiae : Ashy, glassy, isothermic
Diagnostic Criteria WRB (1998): Ochric A, vitric B-horizon
USDA (1992) : Ochric epipedon
Soil moisture regime : Ustic

Location : Nakuru district, 16 km from Naivasha town, in Sulmac farm (end of the 100's), in the mid volcanic plain (Pv211)
Latitude: 0^o 51' 07"S (9905720m UTM) Longitude : 36^o 23' 20"E (0209424m UTM)
Author (S) : Atkilt Girma
Date: September 19, 2000 Altitude : 1975 m a.s.l.

General Landform: Volcanic Plain Topography : Gently undulating
Slope gradient : 3% Form : straight
Position of the site: middle slope Micro-topography : nil
Surface Char. Rock outcrop : nil Stoniness : nil
Cracking : nil Slaking and crusting : nil
Salt : nil Alkali : nil
Surface processes : wind erosion and deposition
Degree : moderate Activity: active at present

Parent Material : Pyroclastic-ashes, agglomerates, & tuffs
Weathering degree : Fresh and/or slightly weathered pumice gravel

Effective soil Depth : >1.5m
Water Table : Not observed
Drainage : well drained
Flooding frequency : nil
Moisture condition of the profile: Very Dry

Landuse : not used, not managed, Sulmac farm plot
Vegetation : grassland (grasses, subordinate thorny shrubs)

Additional Remarks: The depth of the profile is very deep it is composed of an alternating volcanic ashes erupted from the near by volcanoes, later modified by the action of wind (similar to Am1). The profile is not also well developed. Its surface is very compact, probably due to trampling animals-with in 100m distance there is kraal. Penetration was difficult at a depth of 17cm from the top. At a distance 300-400m some in active sand dunes were evident. The area is part of Sulmac farm; it has no cultivation & irrigation history. This mini-pit is paired with mini-pit Am3

PROFILE DESCRIPTION:

Very deep, somewhat excessively drained, light olive brown (topsoil) originated from volcanic materials

Horizon Symbol	Thickness (cm)	**Description**
Ah	00-12	Light olive brown (2.5Y 5/3, dry); sandy loam; weak, fine, subangular blocky structure; non-sticky, non-plastic, loose; very few, fine, subrounded, fresh pumice gravel; few, very fine, interstitial pores; common, fine and medium roots; abrupt smooth boundary to
A	12-36	Light olive brown (2.5Y 5/3, dry); sandy loam; single grained; non-sticky, non-plastic, loose; few, subrounded, fresh pumice gravel; very few, fine roots, abrupt smooth boundary to
C	36-60	Light yellowish brown (2.5Y 6/3, dry); loamy sand; single grained; non-sticky, non-plastic, loose; few, subrounded, fresh pumice gravel; few, very fine, interstitial pores; very few, fine roots
C2	60-78	Light brownish gray (2.5Y 6/2, dry); sandy loam; single grained; non-sticky, non-plastic, loose; no gravel; no roots
C3	78-103+	Light yellowish brown (2.5Y 6/3, dry); loamy sand; single grained; non-sticky, non-plastic loose; few, fine and medium, subrounded, fresh pumice gravel; no roots

Mini-pit Am3 Country: Kenya

WRB (1998) : Areni-vitric Andosol
USDA Soil Taxonomy (1992) : Aridic Ustipsamments
USDA Family Differentiae : Ashy, glassy, isothermic
Diagnostic Criteria WRB (1998): Ochric-A, vitric B-horizon
USDA (1992) : Ochric epipedon
Soil moisture regime : Ustic

Location : Nakuru district, 16 km from Naivasha town, in Sulmac farm (end of the 100's), in the mid volcanic plain (Pv211)
Latitude: 0° 51'10"S (9905638m UTM) Longitude : 36° 23' 17"E (0209298m UTM)
Author (S) : Atkilt Girma
Date: September 19, 2000 Altitude : 1975 m a.s.l.

General Landform: Volcanic Plain Topography : Gently undulating
Slope gradient : 3% Form : straight
Position of the site: middle slope Micro-topography : low hammocks
Surface Char. Rock outcrop : nil Stoniness : nil
Cracking : nil Slaking and crusting : nil
Salt : nil Alkali : nil
Surface processes : wind erosion and deposition
Degree : moderate Activity: active at present

Parent Material : Pyroclastic-ashes, agglomerates, & tuffs
Weathering degree : Fresh and/or slightly weathered pumice gravel

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Effective soil Depth : >1.5m
Water Table : Not observed
Drainage : somewhat excessively drained
Flooding frequency : nil
Moisture condition of the profile: Very Dry

Landuse : irrigated cultivation (rotation), type drip, fallow at present
Vegetation : grasses (grasses, subordinate thorny shrubs)

Additional Remarks: The depth of the profile is very deep it is composed of an alternating volcanic ashes erupted from the near by volcanoes, later modified by the action of wind (similar to Am1 & Am2). The profile is not also well developed. At a depth of 6-17cm it is naturally compacted. The top horizon was modified through cultivation. Within 150m distance, there is kraal. At a depth of 44-55cm few gravel are evident; The area is part of Sulmac farm; it was under carnation flowers before 5 years under rotation with other blocks of Sulmac farm. The irrigation method was drip. At present there is no cultivation.

PROFILE DESCRIPTION:

Very deep, somewhat excessively drained, light olive brown (topsoil) originated from volcanic materials

Horizon Symbol	Thickness (cm)	**Description**
Ah	00-06	Light olive brown (2.5Y 5/3, dry); sandy loam; very weak, fine, subangular blocky structure; non-sticky, non-plastic, loose; very few, fine, subrounded, fresh pumice gravel; few, very fine, interstitial pores; common, fine roots; abrupt smooth boundary to
A1	6-17	Light olive brown (2.5Y 5/3, dry); sandy loam; very weak, fine, subangular blocky structure; non-sticky, non-plastic, slightly hard; very few, fine, subrounded, fresh pumice gravel; few, very fine, interstitial pores; few, very fine roots; abrupt smooth boundary to
A2	17-44	Light brownish gray (2.5Y 6/2, dry); sandy loam; single grained; non-sticky, non-plastic, soft; very few, fine, subrounded, fresh pumice gravel; few, very fine roots; abrupt smooth boundary to
C1	44-70	Light brownish gray (2.5Y 6/2, dry); loamy sand; single grained; non-sticky, non-plastic, loose; few, medium, subrounded, fresh pumice gravel; no roots
C2	70-82	Gray (5Y 5/1, dry); sandy loam; massive; non-plastic, non-sticky, very hard; no gravel; no structure, silica in nature weekly cemented; no roots
C3	82-100+	Gray (5Y 6/1, dry); sand; single grained; non-sticky, non-plastic, loose; no gravel; no roots

Mini-pit Am4 Country: Kenya

WRB (1998) : Areni-vitric Andosol
USDA Soil Taxonomy (1992) : Aridic Ustipsamments
USDA Family Differentiae : Ashy, glassy, isothermic
Diagnostic Criteria WRB (1998): Ochric A, vitric B-horizon
USDA (1992) : Ochric epipedon
Soil moisture regime : Ustic

Location : Nakuru district, 14 km from Naivasha town, in Sulmac farm (beginning of the 30's), in the low volcanic plain (Pv311)
Latitude: 0° 50' 18"S (9907241m UTM) Longitude : 36° 21' 53"E (0206682m UTM)
Author (S) : Atkilt Girma
Date: September 19, 2000 Altitude : 1910 m a.s.l.

General Landform: Volcanic Plain Topography : Gently undulating
Slope gradient : 2% Form : straight
Position of the site: middle slope Micro-topography : no micro-relief
Surface Char. Rock outcrop : nil Stoniness : nil
Cracking : nil Slaking and crusting : nil
Salt : nil Alkali : nil
Surface processes : wind erosion and deposition
Degree : moderate Activity: active at present

Parent Material : Pyroclastic-ashes, agglomerates, & tuffs
Weathering degree : Fresh and/or slightly weathered pumice gravel

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Effective soil Depth : >1.5m
Water Table : Not observed
Drainage : well drained
Flooding frequency : nil
Moisture condition of the profile: Dry

Landuse : irrigated cultivation (vegetables), type drip & sprinkler at present
Vegetation : nil

Additional Remarks: The depth of the profile is very deep, it is composed of an alternating volcanic ashes erupted from the near by volcanoes, later modified by the action of wind (similar to Am1, Am2, & Am3). The profile is not well developed. At the time of survey the land was ploughed to grow vegetables. The area is part of Sulmac farm; it was under carnation flowers in 1998 together with the 70's under rotation with other blocks of Sulmac farm. The irrigation method was drip. Corn was planted on the borders of each plot to minimize the impact of wind.

PROFILE DESCRIPTION:

Very deep, well-drained, dark olive brown (topsoil) originated from volcanic materials

Horizon Symbol	Thickness (cm)	**Description**
Ap	00-22	Dark olive brown (2.5Y 3/3, moist), olive gray (2.5Y 4/2, dry); sandy loam; weak, fine and medium, subangular blocky structure; non-sticky, non-plastic, very friable; very few, medium, rounded, fresh pumice gravel; few, fine roots; clear smooth boundary to
Bw1	22-50	Very dark grayish brown (2.5Y 3/2, moist); sandy loam; weak, fine & medium, subangular blocky structure; non-sticky, non-plastic, very friable; very few, medium, rounded, fresh pumice gravel; few, fine roots; clear smooth boundary to
Bw2	50-68	Dark olive brown (2.5Y 3/3, moist); loamy sand; very weak, fine, subangular blocky; non-sticky, non-plastic, very friable; very few, medium, rounded, fresh pumice gravel; very few, very fine roots
C1	68-82	Olive brown (2.5Y 4/3, moist); loamy sand; non-sticky, non-plastic, loose; no gravel; no roots
C2	82-100+	Grayish brown (2.5Y 5/2, moist); sandy; non-sticky, non-plastic, loose; no gravel; no roots

Mini-pit Am5 **Country: Kenya**

WRB (1998) : Aren-vitric Andosol
USDA Soil Taxonomy (1992) : Aridic Ustipsamments
USDA Family Differentiae : Ashy, glassy, isothermic
Diagnostic Criteria WRB (1998): Ochric A, vitric B-horizon
USDA (1992) : Ochric epipedon
Soil moisture regime : Ustic

Location : Nakuru district, 14 km from Naivasha town, in Sulmac farm (near the 30's), in the low volcanic plain (Pv311)
Latitude: 0^{o} 50' 09"S (9907499m UTM) Longitude : 36^{o} 21' 51"E (0206648m UTM)
Author (S) : Atkilt Girma
Date: September 19, 2000 Altitude : 1900 m a.s.l.

General Landform: Volcanic Plain Topography : Nearly level
Slope gradient : 1% Form : straight
Position of the site: middle slope Micro-topography : little ant mounds
Surface Char. Rock outcrop : nil Stoniness : nil
Cracking : nil Slaking and crusting : nil
Salt : nil Alkali : nil
Surface processes : wind erosion and deposition
Degree : slight Activity: active at present

Parent Material : Pyroclastic-ashes, agglomerates, & tuffs
Weathering degree : Fresh and/or slightly weathered pumice gravel

Effective soil Depth : >1.5m
Water Table : Not observed
Drainage : Somewhat excessively drained
Flooding frequency : nil
Moisture condition of the profile: Dry

Landuse : Not used not managed
Vegetation : grasses (15-20%) and eucalyptus trees (scattered).

Additional Remarks: The depth of the profile is very deep, similar to the others, it is composed of an alternating volcanic ashes erupted from the near by volcanoes, later modified by the action of wind (similar to Am1, Am2, Am3 & Am4). The profile is not well developed. The land is part of Sulmac farm-it was not managed and used before. Few mounds of ants are observed on the surface.

PROFILE DESCRIPTION:

Very deep, somewhat excessively drained, Olive brown (topsoil) originated from volcanic materials

Horizon Symbol	Thickness (cm)	**Description**
Ah	00-09	Olive brown (2.5Y 4/3, dry), very dark grayish brown (2.5Y 3/2, moist); loam; weak, very fine, subangular blocky structure; slightly-sticky, slightly-plastic, soft; common, fine and medium roots; no gravel; abrupt smooth boundary to,
A	09-27	Olive brown (2.5Y 4/3, dry), very dark grayish brown (2.5Y 3/2, moist); silty loam; weak, medium, subangular blocky structure; non-sticky, slightly-plastic, loose; few, fine and medium, subrounded, few, fine roots; abrupt smooth boundary to
Bw1	27-46	Olive brown (2.5Y 4/3, dry), very dark grayish brown (2.5Y 3/2, moist); silty loam; single grained; slightly-sticky, slightly-plastic, loose; common, fine and medium, subrounded, fresh pumice gravel; many, medium & coarse roots; abrupt smooth boundary to
Bw2	46-65	Light olive brown (2.5Y 5/3, dry), dark grayish brown (2.5Y 4/2, moist); gravely sandy loam; single grained; non-sticky, non-plastic, loose; many fine and medium, subrounded, fresh pumice gravel; no roots
C1	65-76	Grayish brown (2.5Y 5/2, dry), dark grayish brown (2.5Y 4/2, moist); loamy sand; non-plastic, non-sticky, loose; no gravel; no roots
C2	76-95+	Light olive brown (2.5Y 5/3, moist); sandy; non-sticky, non-plastic, loose; few, fine, subrounded, fresh pumice gravel; no roots

Mini-pit Am6 **Country: Kenya**

WRB (1998) : Areni-vitric Andosol
USDA Soil Taxonomy (1992) : Aridic Ustipsamments
USDA Family Differentiae : Ashy-pumiceous, mixed, isothermic
Diagnostic Criteria WRB (1998): Ochric A, vitric B-horizon
USDA (1992) : Ochric epipedon
Soil moisture regime : Ustic

Location : Nakuru district, 28 km from Naivasha town, in Oserian research plot, in the low volcanic plain (Pv311)
Latitude: 0° 49’16”S (9909144m UTM) Longitude : 36° 15’25”E (0194707m UTM)
Author (S) : Atkilt Girma
Date: September 20, 2000 Altitude : 1905 m a.s.l.

General Landform: Volcanic Plain Topography : Almost flat
Slope gradient : 1% Form : straight
Position of the site: middle slope Micro-topography : little hummocks
Surface Char. Rock outcrop : nil Stoniness : nil
Cracking : nil Slaking and crusting : nil
Salt : nil Alkali : nil
Surface processes : Slight water erosion and deposition (sheet) & also wind erosion
Degree : slight to moderate Activity: active at present

Parent Material : Pyroclastic-ashes, agglomerates, & tuffs
Weathering degree : Fresh and/or slightly weathered pumice gravel

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Effective soil Depth : >1.5m sealing: medium
Water Table : Not observed
Drainage : well drained
Flooding frequency : not known
Moisture condition of the profile: moist

Landuse : Irrigated cultivation (flowers, Carnation & Perrezi, research plot),
Vegetation : nil

Additional Remarks: The depth of the profile is very deep, similar to the others, it is composed of an alternating volcanic ashes erupted from the near by volcanoes (similar to Am1, Am2, Am3, Am4, & Am5). It is a research plot owned by Oserian farm. Surface crusts of 3-cm thickness were observed. In addition, due to the quality of the drip-irrigation water, they experience salinity problems. The observation point was taken in between raised beds-gangway.

PROFILE DESCRIPTION:

Very deep, well drained, Dark brown (topsoil) originated from volcanic, &fluvial materials

Horizon Symbol	Thickness (cm)	**Description**
Ap	00-09	Dark brown (10YR3/3, moist); Sandy loam; weak, fine and medium, subangular blocky structure; non-sticky, non-plastic, very friable; no roots; abrupt smooth boundary to
A	09-22	Dark brown (10YR3/3, moist); sandy loam; weak, fine & medium, subangular blocky structure; non-sticky, non-plastic, very friable; very few, medium, subrounded, fresh pumice gravel; no roots; abrupt smooth boundary to
B1	22-37	Dark yellowish brown (10YR 3/4, moist); sandy loam; weak, fine & medium, subangular blocky structure; non-sticky, non-plastic, very friable; very few, medium, subrounded, fresh pumice gravel; no roots; abrupt smooth boundary to
B2	37-44	Dark yellowish brown (10YR 3/4, moist); sandy loam; massive; slightly-sticky, slightly-plastic, friable; few, medium, subrounded, fresh pumice gravel; no roots; abrupt smooth boundary to
C1	44-58	Dark yellowish brown (10YR 3.5/4, moist); gravely loam; single grained; slightly-sticky, slightly-plastic, loose; many, medium subrounded, fresh pumice gravel; no roots
C2	58-74	Brown (10YR 5/3, moist); loamy sand; non-plastic, non-sticky, loose; no gravel; no roots
C3	74-98+	Brown (10YR 5/3, moist); loamy sand; non-sticky, non-plastic, loose; few, fine, subrounded, fresh pumice gravel; no roots

Mini-pit Am7 **Country: Kenya**

WRB (1998) : Areni-vitric Andosol
USDA Soil Taxonomy (1992) : Aridic Ustipsamments
USDA Family Differentiae : Ashy, glassy, isothermic
Diagnostic Criteria WRB (1998): Ochric A, vitric B-horizon
USDA (1992) : Ochric epipedon
Soil moisture regime : Ustic

Location : Nakuru district, 28 km from Naivasha town, near the Oserian research plot, in the low volcanic plain (Pv311)
Latitude: 0^{o} 49’ 18”S (9909074m UTM) Longitude : 36^{o} 15’ 25”E (0194701m UTM)
Author (S) : Atkilt Girma
Date: September 20, 2000 Altitude : 1905 m a.s.l.

General Landform: Volcanic Plain Topography : Almost flat
Slope gradient : 1% Form : straight
Position of the site: middle slope Micro-topography : medium gilgai
Surface Char. Rock outcrop : nil Stoniness : nil
Cracking : nil Slaking and crusting : nil
Salt : nil Alkali : nil
Surface processes : Slight water erosion and deposition (sheet) & also wind erosion
Degree : slight to moderate Activity: active at present

Parent Material : Pyroclastic-ashes, agglomerates, & tuffs
Weathering degree : Fresh and/or slightly weathered pumice gravel

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Effective soil Depth : >1.5m sealing: medium
Water Table : Not observed
Drainage : well drained
Flooding frequency : not known
Moisture condition of the profile: Dry

Landuse : Not used not managed, grassland
Vegetation : Grasses (15-40%) and very few scattered cactus trees

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Additional Remarks: The depth of the profile is very deep, similar to the others, it is composed of an alternating volcanic ashes erupted from the near by volcanoes (similar to Am1, Am2, Am3, Am4, & Am5). It is 20 away from the research plot of Oserian farm. Surface crusts of 2cm thickness were observed. This mini-pit is paired with Am6

PROFILE DESCRIPTION:

Very deep, well drained, Dark brown (topsoil) originated from volcanic, &fluvial materials

Horizon Symbol	Thickness (cm)	**Description**
Ah	00-12	Dark yellowish brown (10YR 3/4, moist), brown (10YR 4/3, dry); loamy sand; weak, fine subangular blocky structure; non-sticky, slightly-plastic, loose; very few, fine, subrounded, fresh pumice gravel; few, fine roots; abrupt smooth boundary to
A	12-29	Brown (10YR 5/3, dry), brown (10YR 4/3, moist); sandy loam; weak, medium, subangular blocky structure; non-sticky, slightly-plastic, friable when moist and hard when dry; very few, fine, subrounded, fresh pumice gravel; very few, very fine roots; clear wavy boundary to
B	29-50	Brown (10YR 5/3, dry), brown (10YR 4/3, moist); gravely loamy sand; very weak, fine, subangular blocky structure; non-sticky, non-plastic, friable when moist and soft when dry; common, fine, subrounded, fresh pumice gravel; very few, very fine roots; abrupt smooth boundary to
C1	50-75	Brown (10YR 5/3, dry), brown (10YR 4/3, moist); loamy sand; single grained; non-sticky, non-plastic, friable when moist and soft when dry; common, fine, subrounded, fresh pumice gravel; no roots
C2	75-83	Pale brown (10YR 6/3, dry); gravely sandy loam; non-plastic, non-sticky, very friable; common, fine subrounded, fresh pumice gravel; no roots
C3	83-92+	Gray (10YR 6/1, dry); sandy; non-plastic, non-sticky, loose; no gravel; no roots

Mini-pit Am9 Country: Kenya

WRB (1998) : Areni-vitric Andosol
USDA Soil Taxonomy (1992) : Aridic Ustipsamments
USDA Family Differentiae : Ashy, mixed, isothermic
Diagnostic Criteria WRB (1998): Ochric A, vitric B-horizon
USDA (1992) : Ochric epipedon
Soil moisture regime : Ustic

Location : Nakuru district, 25 km from Naivasha town, in the Oserian farm, in the mid lacustrine plain (Pl211)
Latitude: 0° 49'38"S (9908442m UTM) Longitude : 36° 17' 28"E (0198487m UTM)
Author (S) : Atkilt Girma
Date: September 20, 2000 Altitude : 1925 m a.s.l.

General Landform: Lacustrine Plain Topography : gently undulating
Slope gradient : 3% Form : straight
Position of the site: middle slope Micro-topography : little hummocks (ridges & furrows)
Surface Char. Rock outcrop : nil Stoniness : few subrounded
Cracking : nil Slaking and crusting : nil
Salt : nil Alkali : nil
Surface processes : Slight wind erosion and deposition
Degree : slight Activity: active at present

Parent Material : Pyroclastic-ashes, agglomerates, & tuffs
Weathering degree : Fresh and/or slightly weathered pumice gravel

Effective soil Depth : >1.5m sealing: thin
Water Table : Not observed
Drainage : somewhat excessively drained
Flooding frequency : nil
Moisture condition of the profile: Dry

Landuse : Irrigated cultivation (flowers, Statice),
Vegetation : nil

Additional Remarks: The depth of the profile is very deep, similar to the others, it is composed of an alternating volcanic ashes erupted from the near by volcanoes, later modified by the action of wind and the lake. At the time of the survey the land was ploughed and there were no crops on the field. Previously it was under Statice flowers. The land belongs to the Oserian farm. The method of irrigation used was drip and sprinkler. Due to the problem of wind, trees were planted on the borders of each block to act as a windbreak.

PROFILE DESCRIPTION:

Very deep, well drained, Dark brown (topsoil) originated from volcanic, &fluvial materials

Horizon Symbol	Thickness (cm)	**Description**
Ah	00-15	Light olive brown (2.5Y 5/3, dry), olive brown (2.5Y 4/3, moist); sandy loam; single grained; non-sticky, non-plastic, loose; many, fine and medium, subrounded, fresh pumice gravel; few, very fine roots; abrupt smooth boundary to
A	15-24	Olive brown (2.5Y 4/3, dry), very dark grayish brown (2.5Y 3/2, moist); sandy loam; single grained; non-sticky, non-plastic, soft; common, fine and medium, subrounded, fresh pumice gravel; few, very fine roots; abrupt smooth boundary to
Bw1	24-32	Olive brown (2.5Y 4/3, dry), very dark grayish brown (2.5Y 3/2, moist); sandy loam; weak, fine and medium, subangular blocky structure; slightly-sticky, slightly-plastic, soft; many, fine and medium, subrounded, fresh pumice gravel; few, very fine roots; abrupt smooth boundary to
Bw2	32-68	Olive brown (2.5Y 4/3, dry), dark olive brown (2.5Y 3/3, moist); loamy sand; very weak, fine and medium, subangular blocky structure; non-sticky, non-plastic, loose; few, fine subrounded fresh pumice gravel; no roots
C1	68-77	Grayish brown (2.5Y 5/2, dry); sandy loam; non-sticky, non-plastic, loose; few, fine, subrounded fresh pumice gravel; no roots
C2	77-95+	Light olive brown (2.5Y 5/1, dry); loamy sand; non-plastic, non-sticky, loose; few, fine and medium, subrounded, fresh pumice gravel; no roots

Mini-pit Am10 Country: Kenya

WRB (1998) : Sodi-Fluvic Cambisol (Skeletic, Eutric)
USDA Soil Taxonomy (1998) : Vitrandic Haplustepts
USDA Family Differentiae : Ashy-pumiceous, mixed, isothermic
Diagnostic Criteria WRB (1998): Ochric A, Cambic B-horizon
USDA (1998) : Ochric epipedon, cambic horizon
Soil moisture regime : Ustic

Location : Nakuru district, 18 km from Naivasha town, it is part of the Sher-Agency farm, in the low lacustrine plain (Pl311)
Latitude: 0° 49'39"S (9908419m UTM) Longitude : 36° 20' 55"E (0204893m UTM)
Author (S) : Atkilt Girma
Date: September 20, 2000 Altitude : 1890 m a.s.l.

General Landform: Lacustrine Plain Topography : gently undulating
Slope gradient : 2% Form : straight
Position of the site: middle slope Micro-topography : (ridges & furrows)
Surface Char. Rock outcrop : nil Stoniness : few subrounded
Cracking : nil Slaking and crusting : nil
Salt : nil Alkali : nil
Surface processes : very little impact of erosion.

Parent Material : Pyroclastic-ashes, agglomerates, tuffs, & lake deposits
Weathering degree : Fresh and/or slightly weathered pumice gravel

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Effective soil Depth : >1.5m sealing: thin
Water Table : Not observed
Drainage : well drained
Flooding frequency : not known, but could be from the lake
Moisture condition of the profile: moist

Landuse : Irrigated cultivation (flowers, roses),
Vegetation : Rose flowers

Additional Remarks: The depth of the profile is very deep, similar to the others, it is composed of an alternating, reworked volcanic ash and lake sediment layers. The land is under Sher-Agency farm. To minimise the risk of flooding from the lake they have built dykes. The observation point was located in the open rose flower field. It is paired with P2. The method of irrigation under use was drip. Generally, this plot is under high-tech management.

PROFILE DESCRIPTION:
Very deep, well drained, Dark brown (topsoil) originated from volcanic, & fluvial materials

Horizon Symbol	Thickness (cm)	**Description**
Ap	00-12	Dark brown (10YR 3/3, moist); sandy loam; weak, fine, subangular blocky structure; slightly sticky, slightly-plastic, friable; very few, medium and fine subrounded fresh pumice gravel; very few, very fine roots; abrupt smooth boundary to
Bw	12-37	Very dark grayish brown (10YR 3/2, moist); sandy loam; weak, medium, subangular blocky; slightly-sticky, slightly-plastic, friable; few, medium and fine subrounded, fresh pumice gravel; very few, very fine roots; abrupt smooth boundary to
Bx	37-41	Grayish brown (10YR 5/2, moist); sandy loam; weak, medium, platy structure; slightly plastic, non-sticky, friable; few, fine, subrounded fresh pumice gravel; no roots; abrupt smooth boundary to
C1	41-60	Grayish brown (10YR 5/2, moist); loamy sand; single grained; non-sticky, non-plastic, loose; no gravel; no roots
C2	60-79	Pale brown (10YR 6/3, moist); gravely sandy loam; non-plastic, non-sticky, very friable; common, fine and medium, rounded, fresh pumice gravel; very few, very fine roots
C3	79-96+	Grayish brown (10YR 5/2, moist); loamy sand; non-plastic, non-sticky, loose; few, fine subrounded, fresh pumice gravel; no roots

Mini-pit Am11 Country: Kenya

WRB (1998) : Areni-vitric Andosol
USDA Soil Taxonomy (1992) : Aridic Ustipsamments
USDA Family Differentiae : Ashy, glassy, isothermic
Diagnostic Criteria WRB (1998): Ochric A, vitric B-horizon
USDA (1992) : Ochric epipedon
Soil moisture regime : Ustic

Location : Nakuru district, 27 km from Naivasha town, it is part of the Oserian farm, in the mid lacustrine plain (Pv211)
Latitude: 0° 50'34"S (9906722m UTM) Longitude : 36° 17' 06"E (0197806m UTM)
Author (S) : Atkilt Girma
Date: September 26, 2000 Altitude : 1998 m a.s.l.

General Landform: Volcanic Plain Topography : gently undulating
Slope gradient : 2% Form : straight
Position of the site: middle slope Micro-topography : little hummocks
Surface Char. Rock outcrop : nil Stoniness : very few, medium, subrounded
Cracking : nil Slaking and crusting : nil
Salt : nil Alkali : nil
Surface processes : Slight water erosion and deposition
Degree : slight Activity: not active at present

Parent Material : Pyroclastic-ashes, agglomerates, & tuffs.
Weathering degree : Fresh and/or slightly weathered pumice gravel

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Effective soil Depth : >1.5m sealing: nil
Water Table : Not observed
Drainage : well drained
Flooding frequency : nil
Moisture condition of the profile: dry

Landuse : Intensive grazing
Vegetation : Grassland (40-80%)

Additional Remarks: The depth of the profile is very deep, similar to the others. The land is owned by Oserian farm. It is reserved for cattle grazing. Irrigation (sprinkler) water is used to grow the grasses. This plot was paired with Ao12.

PROFILE DESCRIPTION:
Very deep, well drained, olive brown (topsoil) originated from volcanic, & fluvial materials

Horizon Symbol	Thickness (cm)	**Description**
A1	00-09	Olive brown (2.5Y 4/4, dry), dark olive brown (2.5Y 3/3, moist); loam; weak, fine, subangular blocky structure; slightly-sticky, slightly-plastic, Common, medium, subrounded fresh pumice gravel; common, fine and very fine, roots; abrupt smooth boundary to
A2	09-39	Light olive brown (2.5Y 5/4, dry), olive brown (2.5Y 4/4, moist); loam; weak, fine, subangular blocky structure; slightly-plastic, slightly-sticky, soft; common, fine and medium, subrounded, fresh pumice gravel; few, fine roots; abrupt smooth boundary to
C1	39-52	Light yellowish brown (2.5Y 6/4, dry), light olive brown (2.5Y 5/3, moist); sandy loam; very weak, fine, subangular blocky structure; slightly-sticky, slightly-plastic, loose; few, fine, subrounded, fresh pumice gravel; few, fine roots
C2	58-72	Light brownish gray (2.5Y 6/2, dry), light olive brown (2.5Y 5/3, moist); sandy loam; non-plastic, non-sticky, loose; very few, fine and medium, sub-rounded, fresh pumice gravel; few, fine roots
C3	72-85	Light olive brown (2.5Y 5/4, dry); loamy sand; non-sticky, non-plastic, loose; common, fine and medium, subrounded, fresh pumice gravel; very few, fine, roots
C4	85-97+	Light yellowish brown (2.5Y 6/4, dry); sandy; non-plastic, non-sticky, loose; common, fine, subrounded, fresh pumice gravel; no roots

Profile Am12 **Country: Kenya**

WRB (1998) : Fluvic Cambisol
USDA Soil Taxonomy (1992) : Typic Udipsamments
USDA Family Differentiae : Sandy, mixed, isothermic
Diagnostic Criteria WRB (1998): Ochric A, fluvic soil material
USDA (1992) : Ochric epipedon
Soil moisture regime : Udic

Location : Nakuru district, 12 km from Naivasha town, in kijabe farm (~200m from the lake, low lacustrine plain, Pl311)
Latitude: 0^{o} 49' 38"S (9912194m UTM) Longitude : 36^{o} 17' 28"E (0210450m UTM)
Author (S) : Atkilt Girma, Tilaye Bitew
Date: September 27, 2000 Altitude : 1880 m a.s.l.

General Landform: Lacustrine Plain		Topography	: Flat
Slope gradient	: 0%	Form	: Straight
Position of the site: middle slope		Micro-topography	: no micro relief
Surface Char. Rock outcrop	: nil	Stoniness	: nil
Cracking	: nil	Slaking and crusting	: nil
Salt	: nil	Alkali	: nil

Surface processes : lake influence (deposition), Erosion related with the lake fluctuation
Degree : moderate Activity: recently active

Parent Material : Pyroclastic-ashes, agglomerates, tuffs, & lake sediments (reworked)
Weathering degree : Fresh and/or slightly weathered

Effective soil Depth : >152 cm
Water Table : Not observed
Drainage : Moderately well drained
Flooding frequency : There is risk of being flooded by the lake
Moisture condition of the profile: Moist

Landuse : Not used not managed, left for wild life grazing.
Vegetation : Grass land (cover 40-80%)

Additional Remarks: The depth of this mini-pit is very deep. It is very compacted at the surface. Penetration readings of the 2nd and the 3rd horizons are greater than 4.5 kg/cm^{2}. The layers are compacted probably because it was formerly under the lake. Moreover, it is composed of an alternating, reworked volcanic ash and lake sediment layers. At a depth of 7-40cm termites were found. Dead root debris is common on every horizon.

PROFILE DESCRIPTION:

Very deep, moderately well drained, very dark grayish brown (topsoil) originated from volcanic materials and lake sediments.

Horizon Symbol	Thickness (cm)	**Description**
Ah	00-07	Very dark grayish brown (2.5Y 3/2, moist; loam; very weak, fine, subangular blocky structure; slightly-sticky, slightly-plastic, friable; no gravel; few, fine roots; abrupt smooth boundary to
Bw	07-40	Light olive brown (2.5Y 5/3, moist); clay loam; weak, fine and medium subangular blocky structure; sticky, plastic, firm; no gravel; few, fine roots; few termites and channels; abrupt smooth boundary to
C1	40-64	Gray (2.5Y 6/1, moist); loamy sand; massive; slightly plastic, slightly-sticky, friable; very few, fine roots
C2	64-82	Light yellowish brown (2.5Y 6/4, moist); sandy loam; non-plastic, non-sticky, very friable; no gravel; very few, fine roots
C3	82-96+	Light brownish gray (2.5Y 6/2); loamy sand; non-plastic, non-sticky, very friable; very few, fine, subrounded, fresh pumice gravel; no roots

Profile Am13 Country: Kenya

WRB (1998) : Arenic Fluvisol
USDA Soil Taxonomy (1992) : Typic Ustipsamments
USDA Family Differentiae : Sandy, mixed, isothermic
Diagnostic Criteria WRB (1998): Ochric A, fluvic soil material
USDA (1992) : Ochric epipedon
Soil moisture regime : Ustic

Location : Nakuru district, 12 km from Naivasha town, in kijabe farm (~300m from the lake, mid lacustrine plain, Pl212)
Latitude: 0° 47’ 41”S (9912063m UTM) Longitude : 36° 24’ 07”E (0210827m UTM)
Author (S) : Atkilt Girma, Tilaye Bitew
Date: September 27, 2000 Altitude : 1893 m a.s.l.

General Landform: Lacustrine Plain Topography : Gently undulating
Slope gradient : 4% Form : Straight
Position of the site: middle slope Micro-topography : low hummocks
Surface Char. Rock outcrop : nil Stoniness : nil
Cracking : nil Slaking and crusting : nil
Salt : nil Alkali : nil
Surface processes : lake influence (deposition), slight water erosion
Degree : slight Activity: not active at present

Parent Material : Pyroclastic-ashes, agglomerates, tuffs, & lake sediments (reworked)
Weathering degree : Fresh and/or slightly weathered

Effective soil Depth : >150 cm
Water Table : Not observed
Drainage : Moderately well drained
Flooding frequency : nil
Moisture condition of the profile: dry

Landuse : Not used not managed, left as nature protection & wild life grazing.
Vegetation : Savannah grass land (cover 40-80%)

Additional Remarks: The depth of this mini-pit is very deep. It is sandier than the rest of the pits especially at the 2nd and 3rd horizons. Cultivation on this soil was difficult due to their low water holding capacity. They are formed as a beach ridges. At a distance of 60-100m, it is undulating. The second and the third horizons are the same except the second horizon is a bit more compacted.

PROFILE DESCRIPTION:

Very deep, moderately well drained, very pale brown (topsoil) originated from volcanic materials and lake sediments.

Horizon Symbol	Thickness (cm)	**Description**
Ah	00-05	Very pale brown (10YR 7/3, dry), light yellowish brown (10YR 6/4, moist); loam; weak; fine subangular blocky structure; slightly-sticky, slightly-plastic, soft; common, fine and medium roots; few, ants; abrupt smooth boundary to
Bx	05-30	Gray (10YR 5/1, dry), dark grayish brown (10YR 4/2, moist); loamy sand; single grained; non-plastic, non-sticky, few, medium and coarse roots; clear smooth boundary to
Bw	30-68	Gray (10YR 5/1, dry), dark grayish brown (10YR 4/2, moist); sand; single grained; non sticky, non-plastic, few, medium and coarse roots
C	68-84+	Brown (10YR 5/3, dry); sand; non-sticky, non-plastic, loose; no gravel; no roots

Profile Am14 **Country: Kenya**

WRB (1998) : Orthicalcic Calcisols
USDA Soil Taxonomy (1992) : Typic Calciustepts
USDA Family Differentiae : Coarse-loamy, mixed, isothermic
Diagnostic Criteria WRB (1998): Ochric A, calcic B-horizon
USDA (1992) : Ochric epipedon, Calcic horizon (Diatomitious earth)
Soil moisture regime : Ustic

Location : Nakuru district, 12 km from Naivasha town, in Kijabe farm (near the old airstrip, high lacustrine plain, Pl111)
Latitude: 0° 47' 95"S (9911504m UTM) Longitude : 36° 24' 40"E (0211858m, UTM)
Author (S) : Atkilt Girma, Tilaye Bitew
Date: September 27, 2000 Altitude : 1910 m a.s.l.

General Landform: Lacustrine Plain			Topography	: Gently undulating
Slope gradient		: 4%	Form	: Straight
Position of the site: middle slope			Micro-topography	: low hummocks
Surface Char.	Rock outcrop	: nil	Stoniness	: nil
	Cracking	: nil	Slaking and crusting	: nil
	Salt	: nil	Alkali	: nil
Surface processes		: nil		

Parent Material : Pyroclastic-ashes, agglomerates, tuffs, lake sediments & diatomite
Weathering degree : weathered diatomite

Effective soil Depth : >150-cm sealing; medium
Water Table : Not observed
Drainage : well drained
Flooding frequency : nil
Moisture condition of the profile: dry

Landuse : Not used not managed
Vegetation : grass land (cover 40-80%)

Additional Remarks: The depth of this mini-pit is very deep. This mini-pit is similar to Am15. It differs from the others by its content of diatomite. The profile is light brownish gray at the surface. It becomes whitish while going down to the 2nd and 3rd horizons. The 3rd horizon is more of volcanic than lacustrine in origin. But, the lake could have reworked it. This mini-pit was paired with Am15. Furthermore, it was not put under cultivation.

PROFILE DESCRIPTION:

Very deep, moderately well drained, light yellowish brown (topsoil) originated from lake diatomite and volcanic materials

Horizon Symbol	Thickness (cm)	**Description**
Ah	00-11	Light yellowish brown (2.5Y 6/3, dry); loam; weak, fine and medium, subangular blocky; sticky, plastic, common, fine and very fine roots; very few ants; abrupt smooth boundary to
B1	11-31	White (2.5Y 8/1, dry); loam; very weak, fine subangular blocky structure; sticky, plastic, soft; common, fine and very fine roots; abrupt smooth boundary to
B2	31-52	White (2.5Y 8/1, dry); loamy sand; single grained; slightly sticky, slightly-plastic, loose; common, fine and very fine roots; abrupt smooth boundary to
C1	52-76	Gray (2.5Y 6/1, dry); loamy sand; single grained; slightly-sticky, slightly-plastic, loose; common, fine and very fine roots
C2	76-89+	Grayish brown (2.5Y 5/2, dry); sandy loam; non-plastic, non-sticky, loose; no gravel; no roots

Profile Am15 **Country: Kenya**

WRB (1998) : Orthicalcic Calcisols
USDA Soil Taxonomy (1992) : Typic Calciustepts
USDA Family Differentiae : Coarse-loamy, mixed, isothermic
Diagnostic Criteria WRB (1998): Ochric A, Calcic-B horizon
USDA (1992) : Ochric epipedon, Calcic horizon (diatomitious earth)
Soil moisture regime : Ustic

Location : Nakuru district, 12 km from Naivasha town, in Kijabe farm (green house no.39, high lacustrine plain, Pl111)
Latitude: 0^{o} 48' 04"S Longitude : 36^{o} 24' 36"E
Author (S) : Atkilt Girma , Tilaye Bitew
Date: September 27, 2000 Altitude : 1910 m a.s.l.

General Landform: Lacustrine Plain			Topography	: Gently undulating
Slope gradient		: 2%	Form	: Straight
Position of the site: middle slope			Micro-topography	: raised flowerbeds and furrows
Surface Char.	Rock outcrop	: nil	Stoniness	: nil
	Cracking	: nil	Slaking and crusting	: nil
	Salt	: nil	Alkali	: nil
Surface processes		: nil		

Parent Material : diatomite over pyroclastic-ashes, agglomerates, & tuffs
Weathering degree : weathered diatomite

Effective soil Depth : >150 cm sealing; medium
Water Table : Not observed
Drainage : somewhat excessively drained
Flooding frequency : nil
Moisture condition of the profile: moist

Landuse : irrigated cultivation, method drip, flower cultivation
Vegetation : nil

Additional Remarks: The depth of this mini-pit is very deep. This mini-pit is similar to Am14. It differs from the others by its content of diatomite. The profile is dark yellowish brown at the surface and whitish on the 2^{nd} horizon. The mini-pit was located in green house number 39 of the Kijabe farm. Rose flowers were grown under high-tech management. Furthermore, it is paired with Am14.

PROFILE DESCRIPTION:

Very deep, moderately well drained, light yellowish brown (topsoil) originated from lake diatomite and volcanic materials

Horizon Symbol	Thickness (cm)	**Description**
Ap	00-25	Dark yellowish brown (10YR 3/4, moist); loam; weak, fine and medium, subangular blocky structure; sticky, plastic, very friable; no roots; abrupt smooth boundary to
B1	25-43	Pale brown (YR 6/3, moist); clay loam; weak, fine and medium, subangular blocky structure; plastic, sticky, very friable; few, very fine roots; abrupt wavy boundary to
B2	43-67	Dark yellowish brown (10YR 3/4, moist); loam; weak fine and medium subangular blocky; plastic, sticky, very friable; few, very fine roots
C1	67-78	Dark yellowish brown (10YR 3/4, moist)sandy loam; non-sticky, non-plastic, very friable; very few, fine, subrounded, fresh pumice gravel; no roots;
C2	78-94+	Dark grayish brown (10YR 4/2, moist); sandy loam; non-sticky, non-plastic, very friable; no gravel; no roots

Profile Am16 **Country: Kenya**

WRB (1998) : Areni-Vitric Andosol
USDA Soil Taxonomy (1992) : Aridic Ustipsamments
USDA Family Differentiae : Ashy, glassy, isothermic
Diagnostic Criteria WRB (1998): Ochric A, vitric B-horizon
USDA (1992) : Ochric epipedon
Soil moisture regime : Ustic

Location : Nakuru district, 13 km from Naivasha town, opposite to Ki-jabe farm, in Kedong ranch (low volcanic plain, Pv311)
Latitude: 0° 48' 41"S (9910227m UTM) Longitude : 36° 24' 48"E (0212095m UTM)
Author (S) : Atkilt Girma
Date: September 27, 2000 Altitude : 1930 m a.s.l.

General Landform: Volcanic Plain Topography : Almost flat
Slope gradient : 2% Form : Straight
Position of the site: middle slope Micro-topography : low hummocks
Surface Char. Rock outcrop : nil Stoniness : nil
Cracking : nil Slaking and crusting : nil
Salt : nil Alkali : nil
Surface processes : Wind erosion and/or deposition,
Degree : Slight Activity : Active at present l

Parent Material : Pyroclastic-ashes, agglomerates, obsidian & tuffs
Weathering degree : fresh to slightly weathered obsidian and pumice gravel

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Effective soil Depth : >150-cm sealing; medium
Water Table : Not observed
Drainage : well drained
Flooding frequency : nil
Moisture condition of the profile: dry

Landuse : extensive grazing
Vegetation : grassland (15-40%)

Additional Remarks: The depth of this mini-pit is very deep. At a depth of 40-46 few, distinct carbonate cutains were observed. In addition, the horizon is a bit cemented. The land is protected for grazing purpose only. There was no history of cultivation on this area.

PROFILE DESCRIPTION:

Very deep, well drained, light olive brown (topsoil) originated volcanic materials & lake deposits.

Horizon Symbol	Thickness (cm)	**Description**
Ah	00-03	Light olive brown (2.5Y 5/3, dry); loam; weak, fine and medium, subangular blocky; slightly-sticky, slightly-plastic, soft; no gravel; few, fine roots; abrupt smooth boundary to
A	03-40	Light olive brown (2.5Y 5/3, dry); sandy loam; very weak; fine subangular blocky; slightly-sticky, slightly-plastic, soft; no gravel; few, fine roots; abrupt smooth boundary to
Bx	40-46	Light yellowish brown (2.5Y6/3, dry); massive; hard; no gravel; few, distinct, carbonate cutans on pedfaces; continuous, pisolithic, carbonates, weakly cemented; no roots; abrupt smooth boundary to
C1	46-68	Light gray (2.5Y 7/2, dry); loam; single grained; slightly-plastic, slightly-sticky, loose; very few, fine and medium, subrounded fresh pumice gravel; few, fine roots
C2	68-85	Light brownish gray (2.5Y 6/2, moist); gravely sandy loam; slightly sticky, slightly plastic, very friable; common, fine and medium, subrounded fresh pumice gravel; no roots
C3	85-94+	Light yellowish brown (2.5Y 6/3, moist); loamy sand; non-plastic, non-sticky, very friable; few, fine, subrounded, fresh pumice gravel; and no roots

Observation Id: Ao1-Ao12

Hori-zon Symbol	Thickness (cm)	Description
Ao1	0-8	Very dark grayish brown (2.5Y 3/2, moist); sandy loam; structure destroyed by ploughing; slightly-plastic, slightly-sticky, very friable; very few, fine and medium, subrounded, fresh pumice gravel; few, very fine roots; abrupt, smooth boundary to
	8-32	Dark olive brown (2.5Y 3/3, moist); sandy loam; weak, fine, sub-angular blocky structure; slightly-plastic, slightly sticky, very friable; very few, fine and medium subrounded fresh pumice gravel; very few, fine and very fine roots
Ao2	0-7	Dark olive brown (2.5Y 3/3, moist); sandy loam; structure destroyed by ploughing; slightly-plastic, slightly-sticky, very friable; very few, fine and medium, subrounded, fresh pumice gravel; few, fine and very fine roots; abrupt smooth boundary to
	7-35	Very dark grayish brown (2.5Y 3/2, moist); sandy loam; weak, fine, subangular blocky structure; slightly-plastic, slightly-sticky, very friable; very few, fine and medium, subrounded, fresh pumice gravel; few, very fine roots
Ao3	0-14	Olive brown (2.5Y 4/3, dry), dark olive brown (2.5Y 3/3, moist); sandy loam; weak, fine and medium, subangular blocky structure; non-sticky, non-plastic, soft; common, fine and medium, subrounded, fresh pumice gravel; very few, fine and very fine roots; abrupt, smooth boundary to
	5-25	Grayish brown (2.5Y 5/2, dry, dry); gravely sandy loam; weak, fine and medium, subangular blocky structure; non-plastic, non-sticky, soft; common, fine and medium, subrounded pumice gravel; very few, fine roots
Ao4	0-12	Olive brown (2.5Y 4/3, dry), dark olive brown (2.5Y 3/3, moist); sandy loam; weak, fine and medium, subangular blocky structure; non-sticky, non-plastic, soft; common, fine and medium, subrounded, fresh pumice gravel; very few, fine and very fine roots, abrupt, smooth boundary to
	12-27	Grayish brown (2.5Y 5/2, dry, dry); gravely sandy loam; weak, fine and medium, subangular blocky structure; non-plastic, non-sticky, soft; common, fine and medium, subrounded pumice gravel; few, fine roots
Ao5	0-5	Very dark grayish brown (2.5Y 3/2, moist); loam; very weak, very fine, subangular blocky structure; plastic, sticky, friable; very few, fine subrounded, fresh pumice gravel; very few, fine and very fine roots; abrupt smooth boundary to
	5-23	Dark grayish brown (2.5Y 4/2, moist); loam; weak, fine and medium, subangular blocky structure; plastic, sticky, friable; no gravel; few, fine roots
Ao6	0-10	Very dark grayish brown (2.5Y 3/2, moist); loam; very weak, very fine, subangular blocky structure; plastic, sticky, friable; few, fine subrounded, fresh pumice gravel; fine and very fine roots; abrupt, smooth boundary to

	10-27	Dark grayish brown (2.5Y 4/2, moist); loam; weak, fine and medium, subangular blocky structure; plastic, sticky, friable; no gravel; very few, fine roots
Ao7	0-9	Grayish brown (2.5Y 5/2, dry), dark grayish brown (2.5Y 4/2, moist); loamy sand; weak, fine and medium, subangular blocky structure; non-plastic, non-sticky, slightly hard; few, fine and medium, subrounded, fresh pumice gravel; common, fine and medium roots; abrupt smooth boundary to
	9-27	Gray (2.5Y 5/1, dry), dark grayish brown (2.5Y 4/2, moist); sandy loam; weak, fine and medium, subangular blocky structure; non-plastic, non-sticky, slightly hard; few, fine and medium, subrounded, fresh pumice gravel; common, fine and medium roots
Ao8	0-5	Light olive brown (2.5Y 5/3, dry), dark grayish brown (2.5Y 4/2, moist); sandy loam; weak, fine and medium, subangular blocky structure; non-plastic, non-sticky, slightly hard; common, fine and medium, subrounded, fresh pumice gravel; common, fine and very fine roots; abrupt, smooth boundary to
	5-16	Grayish brown (2.5Y 5/2, dry), Olive brown (2.5Y 4/3, moist); sandy loam; weak, fine and medium, subangular blocky structure; non-plastic, non-sticky, slightly hard; common, fine and medium, subrounded, fresh pumice gravel; common, fine and very fine roots; abrupt smooth boundary to
	16-37	Grayish brown (2.5Y 5/2, dry), Olive brown (2.5Y 4/3, moist); sandy loam; weak, fine and medium, subangular blocky structure; non-plastic, non-sticky, slightly hard; no gravel; few, fine and very fine roots
Ao9	0-10	Very dark grayish brown (2.5Y 3/2, moist); sandy loam; very weak, fine and medium, subangular blocky structure; slightly-plastic, slightly-sticky, very friable; few, fine subrounded, fresh pumice gravel; very few, very fine roots; abrupt smooth boundary to
	10-25	Dark grayish brown (2.5Y 4/2, moist); loam; very weak, fine and medium, subangular blocky structure; slightly plastic, slightly sticky, very friable; no gravel; few, fine roots
Ao10	0-12	Dark olive brown (2.5Y 3/3, moist); loam; very weak, fine and medium, subangular blocky structure; slightly sticky, slightly-plastic, very friable; no gravel; very few, very fine roots; abrupt, smooth boundary to
	12-27	Very dark grayish brown (2.5Y 3/2, moist); sandy loam; very weak, fine and medium, subangular blocky structure; slightly sticky, slightly-plastic, very friable; few, fine and medium, subrounded, fresh pumice gravel; few, very fine roots
Ao11	0-10	Very dark grayish brown (2.5Y 3/2, moist); loam; very weak, fine subangular blocky structure; slightly-plastic, slightly-sticky, very friable; no gravel; no roots; abrupt smooth boundary to

	10-27	Very dark grayish brown (2.5Y 3/2, moist); loam; very weak, fine subangular blocky structure; slightly-plastic, slightly-sticky, very friable; few, fine, fresh, pumice gravel; few, very fine roots
Ao12	0-8	Very dark grayish brown (2.5Y 3/2, moist); sandy loam; weak, fine and medium, subangular blocky structure; plastic, sticky, very friable; common, fine and medium, subrounded pumice gravel; common, fine and medium roots; abrupt smooth boundary to
	8-25	Dark grayish brown (2.5Y 3/2, moist); sandy loam; weak, fine and medium, subangular blocky structure; slightly-plastic, slightly-sticky, very friable; few, fine and medium, subrounded pumice gravel; common, fine and medium roots

Soil Classification, for the shovel hole observation points

Obs_Id	Soil Classification	
	WRB(1998)	USDA(1998)
Ao1-Ao12	Areni-Vitric Andosol	Aridic Ustipsamments

Appendix B Field data

OBS_Id	HOR_No	pH_field	BD (gm/cc)	EC (μS/cm)	% Coa_frag	Ha_pene (Kg/cm2)
Am1	1	7.4	1.34	44	1.58	4
Am1	2	7.3	1.30	59	1.92	1.25
Am1	3					0.75
Am2	1	7	1.32	119	2.18	3.25
Am2	2	7.3	1.43	57	1.13	2.75
Am2	3	7.4	1.31	107	1.40	1
Am3	1	6.95	1.33	104	2.71	0.25
Am3	2	7.2	1.42	57	1.21	3.5
Am3	3	7.1	1.51	52	1.35	2
Am3	4	7.3		37	1.12	1.25
Am4	1	7.4	1.26	75	5.73	1.25
Am4	2	7.65	1.28	72	4.96	1.75
Am4	3	7.85	1.32	52	5.54	2.5
Am5	1	6.76	0.62	260	11.16	1.75
Am5	2	7.1	1.19	77	12.62	4
Am5	3	7.25		64	9.45	2
Am5	4				10.38	2
Am6	1	6	1.24	2410	8.62	0.75
Am6	2	7.82	1.26	137	13.22	2.75
Am6	3	8.3	1.24	151	8.81	3.25
Am6	4	8.6	1.18	164	14.92	3.25
Am6	5	8.7		228	17.97	1.5
Am7	1	7	1.09	88	11.72	2.25
Am7	2	7.1	1.11	99	7.96	4.5
Am7	3	7.7	1.09	214	8.30	2.5
Am7						2
Am9	1	6.86	1.07	275	12.36	0
Am9	2	6.4	1.17	187	15.70	1.75
Am9	3	6.26	1.26	160	16.58	4.5
Am9	4					2.5
Am10	1	8.1	1.03	113	27.15	4.5
Am10	2	8.4	0.92	136	22.92	1.25
Am10	3					3
Am10	4					2.75
Am11	1	7.4	0.87	115	21.52	0
Am11	2	7.1	0.99	100	20.18	4.5
Am11	3					2
Am12	1	8.8		349	2.26	2
Am12	2	8.9		338	5.96	4.5
Am12	3	8.5		83	1.52	4.5
Am13	1	6.7		233	26.07	0.75
Am13	2	7.2		53	0.31	4.5
Am13	3					3
Am13	4					
Am14	1	8.01	0.81	173	2.34	4.5
Am14	2	8.4	0.81	230	4.84	4.5
Am14	3	8.3		545	5.07	2
Am14	4					0.75

Am15	1	7.4	0.71	660	0.21	1
Am15	2	8.2	0.59	385	0.00	1.5
Am15	3					0.5
Am16	1				3.47	4.5
Am16	2				4.50	4.5
Am16	3					4.5
Am16	4				6.62	1.5
Am16	5					1
Am16	6					4.5
P1	1	7	1.36	53	1.44	1.5
P1	2	7.3	1.29	44	0.29	4.5
P1	3	7.3	1.44	26	0.44	0.25
P1	4	7	2.51	22	0.03	4.5
P1	5	7.2	1.47	23	1.08	1.25
P1	6	7.2	2.04	42	0.40	2.5
P2	1	6.39	0.58	1822	5.49	3.5
P2	2	9.75	0.67	1531	8.41	4
P2	3	10.24	0.98	1008	31.43	4
P2	4	10.18	1.21	677	24.32	4
P2	5	10.08	0.77	765	34.38	1.5
P2	6	9.91	0.71	775	64.76	3
P2	7	10.02	1.20	416	9.96	1.25
P2	8	9.85	0.70	732	66.18	4
P2	9	9.91	0.99	561	32.39	1.75
P2	10	9.75	0.61	543	37.50	1.25
P2	11	9.75	0.89	432	20.93	1.75
Ao1		6.3	0.99	805	12.84	1.25
Ao2		6.9	0.94	84	9.39	1.75
Ao3		7.1	1.17	105	8.78	3.25
Ao4		7.3	1.28	106	12.22	2.75
Ao5		7.3	1.16	196	10.40	2.5
Ao6		5.7	1.34	237	8.40	2.25
Ao7		6.7	1.43	82	7.58	2.5
Ao8		6.3	1.30	335	6.20	3.25
Ao9		6.3	1.06	452	17.71	3.25
Ao10		6.7	1.08	108	15.68	3
Ao11		7	1.26	75	20.50	2.25
Ao12		6.9	1.28	220	4.03	3

Appendix C Selected Database Tables

Table design view for topsoil site observation points

TOBS_SITE : Table

Field Name	Data Type	Description
OBS_ID	Text	Unique field observation ID
TCOMP_Id	Text	Soil name ID (coded taxonomic name)
Status	Text	Soil profile description status, classes according to FAO guidelines (section 1.1.2)
T_tex	Text	Topsoil classified according to FAO 1998 book for topsoil characterization (chap 4, section 4.1)
T_gravel	Text	Topsoil classified according to FAO 1998 book for topsoil characterization (chap 4, section 4.1)
T_om	Text	Topsoil classified according to FAO 1998 book for topsoil characterization (chap 4, section 4.2)
T_omstatus	Text	Topsoil classified according to FAO 1998 book for topsoil characterization (chap 4, section 4.3)
T_phy_fea	Text	Topsoil classified according to FAO 1998 book for topsoil characterization (chap 4, section 4.4)
T_chem_fea	Text	Topsoil classified according to FAO 1998 book for topsoil characterization (chap 4, section 4.5)
T_biol_fea	Text	Topsoil classified according to FAO 1998 book for topsoil characterization (chap 4, section 4.6)
T_drain_fea	Text	Topsoil classified according to FAO 1998 book for topsoil characterization (chap 4, section 4.7)
T_landuse	Text	Topsoil classified according to FAO 1998 book for topsoil characterization (chap 4, section 4.8)
T_ero_deg	Text	Topsoil classified according to FAO 1998 book for topsoil characterization (chap 4, section 4.9)
T_extphy_con	Text	Topsoil classified according to FAO 1998 book for topsoil characterization (chap 4, section 4.10)
T_slo_cl	Text	Topsoil classified according to FAO 1998 book for topsoil characterization (chap 4, section 4.11)
Plant_frag%	Number	The percentage of plant fragments in the topsoil
Thick_litter	Number	The thickness of litter measured
dur_wetness	Number	Number of days that the soil is wet in a year
wormholes	Number	The percentage of worm holes in the topsoil
Shear	Number	The shear strength of the soil
Penetration	Number	Penetration resistance measured by penetrometer
Remarks	Text	General site description

Field Properties

General | Lookup

Field Size	6
Format	
Input Mask	
Caption	
Default Value	
Validation Rule	
Validation Text	
Required	Yes
Allow Zero Length	No
Indexed	Yes (No Duplicates)

A field name can be up to 64 characters long, including spaces. Press F1 for help on field names.

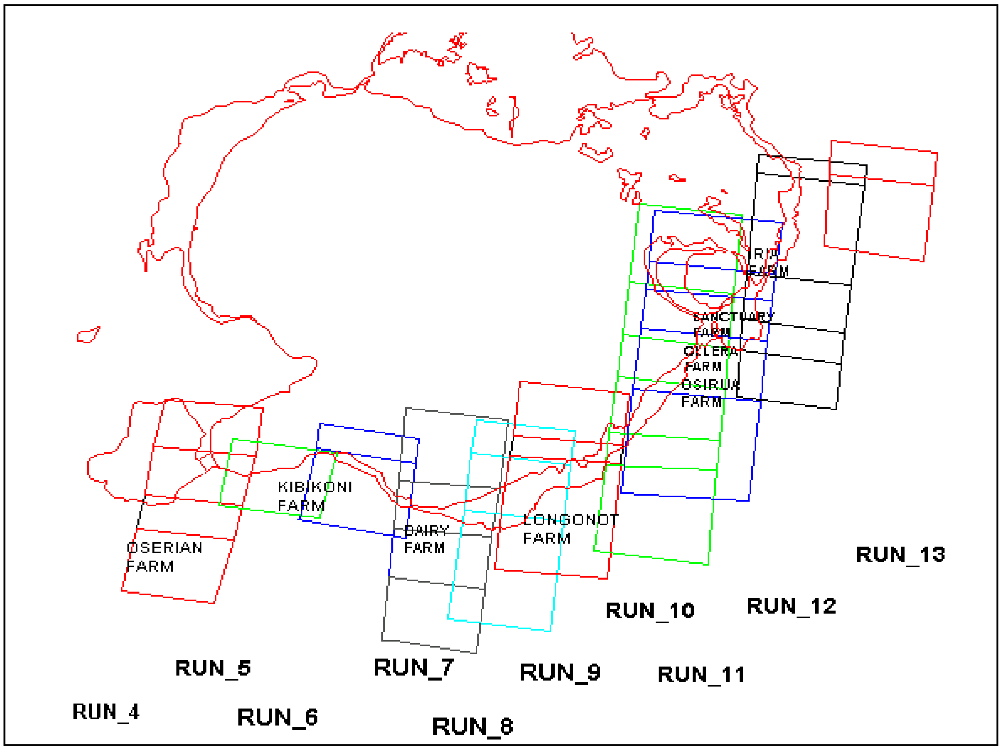
Datasheet view for site observation points

SOBS_SITE : Table

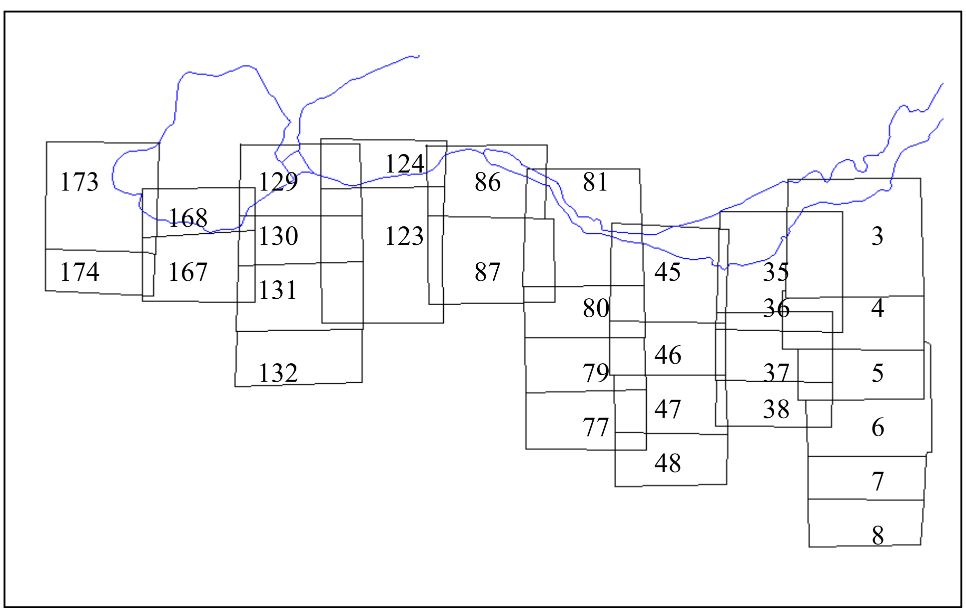
OBS_Id	Easting	Northing	Elevati	Moist_reg	Temp_reg	Parent_m	Rock_ty	Topograp
Am1	208020	9904003	2050	US	IT	VA	PU	G
Am10	204893	9908419	1890	US	IT	LA	PU	A
Am11	197806	9906722	1970	US	IT	VA	PU	G
Am12	210450	9912194	1880	US	IT	LA	PU	F
Am13	210826	9912063	1890	US	IT	LA	PU	G
Am14	211859	9911505	1910	US	IT	LA	PU	G
Am15	211737	9911342	1910	US	IT	LA	PU	A
Am16	212095	9910227	1920	US	IT	VA	PU	A
Am2	209424	9905720	1800	US	IT	VA	PU	G
Am3	209298	9905683	1800	US	IT	VA	PU	G
Am4	206682	9907241	1950	US	IT	LA	PU	A
Am5	206648	9907499	1900	US	IT	LA	PU	F
Am6	194707	9909144	1920	US	IT	VA	PU	A
Am7	194701	9909079	1920	US	IT	VA	PU	A
Am9	198486	9908442	1920	US	IT	LA	PU	G
P1	207718	9906308	1940	US	IT	VA	PU	A
P2	204648	9908546	1890	US	IT			F

Appendix D Aerial Photo Mosaic Making

Aerial photo Index Map of the Study area (For the 1:12,500 Scale photo-digitised in ILWIS)



Aerial photo Index Map of the Study area (For the 1:10,000 Scale photos-digitised in ILWIS)



Aerial photo number and run used for the survey

Photo Number	Run	Year	Scale
3,**4**,5,**6**,7,**8**		Jan 1991	1:10,000
36,**37**,38,**39**,40		Jan 1991	1:10,000
45,**46**,47,**48**		Jan 1991	1:10,000
78,79,**80**,**81**		Jan 1991	1:10,000
86,87		Jan 1991	1:10,000
124,		Jan 1991	1:10,000
129,**130**, **131**,**132**,133		Jan 1991	1:10,000
167,**168**,		Jan 1991	1:10,000
173, 174, 175		Jan 1991	1:10,000
9814-17	Run 4	1972	1:12,500
9754-56	Run 5	1972	1:12,500
9739-41	Run 6	1972	1:12,500
9686-89	Run 7	1972	1:12,500
9618-21	Run 8	1972	1:12,500
9675-78	Run 9	1972	1:12,500
9603-10	Run 10	1972	1:12,500
9542-46	Run 11	1972	1:12,500
9554-64	Run 12	1972	1:12,500
9448-49	Run 13	1972	1:12,500

Aerial photo number, sigma (geo-reference Orthophoto), and accuracy.

Photo No.	Sigma	Pixel Size(m)	Accuracy (m)	Photo No.	Sigma	Pixel Size	Accuracy (m)
3	6.88	0.866	6.0	124	5.527	0.848	4.7
4	3.739	0.858	3.2	129	4.724	0.87	4.1
6	6.121	0.848	5.2	131	6.692	0.861	5.8
8	7.1	0.811	5.8	132	7.854	0.811	6.4
37	5.757	0.852	4.9	168	14.976	0.851	12.7
39	4.087	0.879	3.6	173	6.19	0.899	5.6
45	5.076	0.867	4.4	9544	14.477	1.148	16.6
46	6.046	0.874	5.3	9546	5.03	1.142	5.7
48	8.159	0.841	6.9	9604	6.37	1.147	7.3
78	5.636	0.832	4.7	9607	10.012	1.154	11.6
80	4.516	0.866	3.9	9675	5.646	1.158	6.5
81	3.966	0.86	3.4	9739	4.586	1.123	5.2
86	12.42	0.85	10.6				

Figure Aerial photo mosaic of the study area

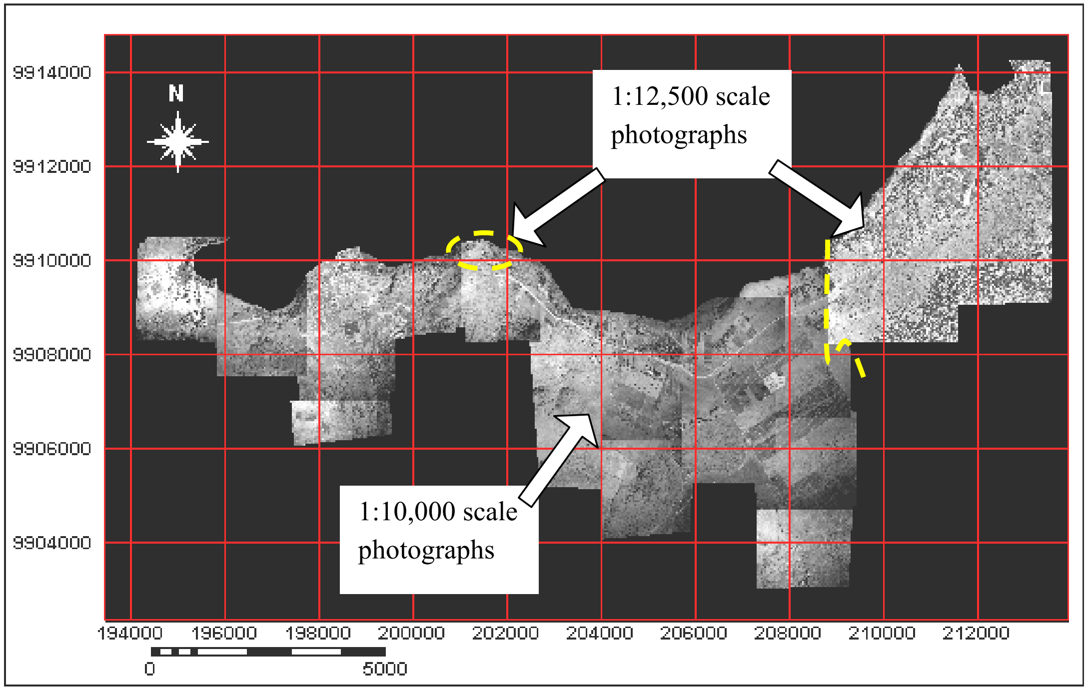
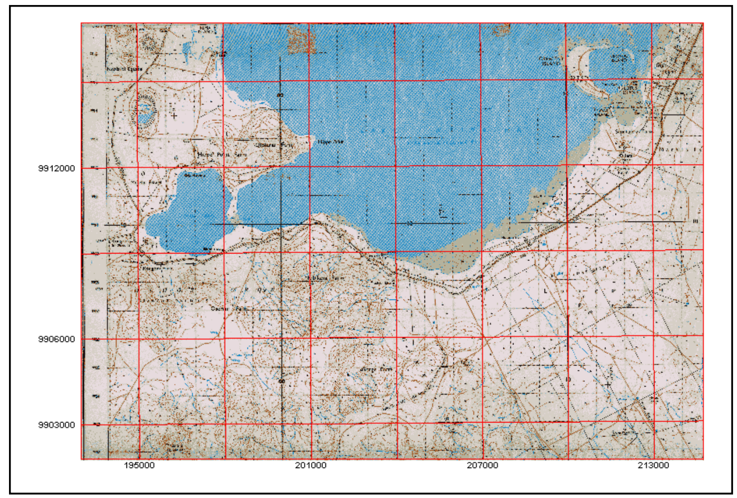


Figure Georeferenced topomap of the study area



Appendix E Management Related Description of Observation Points

Observation Id: Ao5 and Ao6

The observation points Ao5 and Ao6 are located in Roses IV, green house number 17 and 18 respectively. The green houses are under high-tech management-computerised system, including temperature and humidity controls. At the time of the survey two types of rose flower varieties were under cultivation namely, Kawalk and Kilimanjaro.

Land preparation is done by tractor, ploughing it three times, first by disc plough and later using normal harrow to pulverise the soil. Weeding is performed by hand, mechanically. There is no use of herbicides for this purpose. Fertiliser is supplied together with irrigation water as a program which is known as fertigation. Sometimes topdressing of $Ca(NH_4)NO_3$- is used. The source of water for irrigation is from the lake through drip system. Almost every day there is fertigation except on Sundays that they supply only plain water.

Harvesting is done two times a day by cutting the stem of the flowers. There is little residue left for the soil to regain its fertility. Insecticides and fungicides are intensively used upon suspicion of an outbreak suspect. For example, Dipel, Xentari, florbac and Lanneti as an insecticide; and Nimrod, Nustar, & Benlate as a fungicide are used.

Since there is problem of nematode infestation in the area, in general, the land is initially fumigated by, for example, Bassamid for 14 days. This chemical kills also some diseases. After fumigation, leaching and harrowing will follow it.

With this type of soils normally drainage is not a problem. The main problem associated with drainage is the formation of surface crusts. For better infiltration, the crusts are broken almost every week mechanically by hand. The roses were planted on 17/07/99.

Previously the land was under open field Carnation flowers in rotation with the other blocks (See under observation Id Ao9, Ao10 and Ao11 for the previous history of pairing).

Observation Id: Ao9, Ao10 and Ao11

The observation points were located in the beginning of the 60’s and the 70’s (Sulmac farm). The green houses are under high-tech management. In this green houses only fertigation and irrigation water are monitored as compared to Roses IV unit where humidity and temperature are also regulated.

Currently, Hypericum flowers are grown, variety Pinky Flair. The land is initially prepared using chisel plough later followed by disc and normal harrow. Weeding is performed mechanically by hand almost on a weekly basis. Like Roses IV, fertilizer is supplied together with drip irrigation water as a programme. The lake is the source of water for irrigation. Irrigation water is supplied to the Hypericum flowers almost everyday-roughly $40m^3$/ha. Sprinkler irrigation is used once a week to flush excess salts from the surface.

Harvesting is performed manually by cutting the stems of the flowers. The residues are used to produce compost but the compost is used somewhere else. Different chemicals like Platomice for bacteria; Kaskate, & Fusade for insects (white fly); and Dithane M45 for rust are sprayed.

In 1998 the field was under high-tech managed, open-field, drip irrigated Carnation flowers in rotation with the other farm blocks. Block-30's are planted together with the 70's; 40's with 80's; 50's with 90's, 60's with 100's.

Observation Id: Am10

The mini-pit is located in Sher-Agencies farm plot. At the time of the survey, Rumba variety of rose flower was under cultivation. Similar to the high-tech managed plots, land preparation is performed three times -sub-soiling, ploughing & harrowing. During land preparation, residues of the previous flower, mainly waste products from grading, are incorporated in to the soil.

Weeding is performed mechanically by hand. Fertilisers are supplied to the roses as programme-defined proportions. For example, proportion of potassium nitrate, calcium nitrate, borax, magnesium sulphate, potassium sulphate, nitric acid & phosphoric acid. The later two are used to reduce the pH of the soil. The fertilizers are given to the crops together with irrigation water, which is called fertigation. Currently, bore hole & sometimes lake water is used as a source of irrigation. The method of irrigation is drip.

Different types of chemicals are used, for example, Demilin, Dynamec, & Pentak as an insecticide spraying to the crops using spray guns; Nimrod, Meltatox & Rovro as a fungicide using spray guns; and Rugby, Vydate as a nematicide with drip irrigation water. Harvesting is performed mechanically by hand.

The plot has a long history of cultivation, greater than 15 years under high-tech management. The roses under cultivation are one and half years old. Previously it was under Gypsophilla.

Observation Id: Am6

The mini-pit is located in Oserian research field, where Statice (Perezi variey) and Carnations (eight different varieties) are grown. Weeding and land preparations are the same like Am10.

Carnations are heavy feeders of fertilizers as compared to Statice flowers. Therefore, different fertiliser programmes are used. Examples of fertilisers include calcium nitrate, potassium nitrate, magnesium sulphate, ammonium sulphate, potassium chloride, Borax, and Mono Ammonium phosphate (MAP) at roughly 88, 15, 25, 20, 15, 0.4, & 28Kg/ha respectively. Borehole water is used as a source of irrigation, method drip, on a daily basis. During harvesting residues are completely removed and burned. On the other hand, compost is applied before planting.

Like the other observation points, different chemicals are used, for example, Dipel as an insecticide, Redomyl as a fungicide and Vydate as nematicide. The plot was managed as a research plot since in 1995.

Observation Id: Am15

The observation point is located in Kijabe farm. At the time of the survey high-tech managed rose flowers, variety Cream Prophyta, were under cultivation. The land is initially prepared by using tractors. Ploughing, harrowing, sub-soiling, to a depth of one meter and ripping operations are undertaken. For this, disc plough, rippers and harrows are used. Weeding is performed two times a week mechanically by hand. Sticks are used to loosen the soil.

Similar to the other observation points, fertiliser is applied as a programme together with irrigation water. Nitrates, phosphates, potassium, magnesium, zinc, iron, molybdenum, boron, and manganese carrying fertilizers are used. Fertilizers are applied every day together with irrigation water. Lake water is used as a source of irrigation water. Harvesting is performed manually by cutting the stems of the flowers. Compost is applied once a year.

They spray different chemicals to protect their crops. For example, Pyrathroid and Methomyl as an insecticide; Meltatox, and Nimrod as a fungicide. Previously, the land was under vegetables like cabbage, potato, and onion. The vegetables were also managed under high-tech but with sprinkler irrigation.

Observation Id: Am4

The observation point is located in Sulmac farm, in the beginning of the 30's. It was on an open field where vegetables were grown. Land preparation and weeding practices are similar to Ao8, Ao9, and Ao10. Only WVC (NPK ratio of 8:24:16) at a rate of 346 kg/ha is used. In the absence of WVC, di-ammonium phosphate is used. Method is by broadcasting.

Irrigation is performed by both drip and sprinkler. Sprinkler is used till the vegetable seeds germinate. Later, drip irrigation is used every day. Harvesting is performed by hand picking. The crop residues are used to produce compost but they are applied somewhere. They use different kinds of insecticides and fungicides to protect their crops. Before two years the land was under Carnation flowers followed by peas followed by baby corn followed by beans.

Observation Id: Ao1 and Ao2

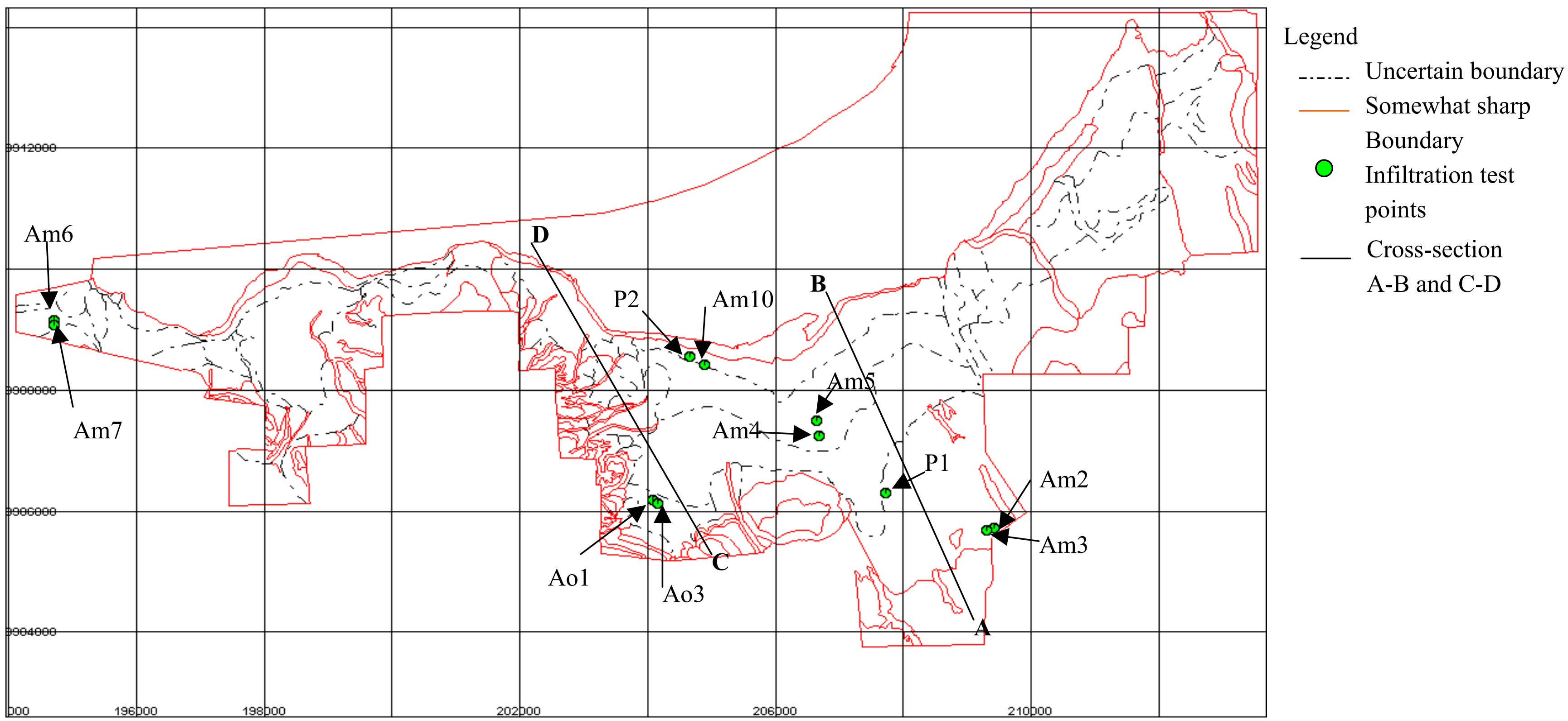
The observation point is located in Sulmac organic farm where squash vegetable, variety Raven, was grown. Land preparation is similar to that of Ao8, Ao9, and Ao10. During land preparation, manure is incorporated in to the soil. Weeding is performed mechanically by hand using hoe.

Manure and rock phosphate are used as a source of fertilisers. Manure is applied on the trenches by covering them manually. The source of irrigation water is from the lake

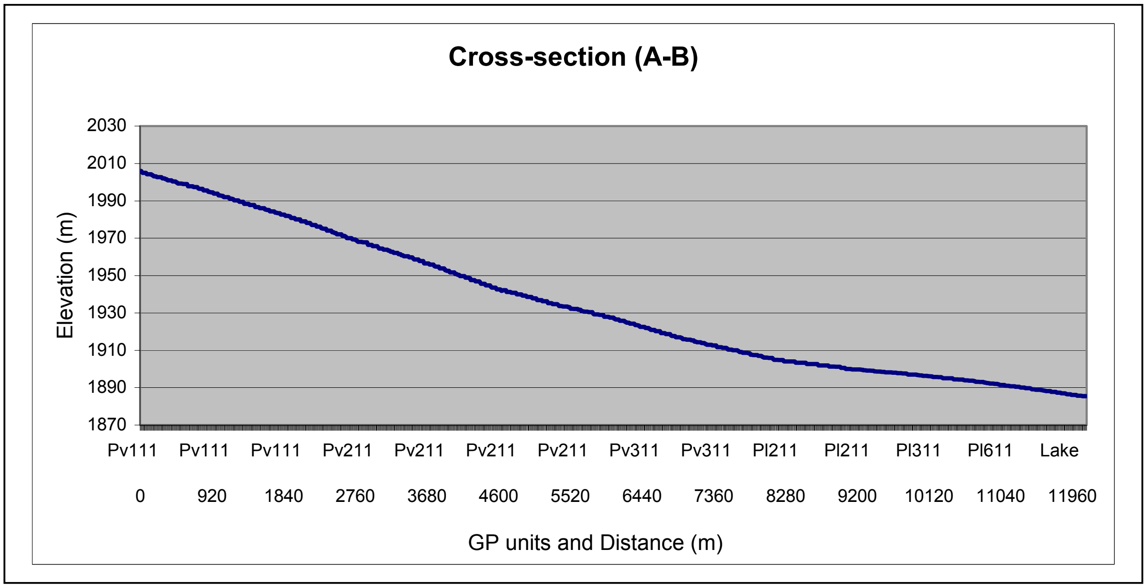
Table__ Summarised description of field observation points

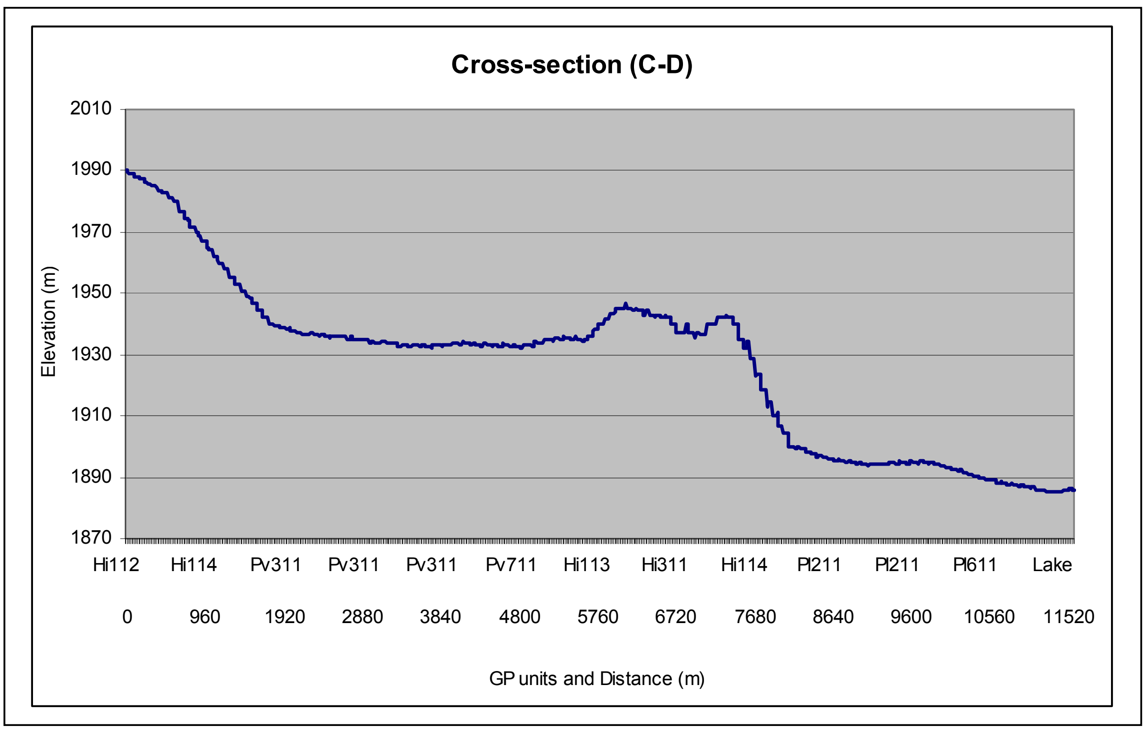
Obs Id	Location	History	GP unit	X(m)	Y(m)
P1	Fallow: Cultivation, Once in 4 yr.'s	Under Carnations in 1998 (by rotation)	Pv211	0207718	9906308
P2	Natural: Under Acacia trees and grasses	No cultivation history	Pl311	0204648	9908546
Am1	Natural: Grassland	No cultivation history	Pv111	0208308	9903996
Am2	Natural: Grassland	No cultivation history	Pv211	0209424	9905720
Am3	Fallow: Cultivation Once in 4 yr.'s	Under Carnations in 1997 (by rotation)	Pv211	0209298	9905638
Am4	Open Field: High-tech vegetable farm	Previously under Carnations in 1998	Pl211	0206682	9907241
Am5	Natural: Under Eucalyptus trees	No cultivation history	Pl211	0206648	9907499
Am6	Research Plot: High-tech managed, since 1995	Previously under Carnations	Pv311	0194707	9909144
Am7	Natural: Grassland	No farming history for at least 15 years	Pv311	0194701	9909074
Am9	Open Field: High-tech Statice field	Under flower cultivation for a long time, >15 yr.'s	Pl211	0198487	9908442
Am10	Open Field: High-tech managed roses field	Under flower cultivation for a long time, >15 yr.'s	Pl311	0204893	9908419
Am11	Grassland: Reserved for cattle feeding	Under grasses for at least 5 yr.'s, from now	Pv211	0197806	9906722
Am12	Natural: Grassland	No cultivation history	Pl311	0210450	9912194
Am13	Natural: Under Acacia and grasses	No cultivation history	Pl212	0210827	9912063
Am14	Natural: Grassland	No cultivation history, not used not managed	Pl111	0211858	9911504
Am15	Green House: High-tech managed (Roses plot)	Under Roses (4yr's old), open Flower, & vegetables	Pl111	0211737	9911342
Am16	Natural: Grassland	No recent cultivation history	Pv311	0212095	9910227
Ao1	Open Field: Organic, vegetable plot	Under Carnations before 5 years (by rotation)	Pv211	0204070	9906187
Ao2	Open Field: Organic, vegetable plot	Under Carnations before 5 years (by rotation)	Pv211	0203995	9906211
Ao3	Open Field: Grass land	Under Carnations before 5 years (by rotation)	Pv211	0204156	9906131
Ao4	Open Field: Grass land	Under Carnations before 5 years (by rotation)	Pv211	0204174	9906172
Ao5	Green House: High-tech managed (Roses plot)	Under Carnations before 5 years (by rotation)	Pv311	0205500	9907248
Ao6	Green House: High-tech managed (Roses plot)	Under Carnations before 5 years (by rotation)	Pv311	0205510	9907170
Ao7	Open Field: Grass land	Under Carnations before 5 years (by rotation)	Pv311	0205555	9907140
Ao8	Open Field: Grass land	Under Carnations before 5 years (by rotation)	Pv311	0205552	9907209
Ao9	Green House: High-tech (Hypericum plots) stage 4	Under Carnations, in 1998 (by rotation)	Pv311	0207412	9906104
Ao10	Green House: High-tech (Hypericum plots) stage 3	Under Carnations, in 1998 (by rotation)	Pv311	0207325	9906154
Ao11	Green House: High-tech (Hypericum plots) stage 1	Under Carnations, in 1997 (by rotation)	Pv311	0207472	9906166
Ao12	Open Field: Roses rootstocks	Previously under roses	Pv211	0197782	9906755

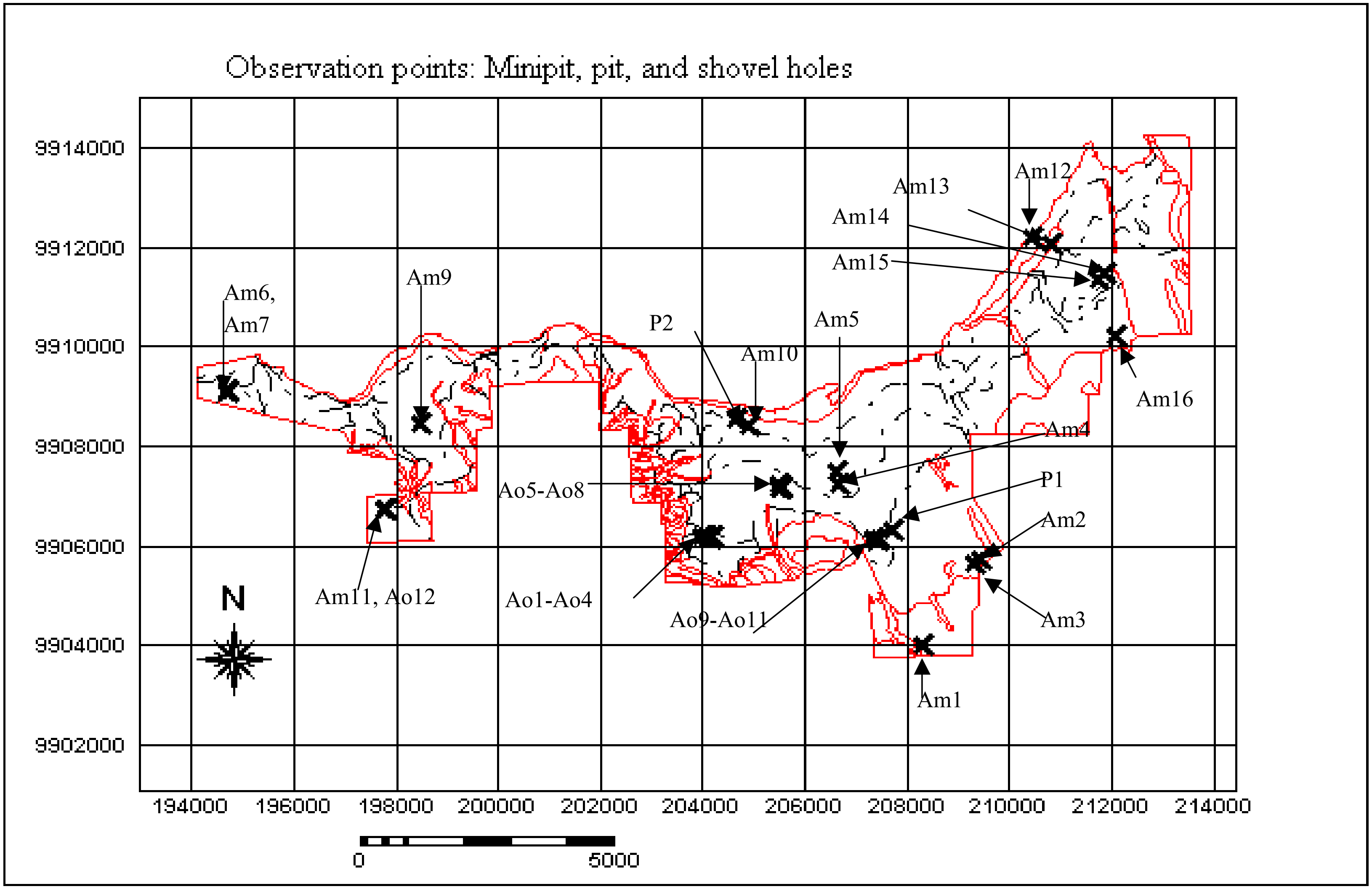
Appendix F Geopedologic Map & Observation Points



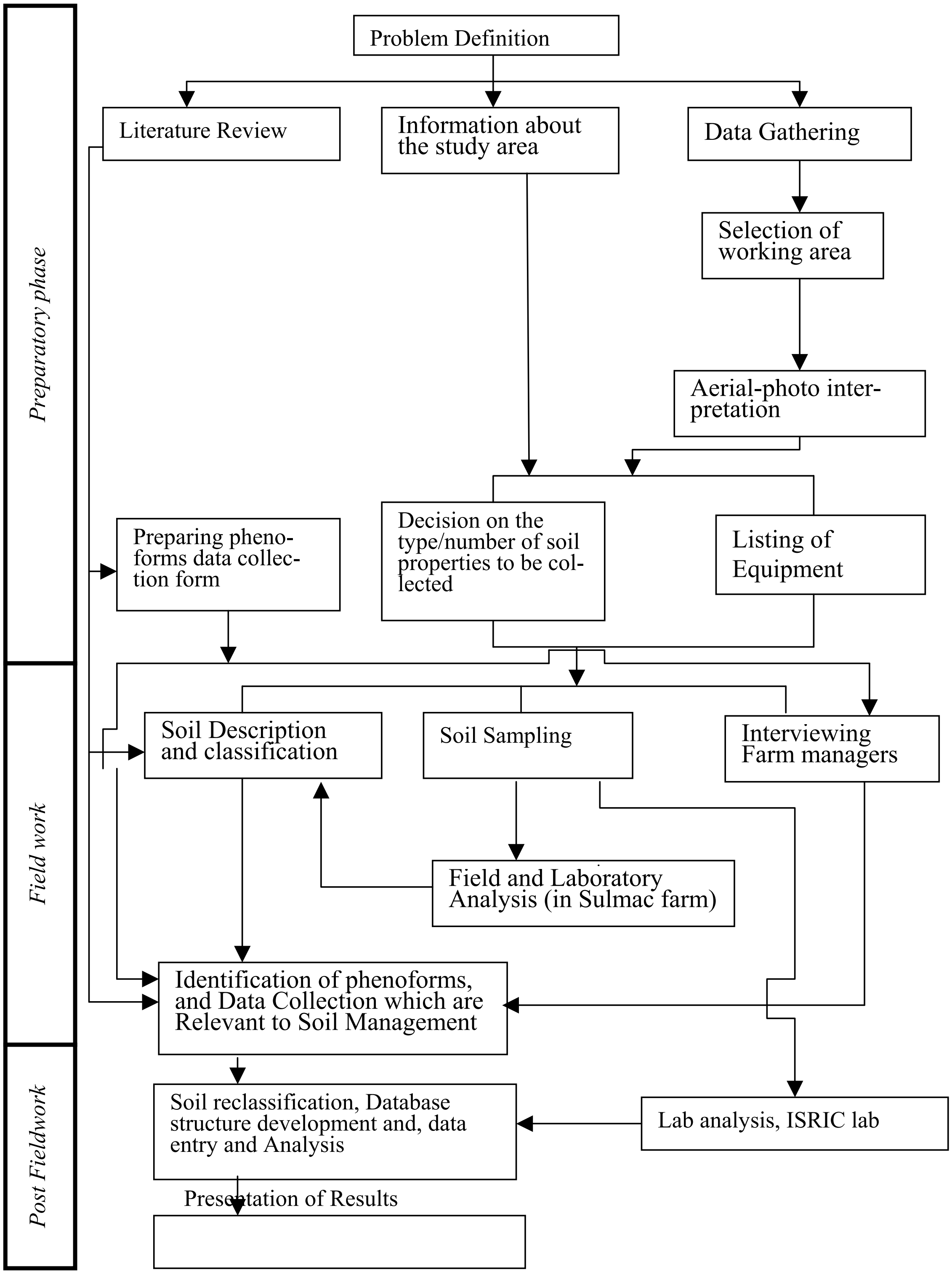
The cross section A-B and C-D were made using ILWIS and Microsoft excel software.






Observation points: Minipit, pit, and shovel holes
9914000
9912000
9910000
9908000
9906000
9904000
9902000
194000
196000
198000
200000
202000
204000
206000
208000
210000
212000
214000
Am6,
Am7
Am9
Am11, Ao12
Ao5-Ao8
Ao1-Ao4
P2
Am10
Ao9-Ao11
Am5
Am4
P1
Am2
Am3
Am1
Am13
Am14
Am15
Am12
Am16
N
0
5000

Appendix G Schematic Representation of the Workflow



Appendix H Interview Form (crop management)

District ______________________________ Village ________________________
Map unit_____________________________ Soil Classification_______________
Farm/Unit location____________________ Farm Owner____________________
Name of Interviewee___________________ Post __________________________

Questions		Produce 1	Produce 2	Produce 3
Crop type				
Variety				
Land Preparation	Source of Power Frequency of Ploughing Type of implement			
Weeding	Method Frequency Herbicide kind Her. Quantity Her. Frequency			
Fertiliser use	Kind Quantity Method History			
Irrigation	Source Method Frequency History			
Harvesting Method				
Post Harvest operation Residue Management				
Chemical Use	Kind Quantity Method History			
Level of Farming				
Remark				
General Farm History				

Appendix I Geostatistical Data

					Mean values/probability				
					378.32	510.74	662.41	996.65	Estimated Values (g)
x	y	EC454	*IRV592	*IRV736	prob<454	prob<592	prob<736	prob>736	
206595	9906766	0.04	0.3	0.7	0.04	0.26	0.4	0.3	712
206595	9907069	0.005	0.3	0.7	0.005	0.295	0.4	0.3	717
206595	9907372	0.03	0.2	0.6	0.03	0.17	0.4	0.4	762
206595	9907674	0	0.2	0.5	0	0.2	0.3	0.5	799
206849	9906766	0.02	0.2	0.7	0.02	0.18	0.5	0.3	730
206849	9907069	0.3	0.2	0.6	0.3	0.1	0.4	0.2	629
206849	9907372	0.02	0.2	0.5	0.02	0.18	0.3	0.5	797
206849	9907674	0	0.09	0.5	0	0.09	0.41	0.5	816
206849	9907977	0	0	0.4	0	0	0.4	0.6	863
207103	9906463	0.08	0.3	0.7	0.08	0.22	0.4	0.3	707
207103	9906766	0.2	0.2	0.7	0.2	0	0.5	0.3	706
207103	9907069	0.4	0.1	0.5	0.4	0.3	0.4	0.1	470
207103	9907372	0.001	0.08	0.4	0.001	0.081	0.32	0.598	850
207103	9907674	0	0.02	0.3	0	0.02	0.32	0.66	880
207103	9907977	0	0	0.3	0	0	0.3	0.7	896
207357	9905858	0.2	0.5	0.8	0.2	0.3	0.3	0.2	627
207357	9906161	0.2	0.5	0.8	0.2	0.3	0.3	0.2	627
207357	9906463	0.1	0.5	0.8	0.1	0.4	0.3	0.2	640
207357	9906766	0.01	0.4	0.7	0.01	0.41	0.3	0.28	691
207357	9907069	0.1	0.3	0.5	0.1	0.2	0.2	0.5	771
207357	9907372	0	0.1	0.4	0	0.1	0.3	0.6	848
207357	9907674	0	0.04	0.3	0	0.04	0.26	0.7	890
207357	9907977	0	0.006	0.3	0	0.006	0.306	0.688	891
207357	9908280	0	0.1	0.4	0	0.1	0.3	0.6	848
207611	9905555	0.04	0.4	0.8	0.04	0.36	0.4	0.2	663
207611	9905858	0.3	0.6	0.9	0.3	0.3	0.3	0.1	565
207611	9906161	0.6	0.8	1	0.6	0.2	0.2	0	462
207611	9906463	0.1	0.7	0.9	0.1	0.6	0.2	0.1	576
207611	9906766	0.4	0.5	0.9	0.4	0.1	0.4	0.1	567
207611	9907069	0.7	0.4	0.8	0.7	0.3	0.4	-0.4	284
207611	9907372	0.03	0.3	0.5	0.03	0.27	0.2	0.5	780
207611	9907674	0	0.2	0.5	0	0.2	0.3	0.5	799
207611	9907977	0.05	0.1	0.5	0.05	0.05	0.4	0.5	808
207611	9908280	0	0.1	0.4	0	0.1	0.3	0.6	848
207864	9905555	0.1	0.5	0.9	0.1	0.4	0.4	0.1	607
207864	9905858	0.2	0.7	0.9	0.2	0.5	0.2	0.1	563
207864	9906161	0.9	0.9	1	0.9	0	0.1	0	407
207864	9906463	0.4	0.8	1	0.4	0.4	0.2	0	488
207864	9906766	0.1	0.7	1	0.1	0.6	0.3	0	543
207864	9907069	0.2	0.7	0.9	0.2	0.5	0.2	0.1	563
207864	9907372	0.006	0.5	0.7	0.006	0.494	0.2	0.3	686
207864	9907674	0.009	0.3	0.6	0.009	0.291	0.3	0.4	749
207864	9907977	0.02	0.2	0.5	0.02	0.18	0.3	0.5	797
207864	9908280	0.0006	0.04	0.4	0.0006	0.0406	0.36	0.5988	856
208118	9905555	0.1	0.7	0.9	0.1	0.6	0.2	0.1	576
208118	9905858	0.4	0.9	1	0.4	0.5	0.1	0	473

208118	9906161	0.6	1	1	0.6	0.4	0	0	431
208118	9906463	0.9	0.9	1	0.9	0	0.1	0	407
208118	9906766	0.3	0.8	1	0.3	0.5	0.2	0	501
208118	9907069	0.3	0.8	0.9	0.3	0.5	0.1	0.1	535
208118	9907372	0.0005	0.6	0.9	0.0005	0.5995	0.3	0.1	605
208118	9907674	0.6	0.4	0.7	0.6	0.2	0.3	0.1	428
208118	9907977	0.2	0.2	0.5	0.2	0	0.3	0.5	773
208118	9908280	0.005	0.03	0.5	0.005	0.025	0.47	0.5	824
208372	9905555	0.1	0.9	1	0.1	0.8	0.1	0	513
208372	9905858	0.2	0.9	1	0.2	0.7	0.1	0	499
208372	9906161	0.2	1	1	0.2	0.8	0	0	484
208372	9906463	0.9	1	1	0.9	0.1	0	0	392
208372	9906766	0.9	1	1	0.9	0.1	0	0	392
208372	9907069	0.8	0.9	1	0.8	0.1	0.1	0	420
208372	9907372	0.07	0.6	0.9	0.07	0.53	0.3	0.1	596
208372	9907674	0.1	0.3	0.7	0.1	0.2	0.4	0.3	704
208372	9907977	0.02	0.09	0.5	0.02	0.11	0.41	0.46	794
208372	9908280	0.03	0.06	0.5	0.03	0.09	0.56	0.32	747
208626	9906161	0.4	1	1	0.4	0.6	0	0	458
208626	9906463	0.6	1	1	0.6	0.4	0	0	431
208626	9906766	0.7	1	1	0.7	0.3	0	0	418
208626	9907069	0.3	0.9	1	0.3	0.6	0.1	0	486
208626	9907372	0.06	0.5	0.8	0.06	0.44	0.3	0.2	645
208626	9907674	0.08	0.2	0.7	0.08	0.12	0.5	0.3	722
208626	9907977	0.04	0.03	0.5	0.04	0.07	0.53	0.36	761
208626	9908280	0	0	0.5	0	0	0.5	0.5	830
208880	9906161	0.5	1	1	0.5	0.5	0	0	445
208880	9906463	0.7	1	1	0.7	0.3	0	0	418
208880	9906766	1	1	1	1	0	0	0	378
208880	9907069	0.5	0.9	1	0.5	0.4	0.1	0	460
208880	9907372	0.3	0.5	0.9	0.3	0.2	0.4	0.1	580
208880	9907674	0	0.3	0.7	0	0.3	0.4	0.3	717

Original Values of pH and EC used for Kriging

X	Y	EC	PH_H2O
206595	9907195	532	8
206680	9907250	730	7
206785	9907305	739	8
206875	9907360	661	8
206965	9907420	1126	7
207070	9907470	1433	7
207165	9907530	787	8
207255	9907580	713	7
207345	9907645	1177	8
207445	9907695	736	7
207540	9907750	929	8
207635	9907815	812	8
207720	9907875	742	8
207815	9907930	531	8
207910	9908000	705	8
207995	9908050	870	8
208080	9908110	652	8
208185	9908170	746	8
208265	9908220	817	8
208360	9908280	691	8
206780	9906880	616	7
206875	9906940	879	8
206980	9907000	435	8
207155	9907115	608	7
207240	9907175	1267	7
207345	9907230	1574	7
207440	9907295	746	8
207535	9907325	522	8
207630	9907390	858	8
207725	9907445	563	8
207825	9907505	819	8
207920	9907570	650	8
208015	9907635	689	7
208095	9907695	416	8
208195	9907745	439	8
208285	9907800	1101	8
208380	9907860	1069	8
208465	9907910	1542	8
208565	9907965	659	8
206995	9906565	2157	8
207165	9906685	774	7
207260	9906745	640	8
207350	9906795	649	8
207460	9906850	617	7
207550	9906900	435	8

X	Y	EC	PH_H2O
207640	9906960	377	8
207925	9907130	640	8
208015	9907190	463	8
208205	9907310	559	8
208300	9907370	463	8
208405	9907415	713	8
208485	9907470	624	7
207550	9906480	486	8
207650	9906545	531	8
207740	9906605	596	8
207825	9906655	518	8
207930	9906710	614	9
208010	9906765	563	8
208105	9906835	499	8
208210	9906885	403	8
208310	9906930	422	8
208395	9906980	409	8
208485	9907050	288	7
208580	9907110	588	8
208675	9907170	512	7
207765	9906150	371	7
207855	9906215	435	7
207945	9906270	320	7
208040	9906325	441	7
208140	9906390	268	8
208230	9906435	198	8
208315	9906500	339	7
208415	9906555	371	7
208505	9906615	454	7
208600	9906670	460	7
208690	9906725	422	7
208790	9906790	332	7
208880	9906850	352	8
207500	9905555	1380	8
207600	9905615	717	8
207690	9905675	495	8
207785	9905735	653	8
207875	9905790	486	8
207965	9905840	550	8
208065	9905890	396	8
208165	9905945	506	8
208245	9905995	512	8
208335	9906060	480	7
208430	9906130	474	8

Appendix I The Study Area


Mid volcanic plain & hummocky surface


Low volcanic plain & wind erosion


Roses IV (High-tech managed green house, Sulmac farm)


Infiltration test using double ring infiltrometer, Sulmac farm


Mini-pit (Am5, Ashy horizons)


Mini-pit (Am15, Diatomite layer)