Soil Investigations on the Sulmac Farm, Naivasha, Kenya by the *International Institute for Aerospace Survey & Earth Sciences* (ITC)

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1. Introduction

This report presents the MSc thesis research conducted by several ITC students on the Sulmac farm, Lake Naivasha, Kenya, in a common format that should be of interest to their hosts, i.e., the Sulmac farm. Kwacha (1998), Atkilt (2001) and Simfukwe (2001) carried out soil survey in the Lake Naivasha area, including most of the Sulmac farm. These authors made detailed analysis on selected soil properties to meet their research objectives. Generally, they determined the pattern of soil cover, characterised the soil and made interpretations for their own research and in some cases for soil management.

Sulmac Farm was an excellent host for ITC students, and we hope with this report to in some small measure repay their hospitality and logistical support, both in the field and laboratory.

Detailed analysis conducted by these researchers includes some aspects that are not relevant to Sulmac farm. The reader is referred to the thesis works of these authors for other aspects not treated here.

Specifically, the work of Simfukwe (2001) focused on the Longonot part of Sulmac farm which attempted to define soil series. The work of Atkilt (2001) has focussed on soil survey to predict soil characteristics related to land management. Moreover, the work of Kwacha (1998) focussed on vulnerability of soils to change in agricultural use around lake Naivasha.

2. Soil survey

2.1. Available data and/or information on Sulmac farm

?? 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 (see **Figure 1**)
?? Thesis papers of Kwacha (1998), Atkilt (2001) and Simfukwe (2001)

2.2. Coordinate system

All maps are shown with the UTM grid.

? ? 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

2.3. Geopedologic Map

Mapping of soil was conducted using the so-called ‘geopedologic’ approach. This approach was developed by Zinck (1988/89) to systematically integrate geomorphology and pedology using geomorphology as a tool to improve and speed up the soil survey. This depends on the truth of two hypotheses: boundaries drawn by landscape analysis separate most of the variation in the soils, and sample areas are representative; viz their soil pattern can be reliably extrapolated to unvisited map units. In the case of Sulmac farm, most of the map units were visited and sampled.

The geopedologic map is drawn during aerial photo interpretation. This is done before going out to the field. Lines are later verified in the field, and may be adjusted. Soil types are of course identified in the field.

Three of the research works Kwacha (1998), Atkilt (2001) and Simfukwe (2001) have identified three major landscape units in the area namely, the lacustrine plain, the volcanic plain, and hilland (see **Figure 2**). The most agriculturally important landscape units are the lacustrine and the volcanic plain.

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 sharp geopedologic boundary in between them, because of the gentle topography, which undoubtedly has been influenced by higher lake levels and wave action in the past. Though the lacustrine plain doesn’t have sharp boundaries with the volcanic plain, its surface features and topography to some degree can separate it from the volcanic plain. Generally, the lacustrine plain has straight, flat to gently sloping topography with no surface features that indicate wind erosion and is less sandy than the volcanic plain occasionally old lake level terraces can be seen.

T**he volcanic plain** has 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 200 years ago (Thompson and Dodson, 1963). This unit, for example around Longonot branch (Sulmac farm), shows hummocky surfaces that are sandier than the lacustrine plain. They are most probably transported and shaped by wind, sand dunes. It also includes areas of ‘black’ (obsidian-rich) sands.

Figure 1. Satellite image of the Sulmac farm and associated areas (FCC452) form Landsat TM 2000

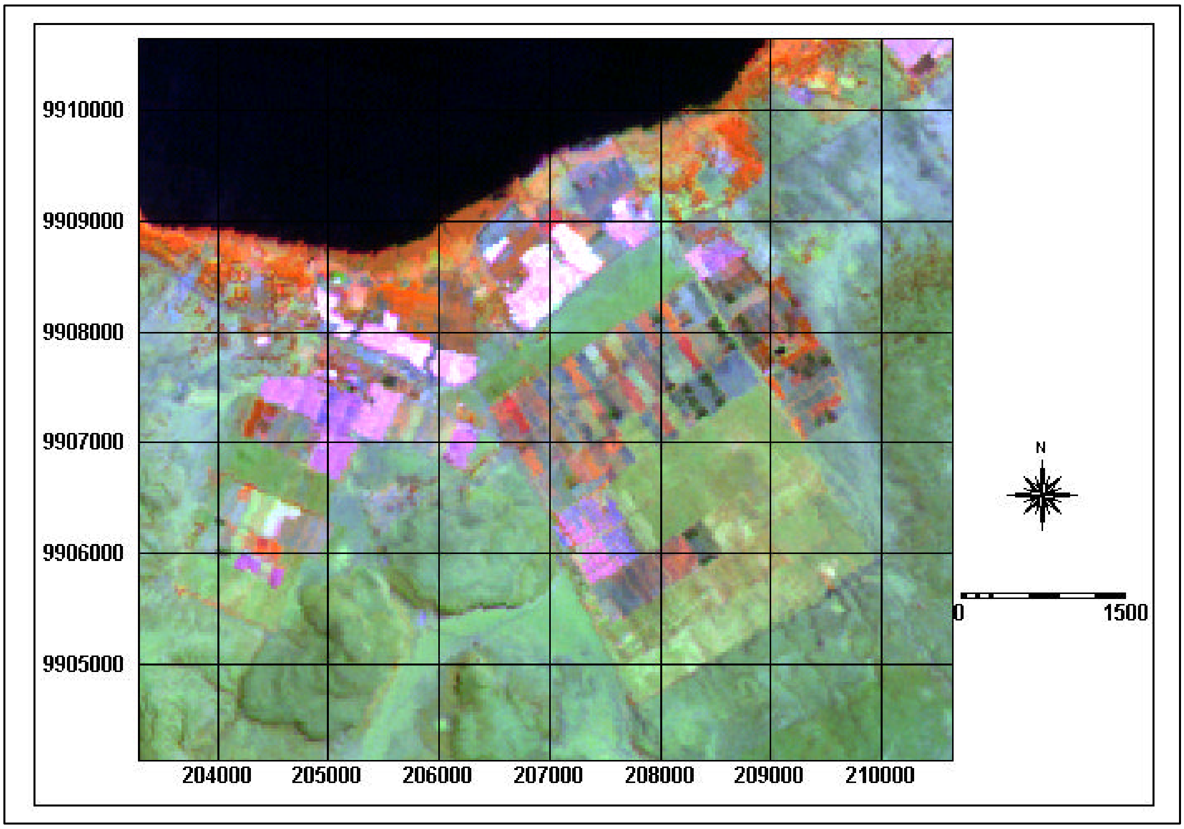


Figure 2. The Geopedologic and sub-block boundary map of Sulmac farm area (Atkilt, 2001)

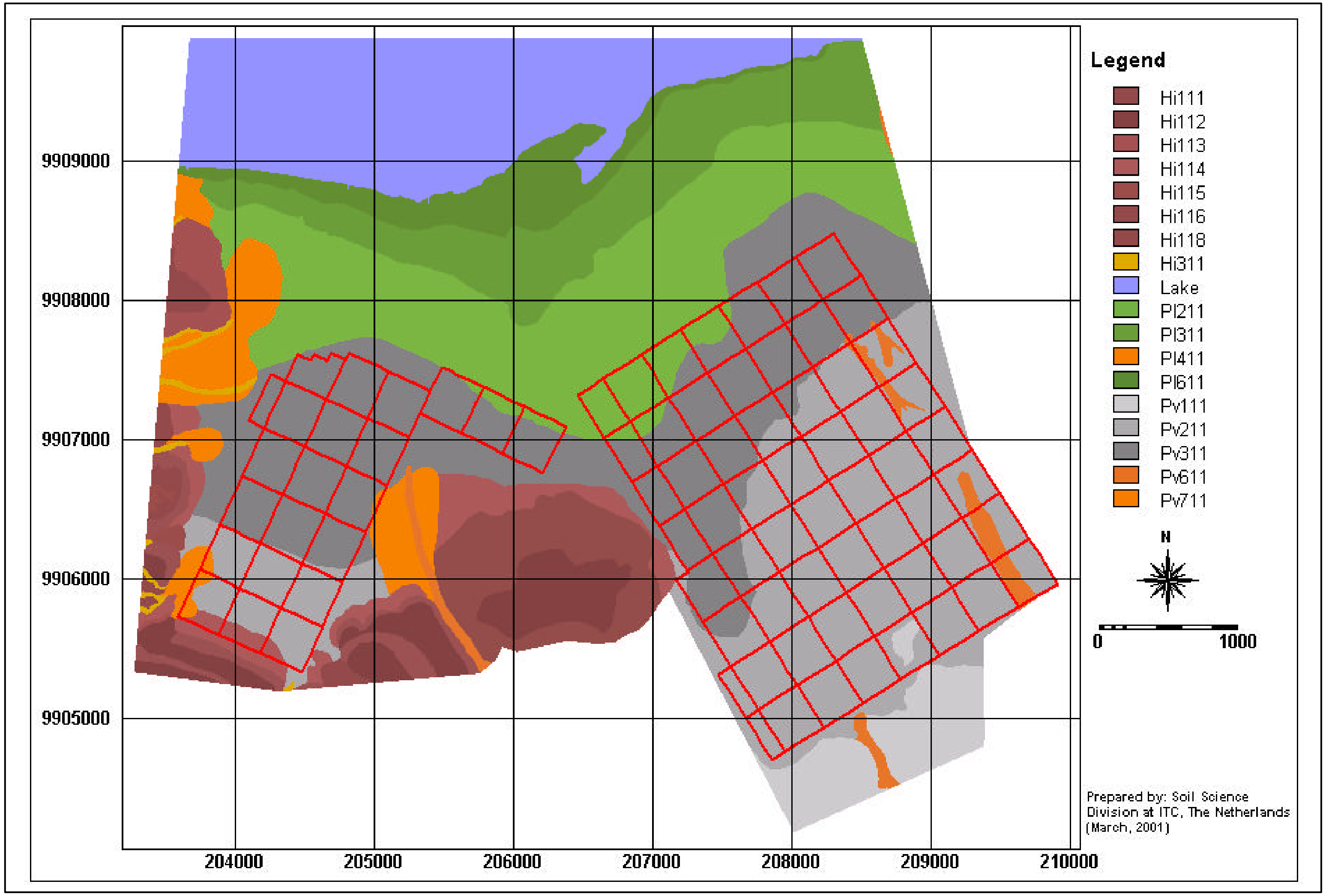


Table 1. The geopedologic map legend

Land-scape	Relief	Lithology	Land form		Soil type according to WRB (1998)	Soil type according to USDA (1998)
Hilland (Hi)	High Hills	Olkaria Comendite; lavaflows in some parts it is covered with Longonot Ash	Hi111	Slope facet complex	Leptosols (?) Not sampled	
			Hi112	Summit/shoulder complex	Leptic Andosols (?) Not sampled	
			Hi113	Backslope/footslope compx		
			Hi114	Foot slope	Skeleti-Vitric Andosol	
			Hi115	Scarp		
			Hi116	Talus		
			Hi118	Backslope		
	Vale	Alluvium	Hi311	Bottom side complex		
Volcanic plain (Pv)	High Volcanic Plain	Longonot ash and Akira Pumice	Pv111	Tread/riser complex	Tephric Arenosol	Aridic Ustipsamments (Ashy, glassy, Isothermic)
	Mid Volcanic Plain	Same	Pv211	Tread/riser complex	Areni-Vitric Andosol (Eutric) & Tephric Arenosol	Aridic Ustipsamments (Ashy, glassy, Isothermic)
	Low Volcanic Plain	Volcanic ash & Akira pumice	Pv311	Tread/riser complex	Areni-Vitric Andosol	Aridic Ustipsamments (Ashy, glassy, Isothermic)
	Swale	Alluvium	Pv611	Bottom side complex	Areni-Vitric Andosol (Dystric)	
	Fan	Alluvium	Pv711	Distal/proximal complex		
Lacustrine plain (P	Mid Lacustrine Plain	Lacustrine sediments and reworked volcanic materials	Pl211	Tread/riser complex	Areni-Vitric Andosol	Aridic Ustipsamments (Ashy, glassy, Isothermic)
	Low Lacustrine Plain	Same	Pl311	Tread/riser complex	Sodi-Fluvic Cambisol (Skeletic, Eutric)	Vitrandic Haplustepts (ashy- pumicious, mixed, isothermic)
	Fan	Alluvium/colluvium	Pl411	Distal/proximal complex		

L)	Riparian	Lacustrine sediments	Pl611	Undifferentiated		

2.4. Topsoil

The main agricultural crops of Sulmac farm are flowers and vegetables. For example, flowers include roses, carnations, and hypericum. 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 in Sulmac farm 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 farmers meaningful results for use.

Topsoil mapping was performed using a continuous model of spatial variability (for topsoil pH and EC) for the Longonot site and the proposed FAO (1998) topsoil characterisation for the observation points. The secondary data used for the topsoil pH and EC was obtained from Sulmac farm at the time of MSc student's research work.

2.4.1. FAO (1998)

The proposed FAO (1998) topsoil characterisation has immerged from the fertility capability classification (FCC). Like the FCC, the proposed FAO (1998) topsoil characterisation attempts to bridge the gap between the soil classification and soil fertility constraints. The observation points used for the topsoil characterisation by Atkilt (2001) are shown in **Figure 16**

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. Accordingly, the observation points are characterised in **Table 2**.

Table 2. Topsoil characterization using the proposed FAO (1998) method

Obs. Id	Characterization	Code
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**
Am4	**Areni-Vitric Andosol (Eutric)** with Sandy, melanic, altaric topsoil	**S m2 a5**
Am5	**Areni-Vitric Andosol (Eutric)** with Sandy, melanic topsoil	**S m2**
Am10	**Sodi-Fluvic Cambisol (Skeletic, Eutric)** with Sandy, melanic, natric, altaric topsoil	**S m2 a3**
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**

The management requirements could be as follows:

Sandy topsoil: most of the soils of the study area including the Naivasha and Longonot 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 (see also section **2.5.1**.)

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 that could be used are: gypsum, phosphogypsum, calcite and other acid forming salts like iron and aluminium sulphates, lime-sulphur and pyrites (see also section **2.5.5 and 2.5.6**).

Low nutrient retention property: some of the soils of the study area are very sandy and have 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 (see also section **2.5.4 and 2.5.5**).

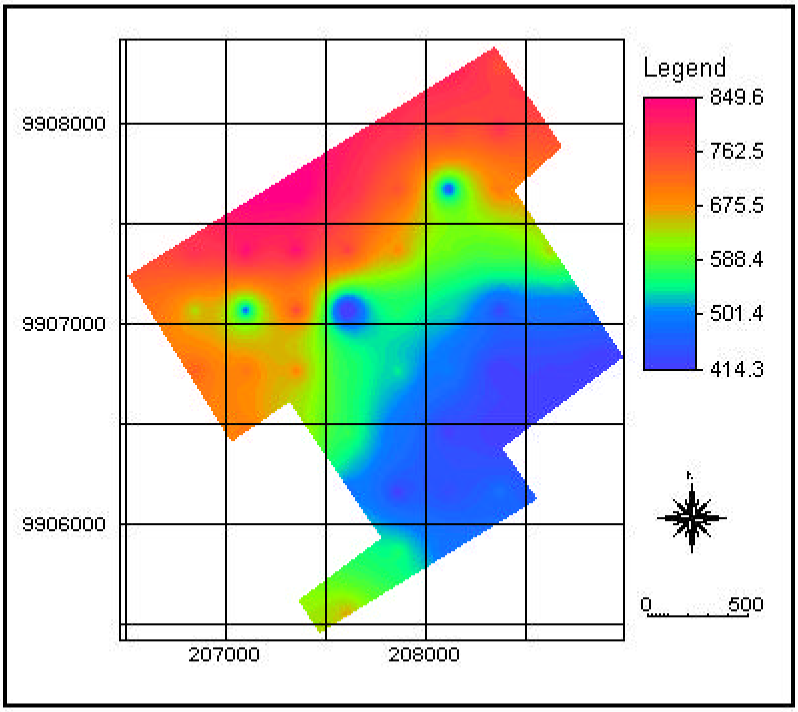
Wind-eroded property: wind erosion is prevalent in the volcanic plain. It is more severe in the high and mid volcanic plain. Therefore, windbreaks are preferably planted at the farm boundaries to reduce its impact. The wind will also have physical impact on the crops.

2.4.2. Mapping with continuous model

Soil EC

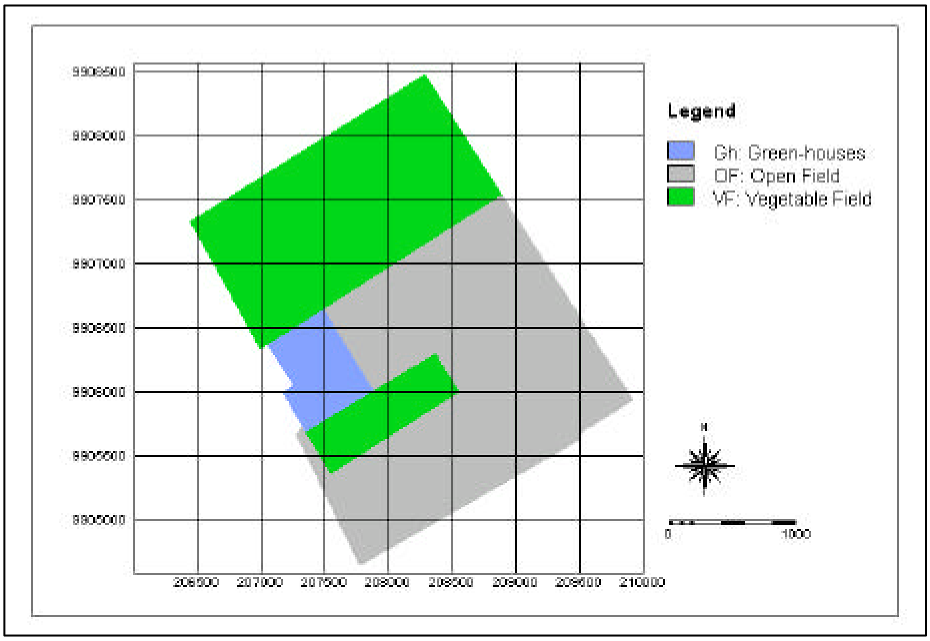
Geo-statistical analysis was applied to determine the nature of spatial variability of the EC (?S/cm) value of the Longonot branch, Sulmac farm. The total number of samples used for this analysis is 92. All the data was measured and analysed by the Sulmac soil lab during the month of July and August 2000 and generously provided to us for further data processing and analysis. They were taken from the first 5-20cm depth by bulking from a plot size of 100m x 300m. In ILWIS, a point map was created by digitising taking the centres of the farm plots. Interpolation between the data points was performed using indicator kriging. Ordinary kriging could not be used, because the data is strongly non-normal, even when log-transformed. The indicator method establishes probabilities of exceeding a set of cutoff values. Then these probabilities are averaged and back-transformed to EC values (Meer, 1999)

Figure 3. Topsoil EC (?S/cm) map by indicator Kriging (Longonot site, Sulmac blocks 30's-80's)



The result of the 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 = .000). But, the difference between the lowest and the highest values of EC are 435 ?S/cm. This difference is not as such very big when it comes to relevance to land management but it is an indicative/suggestive increment in the managed plots. This, to some extent, could also be attributed to the lithology of the area.

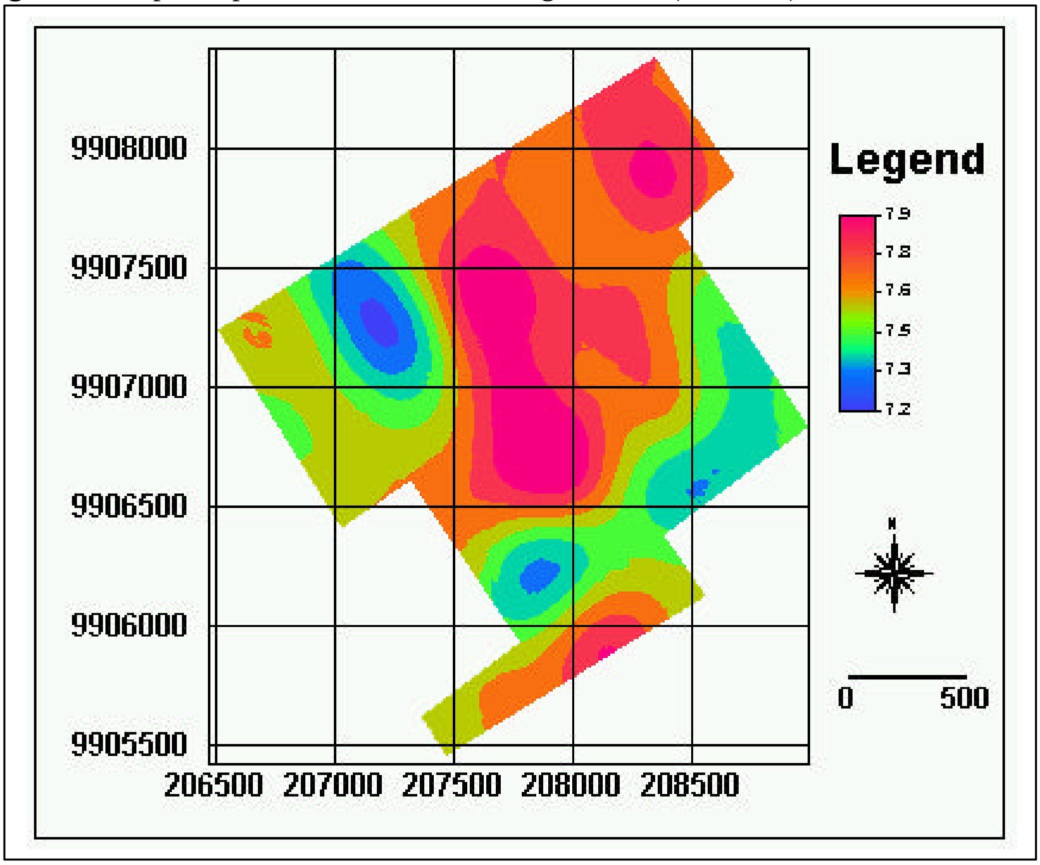
Figure 4. The land cover map of Sulmac farm (Longonot site, 30-100's)



Soil pH

A soil pH map of Sulmac farm, Longonot area was produced in a similar manner to the EC map. But, in this case the data is normally distributed at 95 % confidence interval. Due to this, ordinary kriging was used.

Figure 5 Soil pH map of Sulmac farm, the Longonot area (30's-80's)



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. 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 fields happen to have already an optimal range of pH for the selected crops. Management has a great influence on the adjustment of both EC and pH conditions of the soil for proper cultivation. 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. Similar to soil EC values, differences in soil pH values are not also big approximately 0.7 units.

Spatially, both soil pH and EC can be seen in **Figure 5** and **Figure 3** respectively. The following figures show the sampling points, original values and their respective quartile values.

Figure 7. Post plot of soil EC quartile value

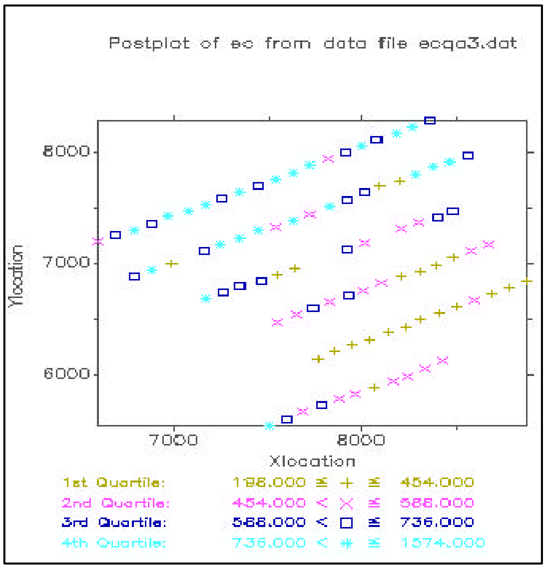
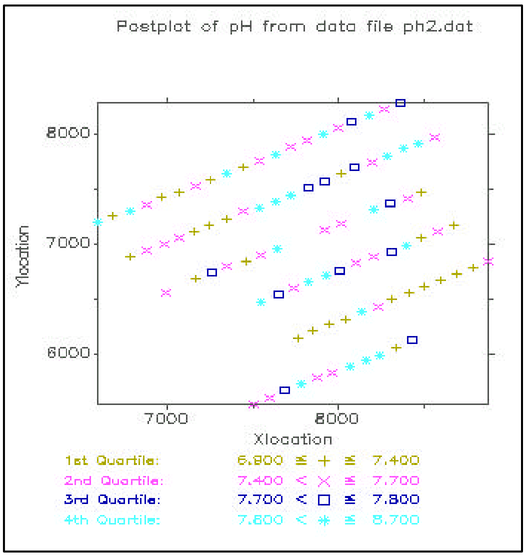


Figure 6. Post plot of soil pH quartile value



2.5. Soil properties

2.5.1. Infiltration

Only one observation point (Am10) is located in SHER-Agencies farm, the rest are all in Sulmac farm. Since the infiltration test points are near the field profiles dug, they are given the same code. Therefore, their location is shown in **Figure 16**. The test points are also made in pairs (one on the managed and the other on the unmanaged area). Am2, Am5, Ao3 and P2 are on the unmanaged plots. Moreover, all the observations have a good power fit model (see **Figure 8**).

Figure 8. Infiltration rates of four paired comparison points

Original measurements

Power fit model

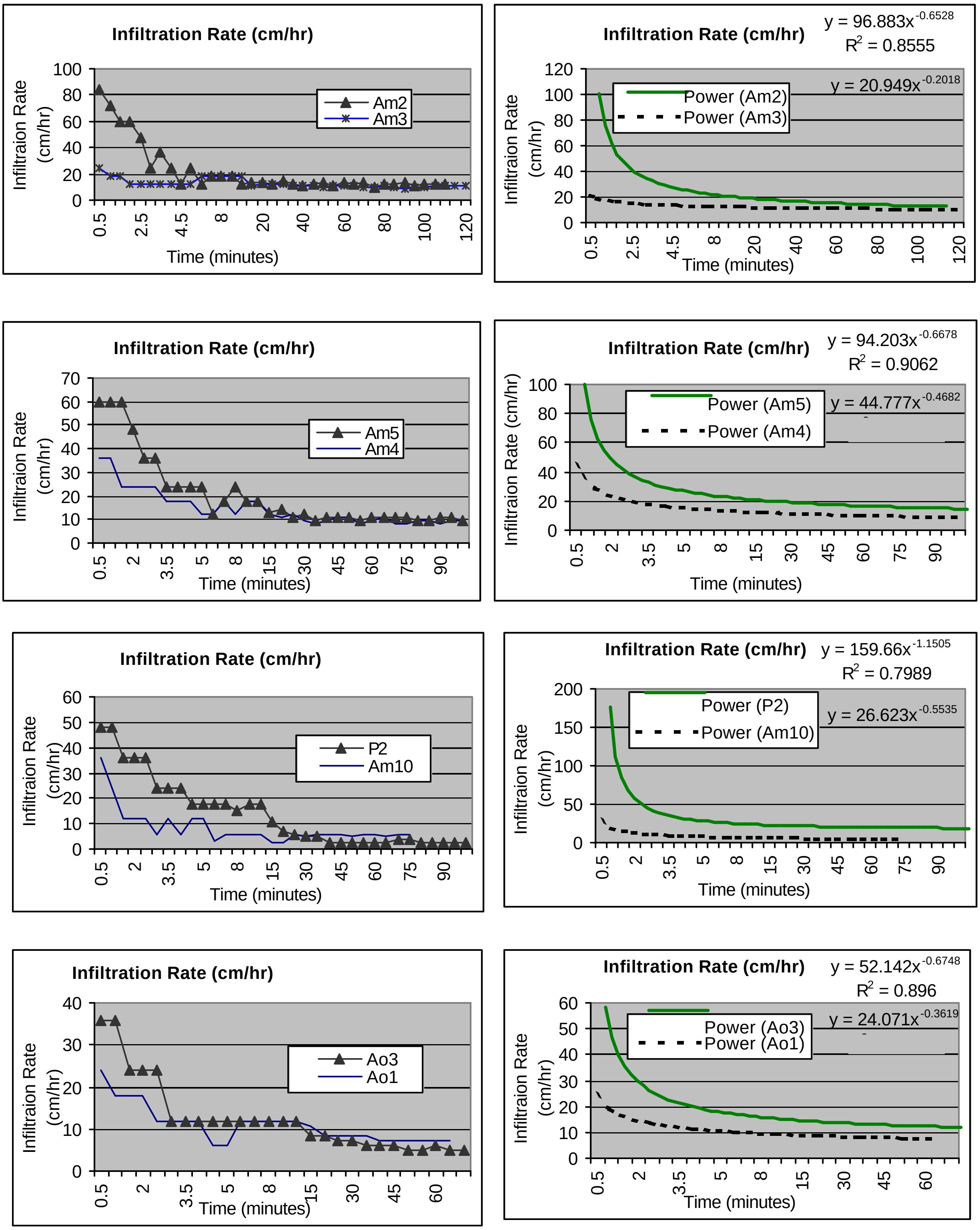


Table 3. Infiltration rate (cm/hr) of the paired comparison observation points

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 (S3)	69	Am3	18	10.8 (S3)	56
Am5	60	9.6 (S3)	57	Am4	36	9.6 (S3)	62
Ao3	36	4.8 (S2)	36	Ao1	18	7.2 (S3)	30
P2	48	2.4 (S1)	50	Am10	24	6.0 (S2)	60

Six options were considered for the analysis of infiltration test results. These are:

A. Using the raw infiltration data

1. At minute one
2. Steady state
3. Depth at which the infiltration water has reached down the profile

B. Using the power fit model

4. At minute one,
5. 1st hour and
6. After 2 hrs

Statistically the test result shows that 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 difference in the infiltration rate results could also be seen from the charts (see **Figure 8**). 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.

However, all rates are high to very high; although there are significant differences, they are minor when compared with heavier-textured or poorly-structured soils. The following table could be used to classify soils suitability for furrow irrigation (considering infiltration rates).

Table 4. Basic infiltration rates suitability for furrow irrigation

Suitability	Infiltration rates (cm/hr)	Interpretation
S1	0.5-3.5	Water infiltrates relatively quickly but can reach the end of a furrow
S2	3.5-6.5	
S3	6.5-12.5 or 0.2-0.5	
N1	12.5-25 or <0.2	
N2	>25 or <0.2	Land that is completely unsuited to the use

2.5.2. 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. During the field survey, there was variability in soil moisture content. Though differences due to Bd and gravel contents of the paired comparison points are not as such significantly different.

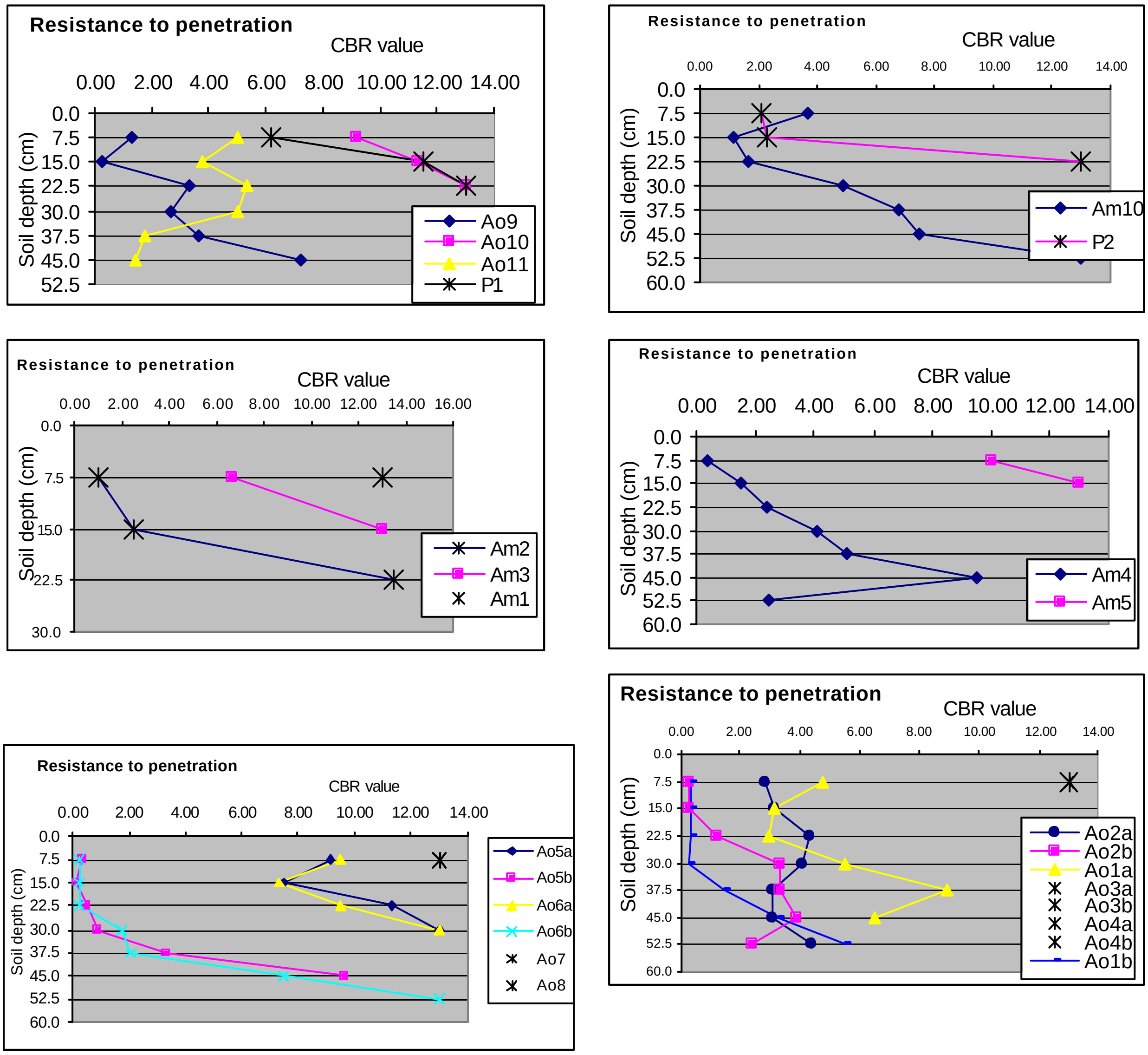
For sites having similar soil moisture, bulk density, and gravel contents it can be noticed, from the graph, that penetration resistance for unmanaged sites is higher near the surface than the managed sites, for example, P2 versus Am10 and Am2 versus Am3. This is mainly because of ploughing. Ploughing pulverises the top 0-30-cm 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. More coarse fragments inhibit penetration. 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 walking.

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 9**

*Using **Hand** Penetrometer:* The Hand Penetrometer can measure only up to 4.5kg/cm^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).

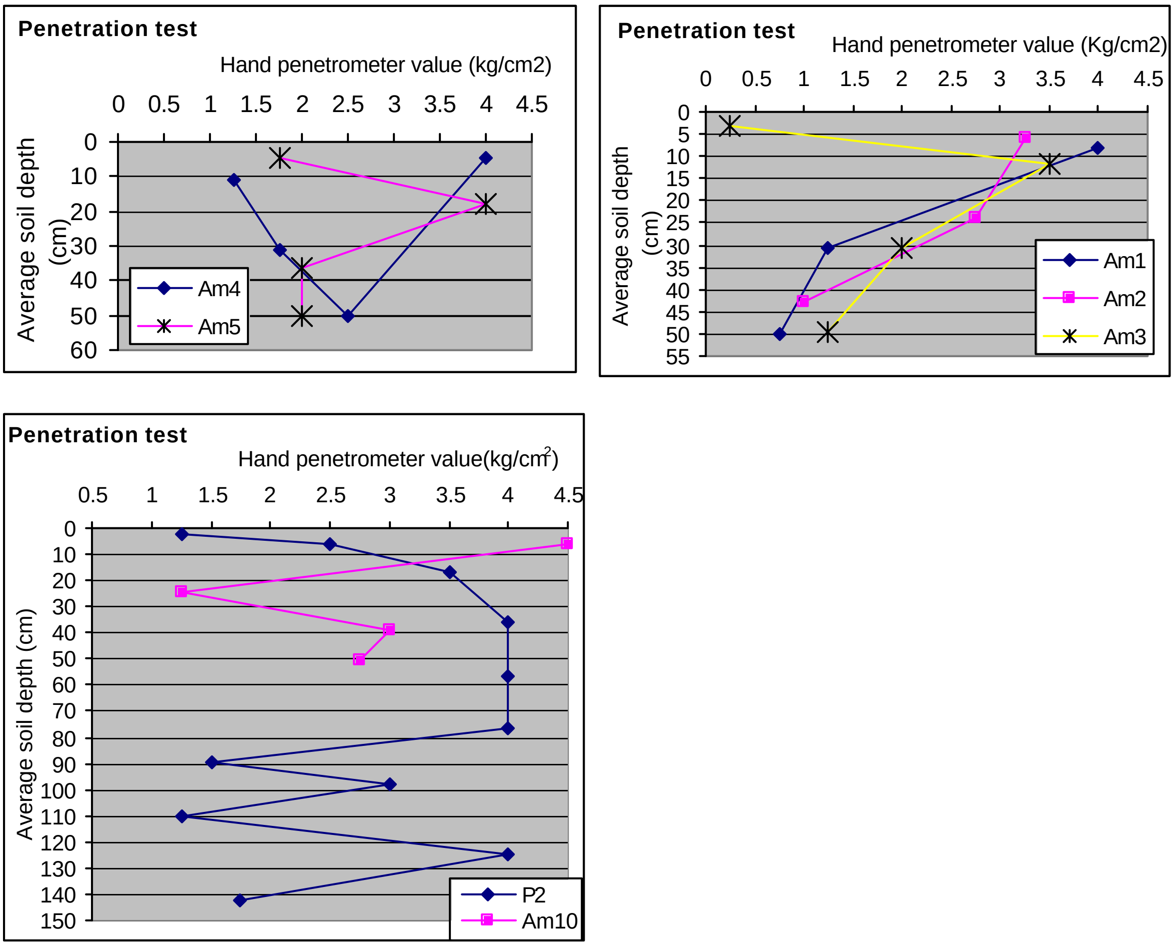
Similar to the C.B.R. method, this test is also affected by the soil moisture condition, bulk density (Bd), gravel and ash content of the horizons. Because of this, there is no clear difference between the unmanaged and high-tech managed observation points. Unmanaged site Am5 show lower values of penetration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

Figure 9. 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 10. Penetration resistance test results using hand penetrometer for each site



2.5.3. Bulk Density

Similar to soil pH and EC, laboratory tests of bulk density soil samples were made in Sulmac laboratory. The result of the three of the horizons, the 1st, 2nd and 3rd, 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. The laboratory data is shown in **Appendix A**.

As shown below 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 (0.8686 and 1.2101, respectively; pooled standard deviation 0.1866) and significant difference in soil pH (7.38 and 6.8, respectively; pooled standard deviation 0.59). 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.
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 (0.83 and 1.25, respectively; pooled standard deviation 0.174) and significant difference in soil pH at 95% confidence level (8.18 and 7.32, respectively; pooled

standard deviation 0.74). This result is the same as the first horizon. On the other hand, all the properties measured are not significantly different at 95% confidence interval for the 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			

```
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
```

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			

```
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			

```
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
```

2.5.4. Organic carbon content

Organic matter content of paired data points for the managed and unmanaged sites of the 1st, 2nd and 3rd horizons was determined in ISRIC laboratory, Wageningen, The Netherlands.

Generally, the soils of the volcanic plain have low topsoil organic matter content (<0.7% weighted average) as compared to the lacustrine plain soils (>1%). This is mainly because of thick vegetation and periodic high water tables.

Increasing the organic matter content of the soil would be important to improve the structure, the water holding capacity, to reduce wind erosion, to increase the CEC of soil and improve its chemical fertility.

2.5.5. Soil pH

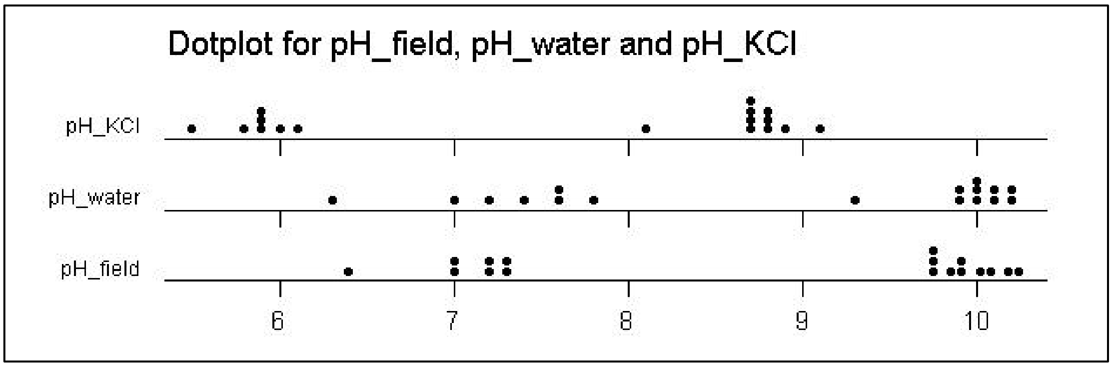
Test of correlation between three-soil pH measurement methods was made. These are pH_field (measured in Sulmac lab using Sulmac instrument), pH_water (measured in ISRIC lab) and pH_KCl (measured in ISRIC lab but with KCl). The main purpose here is to verify similarities or differences between the methods if they exist and to help standardise the measurement methods.

For example, the ratio of soil to water used in Sulmac lab is 1:5 as compared to 1:2.5 in ISRIC lab. The same soil samples were analysed by both methods. There is strong and highly significant correlation between the three methods (**Table 5**). The Sulmac lab 1:5 water pH correlated extremely closely to the ISRIC 1:2.5 water pH. Both correlate well with pH-KCl

The regression pH_field (Sulmac) = -0.396492 + 1.033 pH_water (ISRIC) to predict Sulmac pH-water from ISRIC pH-water shows a bias (**Sulmac is on average 0.4 pH-units lower**) and extremely small gain (i.e., one unit increase in ISRIC pH is matched by 1.03 units increase in Sulmac pH). It seems that the increase in dilution causes this small bias. Regression shows the actual numerical differences between methods as follows:

pH_field (Sulmac) =–0.396492+1.033 pH_water (ISRIC)
pH_KCl (ISRIC) = -1.29371+0.998627 pH_water (ISRIC)
pH_field (Sulmac) = 1.23062 +0.996179 pH_KCl (ISRIC)

Figure 11. Dotplot of the different pH testing methods



NB: pH_KCl: Soil pH measured in ISRIC lab (the Netherlands).

pH_water: Soil pH measured in ISRIC lab (the Netherlands). Using distilled water, 1:2.5.

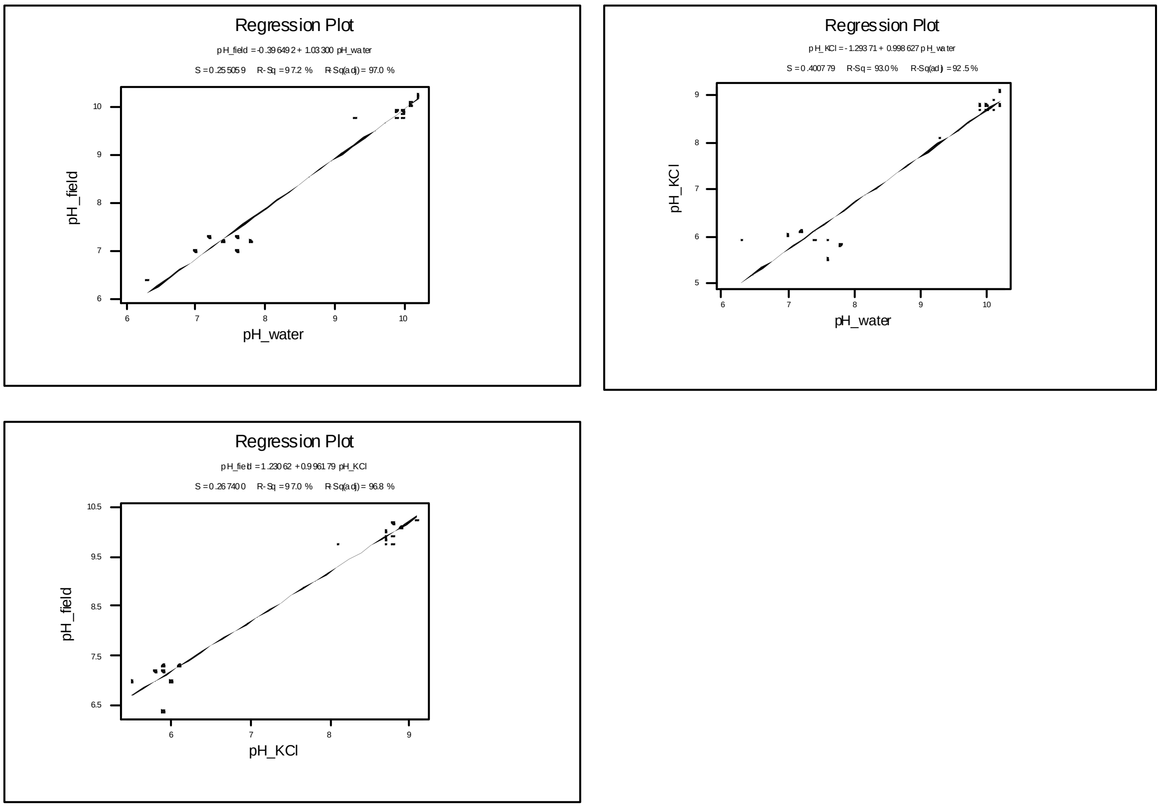
pH_field: soil pH measured in Sulmac farm lab (Naivasha, Kenya). Using distilled water, 1:5

Table 5. Correlation between the three-pH measurement methods

	pH_field	pH_water
pH_water	0.986	
	0.000	
pH_KCl	0.985	0.964
	0.000	0.000

```
Cell Contents: Pearson correlation
               P-Value
```

Figure 12. Regression plot between pH_field, pH_water & pH_KCl

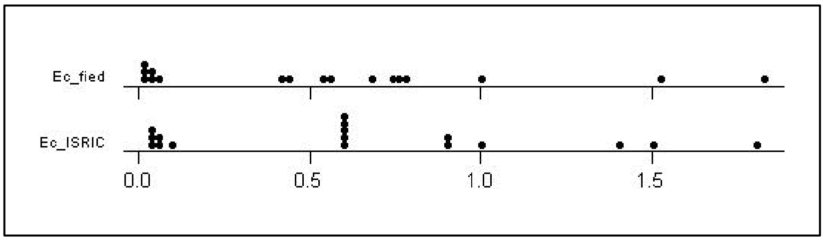


2.5.6. Soil EC

Similar to the three-soil pH lab measured values correlation between two EC analysis outputs was made. One which was measured in Sulmac lab (EC_Field) and the other in ISRIC (EC_ISRIC) lab.

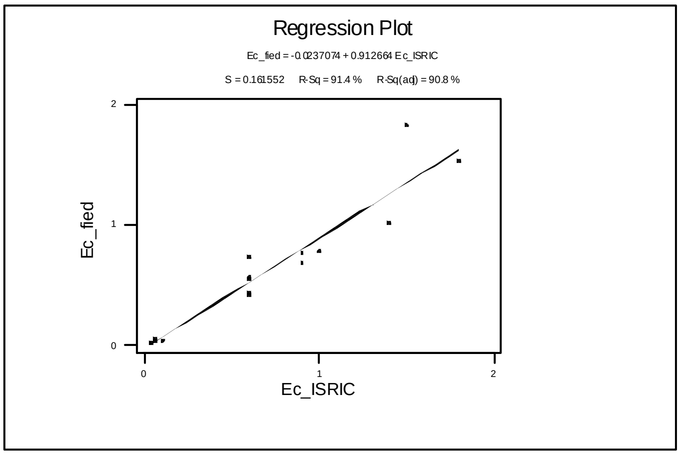
The result shows that there is highly significant correlation between the two methods. However, there is no so much consistency as with pH-water. The values are low in absolute terms, and not so variable, so this result is not so disturbing. The average EC measured by Sulmac and ISRIC lab is 557 and 636 ?S/cm.

Figure 13. Dotplot between EC_field and EC_ISRIC



Pearson correlation between Ec_ISRIC and Ec_fied = 0.956, P-Value = 0.000

Figure 14. Regression plot between EC_ISRIC and EC_field



2.6. Soil series

Simfukwe (2001) has proposed three soil series in the Longonot part of Sulmac farm, considering depth of the weathered soil, gravel percentage (in A and B-horizon) and thickness of A-horizon and the depth of the B-horizon. Synthesising two approaches, based on map units defined by geo-pedologic mapping and by multivariate cluster analysis, he proposed three series: which he called the Naivasha, the Sulmac, and the Longonot series. More over he proposed a field key for the three series (see **Figure 15**). Note that the term thin, moderately thick, thick and very thick refers to <10cm, 10-20cm, 20-30 cm, 30-40cm & >40cm respectively.

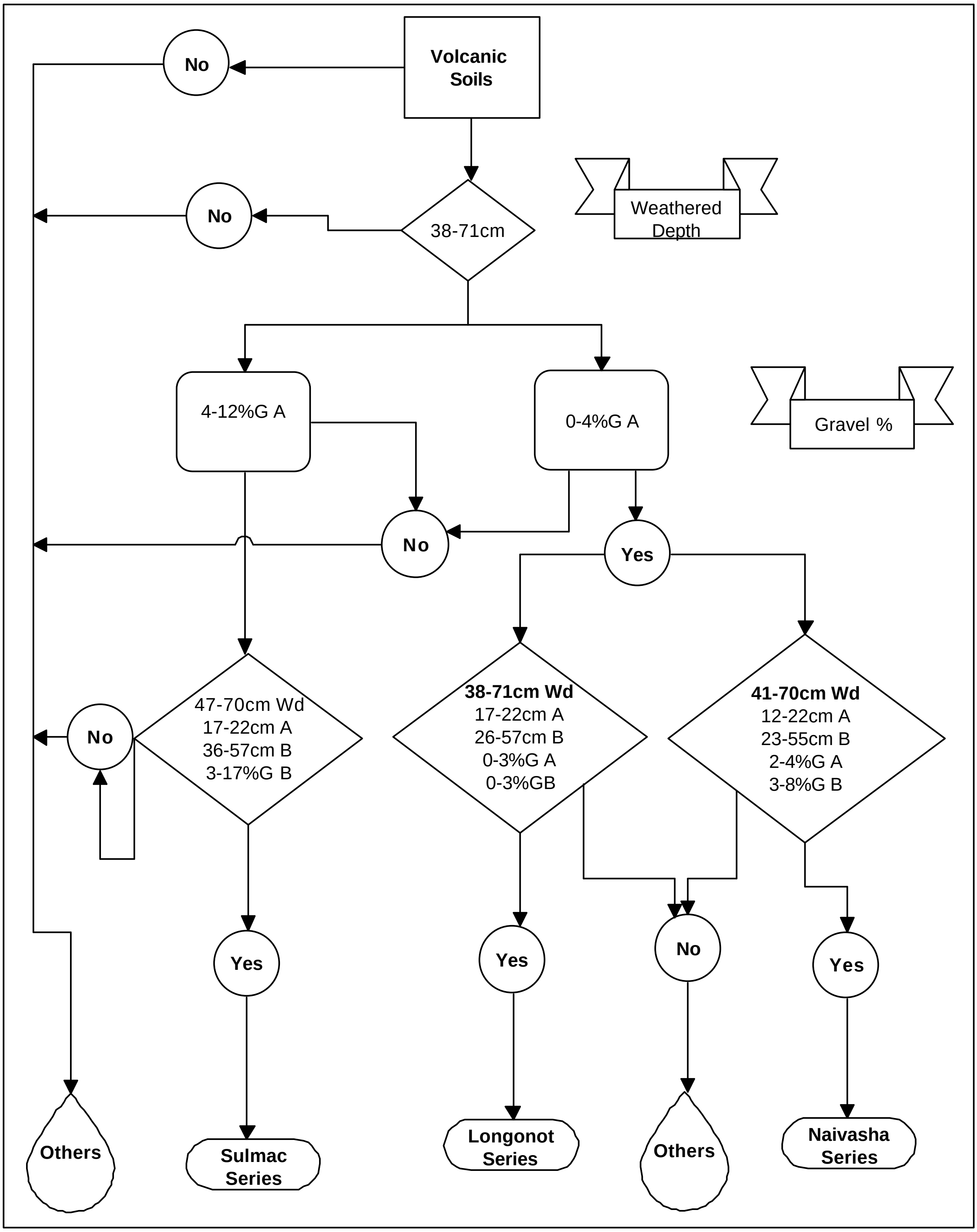
The Sulmac series is gravely sandy loam/loamy sands to loam sands, over volcanic ash slightly shallow to moderately deep, moderately thick A horizon, shallow low to moderately deep limit of Bw horizon, and gravely.

The Naivasha series is sandy loam or loamy sand over lacustrine sediments shallow to moderately deep weathering depth, moderately thick A horizon, shallow to marginally moderately deep lower limit of Bw-horizon, and slightly-gravely.

The Longonot series is sandy loam to loamy sand, glassy, over volcanic ash moderately deep, moderately thick A and very shallow B-horizons, non-gravely to slightly gravelly.

For intensive management purposes the gravellier Sulmac series can be managed differently from the non-gravely Naivasha and the Longonot series. This recommendation is quite preliminary, until more variables are available from the laboratory to confirm the results.

Figure 15. Field key for the proposed (synthesized) series



Where:

A=thickness of A-horizon, B=depth of B-horizon, Wd=weathered depth, G A or G B=gravel % in A or B horizon

2.7. General constraints

In addition to the topsoil characterisation constraints some constraints observed on the farm are:

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 in the soil.

2. *Toxicity:* some toxicity including copper is also reported to be a production-limiting factor.

3. *Nutrient imbalances* due to the potic nature, i.e. excess of K inhibiting uptake of other cations. The soils in the study area 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. Due to moisture content changes, in most managed plots, the compaction when measured by penetrometer instrument didn't show the expected results.

5. *Drainage*: there are some excessively drained soils in the area, which have a high infiltration rate. These soils also need separate management practices.

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

7. *Wind erosion*: there is problem of wind erosion especially in the volcanic plain. It is not easy to quantify the impact of wind erosion of the area. But, previous sand dunes and surface features indicate that there is wind erosion in the area. Unless it is protected it causes physical damage to crops and erosion to the soil.

3. General recommendations

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 for instance to a soil depth of 150cm's.

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

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5. Appendix A Field data (laboratory data)

OBS_Id	HOR_No	pH_field	BD (gm/cc)	EC (?S/cm)	% Coa_frag	Ha_pene (Kg/cm2)	Organic Carbon (%)
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	1.64
Am2	2	7.3	1.43	57	1.13	2.75	0.6
Am2	3	7.4	1.31	107	1.40	1	0.24
Am3	1	6.95	1.33	104	2.71	0.25	1.01
Am3	2	7.2	1.42	57	1.21	3.5	0.64
Am3	3	7.1	1.51	52	1.35	2	0.6
Am3	4	7.3		37	1.12	1.25	
Am4	1	7.4	1.26	75	5.73	1.25	0.64
Am4	2	7.65	1.28	72	4.96	1.75	0.43
Am4	3	7.85	1.32	52	5.54	2.5	0.21
Am5	1	6.76	0.62	260	11.16	1.75	9.68
Am5	2	7.1	1.19	77	12.62	4	1.08
Am5	3	7.25		64	9.45	2	0.63
Am5	4				10.38	2	
Am10	1	8.1	1.03	113	27.15	4.5	1.01
Am10	2	8.4	0.92	136	22.92	1.25	0.79
Am10	3					3	0.79
Am10	4					2.75	
P1	1	7	1.36	53	1.44	1.5	0.84
P1	2	7.3	1.29	44	0.29	4.5	0.52
P1	3	7.3	1.44	26	0.44	0.25	0.28
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	3.96
P2	2	9.75	0.67	1531	8.41	4	3.78
P2	3	10.24	0.98	1008	31.43	4	0.8
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	1.16
Ao2		6.9	0.94	84	9.39	1.75	1.13
Ao3		7.1	1.17	105	8.78	3.25	1.02
Ao4		7.3	1.28	106	12.22	2.75	1.02
Ao5		7.3	1.16	196	10.40	2.5	1.12
Ao6		5.7	1.34	237	8.40	2.25	1.1
Ao7		6.7	1.43	82	7.58	2.5	1.01
Ao8		6.3	1.30	335	6.20	3.25	1.02
Ao9		6.3	1.06	452	17.71	3.25	
Ao10		6.7	1.08	108	15.68	3	1.15
Ao11		7	1.26	75	20.50	2.25	

Figure 16. Field observation points