

**SOILS OF THE MEKELLE AGRICULTURAL RESEARCH
CENTER AND ITS TESTING SITES**

**The Federal Democratic Republic of Ethiopia
Ethiopian Institute of Agricultural Research**



**National Soil Research Center (NSRC)
Soil Survey and Land Evaluation Section**

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FOREWORD

One of the major achievements as a result of the recent restructuring of the national agricultural research system and the establishment of the Ethiopian Agricultural Research Institute (EARI) is the upgrading of the soil and water research to a program level and appointment of a Director of the Program.

One of the four major soil and water research programs under the Directorate is Soil Characterization and Evaluation Program, which is coordinated and largely implemented by the National Soil Research Center (NSRC). The main activity under this program is soil survey and land evaluation research project.

In the past, lack of information on the type and characteristics of soils, even at research centers and benchmark locations, has been a serious drawback, not only for proper implementation of the soil and water research activities, but also for reliable interpretation and extrapolation of the overall agricultural research findings.

With the realization of the seriousness of this problem, the soil survey and land evaluation unit recently established under the NSRC, formulated a research/activity project for surveying the soils of all research centers in the shortest time possible, with the limited facilities and manpower available. As per the priorities set at program level in consultation with the Director of the SWRP, the survey activity started in 2000 season for Kulumsa, Areka and Pawe Agricultural Research Centers.

The report is a standard soil survey report with a soil map at a scale of 1:5,000, showing the different soil units at the research center. The survey report has invaluable information for all researchers, which may help for identification and defining of appropriate research sites for proper interpretation and extrapolation of research results to similar areas.

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ABSTRACT

Soils of the Mekelle Agricultural Research Center and its testing sites were surveyed by fixed-grid technique at 50 by 50m intensity (1:5,000 scale). The total area of the experimental field is about 269ha. Thirteen soil-mapping units were identified on the basis of surface slope, soil depth and surface soil structure. For detail characterization and classification of the soils in the mapping units 13 pedons were described and sampled depth wise from natural horizons for laboratory analyses.

Vertisols and Luvisols are the dominant soil types but also Fluvisols, Nitisols and Phaeozems occur in minor amounts. In general, the soils are deep, have aggregated soil structure and low bulk density that give the soils good physical property for plant growth (workability problem of the Vertisols excepted). The soils have neutral to slightly acidic soil reaction that progressively becomes slightly alkaline with soil depth. The total nitrogen and phosphorous content of the soils is low. The exchange complex of the soil is dominated by Ca. Although the absolute amount of K appears to be adequate in some soils, the relatively higher (Ca+Mg) content may induce K deficiency in these soils. The available zinc and copper content of the soils is also low. Thus future soil amelioration activities should focus to improve chemical fertility problems of the soils.

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1. INTRODUCTION

Research and extension in the agricultural sector has begun long ago aiming at assisting farmers to improve their standard of living through increased agricultural productivity. So far, quite a number of research findings addressing major agricultural problems have been released for wider application. Some of the research findings, if not all, have proved to be more or less successful. However, there were also pitfalls here and there due to a very generalized and approximation of recommendation. Amongst is the difficulty in dissemination and extrapolation of research findings and outputs to other areas due to lack of sufficient soil information.

As regards to soil studies, a number of surveys have been carried out for different purposes at different times by different institutions. These surveys cover a sizeable area of the country. However, the scale and purpose of the studies allow only planning for development undertakings. A very detailed survey is necessary to characterize soils at research centers for the proper understanding of the research media and reliable extrapolation of research outcome.

At present there are more than 37 Agricultural Research Centers and Sub-centers in the country. Except for very few of them, mapping and characterization of soils at research centers and testing sites have not been done. Therefore, this study was undertaken for detail characterization of the soils at Mekelle Agricultural Research Center (MARC) and its testing sites to generate basic soil information to be used by researchers.

The MARC is located in the Tigary Regional State, Ethiopia and it has three testing sites, namely the Wukro, Atsbi and Kwiha, located in different agro-ecological zones. This report presents the characteristics of the soils of the MARC and its three testing sites.

2. DESCRIPTION OF THE AREA

2.1. Location and Access

The Mekelle Agricultural Research Center (MARC) is located in Tigray Regional State, Central Tigray Administrative Zone. It is at about 780 Km north of Addis Ababa. Its geographical extent ranges from 13° 31' 03.5" to 13° 31' 28.9" north latitude and from 39° 30' 04.3" to 39° 30' 31.0" east longitude. It has a total area of 202.5 ha. The Wukro testing site is located in South Tigray Administrative Zone of the Tigray Regional State. Its geographic extent ranges from 13° 45' 37.9" to 13° 45' 41.9" north latitude and from 39° 35' 37.0" to 39° 35' 41.2" east longitude and it has a total area of 6.5 ha. The Atsbi testing site is located in East Tigray Administrative Zone of the Tigray Regional State. Its geographic location is from 13° 52' 49.4" to 13° 52' 53.6" north latitude and from 39° 44' 28.6" to 39° 44' 32.4" east longitude and it has a total area of one ha. The Kwiha testing site is located in East Tigray Administrative Zone of the Tigray Regional State. Its geographic location is from 13° 27' 22.3" to 13° 27' 26.1" north latitude and from 39° 32' 55.4" to 39° 32' 59.3" east longitude and it has a total area of one ha.

2.2. Physiography and Geology

The research center is located on a very gently undulating topography with a gradient of 0 to 5% slope. It has a low relief difference with altitude ranging from 1110 to 1150 meters. In some places where the slope is very flat, flooding and water logging occur. According to Tefera et al. (1996) the geology of the Mekelle ARC, Wukro and Kwiha testing site areas consist of limestone belonging to the Antalo Formation of the Late Jurassic-Jurassic, whereas the Atsbe testing site area consists of limestone of the Late Proterozoic-Proterozoic.

2.3. Climate

According to the climatic records from 1995 to 2005 (Annex 1.), the mean annual rainfall at Mekelle is 475.5 mm. It has a one-season rainfall pattern with extended rainy season from June to September and with the peak season is in August. However, the growing period is indicated by the graph where the graph of the rainfall is above the graph of half evapotranspiration, i.e. from the mid of July to almost the end of September (Figure 2).

The mean annual maximum temperature is 26.6 °C and monthly values range between 24.5 °C in August and 29.1 °C in May and June. The mean annual minimum temperature is 12.0 °C and monthly values range between 9.0 °C in December and 14.4 °C in April.

The coldest month occurs in December while the hottest months are May and June (Figure 1). Generally the area falls under tepid to cool sub-moist mid highlands (SM2-8) agroecological zone.

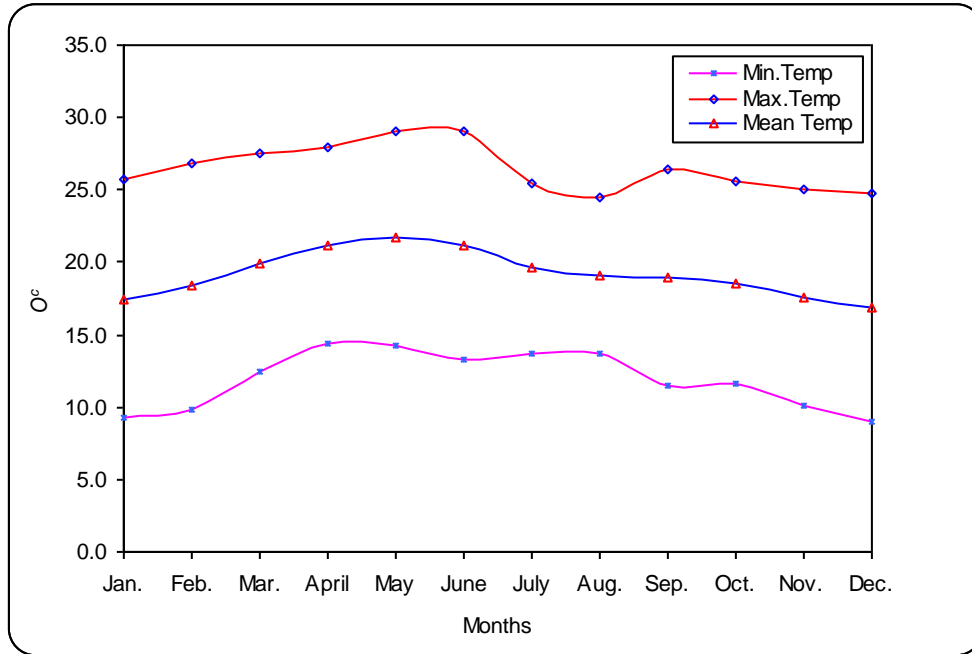


Figure 1 Temperature graph

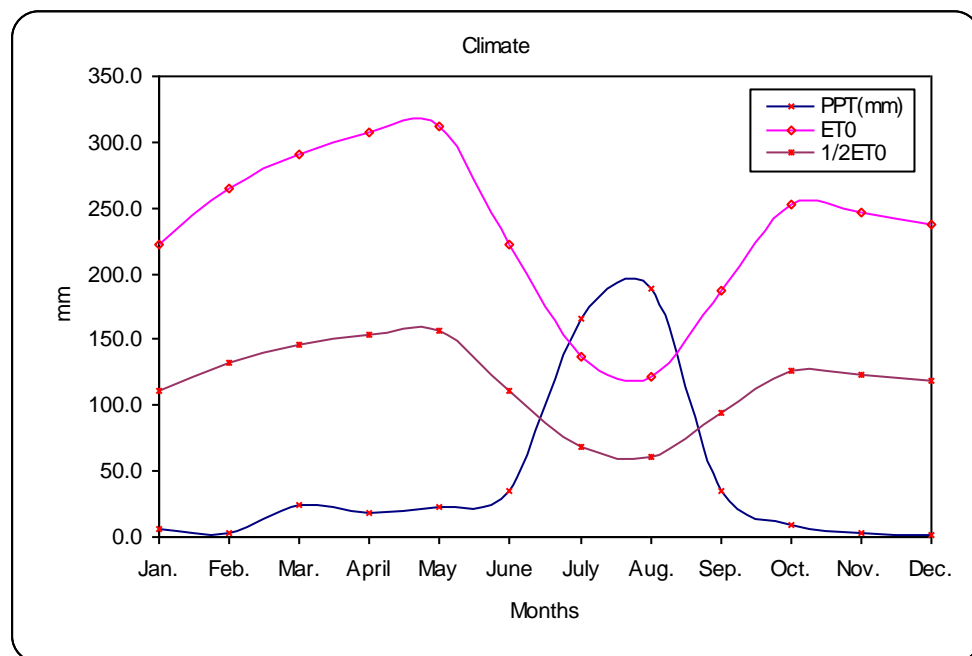


Figure 2 Precipitation, Evapotranspiration and Half Evapotranspiration graph

3. SURVEY METHODS

3.1. Office Work

Prior to the commencement of field soil investigation, a reconnaissance field visit has been conducted to map the overall layout and different attributes of the farmland of the center. During site mapping, altitude and geographic locations of block boundaries and important landmarks were recorded using GPS.

3.2. Field Work Procedure

The field soil investigation was conducted in two successive steps:

Auger observation: After having the preliminary site, auger observations were made to study land and soil characteristics of the farmland. The augerings were made with "Edelman" auger to a depth of 1.2 m unless soil depth is limited or augering is impracticable due to stoniness. Auger observations were recorded on a standard form for auger description. The survey technique was a fixed-grid of 50m by 100m. In some irregular units additional observations were made to study the spatial variability of some of the attributes of the soils. Baselines of the grid system were spaced at an interval of 100m and oriented in such a way that observation traverses cut-across soil boundaries. In total 182 auger observations were made.

Profile sampling: For further soil characterization, soil profile pits were dug on thirteen representative sites. The soil profile descriptions were made according to FAO (1990) guidelines for soil profile description. Composite soil samples were collected from the flat face of each natural soil horizons. Additional undisturbed samples were collected to the depth of 100m from each horizon using core rings for the determination of field capacity, permanent wilting point and bulk density.

3.3. The Soil Map and Legend

Mapping units were distinguished on the basis of the three major land/soil characteristics: slope, soil depth and surface soil texture. Slope in the farm ranges from 1 to 2.5% and land facets were grouped according to their general slope classes at the first level of

generalization. Following, soil depth, as it varies significantly within the farm (25-217cm), was considered to further group land units of the farm. Land with uniform slope and soil depth was further subdivided on the basis of surface soil texture. The distinguishing criterion of the mapping units is described in Table 1. Thus, mapping unit of the farm indicates areas that are uniform in slope, soil depth and surface soil texture. A total of 13 mapping units were identified (Table 2).

Table 1 Distinguishing criteria of the mapping units.

Slope %		Soil depth (cm)		Surface Texture (0 - 30cm)			
Class	Code	Cm	Code	Type	Code	Type	Code
0 - 1	1	> 150	a	Heavy clay	1	Loam	8
1 - 2	2	100 - 150	b	Clay	2	Sandy Loam	9
2 - 5	3	50 - 100	c	Sandy clay	3	Silt loam	10
5 - 10	4	30 - 50	d	Silty clay	4	Silt	11
10 - 15	5	< 30	e	Clay loam	5	Loamy sand	12
15 - 30	6			Silty clay loam	6	Sand	13
>30	7			Sandy clay loam	7		

Each mapping unit is indicated by at least three elements: a number indicating the first criterion (slope class), a lower case letter indicating the second criterion (soil depth class) and a number following the lower case letter indicates the third criterion (surface texture code). For example: **1b2**: wherein, 1-slope class, b-depth class and 2-surface texture.

Table 2 List of mapping units identified in the research center

Mapping units	Pedon No.	Slope %	Soil depth cm	Texture 0 - 30 cm	Area		Soil Units WRB, 1998
					ha	%	
1a6 (Mekelle)	MK1	0-1	217+	SiCL			
2a6 (Mekelle)	MK2	1-2	185	SiCL			
3a9 (Mekelle)	MK3	2-5	200+	SL			
2a8 (Mekelle)	MK4	1-2	180	L			
2a10 (Mekelle)	MK5	1-2	185	SiL			
2a5 (Mekelle)	MK6	1-2	190	CL			
3c8 (Mekelle)	MK7	2-5	82	L			
3d9 (Mekelle)	MK8	2-5	40	SL			
2d9 (Mekelle)	MK9	1-2	37	SL			
2e8 (Mekelle)	MK10	1-2	25	L			
2a8 (Kwiha)	MKW	1-2	1 85	L			
3a7 (Wukro)	MW1	2-5	210+	SCL			
2a2 (Atsbi)	MA1	1-2	175	C			

3.4. Laboratory Analyses

The soil samples were air-dried and ground to pass through a 2-mm sieve before analysis. Soil analysis was carried out as outlined in Van Reeuwijk (1993) unless otherwise specified. Soil texture was determined by the modified Bouyoucos hydrometer method and the pH of the soils was potentiometrically measured by water (pH_{H₂O}) in the supernatant suspension of soil to solution ratio of 1:2.5. Organic carbon content of the soil was determined by the wet combustion procedure of Walkley and Black as outlined by Van Ranst et al. (1999). Total nitrogen content of the soil was determined by wet-

oxidation procedure of the Kjeldahl method (Bremner and Mulvaney, 1982). The available phosphorus content of the soils was determined by 0.5 M sodium bicarbonate extraction solution (pH 8.5) method of Olsen. Exchangeable cations content and the cation exchange capacity (CEC) of the soils were determined by the 1M-ammonium acetate (pH 7) method according to the percolation tube procedure. The available micronutrients content of the soils (Fe, Mn, Zn, and Cu) was determined by diethylenetriaminepentaacetic acid (DTPA) method (Tan, 1996).

4. RESULTS AND DISCUSSION

4.1. *Physico-chemical Characteristics of the Mapping Units*

The physico-chemical characteristics of the mapping units are given in the subsequent sections. The distribution of the different soil units in the research center and its sub-centers are shown in Figure 4 and the major physico-chemical properties of each unit are given in Table 3. Detailed analytical data of the soil profiles are given in Annex 3.

4.1.1 *Mapping unit: 1a1 (Mekelle)*

This unit refers to the moderately well drained soils that occur on a flat to nearly level land (0 - 1%) slope in the eastern part of the farm. It covers 106.39 ha or 39.54% of the farm.

Soils of the unit are very deep (>150 cm) and are dark grayish brown (10YR4/2) when dry and very dark grayish brown (10YR3/2) when moist. The texture is heavy clay with strong coarse angular blocky structure. These soils have consistency that is slightly friable when moist, hard dry and sticky and plastic when wet.

The pH of surface soil is 8.7 (strongly alkaline), decreasing to 8.3 (strongly alkaline) in the subsurface horizons. The electrical conductivity ranges between 0.406 dS/m (non-saline) in the subsurface horizons and 1.625 dS/m (non-saline) in the subsurface horizons (increases with depth). The cation exchange capacity of the soils is high to very high (37.6 to 42.6 cmol (+)/kg soil) and it is highly base saturated (94 to 97%). CaCO₃ content reaches from 16.03% in the surface horizons to 14.63-18.48% in the subsurface horizons. The organic carbon and total nitrogen contents decrease with depth and range from 0.53 to 1.4% (low to medium), and 0.07 to 0.16% (low to high), respectively. The available phosphorous content is very low to low (0.86 to 14.9 ppm). The values of available micronutrients (Fe, Mn, Zn and Cu) range from 7.66 to 9.2 ppm for Fe, 4.16 to 11.97ppm for Mn, 0.09 to 0.57ppm for Zn and 3.08 to 3.72ppm for Cu.

4.1.2 *Mapping Unit: 2a4 (Mekelle)*

This unit refers to the moderately well drained soils that occur on very gently sloping land (1 to 2%) slope in the northeastern part of the farm. It covers 5.64 ha or 2.1% of the farm.

Soils of the unit are very deep (>150 cm) and are brown (10YR4/3) when dry and dark

brown (10YR3/3) when moist. The texture is silty clay with strong coarse angular blocky structure. These soils have consistency that is hard when dry, slightly firm when moist and sticky and plastic when wet.

The pH of surface soil is 8.8 (strongly alkaline), decreasing to 8.3 (strongly alkaline) in subsurface horizons. The electrical conductivity ranges between 0.023 dS/m (non-saline) in the surface horizons and 1.818 dS/m (non-saline) in the subsurface horizons. The cation exchange capacity of the soils is very high (40.6 to 44.86 cmol (+)/kg soil) and it is highly base saturated (79 to 96%). CaCO₃ content reaches from 16.82% in the surface horizons to 16.64-23.21% in the subsurface horizons. The organic carbon and total nitrogen contents range from 0.57 to 1.34% (very low to medium) and 0.07 to 0.17% (low to high), respectively. The available phosphorous content is very low to low (1.02 to 7.66 ppm). Available micronutrients range between 6.69 to 7.55ppm for Fe, 3.15 to 6.95ppm for Mn, 0.09 to 0.26ppm for Zn and 1.74 to 3.26ppm for Cu.

4.1.3 Mapping Unit: 3a3 (Mekelle)

This unit refers to the moderately well drained soils that occur on gently sloping land (2 to 5% slope) in the southern part of the farm. It covers 21.43 ha or 7.96% of the farm.

Soils of the unit are very deep (>150 cm) and are grayish brown (10YR5/3) when dry and dark brown (10YR3/3) when moist. The texture is sandy clay with strong coarse sub angular blocky structure. These soils have consistency that is soft when dry, friable when moist and slightly sticky and non-plastic when wet.

The pH of surface soil is 9.0 (strongly alkaline), increasing to 9.1 (strongly alkaline) in subsurface horizons. The electrical conductivity ranges between 0.143 dS/m (non-saline) in the surface horizons and 0.309 dS/m (non-saline) in the subsurface horizons. The cation exchange capacity of the soils is high (35.40 to 36.26 cmol (+)/kg soil) and it is highly base saturated (83 to 95%). CaCO₃ content reaches from 4.47% in the surface horizons to 2.72-7.01% in the subsurface horizons. The organic carbon and total nitrogen contents range from 0.39 to 0.63% (very low to low) and 0.05 to 0.08% (Low), respectively. The available phosphorous content is very low (0.94 to 2.98ppm). Available micronutrients range between 5.52 to 8.05ppm for Fe, 4.75 to 5.63ppm for Mn, 0.04 to 0.20ppm for Zn and 0.55 to 1.39ppm for Cu.

4.1.4 Mapping Unit: 2a4 (Mekelle)

This unit refers to the well-drained soils that occur on very gently sloping land (1 to 2% slope) in the southern part of the farm. It covers 81.18 ha or 30.17% of the farm.

Soils of the unit are very deep (>150 cm) and are yellowish brown (10YR5/4) when dry and dark yellowish brown (10YR3/4) when moist. The texture is silty clay with weak medium angular blocky structure. These soils have consistency that is hard when dry, slightly firm when moist and slightly sticky and none plastic when wet.

The pH of surface soil is 8.5 (strongly alkaline), increasing to 9.0 (strongly alkaline) in subsurface horizons. The electrical conductivity ranges between 0.142 dS/m (non-saline) in the subsurface horizons and 0.251 dS/m (non-saline) in the surface horizons. The cation exchange capacity of the soils is high (27.98 to 33.00 cmol (+)/kg soil) and it is highly base saturated (90 to 98%). CaCO₃ content reaches from 3.68% in the surface horizons to 4.21-7.01% in the subsurface horizons. The organic carbon and total nitrogen contents range from 0.59 to 1.09% (very low to low) and 0.09 to 0.11% (low to medium), respectively. The available phosphorous content is very low (0.76 to 4.32 ppm). Available micronutrients range between 6.75 to 9.44 ppm for Fe, 4.62 to 10.67ppm for Mn, 0.07 to 0.37ppm for Zn and 0.73 to 2.09ppm for Cu.

4.1.5 Mapping Unit: 2a4 (Mekelle)

This unit refers to imperfectly drained soils that occur on a very gently sloping land (1 to 2% slope) in the western part of the farm. It covers 3.55 ha or 1.32% of the farm.

Soils of the unit are very deep (>150 cm) and are yellowish brown (10YR5/5) when dry and dark brown (10YR3/3) when moist. The texture is silty clay with strong medium sub angular blocky structure. These soils have consistency that is hard when dry, slightly friable when moist and slightly sticky and non-plastic when wet.

The pH of surface soil is 8.6 (strongly alkaline), increasing to 8.7 (strongly alkaline) in surface horizons. The electrical conductivity ranges from 0.168 dS/m (non-saline) in the surface horizons to 3.82 dS/m (slightly saline) in the subsurface horizons. The cation exchange capacity of the soils is high to very high (30.2 to 41.15 cmol (+)/kg soil, and it is highly base saturated (81 to 99%), respectively. CaCO₃ content reaches from 5.26% in the surface horizons to 3.15-11.44% in the subsurface horizons. The organic carbon and total nitrogen contents range from 0.64 to 1.81 (very low to medium) and 0.09 to 0.23% (low to high), respectively. The available phosphorous content is very low (0.82 to 4.2ppm). Available micronutrients range between 7.02 to 14.89ppm for Fe, 4.82 to 9.46ppm for Mn, 0.18 to 0.44ppm for Zn and 1.36 to 3.76ppm for Cu.

4.1.6 Mapping Unit: 2a4 (Mekelle)

This unit refers to the well-drained soils that occur on a very gently sloping land (1 to 2% slope) in the northern part of the farm. It covers 18.1 ha or 6.73% of the farm.

Soils of the unit are very deep (>150 cm) and are brown (10YR4/3) when dry and very dark grayish brown (10YR3/2) when moist. The texture is silty clay with moderate medium sub angular blocky structure. These soils have consistency that is slightly hard when dry, friable when moist and sticky and slightly plastic when wet.

The pH of surface soil is 8.6 (strongly alkaline), increasing to 8.9 (strongly alkaline) in subsurface horizons. The electrical conductivity ranges from 0.298 dS/m (non-saline) in the surface horizons to 0.273-3.23 dS/m (slightly saline) in the subsurface horizons. The cation exchange capacity of the soils is very high (42.2 to 44.98 cmol (+)/kg soil, and it is highly base saturated (92 to 99%), respectively. CaCO₃ content reaches from 14.54% in the surface horizons to 14.45-20.41% in the subsurface horizons. The organic carbon and total nitrogen contents range from 0.68 to 1.4% (very low to medium) and 0.07 to 0.16% (low to high), respectively; while available phosphorous is very low to low (0.84 to 9.72ppm). Available micronutrients range between 6.29 to 9.11ppm for Fe, 1.91 to 6.93ppm for Mn, 0.33 to 0.37ppm for Zn and 2.46 to 3.50ppm for Cu.

4.1.7 Mapping Unit: 3c7 (Mekelle)

This unit refers to the well-drained soils that occur on gently sloping land (2 to 5% slope) in the northern part of the farm. It covers 7.96 ha or 2.96% of the farm.

Soils of the unit are moderately deep (50-100cm) and are yellowish brown (10YR5/4) when dry and brown (10YR4/3) when moist. The texture is sandy clay loam with moderate medium sub angular blocky structure. These soils have consistency that is slightly hard when dry, friable when moist and slightly sticky and none plastic when wet.

The pH of surface soil is 8.7 (strongly alkaline), increasing to 9.0 (strongly alkaline) in subsurface horizons. The electrical conductivity ranges from 0.23 dS/m (non-saline) in the surface horizons to 0.19-0.245 dS/m (non-saline) in the subsurface horizons. The cation exchange capacity of the soils is very high (42.36 to 45.62 cmol (+)/kg soil) and it is highly base saturated (86 to 95%). CaCO₃ content reaches from 33.73% in the surface horizons to 32.88-38.19% in the subsurface horizons. The organic carbon and total nitrogen contents range from 1.03 to 1.76% (very low to low) and 0.13 to 0.20% (medium to high), respectively. The available phosphorous content is very low to low (0.16 to 9.36ppm). Available micronutrients range between 6.93 to 9.72ppm for Fe, 7.66 to 17.38ppm for Mn, 0.24 to 0.88ppm for Zn and 0.46 to 0.66ppm for Cu.

4.1.8 Mapping Unit: 3d12 (Mekelle)

This unit refers to moderately well drained soils that occur on gently sloping land (2 to 5% slope) in the southwestern part of the farm. It covers 9.45 ha or 3.51% of the farm.

Soils of the unit are shallow (30-50cm) and are yellowish brown (10YR5/4) when dry and dark yellowish brown (10YR3/4) when moist. The texture is loamy sand with weak fine sub angular blocky structure. These soils have consistency that is loose when dry, friable when moist and none sticky and none plastic when wet.

The pH of surface soil is 8.7 (strongly alkaline), increasing to 9.1 (strongly alkaline) in subsurface horizons. The electrical conductivity ranges between 0.088 dS/m (non-saline) in the subsurface horizons and 0.157 dS/m (non-saline) in the surface horizons. The cation exchange capacity is high (32.96 to 33.00 cmol (+)/kg soil) and it is highly base saturated (80 to 84%, respectively). CaCO₃ content reaches from 3.07% in the surface horizons to 2.63% in the subsurface horizons. The organic carbon and total nitrogen contents range from 1.07 to 1.17% (low) and 0.10 to 0.15% (medium), respectively. The available phosphorous content is very low (1.48 to 3.06ppm). Available micronutrients range from 6.18 to 7.79ppm for Fe, 3.98 to 21.78ppm for Mn, 0.22 to 0.24ppm for Zn and 0.26ppm for Cu.

4.1.9 Mapping Unit: 2d7 (Mekelle)

This unit refers to somewhat excessively drained soils that occur on a very gently sloping land (1 to 2% slope) in the south of meteorology station. It covers 0.43 ha or 0.16% of the farm.

Soils of the unit are shallow (30-50cm) and are brown (10YR4/3) when dry and dark brown (10YR3/3) when moist. The texture is sandy clay loam with weak medium sub angular blocky structure. These soils have consistency that is slightly hard when dry, friable when moist, and slightly sticky and none plastic when wet.

The pH of surface soil is 8.4 (strongly alkaline), and the electrical conductivity is 0.698 dS/m (non-saline) in the surface horizons. The cation exchange capacity of the soils is high (35.69 cmol (+)/kg soil) and it is highly base saturated (88%). CaCO₃ content is 14.89% in the surface horizons. The organic carbon and total nitrogen contents are 1.19% (medium) and 0.16% (high), respectively. The available phosphorous content is very low to low (13.26 ppm). Available micronutrients are 5.35ppm for Fe, 24.02ppm for Mn, 0.86ppm for Zn and 0.86ppm for Cu.

4.1.10 Mapping Unit: 2e7 (Mekelle)

This unit refers to the well-drained soils that occur on a gently sloping land (2 to 5% slope) near the meteorology station. It covers 1.73 ha or 0.64% of the farm.

Soils of the unit are very shallow (0-30cm) and are dark brown (10YR3/3) when dry and very dark grayish brown (10YR3/2) when moist. The texture is sandy clay loam with weak fine sub angular blocky structure. These soils have consistency that is slightly hard when dry, friable when moist and slightly sticky and slightly plastic when wet.

The pH of surface soil is 8.7 (strongly alkaline), and the electrical conductivity is 0.219 dS/m (non-saline) in the surface horizons. The cation exchange capacity of the soils is high (36.12 cmol (+)/kg soil) and it is highly base saturated (98%). CaCO₃ content is 7.45% in the surface horizons. The organic carbon and total nitrogen contents are 1.79% (very low) and 0.21% (high), respectively. The available phosphorous content is low (6.00 ppm). Available micronutrients are 7.99 ppm for Fe, 17.40ppm for Mn, 0.44ppm for Zn and 0.79ppm for Cu.

4.1.11 Mapping Unit: 2a4 (Kwiha-Mekelle)

This unit refers to well-drained soils that occur on a very gently sloping land (1 to 2% slope). It covers the whole farm of Kwiha testing site and has an area of 1.73 ha or 0.64% of the farm.

Soils of the unit are very deep (>150 cm) and are very dark grayish brown (10YR3/2) when dry and very dark brown (10YR2/2) when moist. The texture is silty clay with massive structure. These soils have consistency that is hard when dry, moderately friable when moist, and moderately sticky and moderately plastic when wet.

The pH of surface soil is 8.8 (strongly alkaline), increasing to 8.9 (strongly alkaline) in subsurface horizons. The electrical conductivity ranges between 0.217 dS/m (non-saline) in the surface horizons and 0.206-0.308 dS/m (non-saline) in the subsurface horizons. The cation exchange capacity of the soils is very high (41.23 to 45.40cmol(+)/kg soil) and it is medium to highly base saturated (72 to 97%). CaCO₃ content reaches from 7.01% in the surface horizons to 9.20-17.96% in the subsurface horizons. The organic carbon and total nitrogen contents range from 0.98 to 1.76% (very low medium) and 0.09 to 0.16% (low to high), respectively. The available phosphorous content is very low to low (0.67 to 5.96ppm). Available micronutrients range between 5.65 to 8.56ppm for Fe, 3.15 to 8027ppm for Mn, 0.24 to 0.73ppm for Zn and 1.65 to 1.91ppm for Cu.

4.1.12 Mapping Unit: 3a3 (Wukro-Mekelle)

This unit refers to the well-drained soils that occur on gently sloping land (2 to 5% slope). It covers the whole farm of Wukro testing site and has an area of 1.73 ha or 0.64% of the farm.

Soils of the unit are very deep (>150cm) and are brown (10YR4/3) when dry and very dark grayish brown (10YR3/2) when moist. The texture is sandy clay with strong coarse angular blocky structure. These soils have consistency that is hard when dry, friable when moist, and none sticky and none plastic when wet.

The pH of surface soil is 7.9 (moderately alkaline), increasing to 8.0 (strongly alkaline) in subsurface horizons. The electrical conductivity ranges between 0.161 dS/m (non-saline) in the surface horizons and 0.187 dS/m (non-saline) in the subsurface horizons. The cation exchange capacity of the soils is high to very high (32.36 to 44.03 cmol (+)/kg soil) and it is medium to highly base saturated (70 to 83%). CaCO₃ content reaches from 1.75% in the surface horizons to 2.19-13.69% in the subsurface horizons. The organic carbon and total nitrogen contents range from 0.44 to 0.83% (low to medium) and 0.06 to 0.11% (low to medium), respectively. The available phosphorous content is low (0.86 to 3.82ppm). Available micronutrients range between 3.43 to 7.44 ppm for Fe, 6.03 to 8.80ppm for Mn, 0.24 to 0.64ppm for Zn and 0.00 to 0.68ppm for Cu.

4.1.13 Mapping Unit: 2a5 (Atsbi-Mekelle)

This unit refers to the well-drained soils that occur on a very gently sloping land (1 to 2% slope). It covers the whole farm of Atsbi testing site and has an area of 1.73 ha or 0.64% of the farm.

Soils of the unit are very deep (>150cm) and are yellowish brown (10YR5/4) when dry and dark yellowish brown (10YR4/4) when moist. The texture is clay loam with moderate medium sub angular blocky structure. These soils have consistency that is hard when dry, friable when moist, moderately sticky and moderately plastic when wet.

The pH of surface soil is 6.9 (neutral), increasing to 7.9 (moderately alkaline) in subsurface horizons. The electrical conductivity ranges between 0.123 dS/m (non-saline) in the surface horizons and 0.366 dS/m (non-saline) in the subsurface horizons. The cation exchange capacity of the soils is high (25.36 to 32.40 cmol (+)/kg soil) and it is medium to highly base saturated (71 to 93%). CaCO₃ content reaches from 0.04% in the surface horizons to 0.20-3.12% in the subsurface horizons. The organic carbon and total nitrogen contents range from 0.40 to 0.68% (very low to medium) and 0.05 to 0.09%

(low), respectively. The available phosphorous content is very low to low (0.94 to 8.24 ppm). Available micronutrients range between 8.36 to 16.63ppm for Fe, 4.47 to 23.3ppm for Mn, 0.31 to 20.44 for Zn and 0.02 to 1.08ppm for Cu.

Table 3 Summary characteristics of the mapping units.

Mapping Unit	Slope %	Soil depth (cm)	Texture (0-30 cm)	pH H ₂ O	CaCO ₃ %	EC dS/m	OM %	T.N %	Av.P.OI. ppm
1a6 (Mekelle)	1.0	217+	Heavy clay	8.7	16.03	0.406	1.40	0.15	14.90
2a6 (Mekelle)	2.0	185	Silty clay	8.8	16.82	0.277	1.34	0.17	7.66
3a9 (Mekelle)	2.5	200+	Sandy clay	9.0	4.47	0.143	0.63	0.08	2.98
2a8 (Mekelle)	1.5	180	Silty clay	8.5	3.68	0.251	1.09	0.09	4.32
2a10 (Mekelle)	1.5	185	Silty clay	8.6	5.26	0.168	1.39	0.16	4.20
2a5 (Mekelle)	1.5	190	Silty clay	8.6	14.54	0.298	1.40	0.16	9.72
3c8 (Mekelle)	5.0	82	Sandy clay loam	8.7	33.73	0.230	1.76	0.20	9.36
3d9 (Mekelle)	2.5	40	Loamy sand	8.7	3.07	0.157	1.17	0.15	3.06
2d9 (Mekelle)	2.0	37	Sandy clay loam	8.4	14.89	0.698	1.19	0.16	13.26
2e8 (Mekelle)	2.0	25	Sandy clay loam	8.7	7.45	0.219	1.79	0.21	6.00
2a8 (Kwiha)	2.0	185	Silty clay	8.8	7.01	0.217	1.17	0.16	5.96
3a7 (Wukro)	2.5	210+	Sandy clay	7.9	1.75	0.161	0.60	0.08	3.82
2a2 (Atsbi)	2.0	175	Clay loam	6.9	0.04	0.123	0.68	0.08	8.24

Mapping Unit	Exchangeable bases (cmol (+) kg ⁻¹ soil)						BSP %	ESP %	Micronutrients (ppm)			
	Na	K	Ca	Mg	Sum	CEC			Fe	Mn	Zn	Cu
1a6 (Mekelle)	0.28	0.41	28.34	6.21	35.24	37.6	94	0.01	8.38	11.97	0.57	3.08
2a6 (Mekelle)	0.55	1.01	33.58	5.10	40.24	41.8	96	0.01	6.69	6.95	0.26	2.95
3a9 (Mekelle)	0.21	0.36	22.46	10.40	33.42	36.3	92	0.01	5.52	5.52	0.09	0.64
2a8 (Mekelle)	0.82	0.25	19.11	6.50	26.68	28.0	95	0.03	6.75	10.67	0.37	1.28
2a10 (Mekelle)	0.88	0.26	18.31	5.84	25.30	30.2	84	0.03	10.23	7.37	0.44	1.36
2a5 (Mekelle)	0.35	1.12	32.82	6.12	40.40	42.2	96	0.01	6.29	6.93	0.37	2.60
3c8 (Mekelle)	0.31	0.88	28.62	6.46	36.26	42.4	86	0.01	9.72	10.91	0.88	0.64
3d9 (Mekelle)	0.19	0.28	18.91	8.32	27.70	33.0	84	0.01	7.79	21.78	0.24	0.26
2d9 (Mekelle)	0.89	0.62	26.35	3.54	31.40	35.7	88	0.02	5.35	24.02	0.86	0.86
2e8 (Mekelle)	1.23	0.91	30.49	2.72	35.34	36.1	98	0.03	7.99	17.40	0.44	0.79
2a8 (Kwiha)	0.13	0.80	39.72	3.38	44.03	45.4	97	0.00	6.89	8.27	0.51	1.91
3a7 (Wukro)	0.89	0.59	11.93	5.88	19.28	23.5	82	0.04	5.46	8.80	0.29	ND
2a2 (Atsbi)	3.15	2.02	9.48	3.46	18.11	25.4	71	0.12	16.63	23.30	0.46	1.08

Figure 3 Mapping Unit of Mekelle Agricultural Research Center

Figure 4 Soil Unit of Mekelle Agricultural Research Center

4.2. Overall Soil Physical and Chemical Characteristics

4.1.1. Physical Properties

Texture

The results of the particle size analysis indicate that the majority of the soils in the research center and the testing sites are fine textured soils containing higher proportions of clay throughout the horizons.

Soil structure

The majority of surface soil layers (0 to 30 cm) of the research center and the testing sites have weak medium to strong coarse sub angular structure while the subsurface soil layers have strongly developed angular blocky structure with poor porosity. The vertisols have the usual workability problem.

Soil depth

The soils are generally moderately deep (50-100cm) to very deep (> 150cm). However, few spots in the research center have soil depth < 50 cm. The overall depth of the soil profiles in the studied sites indicates that soils have adequate rooting depth for soil moisture storage.

Bulk Density

The bulk density of surface soils is medium that ranges from 1.10 to 1.59 g cm⁻³ and it is less than 1.6 g cm⁻³ in the subsurface horizons. The bulk density values indicate that the soils are not compact to inhibit root development except in the horizons of the testing sites of Wukro and Atsbi which is 1.6 to 1.76 g cm⁻³.

4.1.2. Chemical Properties

Soil reaction

The pH values range from 6.9 in the testing sites of Astbi to 8.4 to 9.0 in Mekelle for the

surface soils and 7.6 to 7.9 in the testing sites of Astbi and from 8.3 to 9.1 in Mekelle for the sub surfaces horizons. In general, pH values tend to increase with soil depth.

Electrical Conductivity

Electrical conductivity measurements are used as indications of total quantities of soluble salts in the soil. Electrical conductivity of the soils has no specific trend with soil depth and the values are less than 2.0 dS/m. These values indicate that the soils are generally none-saline, except in some sub horizons of some soils, which is slightly alkaline.

Organic carbon

The organic carbon content of surface soils is very low to low and ranges from 0.60 to 1.79%. In the subsurface horizons its content decreases to 0.39 to 0.59%. The overall high organic carbon content of the surface soils is important for crop growth and development of aggregated soil structure.

Total Nitrogen

The total nitrogen content of the topsoil is generally low (0.08 to 0.21%). However, its content decreases with depth in the same manner as organic matter to about 0.01 to 0.09%. In some of the horizons there is a trend of total nitrogen increase with depth. The low total nitrogen content of the soils indicates that a response to N-fertilizers application is likely in these areas.

Available Phosphorous

The available phosphorous content generally decreases with depth. The available P values are less than 10 ppm, exceptionally high values (13.3 to 14.9 ppm) were obtained in surface horizons of two pedons. Although these sites have been receiving varied amounts of P-fertilizer, the level of available P is yet low. This could be related to high P-fixation capacity of the soils due to high pH of the soils.

Exchangeable Sodium Percentage (ESP)

The exchangeable sodium percentage in the studied soils generally increases with depth. However, the values are < 0.14% and this indicates that the level of Na is low and it has no deleterious effect on the physical properties of the soils.

Cation exchange capacity and Base Saturation Percentage

The cation exchange capacity of the soils ranges between 23.5 and 45.6 cmol(+) kg⁻¹ soil. Surface soils have higher CEC values than subsurface soils. The wider CEC range of the soils could be related to a difference in texture and clay mineralogy of the soils. The base saturation percentage of the soils ranges between 70 and 99%. However, the most common values are greater than 92%. The base saturation percentage is irregularly distributed through out the soil depth. This could be due to high evapotranspiration and leaching of bases to subsurface horizons in different seasons.

Cationic balance

Soils of the research center and the testing sites are low to high base saturated. However, this does not prove a balanced proportion of the exchangeable bases. Thus, the basic cation saturation ratio and the relative proportions of the cations in the surface horizons were examined to evaluate the nutrient availability status of the soils (Table 4). According to Tisdale et al. (1993) the basic cation saturation ratios in the surface horizons indicate that the absolute amount of the exchangeable cations (K, Ca and Mg) is adequate (except in few cases). The ratio of Ca to Mg indicates the presence of proportionally high Mg in the soils that may disrupt Ca uptake to some extent. The ratio of (Ca+Mg) to K indicates that in most of the studied soils the relative proportion of K to (Ca + Mg) is low and this could likely cause K deficiency in these soils.

Table 4 The basic cation saturation ratio and their relative proportions in the surface horizons of the mapping units.

Mapping Unit	Ca/CEC		Mg/CEC		K/CEC		Ca/Mg		(Ca+Mg)/K	
	ratio	Status	ratio	Status	ratio	Status	ratio	Status	ratio	Status
1a6 (Mekelle)	0.8		0.2		0.01		4.6	Very favorable	84.1	Low K
2a6 (Mekelle)	0.8		0.1		0.02		6.6	Very favorable	38.5	Favorable
3a9 (Mekelle)	0.6		0.3		0.01		2.2	Low Ca	92.0	Low K
2a8 (Mekelle)	0.7		0.2		0.01		2.9	Very favorable	102.5	Low K
2a10 (Mekelle)	0.6		0.2		0.01		3.1	Very favorable	92.6	Low K
2a5 (Mekelle)	0.8		0.1		0.03		5.4	Very favorable	34.9	Favorable
3c8 (Mekelle)	0.7		0.2		0.02		4.4	Very favorable	40.0	Favorable
3d9 (Mekelle)	0.6		0.3		0.01		2.3	Low Ca	95.9	Low K
2d9 (Mekelle)	0.7		0.1		0.02		7.4	Very favorable	48.0	Low K
2e8 (Mekelle)	0.8		0.1		0.03		11.2	Favorable	36.7	Favorable
2a8 (Kwiha)	0.9		0.1		0.02		11.8	Favorable	53.7	Low K
3a7 (Wukro)	0.5		0.2		0.02		2.0	Low Ca	30.3	Favorable
2a2 (Atsbi)	0.4		0.1		0.08		2.7	Very favorable	6.4	Favorable

Micronutrients

Generally, the content of available micronutrients (Fe, Mn, Zn and Cu) tends to decrease with soil depth. The studied soils contain Fe and Mn in relatively high amounts; the levels in the surface layers normally falling in the range of 8.38 to 16.63ppm and 5.52 to 24.02ppm, respectively. On the other hand, the amount of Zn and Cu is low; the levels in the surface layers normally falling in the range of 0.57 to 0.88ppm and 0.26 to 3.08ppm, respectively.

CONCLUSIONS

The dominant soils of the MARC and its testing sites are classified as Luvisols and Vertisols. Minor amounts of Nitisols, Fluvisols and Phaeozems were also identified. All the soils have good physical property (deep profiles, low bulk density and soil structure) except the Vertisols that have the usual workability problem. Except in few subsurface horizons of some pedons, all the soils are not saline and sodic. However, all the soils have low total nitrogen and phosphorus content. In most of the soils the relative proportion of K to (Ca + Mg) is low, which may disrupt the availability of K. The available Zn and Cu content of the soils are also low which is true for most soils of Ethiopia. Thus future soil fertility improvement works should focus on the amelioration of chemical fertility problems of these soils.

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Annex 1. Soil profile descriptions

Date: 04/6/05

FIELD NO: MK-1

PROJECT: Mekelle agricultural research center

LOCATION: eastern part of the farm

ALTITUDE: 2022 m asl GPS

COORDINATES: N 13° 31' 14.4" E 39° 30' 27"

AUTHOR (S): Dr. Abayneh E. Ashenafi A. Gebeyehu B. Admasu. B.

SOIL CLASSIFICATION: Eutric Vertisols/Calcic Vertisols

SURROUNDING LANDFORM: plain to mountainous

PHYSIOGRAPHIC POSITION: lower slope

LAND USE/COVER: harvested field of teff

SLOPE GRADIENT: 1%

MOISTURE CONDITION: 0-30 cm dry & moist through out

DRAINAGE CLASS: moderately well drained

GROUNDWATER DEPTH: greater than 2.17m

PARENT MATERIAL: limestone

EROSION STATUS: slight sheet at site and moderately wind erosion surrounding

ROCK OUTCROPS: none

SURFACE STONES: none

Profile Description

- | | |
|-----------------------------|--|
| Ap 0-30cm | Dark grayish brown (10YR4/2) dry very dark grayish brown (10YR3/2) moist; heavy clay; strong coarse angular blocky; hard dry; slightly friable moist, sticky and plastic; highly calcareous; many fine and few medium interstitial pores; few fine roots; clear smooth boundary |
| Bk 30-96cm | Very dark grayish brown (10YR3/2) moist; heavy clay; strong coarse angular blocky; 05cm & 2 0-30cm cracks; firm moist, sticky and plastic; common distinct slickensides; moderately calcareous; many fine interstitial pores; clear smooth boundary |
| Bk2 96-118cm | Very dark grayish brown (10YR3/2) moist; heavy clay; strong coarse angular blocky; 0.5cm-20cm cracks; firm moist, sticky and plastic; few fine iron mottling; common distinct slickensides; highly calcareous; many fine interstitial pores; gradual smooth boundary |
| Bk3 118-175cm | Very dark grayish brown (10YR3/2) moist; heavy clay; strong coarse angular blocky; 05cm-20cm cracks; firm moist, sticky and plastic; few fine iron mottling; common distinct slickensides; many medium CaCO ₃ mineral nodules; highly calcareous; many fine interstitial pores; clear smooth boundary |
| Bk4 175-217 ⁺ cm | Heavy clay; strong coarse angular blocky; firm moist, sticky and plastic; few fine iron mottling; many medium CaCO ₃ mineral nodules; highly calcareous; many fine interstitial pores |

Date: 14/6/05

FIELD NO: MK-2

PROJECT: Mekelle agricultural research center

LOCATION: northeastern part of the farm

ALTITUDE: 2019 m asl GPS

COORDINATES: N 13° 31' 16.5" E 39° 30' 21.7"

AUTHOR (S): Dr. Abayneh E. Ashenafi A. Gebeyehu B. Admasu. B.

SOIL CLASSIFICATION: Eutric Vertisols

SURROUNDING LANDFORM: plain to mountainous

PHYSIOGRAPHIC POSITION: upper slope

LAND USE/COVER: harvested field of wheat and barley

SLOPE GRADIENT: 2%

MOISTURE CONDITION: 0-30 cm dry and moist through out

DRAINAGE CLASS: moderately well drained

GROUNDWATER DEPTH: greater than 1.85m

PARENT MATERIAL: limestone

EROSION STATUS: slight sheet at site and moderately wind erosion surrounding

ROCK OUTCROPS: None

SURFACE STONES: None

Profile Description

Ap 0-30cm	Brown (10YR4/3) dry; dark brown (10YR3/3) moist; silty clay; strong coarse angular blocky; hard dry; slightly firm moist, sticky and plastic; highly calcareous; many fine and few medium interstitial pores; few fine roots; clear smooth boundary
Bk 30-51cm	Very dark gray (10YR3/1) moist; clay; strong coarse angular blocky; 05cm & 20-30cm cracks; firm moist, sticky and plastic; few medium CaCO ₃ mineral nodules; highly calcareous; many fine interstitial pores; few fine roots; clear smooth boundary
Bk2 51-83cm	Very dark gray too grayish brown (10YR3/1.5) moist; clay; strong coarse angular blocky; firm moist; sticky and plastic; common distinct slickensides; many medium CaCO ₃ mineral nodules; highly calcareous; clear smooth boundary
Bk3 83-118cm	Very dark grayish brown (10YR3/2) moist; clay; strong coarse angular blocky; firm moist, sticky and plastic; few fine iron mottling; common distinct slickensides; many medium CaCO ₃ mineral nodules; highly calcareous; many fine interstitial pores; clear smooth boundary
Bk4 118-157cm	Very dark grayish brown (10YR3/2) moist; clay; strong coarse angular blocky; firm moist, sticky and plastic; common distinct CaCO ₃ mineral nodules; highly calcareous; many fine interstitial pores; clear smooth boundary
Bk5 157-185cm	Brown (10YR4/3) moist; clay; strong coarse angular blocky; firm moist, sticky and plastic; common fine iron mottles; common distinct CaCO ₃ mineral nodules; highly calcareous; many fine interstitial pores

Date: 14/6/05

FIELD NO: MK-3

PROJECT: Mekelle agricultural research center

LOCATION: south part of the farm

ALTITUDE: 2011 m asl GPS

COORDINATES: N 13° 31' 07.9" E 39° 30' 17.3"

AUTHOR (S): Dr. Abayneh E. Ashenafi A. Gebeyehu B. Admasu. B.

SOIL CLASSIFICATION: Calcaric Vertisols

SURROUNDING LANDFORM: plain to mountainous

PHYSIOGRAPHIC POSITION: upper slope

LAND USE/COVER: harvested field of wheat

SLOPE GRADIENT: 2.5%

MOISTURE CONDITION: 0 - 87 cm dry and slightly moist through out

DRAINAGE CLASS: well drained

GROUNDWATER DEPTH: greater than 2.0m

PARENT MATERIAL: alluvial limestone

EROSION STATUS: moderate sheet and wind erosion at site, moderate rill and gully at surrounding

ROCK OUTCROPS: none

SURFACE STONES: none

Profile Description

- | | |
|----------------------------|--|
| Ap 0-34cm | Grayish brown (10YR5/3) dry; dark brown (10YR3/3) moist; sandy clay; strong coarse sub angular blocky; soft dry; friable moist, slightly sticky and none plastic; highly calcareous; few gravels; many fine interstitial pores; few fine roots; abrupt smooth boundary |
| A11 34-87cm | Yellowish brown (10YR5/4) dry; brown (10YR4/3) moist; gravelly sandy clay; massive; friable moist, slightly sticky and none plastic; highly calcareous; many gravels; many fine and few medium interstitial pores; few fine roots; clear smooth boundary |
| A12 87-116cm | Very dark grayish brow (10YR3/2) moist; loam; massive; friable moist sticky and slightly plastic; highly calcareous; few gravels; many fine and few medium interstitial pores; clear smooth boundary |
| B 116-144cm | Dark brown (10YR3/3) moist; sandy clay; moderate medium angular blocky; friable moist; sticky and none plastic; highly calcareous; few fresh gravels; few CaCO ₃ nodules; many fine and medium interstitial pores; gradual smooth boundary |
| BC 144-200 ⁺ cm | Dark yellowish brown (10YR3/4) moist; sandy clay; weak to fine to medium angular blocky; friable moist; slightly sticky and none plastic; highly calcareous; few fresh gravels; few CaCO ₃ nodules; many fine and medium interstitial pores |

Date: 16/6/05

FIELD NO: MK-4

PROJECT: Mekelle agricultural research center

LOCATION: southern part of the farm

ALTITUDE: 2018 m asl GPS

COORDINATES: N 13° 31' 9.6" E 39° 30' 15.5"

AUTHOR (S): Dr. Abayneh E. Ashenafi A. Gebeyehu B. Admasu. B.

SOIL CLASSIFICATION: Calcaric Fluvisols

SURROUNDING LANDFORM: Plain to mountainous

PHYSIOGRAPHIC POSITION: lower slope

LAND USE/COVER: Harvested field of wheat

SLOPE GRADIENT: 1.5%

MOISTURE CONDITION: 0-32 cm dry and moist through out

DRAINAGE CLASS: well drained

GROUNDWATER DEPTH: greater than 1.8m

PARENT MATERIAL: limestone

EROSION STATUS: moderate sheet and wind erosion at site, moderately rill and gully at surrounding

ROCK OUTCROPS: none

SURFACE STONES: none

Profile Description

- | | |
|---------------|--|
| Ap 0-32cm | Yellowish brown (10YR5/4) dry; dark yellowish brown (10YR3/4) moist; silt loam; structure hard dry; slightly firm moist, slightly sticky and none plastic; highly calcareous; many fine and medium interstitial pores; many fine and medium roots; clear smooth boundary |
| A11 32-56cm | Dark brown (10YR3/3) moist; clay; weak medium angular blocky; friable moist, sticky and plastic; highly calcareous; few coarse and many medium interstitial pores; common fine roots; clear smooth boundary |
| A12 56-89cm | Yellowish brown (10YR5/4) moist; sandy clay; weak medium angular blocky;; friable moist, slightly sticky and none plastic; highly calcareous; few common fresh gravel; many medium interstitial pores; few fine roots; clear smooth boundary |
| A13 89-122cm | Very dark grayish brown (10YR3/2) moist; clay; moderate medium sub angular blocky; friable moist, sticky and plastic; highly calcareous; few fine fresh gravel; few CaCO ₃ mineral nodules; many medium interstitial pores; very few fine roots; abrupt smooth boundary |
| A14 122-148cm | Dark brown (10YR3/3) moist; clay; weak medium angular blocky; friable moist, sticky and plastic; highly calcareous; common CaCO ₃ mineral nodules; many fine and few medium interstitial pores; very few fine roots; gradual smooth boundary |
| A15 148-180cm | Dark brown (10YR3/3) moist; sandy clay; weak medium angular blocky; friable moist, slightly sticky and none plastic; common medium fresh gravels; highly calcareous; many CaCO ₃ mineral nodules; many fine and medium interstitial pores |

Date: 16/6/05

FIELD NO: MK-5

PROJECT: Mekelle agricultural research center

LOCATION: western part of the farm

ALTITUDE: 2015 m asl GPS

COORDINATES: N 13° 31'12" E 39° 30' 11.2"

AUTHOR (S): Dr. Abayneh E. Ashenafi A. Gebeyehu B. Admasu. B.

SOIL CLASSIFICATION: Fluvisols buried Vertisols

SURROUNDING LANDFORM: plain to mountainous

PHYSIOGRAPHIC POSITION: middle slope

LAND USE/COVER: grassland

SLOPE GRADIENT: 1.5%

MOISTURE CONDITION: 0-100 cm dry and moist below

DRAINAGE CLASS: moderately well drained

GROUNDWATER DEPTH: greater than 1.85m

PARENT MATERIAL: alluvial limestone

EROSION STATUS: none at site and moderately rill and gully at surrounding

ROCK OUTCROPS: none

SURFACE STONES: none

Profile Description

- | | |
|--------------|--|
| Ap 0-20cm | Reddish brown to yellowish brown (10YR5/5) dry dark brown (10YR3/3) moist; silt clay; strong medium sub angular blocky; hard dry; friable moist, slightly sticky and none plastic; moderately calcareous; many fine interstitial pores; many fine and medium roots; clear smooth boundary |
| Ak11 20-40cm | Dark yellowish brown (10YR4/4) dry; dark brown to dark yellowish brown (10YR3/3.5) moist; silt loam; strong sub medium sub angular blocky; slightly hard dry; slightly firm moist, slightly sticky and slightly plastic; moderately calcareous; many fine and medium interstitial pores; common fine and medium roots; clear smooth boundary |
| Ak12 40-60cm | Dark yellowish brown (10YR4/6) dry; dark brown (10YR3/3) moist; silt loam - silty clay; strong coarse sub angular blocky; friable moist, slightly sticky and none plastic; moderately calcareous; many fine and medium interstitial pores; few fine roots; abrupt smooth boundary |
| Bk1 60-80cm | Dark yellowish brown (10YR4/4) dry; very dark grayish brown (10YR3/2) moist; clay; strong coarse angular blocky; hard dry; firm moist, sticky and plastic; moderately calcareous; many fine interstitial pores; very few fine roots; gradual smooth boundary |
| Bk2 80-185cm | Very dark brown (10YR2/2) moist; clay; firm moist, sticky and plastic; 5cm by 20-30cm crack ; moderately calcareous; few CaCO ₃ mineral nodules |

Date: 16/6/05

FIELD NO: MK-6

PROJECT: Mekelle agricultural research center

LOCATION: northern part of the farm

ALTITUDE: 2018 m asl GPS

COORDINATES: N 13° 31' 17.8" E 39° 30' 12.5"

AUTHOR (S): Dr. Abayneh E. Ashenafi A. Gebeyehu B. Admasu. B.

SOIL CLASSIFICATION: Calcic/ Eutric vertisol

SURROUNDING LANDFORM: plain to mountainous

PHYSIOGRAPHIC POSITION:

LAND USE/COVER: harvested field of oat

SLOPE GRADIENT: 1.5%

MOISTURE CONDITION: 0-24 cm dry and slightly moist below

DRAINAGE CLASS: moderately well drained

GROUNDWATER DEPTH: greater than 1.9m

PARENT MATERIAL: limestone

EROSION STATUS: slight sheet at site and moderately rill and gully at surrounding

ROCK OUTCROPS: none

SURFACE STONES: none

Profile Description

- | | |
|-----------------------------|--|
| Ap 0-24cm | Brown (10YR4/3) dry (10YR3/2) moist; silt clay; moderate medium sub angular blocky; 1cm 20-30cm crack; slightly hard dry; friable moist, sticky and slightly plastic; highly calcareous; many fine and few medium interstitial pores; many fine roots; clear smooth boundary |
| Ak 24-84cm | Very dark grayish brown (10YR3/2) moist; clay; strong medium sub angular blocky; 1cm 20-30cm crack; friable moist, sticky and plastic; highly calcareous; many fine interstitial pores; few fine roots; clear smooth boundary |
| Bk1 84-130cm | Very dark brown (10YR2/2) moist; clay; strong coarse angular blocky; 5cm 20-30cm crack; firm moist, very sticky and plastic; common slikenesides; highly calcareous; few fine CaCO ₃ mineral nodules; many fine interstitial pores; clear smooth boundary |
| Bk2 130-190 ⁺ cm | Dark brown (10YR3/3) moist; silty clay; strong coarse angular blocky; firm moist, sticky and slightly plastic; highly calcareous; few fine CaCO ₃ mineral nodules; common fine interstitial pores |

Date: 17/6/05

FIELD NO: MK-7

PROJECT: Mekelle agricultural research center

LOCATION: northern part of the farm

ALTITUDE: 2018 m asl GPS

COORDINATES: N 13° 31' 10.5" E 39° 30' 28.4"

AUTHOR (S): Dr. Abayneh E. Ashenafi A. Gebeyehu B. Admasu. B.

SOIL CLASSIFICATION: Cambisols

SURROUNDING LANDFORM: plain to mountainous

PHYSIOGRAPHIC POSITION: middle slope

LAND USE/COVER: Eucalyptus plantation

SLOPE GRADIENT: 5%

MOISTURE CONDITION: dry through out

DRAINAGE CLASS: some what excessively drained

GROUNDWATER DEPTH: greater than 0.8m

PARENT MATERIAL: limestone

EROSION STATUS: severe sheet at site and moderately rill and gully at surrounding

ROCK OUTCROPS: none

SURFACE STONES: common stones

Profile Description

Ap 0-17cm	Yellowish brown (10YR5/4) dry (10YR4/3) moist; sandy clay loam; moderate medium sub angular blocky; slightly hard dry; friable moist, slightly sticky and none plastic; highly calcareous; common medium gravels; many fine interstitial pores; many fine and medium roots
A117-55cm	Dark yellowish brown (10YR3/6) moist; clay; moderate medium sub angular blocky; firm moist; moderately sticky and moderately plastic; common medium gravels; highly calcareous; common coarse medium and many fine roots
B11 55-82cm	Brown (10YR4/3) moist; clay; moderate medium sub angular blocky; firm moist; moderately sticky and moderately plastic; highly calcareous; many fine interstitial pores; common fine roots
B12 82 ⁺ cm	Dark brown to dark yellowish brown (10YR3/3.5) moist; clay; firm moist; sticky and plastic; highly calcareous; common stones; highly calcareous; common fine interstitial pores; few fine roots

Date: 17/6/05

FIELD NO: MK-8

PROJECT: Mekelle agricultural research center

LOCATION: south western part of the farm

ALTITUDE: 2023 m asl GPS

COORDINATES: N 13° 31' 05.2" E 39° 30' 13.4"

AUTHOR (S): Dr. Abayneh E. Ashenafi A. Gebeyehu B. Admasu. B.

SOIL CLASSIFICATION: Fluvisols

SURROUNDING LANDFORM: plain to mountainous

PHYSIOGRAPHIC POSITION: middle slope

LAND USE/COVER: grassland

SLOPE GRADIENT: 2.5%

MOISTURE CONDITION: dry throughout

DRAINAGE CLASS: excessively drained

GROUNDWATER DEPTH: greater than 0.4m

PARENT MATERIAL: limestone

EROSION STATUS: severe sheet at site and moderately rill and gully at surrounding

ROCK OUTCROPS: none

SURFACE STONES: many stones

Profile Description

Ap 0-10cm	Yellowish brown (10YR5/4) dry (10YR3/4) moist; loamy sand; weak fine sub angular blocky; loose dry; friable moist, none sticky and none plastic; highly calcareous; many fine- medium gravels; many fine interstitial pores; common fine roots; clear smooth boundary
A1 10-40cm	Dark brown (10YR3/3) moist; sand; massive; loose dry; loose moist, none sticky and none plastic; highly calcareous; abundant medium-coarse gravels; porous; few fine roots

Date: 17/6/05

FIELD NO: MK-9

PROJECT: Mekelle agricultural research center

LOCATION: south of meteorology station

ALTITUDE: 2017 m asl GPS

COORDINATES: N 13° 31' 19.9" E 39° 30' 10.3"

AUTHOR (S): Dr. Abayneh E. Ashenafi A. Gebeyehu B. Admasu. B.

SOIL CLASSIFICATION:

SURROUNDING LANDFORM: plain to mountainous

PHYSIOGRAPHIC POSITION: upper slope

LAND USE/COVER: cultivated land

SLOPE GRADIENT: 2%

MOISTURE CONDITION: dry through out

DRAINAGE CLASS: well drained

GROUNDWATER DEPTH: greater than 0.37m

PARENT MATERIAL: limestone

EROSION STATUS: severe sheet at site and moderately rill and gully at surrounding

ROCK OUTCROPS: none

SURFACE STONES: few stones

Profile Description

Ap 0-37cm Brown (10YR4/3) dry; dark brown (10YR3/3) moist; sandy clay loam –sandy clay; weak medium sub angular blocky; slightly hard dry; friable moist, slightly sticky and none plastic; highly calcareous; many gravels; common fine and medium roots; clear smooth boundary

Date: 17/6/05

FIELD NO: MK-10

PROJECT: Mekelle agricultural research center

LOCATION: meteorology station

ALTITUDE: 2015 m asl GPS

COORDINATES: N 13° 31' 23.3" E 39° 30' 7.6"

AUTHOR (S): Dr. Abayneh E. Ashenafi A. Gebeyehu B. Admasu. B.

SOIL CLASSIFICATION:

SURROUNDING LANDFORM: rolling to mountainous

PHYSIOGRAPHIC POSITION: upper slope

LAND USE/COVER: bare land

SLOPE GRADIENT: 2%

MOISTURE CONDITION: dry through out

DRAINAGE CLASS: well drained

GROUNDWATER DEPTH: greater than 0.25m

PARENT MATERIAL: limestone

EROSION STATUS: severe sheet at site and moderately rill and gully at surrounding

ROCK OUTCROPS: none

SURFACE STONES: many stones

Profile Description

Ap 0-25cm Dark brown (10YR3/3) dry; very dark grayish brown (10YR3/2) moist; sandy clay loam; weak fine sub angular blocky; slightly hard dry; friable moist, slightly sticky and slightly plastic; highly calcareous; many rock fragments; few fine interstitial pores; common fine pores; clear smooth boundary

Date: 16/6/05

FIELD NO: MKW-1

PROJECT: Mekelle agricultural research center

LOCATION: Kuwiha testing site

ALTITUDE: 2257 m asl GPS

COORDINATES: N 13° 27' 24.1" E 39° 32' 57.5"

AUTHOR (S): Dr. Abayneh E. Ashenafi A. Gebeyehu B. Admasu B.

SOIL CLASSIFICATION: Vertisols

SURROUNDING LANDFORM: rolling to hilly

PHYSIOGRAPHIC POSITION: lower slope

LAND USE/COVER: harvested field of maize

SLOPE GRADIENT: 2%

MOISTURE CONDITION: moist below 80cm

DRAINAGE CLASS: some what excessively drained

GROUNDWATER DEPTH: greater than 1.85m

PARENT MATERIAL: limestone

EROSION STATUS: severe sheet at site and severe sheet at surrounding

ROCK OUTCROPS: none

SURFACE STONES: very few stones

Profile Description

- Ap 0-40cm Very dark grayish brown (10YR3/2) dry; very dark brown (10YR2/2) moist; silty clay; strong coarse sub angular blocky; hard dry; moderately friable moist, moderately sticky and moderately plastic; moderately calcareous; common medium gravels; many fine and few medium interstitial pores; many fine roots; clear and smooth boundary
- B11 40-80cm Very dark grayish brown (10YR3/2) moist; clay; strong coarse sub angular blocky; 0.1*20cm crack; firm moist, sticky and plastic; highly calcareous; common fine–medium CaCO₃ concretions; common medium gravels; many fine and few medium interstitial pores; clear and smooth boundary
- B12 80-160cm Very dark grayish brown (10YR3/2) moist; clay; strong coarse sub angular blocky; 0.3*10cm crack; firm moist, sticky and plastic; common distinct slickensides; moderately calcareous; common fine –medium CaCO₃ concretions; common medium gravels; many fine and few medium interstitial pores; clear and smooth boundary
- B13 160-185⁺cm Yellowish brown (10YR5/4) dry; very dark grayish brown (10YR3/2) moist; clay loam; massive; friable moist, slightly sticky and slightly plastic; highly calcareous; many medium and common coarse interstitial pores

Date: 15/6/05

FIELD NO: MW-1

PROJECT: Mekelle agricultural research center

LOCATION: Wukro agricultural station

ALTITUDE: 1986 m asl GPS

COORDINATES: N 13° 45' 40.1" E 39° 35' 39.5"

AUTHOR (S): Dr. Abayneh E. Ashenafi A. Gebeyehu B. Admasu B.

SOIL CLASSIFICATION: Vertisols

SURROUNDING LANDFORM: rolling to mountainous

PHYSIOGRAPHIC POSITION: lower slope

LAND USE/COVER: harvested field of wheat

SLOPE GRADIENT: 2.5%

MOISTURE CONDITION: moist below 30cm

DRAINAGE CLASS: moderately well drained

GROUNDWATER DEPTH: greater than 2.1m

PARENT MATERIAL: limestone

EROSION STATUS: slight sheet at site and severe sheet and moderately gully at surrounding

ROCK OUTCROPS: none

SURFACE STONES: none

Profile Description

Ap 0-30cm	Brown (10YR4/3) dry; very dark grayish brown (10YR3/2) moist; sandy loam; cloud ; hard dry; friable moist, none sticky and none plastic; moderately calcareous; many fine interstitial pores; many fine roots; abrupt and smooth boundary
B 30-100cm	Very dark brown (10YR2/2) moist; heavy clay; strong coarse angular blocky; 0.5*20cm cracks ; firm moist, sticky and plastic; few faint slickensides; highly calcareous; many fine and few medium interstitial pores; many fine roots; gradual and smooth boundary
BC 100-135cm	Dark yellowish brown (10YR3/4) moist; sandy loam; strong coarse angular blocky; slightly firm moist, none sticky and none plastic; highly calcareous; powders of lime ; many fine and medium interstitial pores; many fine roots; gradual and smooth boundary
BC 100-135cm	Yellowish brown (10YR5/6) moist; loamy sand; massive; loose moist, none sticky and none plastic; moderately calcareous; many fine and medium interstitial pores

Date: 15/6/05

FIELD NO: MA-1

PROJECT: Mekelle agricultural research center

LOCATION: Astibe testing site

ALTITUDE: 2630 m asl GPS

COORDINATES: N 13° 52' 51.2" E 39° 44' 29.8"

AUTHOR (S): Dr. Abayneh E. Ashenafi A. Gebeyehu B. Admasu B.

SOIL CLASSIFICATION: Luvisols

SURROUNDING LANDFORM: plateau and hilly

PHYSIOGRAPHIC POSITION: lower slope

LAND USE/COVER: harvested field of sesbania

SLOPE GRADIENT: 2%

MOISTURE CONDITION: moist below 32cm

DRAINAGE CLASS: well drained

GROUNDWATER DEPTH: greater than 1.75m

PARENT MATERIAL: limestone

EROSION STATUS: slight sheet at site and severe sheet and moderately gully at surrounding

ROCK OUTCROPS: none

SURFACE STONES: few stones

Profile Description

- | | |
|---------------|--|
| Ap 0-32cm | Yellowish brown (10YR5/4) dry; dark yellowish brown (10YR4/4) moist; clay loam; moderate medium sub angular blocky; hard dry; friable moist, moderately sticky and moderately plastic; many fine interstitial pores; abrupt and smooth boundary |
| Bt1 32-75cm | Dark brown (10YR3/3) moist; clay; moderate medium sub angular blocky; firm moist, sticky and plastic; few distinct clay skin; weakly calcareous; common medium CaCO ₃ concretions; few fine gravels; common fine and few medium interstitial pores; gradual and smooth boundary |
| Bt2 75-120cm | Dark yellowish brown (10YR3/4) moist; clay; strong coarse sub angular blocky; firm moist, sticky and plastic; common distinct clay skin; moderately calcareous; common fine to coarse CaCO ₃ concretions medium gravels; common fine and few fine interstitial pores; gradual and smooth boundary |
| Bt3 120-175cm | Dark yellowish brown (10YR3/4) moist; clay; strong coarse sub angular blocky; firm moist, sticky and plastic; many distinct clay skin; compacted; moderately calcareous; many fine CaCO ₃ concretions; common fine gravels; few fine interstitial pores |

Annex 2. Analytical data of the soils

Field No	Depth cm	P ^H H ₂ O 1:2.5	EC ds/m	Sand %	Silt %	Clay %	Texture class	Na	K	Ca	Mg	Sum	CEC Cmol(+)/Kg	Bas.Sa %	CaCO ₃ %	T.N %	O.C %	C/N	Av.P.Ol. Ppm	Av.K Ppm	Fe ppm	Mn ppm	Zn Ppm	Cu ppm	FC %	PWP %	BD g/cm ³
								Cmol(+)/Kg																			
MK-1	0-30	8.7	0.406	19	46	35	SiCL	0.28	0.41	28.34	6.21	35.24	37.60	94	16.03	0.15	1.40	9	14.90	161	8.38	11.97	0.57	3.08	27.36	17.88	1.29
	30-96	8.3	1.625	17	36	47	C	0.78	0.54	25.99	9.96	37.27	39.20	95	15.77	0.16	0.98	6	1.66	210	7.85	4.93	0.31	3.19	21.98	16.50	1.46
	96-118	8.3	0.028	27	54	19	SiL	1.51	0.53	26.53	10.02	38.60	40.60	95	14.63	0.08	0.68	8	0.86	209	7.66	4.16	0.29	3.32	29.55	20.70	1.38
	118-175	8.4	0.034	19	36	45	C	3.76	0.42	24.87	11.28	40.34	41.80	97	18.48	0.07	0.53	7	0.94	165	9.06	6.51	0.09	3.34			
	175-217	8.4	0.035	21	38	41	C	6.17	0.50	20.31	10.70	37.68	42.60	88	17.96	0.10	0.76	8	0.92	195	9.20	7.15	2.38	3.72			
MK-2	0-30	8.8	0.277	19	48	33	SiCL	0.55	1.01	33.58	5.10	40.24	41.80	96	16.82	0.17	1.34	8	7.66	393	6.69	6.95	0.26	2.95	25.25	16.61	1.24
	30-51	8.7	0.452	13	40	47	C	0.93	0.57	22.69	7.82	32.01	40.60	79	16.64	0.11	1.27	11	2.78	222	6.75	4.60	0.09	2.93	24.49	17.86	1.49
	51-83	8.4	0.880	23	38	39	CL	1.81	0.48	25.90	9.44	37.63	42.80	88	16.82	0.11	1.21	11	1.92	188	7.55	4.18	0.15	3.21	25.51	19.98	1.43
	83-118	8.3	0.023	11	36	53	C	2.37	0.58	26.24	10.99	40.18	42.36	95	17.52	0.10	1.08	11	1.10	228	7.15	3.15	0.11	3.26			
	118-157	8.3	0.029	19	44	37	SiCL	2.16	0.48	24.49	10.67	37.82	43.26	87	17.43	0.07	0.68	10	1.04	189	6.95	3.59	0.13	2.64			
	157-185	8.4	1.818	27	36	37	CL	2.52	0.30	27.01	9.96	39.78	44.86	89	23.21	0.08	0.57	7	1.02	116	6.89	6.38	0.24	1.74			
MK-3	0-34	9.0	0.143	59	26	15	SL	0.21	0.36	22.46	10.40	33.42	36.26	92	4.47	0.08	0.63	8	2.98	140	5.52	5.52	0.09	0.64	10.67	6.78	1.50
	34-87	9.1	0.158	71	14	15	SL	0.91	0.36	22.46	10.40	34.12	36.20	94	6.57	0.08	0.60	8	1.96	34-87	7.06	4.75	0.04	0.55	12.21	8.00	1.50
	87-116	9.0	0.153	75	12	13	SL	1.03	0.20	21.91	9.60	32.74	35.62	92	3.592	0.08	0.52	7	1.98	87-116	8.05	5.63	0.20	0.64	15.47	10.77	1.39
	116-144	9.0	0.221	39	34	27	L	1.26	0.19	18.43	9.37	29.26	35.40	83	2.716	0.06	0.45	7	1.70	116-144	6.64	5.63	0.15	1.39			
	144-200	8.9	0.309	59	20	21	SCL	1.89	0.66	23.15	9.13	34.83	36.80	95	7.006	0.05	0.39	7	0.94	144-200	6.69	5.35	0.18	0.88			
MK-4	0-32	8.5	0.251	39	40	21	L	0.82	0.25	19.11	6.50	26.68	27.98	95	3.679	0.09	1.09	12	4.32	0-32	6.75	10.67	0.37	1.28	17.62	10.40	1.44
	32-56	8.9	0.194	37	32	31	CL	1.02	0.65	20.41	3.89	25.97	28.00	93	6.219	0.11	0.99	9	1.70	32-56	8.16	7.39	0.07	1.61	18.74	12.45	1.51
	56-89	9.0	0.142	69	16	15	SL	1.32	2.29	20.75	4.21	28.56	31.80	90	4.205	0.07	0.65	9	0.76	56-89	8.03	5.72	0.18	0.73	16.89	12.56	1.38
	89-122	8.9	0.203	31	34	35	CL	1.84	0.43	23.77	5.63	31.67	32.40	98	6.57	0.11	0.76	7	1.76	89-122	9.44	7.48	0.18	2.09	18.96	12.87	1.56
	122-148	9.0	0.197	25	46	29	CL	2.01	1.12	21.55	6.66	31.34	32.80	96	7.008	0.09	0.68	7	2.66	122-148	8.03	5.81	0.20	1.61			
	148-180	9.1	0.172	69	16	15	SL	2.36	0.71	19.63	7.16	29.86	33.00	90	3.942	0.08	0.59	7	1.54	148-180	8.32	4.62	0.13	0.79			
MK-5	0-20	8.6	0.168	29	56	15	SiL	0.88	0.26	18.31	5.84	25.30	30.20	84	5.256	0.16	1.39	9	4.20	0-20	10.23	7.37	0.44	1.36	26.82	14.26	1.10
	20-40	8.6	0.200	13	58	29	SiCL	1.21	0.35	20.21	6.05	27.82	34.40	81	7.796	0.22	1.81	8	3.26	20-40	13.86	7.04	0.37	2.27	28.44	19.86	1.23
	40-60	8.7	0.178	25	52	23	SiL	0.50	0.41	25.36	5.86	32.12	33.40	96	6.92	0.15	1.17	8	3.12	40-60	14.89	8.18	0.22	2.29	24.73	15.95	1.22
	60-80	8.7	0.329	17	48	35	SiCL	3.06	0.68	21.36	10.62	35.72	39.60	90	3.15	0.23	1.72	8	3.12	60-80	12.45	9.46	0.42	3.76	28.03	21.42	1.24
	80-185	8.5	3.820	37	20	43	C	1.29	0.50	25.87	13.17	40.82	41.15	99	11.44	0.09	0.64	7	0.82	80-185	7.02	4.82	0.18	3.10			

Field No	Depth cm	PH H2O 1:2.5	EC ds/m	Sand %	Silt %	Clay %	Texture Class	Na	K	Ca	Mg	Sum	CEC Cmol(+)/Kg	Bas.Sa %	CaCO3 %	T.N %	O.C %	C/N	Av.P.OI. PPm	Av.K PPm	Fe ppm	Mn ppm	Zn PPm	Cu ppm	FC %	PWP %	BD g/cm ³
								Cmol(+)/Kg																			
MK-6	0-24	8.6	0.298	21	42	37	CL	0.35	1.12	32.82	6.12	40.40	42.20	96	14.54	0.16	1.40	9	9.72	0-24	6.29	6.93	0.37	2.60	27.13	17.84	1.17
	24-48	8.9	0.273	21	40	39	CL	1.64	1.48	33.98	7.24	44.35	44.98	99	15.24	0.13	1.32	10	5.34	24-48	7.33	5.19	0.33	2.86	26.43	19.03	1.41
	84-130	8.3	3.220	15	38	47	C	2.37	1.04	29.00	8.40	40.81	43.00	95	14.45	0.16	1.17	7	2.34	84-130	8.07	1.91	0.37	3.50	28.83	22.05	1.52
	130-190	8.3	3.230	35	63	2	SiL	2.18	0.27	30.26	8.84	41.55	45.32	92	20.41	0.07	0.68	10	0.84	130-190	9.11	2.51	0.37	2.46			
MK-7	0-17	8.7	0.230	47	30	23	L	0.31	0.88	28.62	6.46	36.26	42.36	86	33.73	0.20	1.76	9	9.36	0-17	9.72	10.91	0.88	0.64	21.28	18.08	1.40
	17-55	8.9	0.197	31	34	35	CL	0.98	0.52	32.65	6.46	40.61	45.23	90	38.19	0.15	1.06	7	1.58	17-55	6.93	7.66	0.77	0.46	18.67	15.97	1.31
	55-82	9.0	0.190	27	36	37	CL	1.32	0.89	35.65	5.64	43.50	45.62	95	34.34	0.16	1.11	7	1.56	55-82	8.18	17.38	0.44	0.48			
	82-190+	8.8	0.245	23	38	39	CL	1.56	1.23	29.78	7.14	39.71	43.40	91	32.88	0.13	1.03	8	0.16	82-190+	9.39	9.04	0.24	0.66			
MK-8	0-10	8.7	0.157	65	28	7	SL	0.19	0.28	18.91	8.32	27.70	32.96	84	3.07	0.15	1.17	8	3.06	0-10	7.79	21.78	0.24	0.26	20.57	12.93	1.35
	10--40	9.1	0.088	89	6	5	S	0.10	0.13	21.03	4.99	26.25	33.00	80	2.63	0.10	1.07	11	1.48	10--40	6.18	3.98	0.22	ND	7.13	5.22	
MK-9	0-37	8.4	0.698	53	32	15	SL	0.89	0.62	26.35	3.54	31.40	35.69	88	14.89	0.16	1.19	7	13.26	0-37	5.35	24.02	0.86	0.86	18.26	12.34	1.31
MK-10	0-25	8.7	0.219	47	32	21	L	1.23	0.91	30.49	2.72	35.34	36.12	98	7.45	0.21	1.79	9	6.00	0-25	7.99	17.40	0.44	0.79			
MKW-1	0-40	8.8	0.217	35	44	21	L	0.13	0.80	39.72	3.38	44.03	45.40	97	7.01	0.16	1.17	7	5.96	0-40	6.89	8.27	0.51	1.91	28.75	20.07	1.25
	40-80	8.9	0.206	29	40	31	CL	0.31	0.52	26.60	4.94	32.36	45.20	72	9.20	0.13	1.76	14	2.38	40-80	8.01	7.50	0.24	1.89	28.83	22.11	1.43
	80-160	7.7	0.308	33	34	33	CL	0.37	0.71	30.17	7.65	38.90	41.23	94	10.95	0.10	1.15	12	1.48	80-160	8.56	6.03	0.73	1.65	28.43	23.37	1.57
	160-185	8.0	0.262	53	30	17	SL	0.44	0.37	32.58	7.32	40.71	42.96	95	17.96	0.09	0.98	11	0.67	160-185	5.65	3.15	0.31	ND			
MW-1	0-30	7.9	0.161	63	2	35	SCL	0.89	0.59	11.93	5.88	19.28	23.53	82	1.75	0.08	0.60	7	3.82	0-30	5.46	8.80	0.29	ND	12.5	8.09	1.59
	30-100	7.9	0.187	43	36	21	L	1.23	0.61	16.30	2.55	20.69	29.57	70	13.69	0.11	0.83	8	1.70	30-100	7.44	6.40	0.26	0.68	22.8	17.67	1.60
	100-135	8.0	0.179	65	20	15	SL	1.45	0.31	15.22	5.64	22.61	27.18	83	3.94	0.08	0.63	8	0.86	100-135	5.17	6.03	0.64	0.02			
	135-210	8.0	0.172	75	2	23	SCL	2.03	0.22	14.33	5.26	21.83	29.86	73	2.19	0.06	0.44	7	0.86	135-210	3.43	8.36	0.24	0.00			
MA-1	0-32	6.9	0.123	43	16	41	C	3.15	2.02	9.48	3.46	18.11	25.36	71	0.04	0.08	0.68	9	8.24	0-32	16.63	23.30	0.46	1.08	15.7	10.42	1.27
	32-75	7.6	0.124	27	32	41	C	2.81	1.33	17.91	6.09	28.15	32.30	87	0.20	0.09	0.51	6	0.86	32-75	9.61	6.56	0.31	0.55	19.5	16.25	1.71
	75-120	7.8	0.366	31	24	45	C	0.18	0.37	19.56	6.09	26.21	28.20	93	1.50	0.07	0.50	7	0.94	75-120	8.36	4.47	7.35	0.11	21.2	16.20	1.76
	120-175	7.9	0.277	27	34	39	CL	0.23	0.38	21.36	7.57	29.54	32.40	91	3.12	0.05	0.40	8	0.94	120-175	8.43	4.86	20.44	0.02			