EASTERN NILE IRRIGATION AND DRAINAGE STUDY/FEASIBILITY STUDY
DINGER BEREHA IRRIGATION PROJECT

ANNEX 3: SOILS, LAND SUITABILITY AND LANDUSE

Table of contents

List of Tables

List of Figures – A3 Maps bound in this report
(Fig 2–9 originally prepared at scale of 1:25,000)

List of Appendices

Supporting Maps – Field Investigations: Volume III: Maps and Drawings (issued as soft copy; pdfs in supporting DVD)

1. Field Investigations: Soils and Profile Pits (8 maps; scale 1:10,000)
2. Field Investigations: Location of Auger Hole Points and In-situ Physical Tests (1 map; scale 1:25,000)
3. Field Investigations: Land Suitability LUT-Onions (2 maps; scale 1:25,000)
4. Field Investigations: Land Suitability LUT-Beans (2 maps; scale 1:25,000)
5. Field Investigations: Land Suitability LUT-Citrus (2 maps; scale 1:25,000)
6. Field Investigations: Land Suitability LUT-Maize (2 maps; scale 1:25,000)
7. Field Investigations: Land Suitability LUT-Sesame (2 maps; scale 1:25,000)

Supporting DVD

Report and Figures of Annex 3

Field Investigations Auger Database (issued as soft copy only)

All GIS related files for maps and figures (Volume Maps & Drawings A1)

1. INTRODUCTION

1.1 SOIL SURVEY REQUIREMENT

As part of the Eastern Nile Irrigation and Drainage Study (ENIDS), a detailed soil survey was conducted during 2009, over some 10,547 ha on the left bank of the Didessa River upstream of its confluence with the Dabena River. The soil survey area lies entirely within Chewaka Wereda in Oromiya Administrative Region, and was one of several Field Investigations (CS) made as a part of the Feasibility Study for the proposed Dinger Bereha Irrigation Project (DBIP). The area is located some 72 km north-west of Bedele, and 555 km south-west of Addis Ababa. The location of the study area is shown in Figure 1.

Since the DBIP area had not been subjected to any soil survey before, it was necessary to make a survey with a sufficiently high density of data points. The level of this survey was set at 'detailed'. The overall density of obervations was one auger site per 8 ha set with observations fixed at regular points along a large number of trace lines, with profile pits placed by free survey amounting to not more than 10% of the total. A total of 1,243 augers and 103 profile pits were examined with 303 samples taken for analyses from the profiles.

The soil survey of the Dinger Bereha area was made by a consultant working as a sub-contractor to the BRL-led consortium, and the full report and supporting maps are provided as a separate volume to the Dinger Bereha Feasibility Study (FS).

For the FS, this supporting Annex (Number 3) has examined the FI Soil report and made additional observations and comments on erosion and crop suitability. Some of these refer to conditions outside the survey area within the catchment and watershed.

The interested reader is strongly advised, as always in such cases where two reports are generated, to refer to the original data, in this case the Complementary Studies Soils Report. Also, the FS has examined particular ranges of crop groupings that were not in the Terms of Reference for the FI soil study.

The survey has included an assessment of the soils – their origins, morphology, physical and chemical properties - and has then evaluated the land suitability of the soils for irrigated land use of the special type of surface irrigation, using piped systems, that is being designed for the Dinger Bereha area.

The Inception Report for the Dinger Bereha Feasibility Study (BRL, 2009) laid out the Terms of Reference (ToR) for the soils and all other parts of the DBFS. The soil survey has followed these ToR.

In this report an executive summary of the work is given at the start. Chaper 1 covers the purpose of the soil survey in this areas, the ToR, and descriptions of the methods used for soil survey and laboratory analyses. Chapter 2 provides details on the environment of the area. The soils and soil mapping units are descibed in Chapter 3. Land suitability evaluation of the area is presented in Chapter 4. In Chapter 5 aspects of soils and land management are given.

INSERT FIGURE 1 - LOCATION - A3 SIZED PULL OUT

The layout of the report follows standard soil report preparation guidelines as given in, for example, the Booker Tropical Soil Manual (Landon, 1991); FAO Soils Bulletin No. 9 on reports (Smyth, 1967) ; FAO Soils Bulletin No. 42 on soil survey for irrigation (FAO, 1979 ; reprinted 1986), and FAO Soil Bulletin No. 55 on land evaluation for irrigated agriculture (FAO, 1985). The consultants have worked with these guidelines in Ethiopia, and elsewhere, since the early 1970s.

1.2 METHODS

1.2.1 Preparation for Field Work

Prior to starting interpretation and field studies, a site visit had been made to the area to guide the field work planning. The results of this were given in the Inception Report (BRL, 2008). Once the soil survey subcontract was signed the soil contractor set to work. The initial phase focused on the collection of aerial photographs, topographic-maps and satellite imagery; a review of previous studies; preparation of field survey guidelines, description sheets for augers and profile pits, as well as hydraulic conductivity and infiltration tests; and a preliminary aerial photographic interpretation (API), as well as interpretation of the SPOT imagery. A number of earlier studies that relate to the region were assessed. These earlier studies were as follows:

- USBR, 1964. In 1964 the United States Bureau of Reclamation (USBR) studied the soils within the Didessa valley region as part of the ‘Land and Water Resources Study of the Blue Nile Basin’. This was a reconnaissance study of soils with land classification assessments. Aerial photography at 1 :50,000 scale was used. The major soils found in the area were Latosols (well drained, deep, reddish brown soils). No data on the soils covered the DBIP area, but in the Arjo-Didessa sub-project 3 profiel pits out of 21 were described.

- Sogreah, 1979. The Lower Didessa Project (Sohreah, 1979) included semi-detailed soil investigations with 50 soil pits described and maps prepared at a scale of 1 :100,000. The mapped area does not lie within the present survey area but the study is useful for comparison of soil types.

Land Use Planning and Regulatory Department - Assistance to Land Use Planning (LUPRD), 1984. The LPURD was a Master Plan assessment of the entire country, with soils mapping and their utilization at 1: 1,000,000 scale. It involved interpretation of satellite imagery and field checking. In the project area two soil types were indentified, Orthic Acrisols and Dystric Nitisols with following characteristics:

- Orthic Acrisols:- Orthic Acrisols having an ochric A horizon; lacking ferric properties; lacking a high organic matter content in the B horizon and lacking hydromorphic properties within 50 cm of the surface.

- Dystric Nitosols:-Dystric Nitosols have a base saturation of less than 50% in at least a part of the argillic B horizon within 125cm of surface: lacking high organic matter content in the B horizon and lacking an umbric A horizon.

While information was at a very general level it provides a basis for comparison of soil morphology and the range of chemical properties, and the study set the standards for future soil surveys in Ethiopia.

- Abbay Master Plan (BCEOM, 1998). The Abbay Master Plan (BCEOM, 1998) produced soil maps at 1:250,000 scale and established the areas where future development should be planned. The study is most useful as background information on geomorphology, soil classification and chemistry, and land classification. Table 1.1 shows the range of soil conditions found in the Abbay Basin. Those found in the Didessa area during the present study, are shown in italics.

Table 1.1 Summary of Morphological Characteristics for the Major Soils of Abbay Basin

Soil Group	**Depth**	**Colour**	**Texture**	**Structure**	**Consistence**	**Drainage**
Acrisols	*Deep to very deep*	*Very dark greyish brown*	*C*	*Subangular blocky*	*Friable, sticky and plastic*	*Well*
Alisols	Deep to very deep	Reddish brown	C – CL - SiC	Subangular blocky	Friable to firm, sticky and plastic	Well
Arenosols	Shallow to moderately deep	Dark yellowish brown	LS	Weak, fine sub-angular blocky & single grain	Slightly hard/friable, sticky and non plastic	Well to excessive
Cambisols	*Moderately deep*	*Brown/dark brown*	*SiC*	*Ang/subangular blocky*	*Hard/friable, slightly Sticky, slightly plastic*	*Well*
Fluvisols	Deep to very deep	Variable	C-SiC	Weak to massive	No data	Well
Leptosols	*Shallow to very shallow*	*Brown to Yell Br*	*L-CL-C*	*Subangular blocky*	*Firm to slightly hard/ friable; slightly sticky & slightly plastic*	*Well*
Luvisols	Deep to very deep	Brown/Reddish brown	C-SiC	Subangular blocky	Friable to firm, sticky and slightly plastic	Well
Nitisols	*Deep to very deep*	*Reddish brown*	*C-CL-SiCL*	*Subangular blocky*	*Friable to firm, sticky and plastic*	*Well*
Phaeozems	Deep	Dark grey	CL-C	No data	Slightly sticky & slightly plastic, wet	Moderately well to poor
Regosols	Shallow – mod. Deep	Brown	C-Si-LS-SiC- Sl	Angular/Sub-angular blocky	Slightly hard/friable, slightly sticky & plastic	Well
Vertisols	*Deep to very deep*	*Dark grey/black*	*C*	*Subangular - angular blocky*	*Hard/firm, very sticky and very plastic*	*Imperfect to poor*

Source: Abbay Master Plan Project, Phase 2, Reconnaisssance Soil Survey BCEOM, 1998. Soil textural classes are given in Appendix A.

1.2.2 Interpretation of Aerial Photography and Satellite Imagery

The topographic base maps used for the study area were the from the 1:50,000 series (Sheet 0836 A1 Dinger, and Sheet 0936 C3 Didesa). These maps were georeferenced by the study and used for baseline compilation at a scale of 1 :20,000. In addition ten panchromatic aerial photographs, at 1:50,000 scale, and dated mid 1970s', were purchased from the Ethiopian Mapping Authority (EMA). The project acquired recent SPOT imagery, dated January 2008, and this was compiled as a simulated true colour mosaic and printed out for interpretation and field use. Interpretation of the aerial photography was made with a stereoscope to establish the principal slope types, landforms and likely association of any photo-tones to soils. These were related to the preliminary legend given in the Inception Report (BRL, 2008).

1.2.3 Soils Base Map Production

Subsequently, and with some difficulty as the aerial photography and imagery were over over 30 years apart, interpreted boundaries of landforms and possible associated soils were transferred to the SPOT image, which provided an up-to-date view of roads, settlements, and land use in the area. A grid of the proposed auger sites was placed over this interpreted landform-soil base map and formed the basis for the soil field work. On the base map, surface drainage patterns, and basic land use and land cover were added. These features would be added to as the field studies progressed. In addition, the location and numbers of auger holes, profile pits, infiltration and hydraulic conductivity test sites were marked on the base map. A total of 47 routine auger hole observation transects were laid on the base map, and the overall grid was transects spaced 200m apart with auger hole observations spaced 400m along the transects.

Based on the interpreted landforms, breaks in slope, and erosion features were added to the base map. The preliminary landform units established for the field teams, included twelve landform / slope classes, within four major land units (G - Gently undulating plains and interfluves ; V – Valley Floors ; U – Strongly sloping and steep lands ; and a Miscellaneous lands). These units, which guided the field work, were described in following sections.

G - Gently Undulating Plains with Convex Interfluves : These were characterized by slopes from 0-6 %, and lie on relatively un-dissected uplands and interfluves lying between stream valleys. The lands are under rainfed cultivation. This unit was subdivided into three sub-land units:

- G1- Upper Part of Gently Undulating Plains
- G2 - Middle and Lower Part of Gently Undulating Plains and
- G3 - Sloping Basement Ridges and Tors

V - Valley Floors: These lands occurred in low-lying araes and were bounded by a sharp break-in-slope to the sloping lands of G. The centre and lowest point of these lands was usually dissected by a perennial stream, with flow derived from the higher upland and forested slopes outside the command area. The slope range was from 0-4%. It was similarly divided into three sub-land units:

- V1- Seasonally Wet Valley Floor
- V2- Permanently Wet Valley Floor and
- V3- Moderately Dissected Valley Side

U- Strongly Sloping and Moderately Steep Lands: The major land unit is covering the steep and dissected project. In this area the streams are high. It is also characterized by three sub-land units:

- U1 -Strongly Sloping Upper & Midel Slope of Hills& Ridges
- U2-Strongly Sloping Lower Part of Hills & Ridges
- S- Moderately Steep Side of Hills& Ridges

Miscellaneous lands: The soil subcontractor initially placed other units into this category:

- R- Incised Stream Channels
- F- Forest areas
- St- Settlements

Later the sloping basement ridges & tors (G3 shown above) was mapped as a miscellaneous land- unit, but for this Annex it has been indicated differently so that every piece of the landscape land can be related to soil conditions, and be of use for future land use proposals

The slopes of the study area are shown in Figure 2, and topography in Figure 3. These were derived from the 1:50,000 topographic maps.

1.2.4 Field Work

The TOR called for a detailed soil survey of the Dinger Bereha Irrigation Project area. The data obtained was then to be evaluated for the proposed irrigation system and selected crop groups or land utilization types (LUTs). With this in mind the soil survey was then carried out in compliance with the following specifications given in the TOR :

- The overall intensity of soil observations would be one per 8 ha. However, in practice this intensity varied from 1 observation per 4 ha to 1 per 10 ha depending on the local complexity of soils. The total number of augers would be 1223. In fact 1243 were made. As noted above 47 transects were laid on the base map, and the overall grid of auger sites was made up of long transects spaced 200m apart and auger holes at 400m intervals along the transects.

- All auger holes observations were described for a maximum depth of 125cm to check and describe surface features, soil depths, and to delineate soil boundaries. All soil descriptions were recorded on soil description sheets. All sites were geo-referenced using GPS and the Adindan datum. The details of auger holes observations recorded in the field have been encoded and presented in the revised Final Report version of the Field Investigations. Soil auger data is also given in the Appendix section of this Annex.

- Soil profiles descriptions followed that of FAO (1998, 2006). Site data included slope %, land form, land use, land cover, presence of stoniness, drainage class, erosion hazards. Soil prfiole data included soil depth, texture, soil color, structure, depth to groundwater. The details of profile pits observations recorded in the field have been encoded and presented in the revised Final Report version of the Field Investigations. Soil profile data is also given in the Appendix section of this Annex.

- Soil profile pits have constituted about 10% of the Auger hole observations. About 10 % of the profile pits were considered for deep boring, infiltration tests and hydraulic conductivity measurements. From the total number of profile pits that were dug, 75% were described (see Appendix H in Field Investigations). From each described profile pit, between 3 and 4 disturbed soil samples were collected for laboratory analyses. A total of 303 samples were prepared for laboratory analysis. The soil pits were dug to a depth of 2m. The details of profile and auger hole observations recorded in the field have been encoded and presented in the revised Final Report version of the Field Investigations: they have also been included as a DVD attachyed to this report. The 303 samples were dried, crushed and determinations made of pH, EC, Texture, Total Nitrogen, Organic Carbon etc,), were collected. Further more 15 samples for deep boring (pH and Ec), were also collected and analyzed in Water Works Design and Supervision Enterprise Laboratory Center.
- In addition a number of mini profile pits of about 1m depth were dug, where the soil units looked heterogeneous. Descriptions of these are in the auger records.
- Deep auguring in the base of pits down to 3m or 4m depths, was made at representative sites to determine the presence of any salinity problem and depth of ground water table. Moreover, in-situ pH tests were conducted. A total of 15 samples from deep borings were tested for pH and EC.

INSERT FIGURE 2. - SLOPES - A3 SIZED PULL OUT

INSERT FIGURE 3– TOPOGRAPHY - A3 SIZED PULL OUT

- All soil and land characteristics description were made according to the FAO guidelines for soil description (FAO, 1998). Reference was also made to the revised guidelines (FAO, 2006).
- Physical tests made in the field included 11 hydraulic conductivity tests, and 11 infiltration tests. The infiltration tests were made in triplicate, ten metres apart, at each site. The permeability measurment used the inverse auger method at the same 11 sites.
- Samples for other soil physics and soil water measurements included taking intact cores from 68 samples to measure bulk density. In addition 68 disturbed samples were taken for soil water measurements, and for the determination of soil moisture availability. These were analyzed in the National Soil Testing Center of the Ministry of Agriculture and Rural Development
- All field data was encoded at the soil site, and was then transferred onto an Excel spread sheet. Databases were assembled for location and site description, horizon description, analytical data, physical tests.

1.2.5 Laboratory Methods

Analyses were made in Addis Ababa at the laboratories of the National Soil Testing Center, Ministry of Agriculture and Rural Development. All analysis were performed on the air-dried fine earth fraction (<2 mm). The chemical analyses for the profile pits were made on 304 soil samples sent for determination of the following parameters:

- Particle size distribution. Determined by hydrometer method, following pretreatment with H_2O_2 to remove organic matter, and dispersion aided by sodium hexametaphosphate.
- Bulk density. Determined on oven-dry weight basis using intact core samples.
- Water content at field capacity and permanent wilting point (0.33 and 15 atmospheres respectively) were determined by pressure plate extractor on 68 disturbed samples that had been placed in core rings Tests were made at the National Soil Testing Center of the Ministry of Agriculture and Rural Development.
- Electrical conductivity (EC). Determined on the soil/water ratio of 1: 2.5
- Soil pH. Measured in H_2O and 1 M KCl at a soil/solution ratio of 1:2.5
- Organic carbon. Determined by the wet combustion procedure of Walkley and Black.
- Exchangeable Ca, Mg, K and Na. These were extracted by leaching with 1 M NH4OAc at pH 7, and the cations in the leachate were measured by atomic absorption spectrophotometer.
- Cation Exchange Capacity (CEC). Determined by saturation with NH4OAc at pH 7 and subsequent replacement of NH4 by NaCl extraction.
- Available Phosphorus. Determined by 0.5 M sodium bicarbonate extraction solution (pH 8.5) method of Olsen.
- Free $CaCO_3$ content. Determined by acid neutralization method.
- Exchangeable Acidity was determined using Van Reeuwijk's (1992) procedure 3rd Edition was used for the analysis.
- Available Micronutrients. Determinations used methods of Houba, V.J.G.,J.J. Van der Lee, I.Novozamsky and I.Walinga. 1989, Wageningen Agri.Univ.The Nerterlands.

1.2.6 Soil Mapping Units

The soil mapping units described for this survey are based on a full assessment of the field data and the accompanying field tests and laboratory analyses. The units that have been chosen relate to a complex mix of landforms, topographic information, parent materials, slopes, soil depths, soil morphology and apparent soil genesis, and assisted by observations on present land use where these are appropriate to soil conditions.

Detailed soil maps of the study area have been produced at scales of 1 :10,000 with summary map at 1 :25,000. The latter is shown in Chapter 3. . The soil mapping unit codes have been modified from those given in the Field Investigations, to give a simpler numbering system, but the old codes have been retained in the text at certain points, for the purposes of cross referencing.

Three other mapping units, defined as ‘miscellaneous units’ in the Field Investigations have been given a revised status, so that they can be included in the irrigation, settlement and general land use planning, that, and independently of the Field Investigations that were not complete at this stage, included the clearly more suitable of these lands in the proposed irrigation layout. These three units were: forests, valleys with channels, and steep rocky lands. Area measurements of all the mapping units are tabulated.

1.2.7 Land Suitability Evaluation

The Land suitability assessment used to evaluate the soils of the Dinger Bereha area follows the FAO's *Framework for Land Evaluation* (FAO, 1976) and *Guidelines: Land Evaluation for Irrigated Agriculture* (FAO, 1985). The assessment is based on the analysis of a number of site and soil characteristics matched against the requirements of the intended land use. The DBIP is planning for irrigation on the basis of several groups of crops, and the land suitability is the appropriateness of land for these specified types of land use, termed Land Utilisation Types (LUT), under a stated type of land management. The crop groups that have been considered in the DBIP Feasibility Study planning are:

- A. On well drained slopes Irrigated cereals (sorghum, maize, upland rice) and oil crops (sesame) ;
- B. Irrigated Vegetables and Pulses on well to moderately well drained soils;
- C. Irrigated Citrus and Fruit Trees on suitable, well drained soils;
- D. Irrigated Wetland Rice on Vertisol clays of flat wetland plains.

The suitability of each soil mapping unit for each of these LUTs has been assessed and area measurements given for land suitability classes. All these are discussed in detail later in this Annex.

2. ENVIRONMENT

2.1 CLIMATE

The climate of the study area has been based on the nearest full climate station at Jimma. The average temperature during the hot dry season ranges from 35º to 41º C, and during the rainy season (June-October) varies from 21º to 27º C. Rainfall is up to 1.453 mm per annum. The study area lies within the *moist kola* Ethiopian agro-climatic zone. Detailed analyses of the climate and water resources are given eslewhere in the Feasibilityt Study report. For crop grow the and soil classification, the soil moisture and soil temperature regimes are important to establish.

2.1.1 Soil Moisture Regimes

The Abbay Master Plan established the limits for soil moisture regimes (Soil Taxonomy, 1992) over the whole basin, and was based on rainfall. With relevance to the Dinger Bereha area the basin has the following moisture regimes:

Ustic moisture regime- this is the most widespread moisture regime within the basin. Soil moisture is in general limited, but it is present at a time when conditions are suitable for plant growth. The common soil moisture regime of the Dinger Bereha area.

Aquic moisture regime- Soils are saturated with water for at least a few days in the year. These areas are depressions characterised by a reducing regime usually influenced by ground water. Includes the wet soils of the Dinger Bereha area.

Udic moisture regime- this moisture regime is common to the soils of humid climates which have a well distributed rainfall or which have enough rain in summer so that the amount of stored moisture plus rainfall is approximately equal to, or exceeds, the amount of evapotranspiration. The regime mostly occurs in the south and south-west of the basin where the mean annual rainfall is greater than 1,600 mm. This would appear to lie outside the range of the Dinger Bereha area.

2.1.2 Soil Temperature Regimes

Soil temperature regimes (Soil Taxonomy, 1992) were estimated by the Abbay Master Plan from air temperature, as no soil temperature data was available. Within the basin, and with relevance to the Dinger Bereha area, the following occur:

Thermic temperature regime- this regime encompasses areas with temperatures between 15 to 22^{o}C and is the most widespread within the basin. The Dinger Bereha area lies within this regime.

Hyperthermic temperature regime- the mean annual soil temperature is 22^{o}C or higher. This regime is prevalent in areas along the Ethio-Sudanese border in the north-western part of the basin. This regime of higher temperatures are occur at lower elevations than the Dinger Bereha area.

Mesic temperature regime- this regime includes relatively small areas of the volcanic massifs and isolated uplands which have mean annual soil temperatures between 8 and 15^{o}C. This regime of lower temperatures is not found in the Dinger Bereha area.

2.2 GEOLOGY AND GEOMORPHOLOGY

The study area lies on the western edge of the Ethiopian volcanic escarpment. From the plateau at Bedele, the land drops steeply to the Didessa River valley passing through almost 1000m or so of the Tertiary volcanic succession down into the Pre-Cambrian Basement Complex, here comprising gneisses, schists and granites. There are what appear to be a series of erosion surfaces in the landscapes: the high plateau at around 2000 m is one, but this is well oustside the area; a prominent one is at about 1700 m asl on the watershed; the DBIP lies mainly on a lower gently dissected surface, at about 1240 - 1270m, herewith termed the 'Chaweka Plains'. The Basement Complex rocks are exposed in the Didessa River, and also as an elevated fault-bounded horst block which forms a massive ridge along the eastern edge of the study area. The Dinger Bereha area, the subject of this soil survey, lies west of this horst block, mostly on gently to moderately undulating landforms with steeper slopes towards the Didessa and Dabena rivers.

The soil-landforms associations are developed over a thin veneer of highly weathered basalt lava and ash on the interfluves. These weathered volcanics, that appear to be either a downfaulted fragment of the Ethiopian volcanic plateau, or the residue of a lava flow that filled this part of the Didessa valley, passes down into the underlying Basement Complex metamorphic rocks that are exposed mostly on middle and basal slopes and in the rivers at the numerous rapid sites. The actual boundary between these geological formations is obscured by thick colluvial and soil mantles. On the undulating lands of the Chaweka Plains, where slopes range up to 15%, the soils vary from shallow to lithic on convex sedentary soil exposures, down to moderately deep and deep on the colluvial slope deposits of the middle and lower slopes and valley floors: this can be considered to be a catenary association of soils.

These valleys, as noted, become much more incised near the Didessa River due to the downcutting of the main rivers in response to deepening of the Abbay gorge, but there has also been isolation and preservation, to a certain extent, of the Chaweka Plains. It is not clear why this has happened, as the landscape of the wetlands is unusual that they remain as 'perched' above the more incised streams. The same type of landscape occurs on the right bank of the Didessa in the 'Didessa State Farm' area, and beyond. It may be that beds of volcano-lacustrine sediments - of unknown age and remnants of an ash fall blanket into wetlands- noticed in sections in a few of the streams that dissect the Chaweka Plains have acted as a knick point control on erosion and downcutting in the area. This has preserved the undulating nature of the Chaweka Plains, but it is considered to be fragile: if gallery forests are removed then there is a great risk that this protection, and other contributory aspects that are undoubtably playing a part also, could be altered and erosion accelerated throughout the DBIP.

Much of the soil study area includes the undulating lands with convex interfluves, some granite tors, deep soils on middle and lower slopes, and passing down into flat, poorly drained uncultivated wetlands where significant parts remain as a dense gallery forest. The major landform units and associated vegetation and land use are shown in Table 2.1.

Table 2.1 : Landforms and Land Use at Dinger Bereha

Landform Group	Soil-Landform Association	Natural Vegetation	Land Use
Steeply sloping hills and ridges on Basement Complex and volcanic rocks (outside the command area but within catchment protection area); 1200 – 1900 m asl	**Upper and middle slopes**	**Deciduous woodland with perennial grasslands subject to slash and burn and wildfires**	**Rough grazing, illegal burning and tree felling, wildlife refuges; limited sorghum fields.**
	Lower slopes	**Deciduous woodland with perennial grasslands subject to slash and burn**	**Rough grazing, illegal burning and tree felling, wildlife refuges; sorghum fields, some irrigation at spring sites**
	Spring sites	**Gallery forest**	**Includes areas of small scale irrigation or remain as forest**
Undulating plains with convex interfluves on weathered basic volcanic rocks 1200 to 1400 m als	**Interfluves and ridges**	**Deciduous wooded savanna and scrub vegetation**	**Rainfed sorghum.**
	Middle and lower slopes	**Deciduous wooded savanna with emergents; tree cover being burnt; some species remain as parkland**	**Mostly rainfed crops (sorghum, sesame,); dry season grazing lands, rice on flat lower lands**
	Floors of the tributary valleys	**Gallery forest, including Ficus spp.**	**Tree nurseries; small scale irrigation for vegetables; forest products; sand extraction**
Undulating plains with convex interfluves and ridges with tors on Basement complex rocks 1200 to 1300 m als	**Basement Complex ridges and tors**	**Savanna woodland**	**Settlements; grazing areas**
	Basement Complex on middle to lower slopes	**Wooded savanna that is regenerating on abandoned lands**	**Scattered rainfed sorghum;**
Didessa Alluvial Landforms 1260 to 1200 m asl	**Didessa valley floodplain**	**Riverine and Gallery forest with various species**	**Generally remains wooded due flood risk;**

Source: field surveys by BRL, 2008-2009

2.3 VEGETATION, FAUNA AND LAND USE

The natural vegetation of the area includes irregular patches of dense riverine forest along the Didessa River, gallery forest along the tributary valleys that reach up to the a local plateau level at about 1700m asl. In both riverine and gallery forests the vegetation includes a wide mix of species, that include *Ficus spp*., and palms, and both soft and hardwood trees. On the steeply sloping lands of the escarpment there is a mix of *Ficus spp*. and *Acacia abyssinica* (above 1500 m asl) with a *Combretum spp* dominated woodland at lower elevations. On the undulating plains that are cultivated for rainfed crops, and the subject of this soil survey, the natural vegetation, dominated by *Combretum*, is being cut or burn by recent settlers and this is leading to substantial erosion on the more sandy soils. A few tall emergent species remain, and show that this deciduous savanna woodland was once a very dense and productive wooded savanna. Many of the trees on these undulating slopes, the future DBIP, have been burn without being harvested first: a very substantial timber resource has been wasted and lost. A fuller account of the vegetation is given in the Environmental Annex (Annex No.10) of this FS.

The area has some residual wildlife. Oribi gazelle have been seen close to Ilullu Harrar settlement and Pangolin (ant eater) holes are quite common. Elsewhere in the Didessa valley, upstream of the proposed weir site, it was noticed that there are Warthog in bushlands, and Crocodile and Hippopotamus along the river. On the steep slopes of the catchment above the irrigation area Black and White Colobus Monkey, Anubis Baboons, and other small monkeys are common. To the west of the Chaweka area the steeply sloped and well wooded hills are being proposed by the state govt to be a wildlife reserve. This move is being backed by the Chaweka Woreda administration.

The DBIP area is settled by families who have been resettled over the past five years from the Harrar area of Ethiopia. The numbers of settlers is increasing. There are also several hundred older residents of the area, Gumuz, who now live along the Didessa River, but on the right bank and outside the proposed irrigation area.

Other settlers, whose origins and national affinity are not known, but are though to have moved across from the Didessa State Farm, used to live within the DBIP area, as witnessed by several stands of mature (10 m high) mango trees: reportedly, from those of the Harar peoples who live in these same locations now, they either died or moved out entirely, partly it is stated due to effects of testse fly on their cattle.

The farming system of the Chaweka area, initiated inthe past five years as settlers arrived from the Harrar area of south eastern Ethiopia, is based on a single rainfed crop, mostly cereals including sorghum, maize, sesame, and upland rice. Some fruit trees are also grown around farmsteads, and there are several mango groves that date as mentioned from a previous settlement attempt in the valley. Livestock are kept at the home, tied up, and all ploughing is done by the laborious method of using traditional digging sticks, though often in communal efforts.

There is some irrigation in the valleys made by diverting waters from perennial streams. However, as the woodlands are cut back the Gallery forest disappears it is likely these sources will dry up: therefore, protection of the steep slopes and gallery forested areas is both necessary and essential.

The rainfed farming system, which accounts for most of the food produced in the area, is one of subsistence with low input–low output productivity. The official land use data for Chaweka Woreda is shown in Table 2.2, below. The land use data for the project area is also shown, as assessed during the detailed soil survey work. It is evident that the estimate for cultivated area is increasing annually, as new settlers clear forest and shrub lands for agricultural use. A map of the land use of the area has been devised from the soil studies and is shown in Figure 3.

Table 2.2: Chaweka Land use

Category	Woreda Area (ha)[1]	Soil Project Area (ha)[2]
Cultivated land	19,400	4,942
Grassland	3,500 [3]	1,053
Natural forest (gallery & riverine forests)	24,900	1,721
Shrubland and wetlands	5,500 [3]	2,577
Settlements, farmsteads	1,100 [3]	253
Total	**54,400**	**10,546**

Sources. 1: Chaweka Woreda Agriculture & Rural Development Office; 2: Soil Survey Report, Field Investigations, BRL-MCE, 2009; 3: GIS estimated area. Numbers have been rounded off to nearest hecatare.

The land use map (Figure 4) has been derived from the soil survey. Each mapping unit has a particular type of land use that include: dryland agriculture for a wide range of rainfed crops, grazing on waterlogged areas, forest and woodlands, rocky areas with woodlands, and settlements. Table 2.3 provides a summary of these units and their extent.

Table 2.3 Land Use / Land Cover in Dinger Bereha Project Area

Code	Colour on map	Description
DA	Brown	Dryland (rainfed) agriculture on upper amd middle slopes, 0-3 % and 4-8%. Primarily on soil units, 1,2,3,4. Cereals: Sorghum, maize, millet, upland rice, some teff, some barley; sesame; soya; haricot beans; fruit tree crops including mango, papaya; within degraded savanna woodland; livestock grazing on stubble and fallow grass areas. 1053.1 ha.
DAG	Yellow	Steeper slopes on margins of area with grassland, woodland fragments, rainfed cropping (extensive in east); abandoned areas under dense 'elephant' grass. Grasslands peridiodicaly burnt. Soil units 5,7,8,11 mainly. 4946.05 ha.
GWF	Light Blue	Seasonally flooded to permanently waterlogged grasslands of flatter valleys adjacent to stream with gallery forest. Likely former wetland forest cleared since 1970s. Now livestock grazing, and some drainage ditches being cut for probable cultivation in future. Soil unit 9 mainly. 1580.33 ha
GW	Dark Blue	Seasonally flooded grassland areas on valley bottoms. Livestock grazing. Some development of sugar cane. Few wetland tolerant trees. Soil unit 10 mainly. 67.25ha.
RF	Orange	Rocky boulder land on granite tors and basalt outcrops with variable cover of dryland savanna woodland; some wildlife gazelle seen; livestock grazing; settlements; soil unit 12. 126.83ha.
GF	Light Green	Upland Gallery,and Didessa Riverine Forest. Moist to wet lands, flat to steep sided valleys. Mostly gallery forests with secondary forest and shrub growth, along streams, merging with riverine forest at Didessa, and extending upwards to watershed area outside soil survey area. Many rainforest type trees including Ficus spp., Palmae spp. and hardwoods; unauthorised tree felling of hardwoods in places; groundwater sources for settlements; important floral and faunal biodiversity value with wildlife refuges for birds, primates, snakes. Mainly soil unit 13 and 14. 2471.87 ha
ST	///////	Settlements and administrative centres of Chewaka Woreda.

Source: Complementary Soil Survey, and BRL soils and environmental field studies, 2008-2009.

INSERT FIGURE 4– LAND USE - A3 SIZED PULL OUT

3. SOILS AND SOIL MAPPING UNITS

3.1 SOILS IN THE FIELD

For the Dinger Bereha soil survey, internationally accepted standard procedures for soil survey (FAO, 1979, 1990 and 2006) were applied to describe the soils, the landforms they occur on, and the land cover / land use. The reconnaissance studies made by BRL for the Inception Report had shown what were estimated to be the broad range of soils in the area. The detailed soil survey made by the sub-contractor now examined the soils in the field at profile pits and auger sites. The profile pits were excavated on a free survey basis, either along traverse lines where augers had shown features of interest, or at other locations where modal profiles were believed to be expected on the basis of field and auger observations. Soil samples were taken from the profile pits for all detailed chemical and certain physical (AWC) analyses in Addis Ababa, whilst other soil physical tests (infiltration and permeability) were made on the spot.

The auger survey was made along traverses 200 m apart with pre-selected soil sites at fixed points at intervals of 400 m along the traverse. The auger sites were used to refine the soil boundaries that were identified in the preparation work and preliminary stages.

Using the large database on field data acquired by the profiles and augers the preliminary base map was then revised and a full legend was prepared that merged the surface site information (soil surface features, slope, topography, landforms, erosion status, flood risk, site drainage, land use practices and land cover) with the topsoil and subsurface morphological data (soil and root depths, structure, secondary segregations, profile drainage features, textures, horizons, consistence, and observed parent materials) provided in particular by the open profiles, and to a lesser extent by the augers.

Later, as laboratory data became available the soil map was refined into its final product. The Complementary Studies soil survey boundaries have been utilised for the soil maps that accompany this Annex of the Feasibility Study report, and only the coding system has been used to provide a simpler and purely numerical system to cover the 14 soil mapping units (SMU): thus, for example SMU G1b_1 is now re-labelled as 1; Sg-6 is now 5.

A summary of the soil mapping units is given in Table 3.1, below. The extent of the soils is shown in Figure 5. Soil chemical and physical properties of the mapping units are shown in Table 3.2. A summary of the morphological properties of the soils is given inTable 3.3

This soil map is derived from the field surveys. Quite deliberately it is designed to be used in several ways by users with differrent interest: it provides the areal and numerical extent of each mapping unit, whether they are soils or the settlements; it describes the landforms and parent material of the area ; and the soil classification according to the FAO system.

In this chapter the soil mapping units, as established in the field, are described first of all. The mapping units and the subsequent land suitability analysis of these soils have formed the basis for agricultural planning in the Dinger Bereha area with the spatial relations of the soils being examined as part of the irrigation design, agronomy and livestock issues, land tenure, conservation of natural resources, and economic and financial analysis.

The soils subcontractor made an analysis of the soils according also to their chemical and physical properties. The soils were also classified in terms of their taxonomy, in this case according to the FAO system. These different analyses are presented in the following sections. It is important to note though that for the proposed project, which will adopt a specialised irrigation system largely new to Ethiopia, it is the mapping units that are the key to understanding the land suitability classification and the successful development of the project. This surevy is made for a Feasibility Study of the Dinger Bereha area. The survey has shown that many interesting chemical and physical properties in the soils that for the moment we have to leave: there is a research opportunity here for interested soil scientists in the research community to take this further and support the proposed developement at Dinger Bereha.

Table 3.1 : Summary of Soil Mapping Units

Map Code	Soil Landform Description	Area ha	%
1	Deep, well drained, dark reddish brown, loam / clay loam over clay, on colluvial upper convex 0-3 % slopes; no stones or boulders, no flood risk (Orthidystric Nitisols)	1630.4	15.5
2	Deep, well drained, reddish brown, clay loams over clays, on colluvial upper convex 0-3% slopes; no stones or boulders, no flood risk (Hyperferric Acrisols)	675.3	6.4
3	deep, moderately well drained, dark reddish brown, clay loams over clays, on middle & lower 4-6 % slopes, no stones or boulders, no flood risk (Orthydystric Nitisols)	2430	23.0
4	Deep, moderately well drained, dark reddish brown, clay loams / clays on middle & lower 4-6 % slopes, no stones or boulders, no flood risk (Rhodic Nitisols)	242.4	2.3
5	Shallow to moderately deep, at least 60 cm deep, dark reddish brown, loams / clay loams on steep slopes >15%, on basaltic materials, stony and rocky in profile below 60 cm (Orthieutric Leptosols)	787.5	7.5
6	Deep, well drained, dark reddish brown, loams / sands / sandy clay loams, on middle to upper slopes 5-8 % of rock ridges, stones in profile below 160 (Hyperferric Acrisols)	387.5	3.7
7	Moderately deep, well drained, brown, clay loams, of middle to upper 5-8 % slopes on basaltic materials , stony below 70 cm, (Orthidystric Cambisols)	152.5	1.5
8	Deep, moderately well drained, dark brown, loams over clays on hillside slopes 8-15 % , stony below 150 cm (Hyperferric Cambisols)	958.7	9.1
9	Deep, imperfectly drained, dark grey, clays, on 0-3 % lower slopes of seasonal flooded valleys, no stones (Mesotrophic Vertisols)	1053.1	10.0
10	Deep, poorly drained, black, clays on valley floor, 0-2 % slopes, alluvium , no stones (Gelic Gleysols)	30	0.3
11	Deep, moderately well drained, dark brown, loams over clay loam / sandy clay loam, on colluvium of 2-4 % lower slopes in dissected valleys, may be gravelly > 1m (Fluvic Cambisols)	200.2	1.9
12	Shallow to rocky, reddish brown, sandy and skeletal soils on bedrock granite and basalt outcrops >5 % slopes (Leptosols)	67.3	0.6
13	Deep, poorly drained, black, clays and loams on 0-3 % valley floor alluvium with incised central stream channel (Nitisols, Acrisols, Vertisols)	1585.5	15.0
14	Deep, dark grey clays to black clay loams on undulating 4-8 % slopes under forest (Nitisols, Vertisols, Acrisols)	130.4	1.2
ST	Settlements (sited on well drained upper and middle slopes of various soil units)	216	2.1
	TOTAL	10546.8	100.0

Source: Field work and interpretation by MCE-BRL, 2009

INSERT FIGURE 5. SOILS A3 SIZED PULL OUT

3.2 SOIL MAPPING UNITS

3.2.1 Mapping Unit 1

This soil unit (old code G1b_1) is found on upper parts of the gently undulating plains in the central part of the study area. Slope range is 0-3%. In this mapping unit 17 profile pits were examined and the typical profile shows a very deep, dark reddish brown (5YR3/2), clay overlying a dark reddish (2.5YR3/6) clay. The soil is well drained throughout. Consistencies are sticky and plastic when wet, and firm when moist. The surface layers have a moderate, medium coarse sub angular blocky structure. A representative profile is DP78 (note that chemical data for this profile and all other profiles are given in Appendix A of this Annex).

Chemically, the soils of SMU 1 show that the mean pH of the surface is 5.6, becoming more acidic with depth. The average organic carbon and total nitrogen contents of soils on surface are low to medium (4.1%) and very high (0.32%) respectively. The ratio of organic carbon to total nitrogen varies from 13 to 20 with an average value of 14 showing that the value is in the optimum range. Throughout the profile the soils are seen to be non-saline and non-sodic with an EC of <0.1 dS/m and ESPs of < 4 %. No $CaCO_3$ concretions were seen. The average value of CEC is less than 29 meq/100 g and base saturation is more than 28% indicating that the potential soil fertility status is high. The relative proportion of Mg and Ca in the exchange complex is low, indicating that the uptake of Ca may be inhibited by Mg. The available P content of the surface soils is 2.68 (ppm) which is very low.

The trace elements (Fe, MN, Cu, Zn) are also low. The soil physical data gave an average water holding capacity of about 98 mm/m, and infiltration and hydraulic conductivity values averaged at 9.2cm/hr and 1.5m/day respectively. Their chief limitations as soils is that they have reduced moisture availability and existing fertility levels are low. The latter can be corrected by inputs. Based on the field investigation and laboratory results, the soils were classified as Orthidystric Nitisols (FAO code: Ndyo). Land that belongs to this unit covers about 1,630 ha and occupies 15.5% of the surveyed area.

The Complementary Survey report provides the following information on these soils (Box 1) and we concur with these findings:

Box 1. Mapping Unit 1 (G1b_1)

This unit is found on elevated upper part of gently undulating plain mainly in the central part of the study area with slope percent of 0-3. Land that belongs to this unit covers about 1,630.38ha and occupies 15.46% of the surveyed area. For the study of soils of the mapping unit 17 representative profile pits were described. The soils are very deep with this well drained drainage characteristics. The color of the surface soils is dark reddish brown (5YR3/2) and gets dark reddish color (2.5YR3/6) in sub-surface and the texture is clay throughout the soil depth. Consistencies are sticky and plastic when wet, and firm when moist. Surface soils have moderate, medium course and sub angular blocky structure. The pH of the surface soils (0-18) is about 5.6, which is decreasing gradually to 5.0 in sub surface. The average organic carbon and total nitrogen contents of surface soils are 4.1% (medium) and 0.32% (very high) respectively. The ratio of organic carbon to total nitrogen varies from 13 to 20 with an average value of 14 showing that the value is found in a good range. Throughout the depth the soils are non-saline and non-sodic with average EC of 0.dS/m and ESPs of < 4%. The average value of CEC on surface is less than 28 meq/100g and base saturation is 52.1% while the value in sub-surface is decrease to 19.97 meq/100g and 51.3% respectively, indicating that the soils fertility status is medium. The relative proportion of Mg and Ca in the exchange complex is 3:1 (optimum) on top and decreases in sub-surface to 1.3:1 low, indicating that available P up take may be inhabited. The available P content of the surface soils and sub-surface is 2.68 (pmm) and 0.45ppm which are found in a very low range. The trace elements like Iron, Manganese and Copper are adequate with value of 50, 58 and 1.2 mg/kg soil respectively, whereas Zinc is found in marginal level with an average value of 1.49 mg/kg soil. The average water holding capacity of this unit is 97.86mm/m with infiltration and hydraulic conductivity values of 9.2cm/hr and 1.5m/day respectively. In order to check fluctuation of water table and impervious horizon deep boring was done up to 400cm.Then, after 400cm due to solid contact auguring was not preceded. Following that two samples at the depth of 200-300cm and 300-400cm were taken. They have acid pH reaction, greater than 5.3 and very low EC of 0.01dS/m. Based on the field investigation and laboratory results, the soils are classified as Orthidystric Nitisols (Ndyo). For representative profile and analytical data see Profile Pit DP78.

3.2.2 Mapping Unit 2

This soil mapping unit (old code G1b_4) is is mapped on gently undulating plains with slope range 0-3 %. A representative profile is DP90. The soils are developed on well drained, deep to very deep, clayey colluvial parent material. The topsoil is a reddish brown (5YR4/4) sandy clay loam to silty clay loam, passing down in to yellowish red (5YR4/6) clay. Soil structure is moderate, medium to weak subangular blocky surface structure, with medium to coarse angular and sub angular blocky subsoil structure. Soi physical tests showed that water holding capacities range up to 134 mm/m with basic infiltration rate of 8.6cm/hr and hydraulic conductivity value of 1.96m/day. The pH of the topsoil shows a moderately acidic soil (range 5.1 to 4.6). The organic carbon content on surface soil is 3.9%, indicating low level of organic carbon and the total nitrogen content of these soils is moderate at 0.28. The C/N ratio of the top metre was 14 but available phosphorus was low at 6.1 ppm. These soils have a high CEC, > 31meq/100g soil but they have very low base saturation percentage. Micronutrients (available Fe, Mn, Cu and ZN) were found to be sufficient. The soils have good drainage and are deep but show low levels of nutrients. Based on the field investigations and laboratory results, the soils are classified as Hyperferric Acrisols (ACfrh). The soils cover some 675 ha (6.5%) of the DBIP, mostly in the western parts.

The Complementary Survey report provides the following information on these soils (Box 2) and we concur with these findings :

Box 2. Soil Mapping Unit 2 (G1b_4)

The unit is mostly located in the western part of the study area. It occupies 675.27ha and forms about 6.46% of the total surveyed area. It is characterized by gently undulating plain land with slope of 0-3%. The soils are developed on colluvial parent material. The color of the surface soil varies from reddish brown (5YR4/4) to yellowish red (5YR4/6). The soil texture ranges from sandy clay loam to silty loam on surface and throught clay in sub-surface.They have very deep soil profile (> 200 cm), with well drainage. It has moderate and medium to weak surface structure. The subsoil has medium to coarse angular and sub angular blocky structure and the profiles have diffused and sometimes wavy boundary. The water holding capacity of this unit is 133.7mm/m with basic infiltration rate and hydraulic conductivity value of 8.6cm/hr and1.96m/day respectively. The pH of the topsoil is found moderately acidic with value of 5.1. The reaction decreases in sub-surface to 4.5. The organic carbon content on surface soil is 3.9% and decrease in sub-surface to 2.7%, indicating low level of organic carbon and the total nitrogen content of the same layer is high (0.28%) and medium (0.17%)respectively. The C/N ratio of (100cm) top surface soil is 14:1 and the available phosphorus of this unit is low with value of 6.11ppm. They have high CEC, which is greater than 31meq/100g soil and has medium base saturation percentage. The micro nutrient like, Iron, Manganese and Copper are found in adequate level with value of 65.42 and 2.1 while, Zinc is found low with value of 0.41mg/kg soil. Based on the field investigations and laboratory results, the soils are classified as Hyperferric Acrisols (ACfrh). For representative profile and analytical data see Profile Pit DP90.

3.2.3 Mapping Unit 3

Soil mapping 3 (old code G2d_1) is found on the middle and lower slopes of the gently undulating Chaweka Plains land, with slope of 4-6 percent, and is found throughout the study area. The soils are deep and moderately well drained. A representative profile is Pit DP3. The Clay Loam topsoils have dark reddish brown (5YR3/4) surface colours, becoming red (2.5YR4/6) in the Clay subsoil. The soils have weak, fine and granular structure in the surface, and have a slightly sticky and plastic consistency when wet. Chemiclaly, these soils are slightly acidic, being 5.3 in the surface and more acid in subsoils, with mean of 4.7. The average organic carbon and total nitrogen values for the topsoil (0-30 cm) are 2.6% and 0.29% respectively. Organic carbon and total nitrogen values are very low and medium respectively, and as might be expected, decline with depth. Salinity and sodicity levels in these soils are very low, with an average EC of <0.07 dS/m and ESP of <0.5%. The soils whilst they have a high CEC, >35meq/100g soils are very low in terms of their base saturation percentage, an indication of long term leaching in the soils. The average available P content in the top metre is 1.9 ppm, a very low low. The water holding capacity, infiltration rates and hydraulic conductivity of the soils are 106.5mm/m, 8.6cm/hr and 1.3 m/day respectively. Even though the pH of the soil is low, toxic levels of micro nutrients are not found : the average value of Fe, Mn, Cu and Zn are 24, 74, 1.8 and1.3 mg/kg soil respectively. The soils should react well to inputs and better management that has the potential to raise nutient levels. Based on the field study and laboratory results, the soils are classified as Orthidystric Nitisols (NTdyo). Their total area is about 2,430 ha, some 23 % of the study area. The Complementary Survey report provides the following information on these soils (Box 3) and we concur with these findings:

Box 3. Soil Mapping Unit 2 (G2d_1)

This land unit is described as middle & lower slope of gently undulating plains land with slope of 4-6%, found throughout the study area. Its total area extent is about 2,429.96ha, which is about 23.04% of the study area. The soils have deep soil depth, moderately well drained and dark reddish brown (5YR3/4) color on surface and it changes to red (2.5YR4/6) color in sub-surface. The texture is characterized by clay loam in surface and changes to clay in sub-surface. The soils have weak, fine and granular structure. Their consistency is slightly sticky and plastic when wet. The pH of the top (0-30) soils is 5.33, which is slightly acidic and decreases in subsurface to 4.7. The average organic carbon and total nitrogen values are 2.6 and 0.29% respectively. Both the organic carbon and total nitrogen values are very low and medium respectively and decreases gradually with profile depth. With this level of content, plough back of crop residues and mulching should be encouraged to raise the level of organic carbon and nitrogen to improve the top soils structure and fertility level of the soils. Salinity and sodicity in the area are negligible with an average ECs <0.07 dS/m and ESPs <0.5% on surface. They have high CEC more than 35meq/100g soils and low base saturation percentage of 40.0%. The average available P content on the first 100cm depth is 1.9ppm which is very low. The water holding capacity, infiltration rates and hydraulic conductivity test results of the soils are 106.5mm/m, 8.6cm/hr and 1.3m/day respectively. The micronutrients like Fe, Mn and Cu have adequate content with value of 26, 74 & 1.8mg/kg soil respectively. Comparing with others Zinc is found in a marginal level with value 1.3mg/kg soil. Based on the field study and laboratory results, the soils are classified as Orthidystric Nitisols (NTdyo). For representative profile and analytical data see, Profile Pit DP3.

3.2.4 Mapping Unit 4

Soil Mapping Unit 4 (old code G2d_2) occurs on middle and lower slopes of gently undulating Chaweka Plains, where slopes range from 4 to 6%. This area is extensively cultivated for sorghum and sesame. A representative profile is Pit DP2. The soils are deep to very deep, well drained, with a dark reddish brown (5YR3/4) Clay Loam surface over a dark red (2.3YR3/6) more Clayey subsoil.

The soils have moderate to coarse sub-angular blocky structure. The water holding capacity of the representative soil is 105 mm/m, and the basic infiltration and hydraulic conductivity rates are 7.9 cm/hr and 3.6 m/day respectively. These soils are slightly acidic (pH 5.0-5.4) in the topsoil and 5.2 in the subsoil. Organic carbon and total nitrogen content in the top soil are respectively low (3.2 %), and medium (0.3 %) in the surface layer, whilst the C/N ratio ranges from 7 to 11. Like soils elsewhere in the DBIP area, available phosphorus is very low, averaging 0.5 ppm. The exchange complex of the topsoil is dominated by magnesium, and Ca/Mg ratio is in the range of 3:1. The average value of the CEC at 40.8meq/100 g of indicates a the soils have a potential even if nutrient levels are low, as indicated by low base saturation percentages. The soils are non-saline and non-sodic (ECs generally < 0.09dS/m and ESP of 0.5%). The available micronutrient levels (Fe, Mn, Cu and Zn) are low and there is no indication of toxic levels. Based on the physical field information and the laboratory results the soils of this unit are classified as Rhodic Nitisols (NTro). The total extent of these soils is only 242.4 ha, some 2.6 % of the area. The Complementary Survey report provides the following information on these soils (Box 4) and we concur with these findings:

Box 4. Soil Mapping Unit 2 (G2d_2)

This unit refers to the middle and lower slope of gently undulating plain elevated lands, with slopes ranging from 4 to 6%. This area is mostly used for sorghum and sesame cultivation. Its total area extent is 242.42ha, which is about 2.57% of the study area. The soils have dark reddish brown (5YR3/4) color on surface and dark red (2.3YR3/6) color in sub-surface layer. The texture is clay loam on surface and increases gradually in sub-surface. They have deep to very deep soil depth and well drainage class. The soils have moderate to coarse sub-angular structure. The water holding capacity of this unit is 104.8mm/m and the basic infiltration and hydraulic conductivity results are marginally suitable (7.9cm/hr) and moderate level (3.6334m/day) respectively. The soil pH of the topsoil is slightly acid and ranges from 5.4 to 5.0, with average value of 5.2. The organic carbon and total nitrogen content of the top soil is 3.2% (low), and 0.0.29% (medium) in the surface. The C/N ratio found in the range of 7:1 to 11:1, which indicates that the total Nitrogen content is found in the range of medium to low level. The available phosphorus content of this mapping unit is very low with an average value of 0.5ppm.The exchange complex of the surface soils appears to contain relatively lower exchangeable Ca which is dominated by Mg. There ratio is found in the range of 3:1. When the Ca/Mg ratio is in the range of 3:1 to 4:1 the soil is found on the level of approximately optimum range for most crops. The value of CEC on surface is 40.8meq/100 g of soil showing very high level of CEC and to the contrary they have low base saturation percentages. The soils are non-saline and non-sodic with ECs on average < 0.09dS/m and ESPs of 0.5%. As it is seen from laboratory results the soils have low fertility level. The micronutrient values of Fe, Mn and Cu are found on adequate level. But, the value of Zn is found on marginal level with 1.0mg/kg soil. Based on the physical field information and the laboratory result the soils of this unit are classified as Rhodic Nitisols (NTro). For representative profile and analytical data see Profile Pit DP2.

3.2.5 Mapping Unit 5

Soil mapping unit 5 (old code Sg-6), occurs on the moderately steep side of hills and ridges over basaltic materials. The slopes are >15 %. A representative profile is DP 56. The soils have shallow and moderate depth (< 60cm) and are excessively drained. The topsoil is a dark reddish brown (5YR3/2) Clay Loam over reddish brown (5YR4/3) Clay Loam to Clay subsoil. Consistencies are firm when dry, and slightly sticky and slightly plastic when wet. The soils have weak, fine to medium sub angular blocky structure. The pH of the soils is neutral (average 6.8) Organic carbon and total nitrogen content of the topsoil average 6.8% (medium) and 0.66% (very high), respectively.

The soils have a high CEC, on average (31.1 meq/100 g soils) and high base saturation percentage. The exchange complex is calcium dominant : exchangeable calcium and magnesium are 26 and 3.6 meq/100 g soils respectively. The ratio of calcium to magnesium on the surface is 7:1 and decreases downward to 3:1. Micronutrients are low.The available P content of the soils is very high. Even though they have shallow soils the fertility status of the soils is found is actually high, probably due to their non-agricultural use at present. The soils are shallow in many areas and this will limit their suitability for deeper rooting crops. Based on the field investigation and laboratory results the soils are classified as Orthieutric Leptosols (LPeou). They cover some 787.5 ha, 7.5% of the area. The Complementary Survey report provides the following information on these soils (Box 5) and we concur with these findings:

Box 5. Soil Mapping Unit 5 (Sg-6)

This land unit is characterized by moderately steep side of hills and ridges developed on basaltic tuffs and has a slope percentage of >15. It occupies 787.51ha and forms about 7.46% of the surveyed area. The soils of this land unit have shallow depth less than 60cm and excessive drainage. The soil color is dark reddish brown (5YR3/2) color on surface and reddish brown (5YR4/3) in sub-surface. Consistencies for both layers are friable when dry and slightly sticky and slightly plastic when wet. The soils have weak, fine to medium sub angular blocky structure. The pH of the soils is throughout the depth is greater than 6.8 which is neutral level. The organic carbon and total nitrogen content of the surface soils are 6.8% (medium) and 0.66% (very high), respectively. They decrease in sub-surface with values of organic carbon 1.6% and total nitrogen 0.22%. The soils have high CEC, on average (31.1meq/100 g soils) and high base saturation percentage (70.9%). Similarly the exchangeable calcium and magnesium content of the surface soils are 26 and 3.6meq/100 g soils respectively. The value is found at very high and high level respectively. The ratio of calcium to magnesium on the surface is 7:1 and decreases downward in the sub-surface to 3:1. In the exchangeable complex calcium occupies high value than the others cations. On surface soils Mg increasingly unavailable due to high content of Ca and P availability may be reduced. The available P content of the soils is very high (33.3ppm) on top and low (5.6ppm) in sub-surface. Despite, they are shallow and stony, fertility status of the soils is found to be in high level. The Iron, Manganese and Zinc trace elements are adequate in the soils but Copper is found on marginal level. Based on the field investigation and laboratory result the soils are classified as Orthieutric Leptosols (LPeou). For representative profile and analytical data see Profile Pit DP56.

3.2.6 Mapping Unit 6

Mapping Unit 6 (old code U1e_4) occupies the moderately sloping middle and upper parts of hills and ridges, where slopes range from 5 to 8%. A representative profile is DP 67. The soils are very deep (>160cm), with well drained, dark reddish brown (5YR3/2) Loamy surface. The subsoil is also dark reddish brown and Sandy textured. Consistencies are sticky and plastic when wet, and the soils have a moderate to strong coarse angular structure. Chemically, these soils have a pH in the topsoil of 5.2, that decreases to 5.0 in the subsoil. Nutrient contents of the topsoil varies from very low (2.8%) to medium (4.0%) for Organic Carbon and medium (0.22%) to very high (0.33 %) for Nitrogen.

The soils, like many of the DBIP soil-landform associations, have a high CEC (34 me/100g) and medium base saturation percentage. The relative proportion of Ca to Mg in the exchange complex is low which indicates the availability of Ca is low. For this reason it is thought the available P content in topsoils is high on average 4.61 (ppm) but decreases in subsoil to 2 ppm. The water holding capacity of this soil is 88.5 mm/m. Available micronutrients levels are low and there is no toxic levels. These soils are classified as Hyperferric Acrisols (ACfrh). They cover some 387.5 ha, 3.7 % of the surveyed area. The Complementary Survey report provides the following information on these soils (Box 6) and we concur with these findings :

Box 6. Soil Mapping Unit 6 (U1e_4)

This unit refers to the strongly sloping upper and middle part of hills and ridges of study areas, with slope range of 5 to 8%. The land unit occupies around 387.45ha and forms about 3.67% of the study area. The soils are very deep (>160cm), well drained, and have dark reddish brown (5YR3.2) soil color throughout the soils depth. The soil texture is loam on surface and sandy texture in sub-surface. Consistencies are sticky and plastic when wet. The soils have moderate to strong coarse angular structure. The pH of the surface soils is 5.4 and it decreases to 5.0 in the sub-surface. The average organic carbon and total nitrogen contents of the top soils vary from medium (4.0%) to very low (2.8%) and very high (0.33%) to medium (0.22%) respectively. The soils have high CEC (34.7meq/100g soil) and medium (41.1%) base saturation percentage on surface layer and decrease for both parameters in depth. The relative proportion of Ca to Mg in the exchange complex of surface soils is low (2:1) which indicates the availability of Ca is low and doesn't hinder the availability of Mg, but available P up take may be inhibited. The available P content in the surface soils is very low (4.61ppm), and decrease gradually in depth to value of 2ppm. The water holding capacity of these soils is 88.5mm/m. The soils micronutrients like, Iron, Manganese and Copper are adequate except Zinc. They have values of 34, 56 and 3.5 mg/kg soil respectively. Similarly zinc has value of 0.45mg/kg which is low. These soils are classified as Hyperferric Acrisols (ACfrh). For representative profile and analytical data see Profile Pit DP67.

3.2.7 Mapping Unit 7

Soil mapping unit 7 (old code Ue1_5) lies on middle and upper slopes of hills and ridges found mostly to the north western of the study area with slope ranges from 5 to 8%. A representative profile is Pit DP94. The soils have only a moderate depth (0-70cm) and are well drained. The topsoil is a weak, fine and medium granular, brown (7.5YR4/4) Sandy Clay, over moderate medium coarse sub-angular blocky, strong brown (2.5YR4/6) Clay subsoil. The soil is developed from weathered basaltic materials. The pH of the surface soil (0-38) is 5.3 and it decreases with depth to 4.8. Total nitrogen ranges from 0.55 % (very high) in topsoil to 0.12 % (medium) in subsoil; organic carbon contents vary from 3.9% (low) to 1.4 % (very low). Salinity and sodicity levels are very low with EC values of < 0.25 dS/cm and ESP of < 0.45. CEC in the soils is low at 16.7 meq/100g of soil, and base saturation percentage is very low (37%). Average available P content of the top soils is relatively high at 13.8 ppm, and micronutrients (Fe, Mn, Cu, and Zn) are at an adequate level. Based on field information and laboratory results the soils are classified as Orthidystric Cambisols (MCdyo). The soil unit covers some 152.5 ha, 1.4% of the study area. The Complementary Survey report provides the following information on these soils (Box 7) and we concur with these findings:

Box 7. Soil Mapping Unit 7 (Ue1_5)

This unit refers to strongly sloping upper and middle part of hills and ridges found mostly to the north western of the study area with slope range of 5 to 8%. Total area extent is about 152.51ha and forms about 1.44% of the study area. The soils have moderate depth (0-70cm), well drainage and brown (7.5YR4/4) color on surface and strong brown (2.5YR4/6) in sub surface. The structure of the top soils is weak, fine and granular while, in sub-surface it is characterized by moderate, medium and coarse sub-angular blocky structure. The soil is developed on basaltic tuffs. The pH of the surface soils (0-38) is 5.3 and it decreases to 4.7in sub-surface. The total nitrogen and organic carbon contents of the soils are very high (0.55%) and low (3.9%) on surface layer respectively. whereas in sub-surface they decrease to medium (0.12%) and to very low (1.4%) respectively. With this level of content ploughing back of crop residues and mulching should be encouraged to raise a very low level of organic carbon

and total nitrogen content of the soils and to improve the top soils structure. In this mapping unit salinity and sodcity is not a problem; since they have low average values of < 0.05 dS/cm and less than 0.9 ESPs. The soils have on average low cation exchange capacity of 16.7 meq/100g of soil and low (37%) base saturation percentage on top and they decrease in sub-surface to 13.76meq/100gsoil and 22% respectively.The exchange complex of the surface soils appears to contain relatively higher exchangeable Mg than the Ca with an average value of 2.71 and 2.71 meq/100 g soils respectively. The Ca/Mg ration is also very low 1:1 on top and and 2:1in sub-surface, which is low. With this range the soil is not favorable for plants growth. Calcium availability slightly reduced. Nevertheless, the average available P content of the top soils is relatively high with an average value of 13.8ppm. The micronutrient value of the four elements Fe, Mn, Cu, and Zn is found in sufficient level. They have value of 35,32,2.1 and 37.4mg/kg soil in that order. Based on the field investigation and laboratory result the soils are classified as Hypereutric Cambisols (CMeuh). For representative profile and analytical data see Profile Pit DP94.

3.2.8 Mapping Unit 8

Soil mapping unti 8 (old code U2f_9) is mapped on the strongly sloping sides of hills, slopes 8-15 %. The soils are deep, and moderately well drained. A representative soil is DP 15. The topsoils are fine, medium and granular structured, dark brown (10YR3/3), Loams; subsoils are dark yellowish red (10YR3/4) Clays. Their wet consistency is slightly sticky and plastic. Chemically, the topsoils have a neutral pH (average 6.7) decreasing gradually downwards to 6.5. They are non-saline and non sodic with ECs of < 0.5 dS/m and ESPs of < 0.3%. The C/N ratio value ranges from 7-14. These soils have a high CEC (>30.5 meq/100g soil) and and also have high base saturation throughout the profile (95.6 to 122 %). The Ca to Mg ratio in the exchange complex of topsoils is moderately high (4: 1), considered to be very favourable soil for agriculture development. Except for Mn, micronutrients (Fe, Zn, Cu) are deficient. In general, apart from the steepness of the soils, they have a high fertility status. Based on the field investigation and laboratory result the soils of this land status unit are classified as Hypereutric Cambisols (CMeuh). Most of the soils occur in the north east of the study area, in particular north and east of village No. Seven (Sebategna). The soils cover some 959 ha, 9.1 % of the study area. The Complementary Survey report provides the following information on these soils (Box 8) and we concur with these findings:

Box 9. Soil Mapping Unit 9 (U2f_9)

This unit refers to the strongly sloping side of hill and ridge with slope percentage of 8-15. Major part of this land unit is located to the north eastern part of the study area in particular to north and east of village No.7 or Sebategna. It has an area extent of 958.68ha and forms about 9.09% of the study area. The soils are relatively deep and moderately well drained with dark brown (10YR3/3) color on surface and dark yellowish red (10YR34) in sub-surface. The soils have loam soil texture class on top and clay in sub-surface. Their consistency, when wet is slightly sticky and plastic and has fine, medium and granular structure. The pH of the surface soils is nearly neutral with value of 6.7 and decreases gradually in the sub-surface to the value of 6.5.The organic carbon and total nitrogen percentage of the surface soils are medium and very high with value of 7.8% and 0.6% respectively. In sub-surface they decrease to 1.1% and 0.15% respectively in depth of 52-100cm. The C/N ratio value ranges from 14:1 to 7:1 indicating that the total Nitrogen % is relatively higher than the organic carbon, even though their fertility statue is found in good range. The soils have high CEC greater than 30.46 (meq/100g soil) and high base saturated percentage throughout the soil profile pits depth. The relative proportion of Ca to Mg in the exchange complex of the surface soil is moderately high (4: 1) which is very favorable soil for crop production. In general the average exchangeable value of Mg, Ca, and K are 27.4, 6.84 and 1.7meq/100g soil respectively and they are found in high level. Concerning micronutrients content they found in adequate level, with value of Fe 24, Cu 3.5 and Zinc 8.91mg/kg soil. In general except the steepness of the area the fertility statue of the soils is found to be in the moderate to high range. Based on the field investigation and laboratory result the soils are classified as Orthidystric Cambisols (CMdyo). For representative profile and analytical data see Profile Pit DP15.

3.2.9 Mapping Unit 9

Soil mapping unit 9 (old code V1b_3) is mapped on the seasonally wet valley floor areas, with slope range of 0-3%. The lands are wet for a considerable part of the year, and are currently used for livestock grazing. A representative profile is DP 83. The soils are very deep (> 200 cm) and are imperfectly to poorly drained. The topsoils are moderate, medium sub angular blocky, very dark brown (10YR3/1) Clays, over moderate, medium and coarse wedged-shaped, dark gray (10YR4/1), Clays in subsoil. The chemical data shows the soil pH ranges from 5.5 in topsoil to 7.9 in subsoil. Increase in pH is correlated with subsurface accumulation of $CaCo_{3.}$ Topsoil values for total nitrogen are 0.3% and for organic carbon 4.6% (low). The soils are non-sodic and non-saline : ESP < 1.4% and EC of < 0.03 dS/m. CEC are high (51.59 meq/100g soils) and there is high base saturation (> 60 %). The infiltration rate and hydraulic conductivity tests of the soils are 6.3 cm/hr and is 0.10 m/day respectively. These soils are classified as Mesotrophic Vertisols - (VRms). The soils cover 1,053 ha, some 10 % of the study area. The Complementary Survey report provides the following information on these soils (Box 9) and we concur with these findings:

Box 9. Soil Mapping Unit 9 (V1b_3)

This unit refers to soils developed on seasonally wet valley floor area with slope range of (0-3%). It is wet for some time of the year and currently used for extensive grazing. It has an area extent of 1,053.1ha, and about 10.0% of the study area. The soils are very deep greater than 200 cm, with imperfectly to poor drainage and clay soils texture. They have very dark brown (10YR3/1) color on surface and dark gray (10YR4/1) in the sub surface.Their consistencies are slightly sticky and plastic when wet. The soils have moderate, medium sub angular blocky structure in subsurface and moderate, medium and coarse wedged-shaped in sub-surface. The pH of the soils is 5.5 on surface and 7.91 in sub-surface, the pH value increases due to $CaCO_3$ accumulation at sub-surface (70-160cm). The total nitrogen and organic carbon content of the surface soils are 0.3% (very high) and 4.6% (low) respectively. The soils are non-sodic and non-saline on surface and sub-surface. The top soils have an average value of ESP < 1.4% and ECs of < 0.03 dS/m and have 2.24% (low) calcium carbonate percentage. The soils have high CEC on average (51.59 meq/100g soils) and high base saturation percentage greater than 60 on surface. The average values of exchangeable calcium and magnesium of the surface soils are 21.7 and 8.1meq/100 g soils respectively and they are at a high level. They increase gradually in sub-surface to 52 and 10.41meq/100 g respectively. The ratio of calcium to magnesium on the surface is 3:1 which is found optimum for most of the crops. The available P content of the surface soils is 9.22ppm, which is medium and decrease in sub-surface to very low (0.59ppm).The infiltration rate and hydraulic conductivity tests of the soils are 6.3cm/hr (Suitable for surface irrigation) and 0.10m/day(very slow) respectively. Available water holding capacity of the soil is also 185.3 mm/m (high). With regarded to micronutrients content Iron, Manganese and Copper are found at sufficient categories with values of 402, 101 and 5 mg/kg soils respectively. To the contrary Zinc is found on low (0.19 mg/kg soils) category. The soils are classified as Mesotrophic Vertisols - (VRms). For representative profile and analytical data see Profile Pit DP83.

3.2.10 Mapping Unit 10

Soil mapping unit 10 (old code V2a_7) occurs in the valley bottoms on river alluvium with a slope range of 0-2%. A representative profile is DP 91. The soils are currently used for grazing and some smallholder sugarcane. Soils are very deep and poorly drained. Topsoils are moderate to medium sub angular blocky, black (10YR2/1), Clays, over dark grayish brown (10YR3/2) Clays. They have a wet sticky consistency.

Their pH is moderately acidic (average 5.3). Organic carbon and total nitrogen values for the topsoil are 4.6% and 0.2% respectively, and decrease with depth. The soils are non-saline and non-sodic with average EC of < 0.04 dS/m and ESP of <3%. The soils have a high CEC (> 35) and a medium base saturation percentage (> 50 %). The average available P content in the top metre is very low at 1.9 ppm. Based on the physical field investigations and the laboratory results, the soils are classified as Gelic Gleysols (GLge). They cover only about 29 ha, some 0.27% of the study area. The Complementary Survey report provides the following information on these soils (Box 10) and we concur with these findings:

Box 10. Soil Mapping Unit 10 (V2a_7)

This unit occupies insignificant portion of the study with an area extent of 28.99ha, which is about 0.27% of the study area. It is located in the valley bottom with a slope range of 0-2%. The soils are developed on alluvial/fluvial parent material. The unit is currently used for extensive grazing and sugarcane plantations. The soils are very deep and poorly drained. Surface soils have black (10YR2/1) color, and in sub-surface the color is dark grayish brown/red (10YR3/2). The texture of the surface and surface is throughout clay. The surface soils are characterized by moderate to medium sub angular blocky structure. When the soils are wet they have sticky non plastic consistency and when they are moist their consistency is loose to friable. The pH of the soils is throughout moderately acidic with an average value of 5.2. The organic carbon and total nitrogen values at 0-42cm depth are 4.6% (medium) and 0.3% (high) respectively. The determined values of both elements are very low in subsurface with value of 1.0 and 0.1. The soils are non-saline and non-sodic with average ECs of < 0.04dS/m and ESPs of <0.5%. The soils have high CEC, more than 35.6 meq/100g soils and medium base saturation percentage, which is greater than 47%. The average available P content on the first 100cm depth is 1.9 ppm which is very low. The micronutrient content values of Iron, Manganese, Copper and Zinc are found in adequate category with value of 196, 16, 2.3 and 17.1mg/kg soil respectively. Based on the physical field investigations and the laboratory results, the soils are classified as Glic Gleysols (GLge). For representative profile and analytical data see Profile Pit DP91.

3.2.11 Mapping Unit 11

Soil mapping unit 11 (old code V3C_8) occurs on moderately dissected valley floors, with slopes 2-4 %, where fresh alluvial material is deposited. A representative profile is DP 75. The soils are deep (>120cm) with moderately well drained, with moderate, medium and coarse sub-angular block, dark brown (7.5YR3/2) Loamy topsoils, over sandy clay loam subsoils. Their consistency is sticky and plastic when wet. Topsoil pHs' are neutral, with average 7.1, decreasing gradually down to 6. They are non-saline and non sodic: EC of <0.2 dS/m and ESP of <0.35. The organic carbon at 1.46%, and total nitrogen at 0.18 % are very low to medium respectively. The C/N ratio value ranges from 8-11. The soils have a high CEC (> 56.0 meq/100g soil). Base saturation is also high at 83%. The available P content of the surface soil is high at 29.7 ppm but decreases in subsoil to to 5.1 ppm. The soils have about 152.3 mm/m available water holding capacity. Based on the field investigations and laboratory result they are classified as Fluvic Cambisols – (CMfv). They occupy 200.2 ha, 1.9% of the study area. The Complementary Survey report provides the following information on these soils (Box 11) and we concur with these findings:

Box 11. Soil Mapping 11 (V3C_8)

This unit refers to the moderately dissected valley floor areas, where the soils receive fresh soil materials. It is developed mainly on colluvial parent materials. The effect of erosion seems to have a significant and active role in the soil formation process as well as in the sediment composition. The slope of the land units ranges from 2-4%. It occupies 200.21ha and forms about 1.9% of the study area.The soils are deep (>120cm) with moderately well drained and dark brown (7.5YR32) color on surface. They have loam soil texture class on surface and sandy clay loam in surface. Their consistency is sticky and plastic when wet and have moderate, medium and coarse sub-angular block structure. The pH of the surface soils is neutral with average value of 7.1 and decreases in the sub-surface to the value of 5.85. They are non-saline and non sodic soils with ECs of <0.18dS/m and ESPs of <0.4. The organic carbon and total nitrogen percentage of the surface soils are 1.46 (very low) and 0.18 (medium) respectively.

The C/N ratio value ranges from 8:1-11:1 indicating that the organic carbon% is relatively higher than the total nitrogen%, which indicates that the soils are found in good to medium range. The soils have high CEC greater than 56.0 meq/100g soil and high (83%) base saturated percentage throughout the soil profile pits. The relative proportion of Ca to Mg in the exchange complex of the surface soil is moderately high, which is very favorable soil for crop productions. The available P content of the surface soil is on the average is 29.73 ppm which is very high but it decreases to low (5.05ppm). They have 152.3mm/m available water holding capacity, which is medium level. The soils infiltration rate and hydraulic conductivity tests are 9.7cm/hr (marginally suitable) and 1.4m/day (slow) respectively. The micronutrients of the soils like Iron, Manganese, Copper and Zinc are found in sufficient categories with value of 30, 89, 1.5 and 3.54mg/kg soil respectively. Based on the field investigation and laboratory result the soils are classified as Fluvic Cambisols – (CMfv). For representative profile and analytical data, see Profile Pit DP75.

3.2.12 Mapping Unit 12

Soil mapping unit 12 (old code G3d) occurs on the steeply sloping ridges and tors of Basement Complex rock outcrops. The slope range of 4-6%. The larger part of this land unit is occupied by rock, boulders and rough surface features, and occurs on elevated parts of the study area. Due to the rocky nature of thse lands no profile pits were studied. Several auger sites characterise these lands. The lands are not suitable for agricultural development. Their total area coverage is 67.3 ha, some 0.6 % of the area. The Complementary Survey report provides no further information.

3.2.13 Mapping Unit 13

Soil mapping unit 13 (old code R) covers the moderately and deeply incised stream channels found throughout the study area. They include the drainage lines of the Didessa River and its tributaries. They include dense areas of riverine / gallery forest, and currently are at risk from clearance. Unless they are treated with soil conservation measures in the near future, degradation of the areas has negative influence on the anticipated irrigation developments. There is no represeentative profile in these channel units. The soils are deep and are a complex of soils, similar to those of SMUs' 10 and 11, and include black (10YR2/1), Clays to dark brown (7.5YR3/2) slightly organic Loamy topsoils, over dark grayish brown (10YR3/2) Clays and Sandy Clay Loams. The soils are classified as Nitisols, Acrisols and Vertisols. The unit covers 219 ha, some 2.1 % of the survey area. The Complementary Survey report provides no further information.

3.2.14 Mapping Unit 14

Soil mapping unit 14 (old code F) covers lands currently occupied by very dense forest. There is no representative soil profile on these lands, but soils are a complex of other units including SMUs 3,4, 9, 10. Based on the auger database the soils are shown as deep, dark grey clays to black clay loams on undulating 4-8 % slopes under forest and they include Nitisols, Vertisols and Acrisols. The soil unit covers some 130 ha, (1.2%) of the study area. The Complementary Survey report provides no further information on these soils.

3.2.15 Mapping Unit ST

This non-soil mapping unit (old code also ST) occupies the settlement area and towns. Soil units were not described but it is clear that most settlement locations, in the recent and earlier phases of settling this area, were located on well drained soils on interfluves. This indicates a good knowledge of the soil conditions suitable for settlement planning by the Chaweka administration. The area extent of the land unit is 216 ha, some 2 % of the area.

Table 3.2: Summary of Physical and Chemical Properties of Soils of the Study Area

Mapping Symbol	pH	EC dS/m	CEC	TN	O.C	C:N	ESP	P_2O_5	$CaCO_3$	B.d	AWC	Infiltration Rates		Hydraulic Conductivity		Area	
	Av. top 25cm	Av.Top. 100cm	AV.Top 25cm	Av.top 25cm	Av.top 25cm	Av.Top 100cm.	Av.Top 100cm	Av.Top. 25cm	Av.Top. 100cm	g/cc^3	mm/m	Measured	FAO Stand.	Measured	FAO Stand.	Ha	%
1 (G1b-1)	5.4	0.05	24.8	0.31	3.6	13	1	9.1	-	1.4	98	9.2	1.5	1.5	0.5	1630.38	15.46
2 (G1b-4)	5.3	0.06	25.8	0.28	3.2	13	6.7	20.02	1.78	1.3	130.9	9.23	8	2.43	0.5	675.27	6.4
3 (G2d-1)	5.2	0.05	31.1	0.26	3.2	13	39.9	9.02	6.17	1.33	80.5	9.8	1.5	1.76	0.5	2429.96	23.04
4 (G2d-2)	5.3	0.1	43.2	0.3	4	12	0.5	10.89	-	1.33	101.8	6.9	1.5	3.63	0.5	242.42	2.3
5 (Sg-6)	5.8	0.1	29.9	0.4	4.7	12	1.3	13.6	-	1.2	102.8	-	2	-	0.5	787.51	7.47
6 (U1e-4)	5.3	0.04	28.5	0.27	3.4	11.2	0.8	3.27	-	1.33	88.5	-	8-	-	1.5	387.45	3.67
7 (U1e-5)	5.0	0.06	15.5	0.4	3	9	1	52.75	-	1.3	102.8	-	8	-	0.5	152.51	1.45
8 (U2f-9)	6.3	0.09	31.4	0.4	4.4	11	0.6	45.9	-	1.2	94.5	-	2	-	0.5	958.68	9.09
9 (V1b-3)	5.1	0.09	39.1	0.2	2.5	10	0.7	12.7	2.24	1.3	138.4	6.5	0.8	0.4	0.3	1053.1	9.99
10 (V2a-7)	5.2	0.03	35.6	0.3	4.59	15.6	0.6	3.36	-	1.3	130.3		0.8		0.3	28.99	0.27
11 V3c_8)	6.5	0.2	22.8	0.31	3.1	11.25	0.7	53.125	5.33	1.3	95.6	9.7	2	1.40	0.3	200.21	1.9
12 (G3d)	-	-	-	-	-	-	-	-	--	-	-	-	-	-	-	67.25	0.64
13 (R)	-	-	-	-	-	-	-	-	--	-	-	-	-	-	-	1585.46	15.03
14 (F)	-	-	-	-	-	-	-	-	--	-	-	-	-	-	-	130.35	1.24
ST	-	-	-	-	-	-	-	-	--	-	-	-	-	-	-	216	2.05
															Total	10,546	100

Source: Laboratory analyses result, MCE, 2009

Table 3.3: Summary of Morphological Properties of the Soils of Study Area

Symbol	Physio - Geomorphic Land Unit	Slope %	FAO-1998 Soil	Depth cm.	Drainage Class	Texture Class	Muncull Color	Rock/ Boulders	Flood Class	Erosion hazard		Water Table Cm.
										Sheet	Gully	
1	Upper Part of Gently Undulating Plain With Convex Interfluves	0_3	NTdyo	>200	WD	C-Cl	Dark reddish br.-Dark Red	None	Fo	Active	Active	>400
2	Upper Part of Gently Undulating Plain With Convex Interfluves	0_3	ACfrh	>200	WD	Sacl-SiCl	Dark red-Dar reddish bro.	None	Fo	Active	Active	>400
3	Middle & Lower Part of Gently Undulating Plains With Convex Interfluves	4_6	NTdyo	>180	WD	Cl-C	Dark reddish brown- Red	None	Fo	Active	Active	>400
4	Middle & Lower Part of Gently Undulating Plains With Convex Interfluves	4_6	NTro	>200	WD	Cl-C	Dark reddish Brown-Red	None	Fo	Active	Active	>500
5	Moderately Steep Side of Hill & Ridge	>15	LPeou	>60	SWED	L--Cl	Dark red bro.	>60 Stony, Rocky	F2	High	High	>60
6	Strongly Sloping Valley & Hill Side	5_8	ACfrh	>160	WD	L-Sacl	Dark red bro.	>160 stony	Fo	High	High	>160
7	Strongly Sloping Upper part of Hill &Ridge	5_8	CMdyo	>70	WD	Sac-Cl	Brown	> 70 stony	Fo	High	High	>70
8	Strongly Sloping Hill & Ridge Side	8_15	CMeuh	>100	WD	L-C	Dark brown	>100 stony	Fo	High	High	>100
9	Seasonally Wet Valley Floor	0_3	VRms	>200	ID	C	Black -Gray	None	F1	No	M	>300
10	Permanently wet Valley Floor	0_2	GLge	>184	PD	C	Black- Gray	None	F2	No	M	>184
11	Moderately Dissected Valley Side	4_6	CMfv	>114	WD	L-Sacl	Dark brown	> 114 Gravely	Fo	High	M	>114
12	Sloppy Basement Ridges & Tors	-	-	-	-	-	-	-	-	-	-	-
13	Incised Stream Channel	-	-	-	-	-	-	-	-	-	-	-
14	Forest	-	-	-	-	-	-	-	-	-	-	-
ST	Settlement	-	-	-	-	-	-	-	-	-	-	-

Source : Laboratory analyses result, MCE, 2009

3.3 SOIL CLASSIFICATION

3.3.1 Introduction

The field work and accompanying laboratory analyses have enabled the soils of the Dinger Bereha area to be classified according to the FAO system (FAO, ISRIC and ISSS, 1998). The survey has identified six major soil types: Nitisols, Acrisols, Cambisols, Vertisols, Gleysoils and Leptosols.

The classification has three levels of generalization and structured in hierarchical order, namely geomorphic units (level 1), soil unit (level 2) and slope class (level 3). The level 1 was recognized and measured from field observation. Likewise, the second level was studied from morphological properties of the soils such as physical and chemical properties of the soils. Finally, by measuring or estimating gradient of the project areas the third hierarchical level was recognized. As a result, six major soil types and 9 sub-soil types have been identified in the project area. List of these major and sub-soil types are shown in Table 3.4. Summaries of their characteristics are given in the following sections and tabulated in Table 3.5. Chemical and physical data for the major soil types is given in Appendix A. The soil map (Figure 4) shows the distribution of the soils.

Soils of the valley floor area are very deep and have poor drainage, hard strong, coarse and blocky structure. The organic carbon content of these soils is mostly low. To the contrary the nitrogen content of the soil is relatively high compared to the organic carbon content. The base saturation percentage of both surface and subsurface is high for all areas.

The soils are developed on alluvial parent material and they have relatively high clay contents and imperfect to poor drainage characteristics, and strong hydromorphic properties. Their infiltration rates and hydraulic conductivity testes are found moderate to high. They are characterized by high content of clay that swells when wet and shrink when dry. Soils of the elevated plain lands have deep profiles with predominantly very dark reddish brown (5YR3/2) to dark reddish (2.5YR3/6) soil color on the surface. Although the soils have relatively higher nitrogen content, the surface horizons are recognized as nitic and cambic horizon due to evidence of alteration to the underlying horizon.

3.3.2 Nitisols

Nitisols are old soils, with a B horizon and charactersitic shiny pedfaces that suggest downward clay movement at some stage in the past. They have an average clay distribution which does not decrease from its maximum within 150cm of the surface. Nitisols have red color with diffuse horizon boundaries and a sub-surface horizon has more than 30% clay and moderate to strong angular blocky structure that easily fall apart into characteristics of shiny elements. The soils in the DBIP area are deep, well-drained, red (2.5YR hue colours) with over 20% clay. Soil horizon differentiation is diffuse.

The total nitrogen percentage of the soils are moderate (0.29%), and for and organic carbon are low with an average value of 3.6%. Available phosphorous of the soils are very low, with average of 9.67ppm. The soils have soil pH reaction of 5.3 on surface and 5.1 in sub-surface. Similarly the Cation exchangeable capacity and base saturation percentage are characterized by high (30.4meq/100gmsoils) and medium (41.9) on the surface soils. But their values decrease in subsurface to 23.6 meq/100g soil (medium) and 34% (low) respectively. The available micronutrients of the surface soils are found in adequet category with average values of 49.9, 59.7, 1.7 and 3.4mg/kg soil for Iron, Manganus, Copper and Zinc respectively. They are mapped over 4,303 ha, some 40.8% of the survey area.

3.3.3 Acrisols

Acrisols are those soils that have higher clay content in the subsoil than the surface, and have low base saturation percentage and low activity clays. In the DBIP area they occur on gentle undulating sloping lands and are deep to very deep, with dark red, sandy clay and silty clay textures. The soils are well drained, and show many fine and medium pores from old roots, and there are faint cutanic (clay movement) features in the subsurface B horizon. The soils have a low pH reaction with an average of 5.2. The total nitrogen and organic carbon of the soils are 3.3% and 0.3% respectively. In general they have fertility status of the soils is low, similar to the Nitisols. The average organic carbon content of surface soil and sub-surface are 3.6% (low) and 1.6 % (very low) respectively, indicating that the soils need mulching to raise low organic carbon content of the soils. The total nitrogen content of the surface and sub- surface soils are respectively 0.3 % (high) and 0.2 % (medium). Similarly, the average available phosphorus content of the surface and subsurface soils are 25.6ppm and 4.64ppm respectively, which is very low for both layers. The average value of CEC and base saturation percentage of the surface soils are 27.1 meq/100g and 48% respectively. Their values decrease in sub-surface to 16.9 meq/100g and 41% respectively showing that the soils fertility is found in medium range. They cover some 1,062 ha, or 10.1% of the area.

3.3.4 Cambisols

The Cambisols are developed on strongly sloping lands, slope range of 5-8%. They have have very dark brown (10YR3/2) Clay Loam topsoils over to dark brown (10YR3/4) Clays in subsoil. They are of moderate depth, and despite this they have a medium to high fertility status. They have a nearly neutral soil reaction, average pH value of 6.0. The CEC and base saturation % of the soils are high throughout the profile. Similarly, available phosphorous and total nitrogen % are high, with average value of 50.6 ppm and 0.4 % respectively**.** The pH throughout the profile is nearly neutral with an average value of 6.3 on surfaces and 6.1 in sub-surface. The average total nitrogen and organic carbon contents of the surface soils are very high (0.4%) and medium (4.7%) respectively. The average C/N ratio value of the surface and sub-surface are 11:1 and 10:1 which indicate a relatively higher carbon value on both depths**.** The available micronutrients of the surface soils are found in adequet category with average values of 52, 66.5, 3.0, and 19.1mg/kg soil for Iron, Manganus, Copper and Zinc respectively**.** The soils have on average high CEC of 30.7meq/100g of soils and a base saturation of 66% on surface.Currently the soils are mostly used for sorghum cultivation by rain-fed. The Cambisols occupy 1,311 ha, some 12.6% of the surveyed area.

3.3.5 Vertisols

Vertisols are the deep soils developed on imperfect to poorly drained valley floors. They are characterized by a high Clay content and vertisolic properties. They have a black to very dark gray soil colours, wide surface crakes that extend to 1 m or more in the dry season and show swelling features during wet season. The soils texture classes vary from clay to clay loam. They have strong and coarse angular block structure on top and moderate to coarse prismatic and angular blocky structure in subsurface. Their consistencies are also very firm to firm when moist and sticky and very plastic when wet. The soils are slightly acidic with an average value of 5.1 on the top (0-25cm). Organic carbon and nitrogen content are 2.5 % (low) and 0.2% (medium) respectively. These Vertisols are non-saline and non-sodic, have relatively high CEC (> 53 meg/100g soil), and high available phosphorous; C/N ratios are almost within the optimal range 10:1. Currently these soils are used for extensive grazing. They cover around 1,053.1 ha, some 10 % of the study area.

The Vertisols are slightly acidic with an average value of 5.1 on the top and 5.7 in sub-surface. The average content of organic carbons and total nitrogen percentage of the surface soils are 2.9% (low) and 0.2% (medium) respectively. They are non saline and none sodic soils on surface and in sub-surface soils with average value of 0.1dS/m and 0.0.01% respectively. The soils have relatively high average CEC greater than 40.5meg/100g soil on surface and 40.9meg/100g soil in sub-surface. The average base saturation of surface and sub-surface soils are greater than 48 and 68% respectively. Their available water holding capacity (AWC) of the soils is about 138.35mm/m which is medium.

3.3.6 Gleysols

The Gleysols are wetland soils that remain saturated with groundwater for long enough periods to develop characteristic gleyed colours, that include reddish, brownish or yellowish colours in the topsoil and with grayish/ bluish colours in the subsoils or within peds. They have high clay content throughout the profile depth with poor drainage class and a sticky and plastic consistence. The pH of the topsoil is 5.2. This value increases in sub-surface to the value of 5.4 and organic carbon and total nitrogen of top soil on average being 4.6% (medium) and 0.3% (very high) respectively. The soils are non-saline and non-sodic with average ECs of < 0.04 dS/m and ESPs of <0.5% on surface. The average cation exchange capacity of topsoil is 35.5 meq/100gm of soil; this value decreases to 25.1 meq/100gm of soils in sub-surface. The base saturation percentages of the top and sub-surface soils are 47% and 55% respectively and the average exchangeable sodium percentage of the same layer is 0.2meq/100gm of soil and 0.22meq/100gm of soil respectively. The Ca: Mg ratio of the exchange soil complex on surface is 3:1 and in sub-surface it is 4:1 which are found optimum. These soils occupy a small part of the study area, 29 ha, some 0.27%.

3.3.7 Leptosols

Leptosols are shallow soils, that occur over bedrock or extremely gravelly and /or stony soils, on the strongly sloping and steep areas of the project area. Even thought they are shallow they have moderate fertility level: organic carbon and total nitrogen percentage of the surface soils are on average (4.7%) medium and (0.4%) very high, respectively. The cation exchange capacity and base saturation percentages are also high. The fertility status is good, with a C/N ratio within the optimal range. The main constraints are depth and steepness. . Inspite of shallow depth they have moderate fertility status. The soils have dark reddish brown (5YR 3/2) color on surface and reddish brown (5YR 4/3) in sub-surface. The surface soils are gravely and filled with coarse fragments. The soils have strong, medium, coarse and angular blocky structure in sub-surface and strong, coarse and very coarse, platy in sub-surface. The pH is 5.8 on top and 5.7 in sub-surface. The total nitrogen and organic carbon content of the surface soils are on average 0.4% (very high) and 4.7% (medium), respectively. They have high CEC on average (29.9 meq/100g soils) and base saturation 56% (medium) on surface. Similarly, the average values of exchangeable calcium and magnesium of the surface soils are 14 and 3.29 meq/100 g soils respectively and they are at a high level. The ratio of calcium to magnesium on the surface is 4:1, which is optimum. The average available P content of the same layer is 13.6 ppm, which is very high. The C/N ratio is also found within the optimal range. Currently they are used for sorghum cultivation, and cover 787.5 ha, some 7.5 % of the study area.

Table 3.4 Identified Soil Types as Classified Based on World Reference Base (1998)

Code	Sub- soil Type	Main Soil Type	Sub / Main Soil Type & Code
1	Orthidystric (dyo)	Nitisols (NT)	Orthidystric Nitisols (NTdyo)
2	Rhodic (ro)	Nitisols (NT)	Rhodic Nitisols(NTro)
3	Mesotrophic (ms)	Vertisols (VR)	Mesotrophic Vertisols (VRsm)
4	Hyperferric (frh)	Acrisols (AC)	Hyperferric Acrisols (ACfrh)
5	Orthidystric (dyo)	Cambisols (CM)	Orthidystric Cambisols (CMdyo)
6	Orthieutric (eou)	Leptosols (LP)	Orthieutric Leptosols (LPeou)
7	Gelic (ge)	Gleysols(GL)	Gelic Gleysols (GLge)
8	Fluvic (fv)	Cambisols (CM)	Fluvic Cambisols (CMfv)
9	Hypereutric (euh)	Cambisols (CM)	Hypereutric Cambisols (CMeuh)

Table 3.5 : Summary of Average Soil Chemical Properties of Soil Types (FAO Classification)

Soil Type	pH	EC dS/m	CEC	Base satn	Total N %	OC %	C:N	ESP	P_2O_5	$CaCO_3$	B.D.	AWC mm / m	Infilt cm/hr	H.C. (K) m/day	Texture	Depth cm.	Drainage Class
Nitisols	5.31	0.07	33.03	44.00	0.29	3.60	12.67	13.80	9.67	6.17	1.33	109.0	8.63	2.29	CL-C	>180	WD
Acrisols	5.30	0.05	27.14	43.10	10.15	3.30	12.10	3.75	11.65	1.78	1.30	130.9	9.23	2.43	L-SCL	>160	WD
Leptosols	5.80	0.10	29.90	56.00	0.40	4.70	12.00	1.30	13.60	-	1.2	-	-	-	L-CL	>60	SWED
Cambisols	5.90	0.12	23.25	58.00	0.37	3.50	10.42	0.77	50.59	5.33	1.30	130.0	-	-	L-SCL	>70	WD
Vertisols	5.10	0.09	39.10	53.00	0.20	2.50	10.00	0.70	12.70	2.24	1.3	138.3	6.50	0.1	C	>200	ID
Gleysols	5.20	0.03	35.55	53.00	0.30	4.59	15.60	0.60	3.36	-	1.3	130.3	-	-	C	>184	PD

Source: BRL-MCE, 2009.

Notes. 1:- A dash – indicates no supporting data. 2:- Soil textural classes: CL = Clay Loam; C = Clay; L = Loam; SCL = Sandy Clay Loam.; 3. Drainage classes: WD =well drained; SWED = slightly well drained; ID = imperfectly drained; PD = poorly drained.

3.4 Interpretation of Analytical Data, Dinger Bereha Area

This section provides details of the chemical and physical properties of the soils. Mean values of the soil data are shown in Table 7 at the end of this chapter. For the further interpretation of analytical data, the reader is referred to Appendix A and to the Final Report of the Field Investigations. Summary data of certain properties are shown Table 3.4 and full data in Appendix A.

3.4.1 Soil Reaction pH

The average pH value of the surveyed area is 5.6, and the maximum and minimum pH values as measured in 1:2.5 soil-water suspension, range from 4.5 to 7.1. These indicate that the soil reaction ranges from acidic to neutral. Similarly the sub-soils have average 5.4, maximum 7.9 and minimum 4.2values. The Δ pH, defined as pH KCl – pH H_2O, of all the soil samples have constantly negative values, indicating that the soils have colloidal complexes of net negative charges.

3.4.2 Organic Carbon, Total Nitrogen, C/N Ratio

The minimum and maximum values of organic carbon (OC) content of the average upper 25cm layer of the soils of the area ranges from1.1% to 7.8%, which is low. In general, the organic carbon decreases regularly with depth, which indicates that top horizons are relatively characterized by accumulation of higher, humidified organic matter than the sub surface soils. Average values are less than 3.7% organic carbon, and responses of the soils to organic fertilizer are expected to be high. The C: N ratios are commonly quoted are indications of organic matter present and, in particular, the degree of humification, and is an indicator of transformation of organic nitrogen to available nitrogen forms (ammonium nitrite, nitrate). For Total Nitrogen maximum and minimum values of the total nitrogen percentage of the surface soils range from 0.7% to 0.1% and have an average value of 0.3%. Likewise, the sub-surface soils have average, maximum and minimum values of 0.1%, 0.4% and 0.02% respectively. Therefore, the average values for surface and sub-surfaces are found in the range of high (0.3%) to medium (0.1%). A minimum acceptable C: N ratio value is 10 and; in the DB area the range is from of 0.6 to 21.8.

3.4.3 Cation Exchange Capacity and % Base Saturation

Cation Exchange Capacity (CEC) measurements and the derived base saturation percentage are important for the overall assessment of soil fertility and likely, or hoped for, response to fertilizer applications. FAO (1979) states that CEC values of 8-10 meq/100 gm of soil are indicative minimum values in topsoils, and values < 4 meq/100 gram of soil indicate a state of infertility or general unsuitability of the soils for agricultural development. The average CEC of the soils is 30.09, which is high. Similarly, the sub-surface soils have an average, maximum and minimum value of 24.0 meq/100 gm soils, 71.6 meq/100 gm soils and 6.9 meq/100 gm soils respectively.The study has found that CEC distribution in the soil profiles was irregular, with maximum of 63.8 and minimum value of 6.9. In most cases was higher in the surface layers. There is a correlation between CEC and soil texture: soils with fine textural classes have higher value of CEC and base saturation for all profile pits.

In determining the Percentage Base Saturation, the proportion of the CEC accounted for by exchangeable bases (Ca, Mg, K & Na) can be used as a soil fertility indicator, but taken alone does not distinguish between different bases, and imbalances can occur. BS values > 50% is considered as fertile soil and BS < 50% is taken as less fertile soil. The calculated value of base saturation of all soil mapping units were found between 11% and 122%, with an average of 47%, indicating that the inherent fertility status of the soils of study area is very low. In general soils such as Vertisols, Cambisols, and Leptosols have average base saturation percentage greater than 50% on surface and sub-surface. To the contrary, Nitosols and Acrisols have less value base saturation percentage.

3.4.4 Exchangeable Cations (Ca, Mg, K & Na) and ESP

Within the exchange complex, the levels of exchangeable cations in a soil indicate existing nutrient status and refelct balances amongst cations. Their balances vary in the soil. A hypothetical ideal cation balance in the soil is where Ca occupies 76%, Mg 18%, K 6% and Sodium around 0%. In practice these vary and in leached soils as found here there are both low and high values that reflect the relative mobility of cations over time.

- **Potassium:** The overall K status varies from 0.1 to 3.3 with average of 0.4 mg/100 grams of soil, indicating the low content of K. This may be as a result of the nature of the parent material, mainly volcanic rocks with some Basement Complex acidic rocks.

- **Magnesium:** The presence of Mg deficiency in a crop may not only be associated with low Mg content in the soil, but also with the presence of large amount of other cations, particularly Ca and K. With increasing Ca:Mg ratios above about 5:1, the Mg may become progressively less available to plants. Although soils can remain fertile over a very wide range of Ca: Mg ratios. When Mg is present in very much larger amount than Ca, the calcium can become less available due to increased deflocculating of the clay. In the DBIP area the average value of exchangeable magnesium on surface soils is 3.6 meq/100 g soils, which is high. Its average value decreases in subsurface to 3.0 meq/100 g soils. Its value in surface vary from 0.9 to 17 meq/100 g soils which is found in high rang. Anomalous values occur and future soil management will need to look closely at these issues.

- **Calcium:** Normally, Ca deficiency as a plant nutrient occurs only in soils of low CEC at pH values of 5.5 or less. Calcium may also be effectively deficient at high pH levels when there is excessive sodium content. This is not an issue here as the soils are not calacareous and pH values are neutral to acidic. Although it is known that Ca ions have an affinity for phosphate, the effect of the interaction on availability to plants is not well understood. It should be noted, however, that in calcareous soils and soils with high exchangeable Ca phosphorous may be less available to plantsThe laboratory data shows exchangeable calcium ranges from low to high (1.8 to 32 mg / 100 g) with an average value of 8.7. Whereas, in subsurface the value are ranging from 1.8 to 52 with an average value of 7.4meq/100 grams of soils. Exchangeable calcium cation greater than 20 meq/100g soil is considered as high level in the soils.

- **Sodium:** The overall content of exchangeable sodium of the surface soils of the study area in meq/100 grams of soil, varies from 0.1 to 0.9 with an average of 0.2. Interms of the profile values vary from 0.07 to 1.95 with an average of 0.19 mg/100 grams of soil. In general the content of Na is low, thus it will not imply any adverse effect on soil profile such as increasing dispersion.

- **Exchangeable Sodium Percentage (ESP)**: Sodium is not an essential crop plant nutrient, though sodium tolerant plants are not uncommon. Its absence or presence in only very small quantities is therefore not usually detrimental to plant nutrition. At high levels it is toxic to plants and blocks the uptake of other cations, and can also cause soil structure dgradation, a seriously deleterious situation for farming operations. The ESP provides a yardstick to assesss sodium ion toxicity. In the DBIP area the exchange complex is largely occupied by calcium and magnesium followed by potassium. Sodium is fortunately very low. With high exchangeable potassium percentages (EPP) above 25% the permeability and structure of the soil may be adversely affected. The average ESP within 100 cm depth is 2%, which is low and well within acceptable limits

- **Ca:Mg Ratio.** In acid soils Calcium supplies are smaller than in alkaline soils. Part of the risk of aluminum toxicity is related to calcium deficiency. Magnesium excess is indicated when exchangeable Magnesium represents more than 40-60% of the cation-exchange capacity, or the Ca: Mg ratio is less than 1. With increasing Ca: Mg ratio above about 5:1 the Magnesium may become progressively less available to plants. When Mg is present in very much larger amount the Ca, the latter may become somewhat less available, and soil structure become weaker due to increased deflocculated of the clay. In the DB area laboratory result show the average Ca: Mg ratio of the surface and sub-surface soils of the study area are 3:3 and 2:8 respectively, which is found at optimum range for most of the crops.

- **Ca+ Mg / K ratio**. Estimation of ratio of Calcium plus Magnesium to Potassium helps for the estimation of the amount of fertilizer needed to manurate the soils. Ca+Mg/K ration greater than 40 indicates relatively overdose of Ca+Mg or lack of potassium in the soils. Likewise, when the value is found between 0 and 15 it shows lack of Ca or Mg in the soils. In the case of the study area the average rate of surface and sub-surface soils are found to be 35 and 47 respectively. The difference of the value shows that accumulation of the cations in sub-surface due to percolation from surface soils.

3.4.5 Exchangeable Aluminium

Since pH does not precisely identify soils that need lime, determination of acidity and lime required should preferably be measured in terms of exchangeable acidity rather than pH reading. In acid soils the exchange acidity equals the sum of the exchangeable bases plus the exchange acidity. For the determination of exchangeable acidity of soils of the study area 40 soil samples that have < 5.5 pH and falls in strong acid category were selected for analysis. In consequence, when they were tested for Aluminum toxicity only 6 samples out of the suspected 40 samples of the soil confirm Aluminum toxicity. Based on these fact, profile pits DP (52, 79, 80, 86, 90 ,and 94) havehigh exchangeable acidity in the ploughing layer. The maximum acid saturation percentages of profile pits are 46.5, 42.4, 42.5, 38.0, 67.7 and 42.1% respectively. Data on exchangeable aluminium is shown in Tabel A.4.

3.4.6 Electrical Conductivity

The electrical conductivity (EC) is measured in a saturation of extract of the soil water suspension using a conductivity meter. The EC is an an indicator of total soluble salts in the soil. In the DBIP area, EC varies from 0.01 to 0.41 with average of 0.06 dS/m. These are all very low and not unexpected in an area of higher rainfall, and old leached soils. A certain amount of salts will be added to the soils each year by dust blowing in from other parts of Africa but these will amount to very little, and in general it can stated that the soils are non-saline and this is not an issue of concern in DB.

3.4.7 Available Phosphorus

Available Phosphorus is the amount of phosphorus that is readily available for nutrient absorption by plant roots. To determined available phosphorous content of the soils of the study area Olsen's method of bicarbonate extraction method was used. As a result, the average available phosphorus content of the surface soils of the study area is found to be 18.8 ppm which which is high (sufficient) and its value decreases gradually to 12.8ppm (medium) in sub- surface. The overall available phosphorus content of the project area ranges from 0.6 to 153 ppm with an average value of 18.5 ppm. In an area where high amount of free carbonates might be present then deficiencies of phosphorous would be expected, but in the DBIP area this is not an issue, as phosphorus is readily available to plants in the slightly acidic soil. A response to phosphorus fertilizer is unlikely at present but may change after some years of intensive cropping.

3.4.8 Calcium Carbonate (CaCO3)

The presence of calcium carbonate in the soil in general indicates that the clay complex can be dominated by exchangeable calcium, and this can imply a favorable soil structure. The presence of calcium carbonate in the field was determined using a 10% HCl solution ; quantitative analyses was made in the laboratory. There is almost no indication of $CaCO_3$ for the most of the soil samples, but it was observed in 7 profile pits (nos. DP 32, 34, 56, 83, 98 & 105) where the content was also very low (range of 0.45 to 6.2%) : these data are shown in Table 3.6.

Table 3.6: $CaCO_3$ Content

Profile No.	Depth	$CaCO_3$ %
DP 56	0-23	1.23
	23-60	0.56
DP 83	70-160	2.24
DP 98	25-75	0.45
DP 103	160-190	5.27
	190-300	2.80
DP 105	0-22	2.24
DP 32	0-25	2.02
	25-40	6.20
DP 34	45-100	0.56
	100-125	5.61

Source : DBIP Soil Survey (BRL-MCE, 2009).

3.4.9 Micronutrients

A micronutrient is an element that plants must have to complete their life cycles, but only a small amount is required. These elements, micronutrients, are also called trace elements (FAO, 1972). Usually trace elements are only measured in the topsoils, but in leached or degraded soils the amounts in the subsoil can be useful, in a research programme, to provide a prognosis on soil conditions. The amounts of various micronutrients present in soil are extremely variable both among the micronutrients and from one soil to another. Soils properties, especially pH and degree of aeration have a strong influence on the availability of the micronutrients. Since, the pH of soils of the area is low determination of micronutrient availability of the soils were undertaken for nutrients like, Iron (Fe), Manganese (Mn), Copper (Cu) and Zinc (Zn) by using DTPA extracting agent. These micronutrients are characterized by the following properties.

1. Iron (Fe)
Iron toxicity severely limits on strongly acid soils (with a pH of more than 5), which contain moderate to high amounts of organic matter and reactive iron. Iron toxicity is often associated with a deficiency of phosphate, potassium, zinc, calcium and manganese. Soil features that are also associated with iron toxicity, aside from low pH, are low cation exchange capacity, low base status, low levels of potassium, and zinc.

2. Manganese (Mn)
The chemical behavior of Mn in soil is very similar to that of Iron. Its deficiency occurs mainly in poorly drained soils. Total quantities of Mn in soil vary from 100ppm to several thousands of ppm. Manganese availability is closely related to the degree of soil acidity. Nevertheless, when the pH is acidic with pH values of about 5.5 or less it becomes toxic. Values below 20ppm or mg/kg soil are considered as deficient and those over 300 ppm are considered toxic. (Department of Crop and Soil Science, Michigan State University, Extension Bulletin, August, 1994)

3. Copper (Cu)
Total Cu in soil falls in the range of 2-100ppm. Its availability is also influenced by soil pH. It decreases slowly with increasing pH. In general, high level of total Cu in soils can be taken as those above about 100ppm and with average value of 30ppm. (E.E. Schulte, University of Wisconsin 1999)

4. Zinc (Zn)
In high rainfall area quantity of Zinc is relatively low. For most crops deficiency system are rarely encountered in the crops in the field. Total Zinc contains in the soil vary from 10-100ppm. In, general its deficiency system occur in acidic soils. Zinc deficiencies are most often seen on sandy soils with high pH levels. Large applications of phosphorus may aggravate zinc deficiencies. Livestock manure is often an excellent source of zinc. (Ontario, 2009)

Based on the laboratory analysis results, the overall average micronutrient value of the Iron, Manganese, Copper and zinc of the ploughed layer of soils of the study area are found to be in adequate category with average values of 67.3, 55.1, 2.1 and 8.5 mg/kg/ppm soil respectively, Data is given in Appendix A. A global assessment of micronutrients by FAO (Silanpää, 1990) included a site in western Ethiopia on a heavy clay Nitisol at Nekemte, with CEC of 36, 85% clay, and pH ($CaCl_2$) of 4.43, that showed 'alarmingly low' levels of Zn (0.36 to 0.48 mg/l), and also low Molybdenum. Application of Mn, Zn and P resulted in a rise in content of these in maize.

3.5 PHYSICAL CHARACTERISTICS OF DINGER BEREHA SOILS

3.5.1 Texture

Soil texture is the first physical and perhasp most important characteristic of a soils that is examined inte field. The soil texture analysis has been carried out in the field using standard manual procedures for indentifying soil tetxural classes, and then has been subjected to laboratory investigation. The major textures of the investigated soils vary from clay loam to clay for reddish and reddish brown soils and clay to heavy clay for Vertisols. The result of laboratory analysis showed that the content of clay in Vertisols varied from 28.7% to 67.3%, where as in reddish brown soils which are located on gently undulating plain, up land areas have on average loam and clay loam texture with up to 80% clay. Similarly soils like Fluvic Cambisols, with very dark brown soil color have clay loam texture. The soil texture is used to drive hydro-dynamic properties such as water holding capacity (WHC), drain ability of the soil. Workability and the draft requirements of the soil are also determined with soil texture as well as soil structure. In addition to that pore-size distribution or pore-geometry of soils is also determined with soil texture. Laboratory results of soil texture of each soil profile are presented in Appendix A.

3.5.2 Soil Colour

Soil color is the most obvious features of the soils that can be easily identified. It has relates to specific chemical, physical and biological properties of the soil. It was measured under dry moist conditions by determining the Hue, Value and Chroma of the soils using Munsell soil color chart. Soil color of the survey area is mainly related to drainage and to lesser extent, to parent material. Accordingly, the imperfectly to poorly drained valley floor area soils have dark brown (10YR3/1) color on surface and grayish brown (10YR5/2) color in sub-surface, while moderate to well drained soils are characterized by dark reddish (5YR3/4) color on surface to red to yellowish color in sub-soils.

3.5.3 Drainage Classes

The moisture condition of the valley floor area soils was found moist in topsoil up to 30cm depth and increases in sub-soils while, other soil types were dry and slightly moist during investigation time. In general, the soils in the valley floor areas have imperfect and poor drainage systems whereas, the soils of elevated areas and hilly areas are somewhat excessively to well drain. The Vertisols in most parts of the areas have encountered ponds or sink holes up to 1.0m diameter, which holds water during rainy season. As it has been investigated by deep boring most of the soils of survey areas have deep water table. Depth of ground water table is not a key constraint, which is greater than 5m.

3.5.4 Water Movement in Soils

Two methods are used to asses this, the infiltration of water from the surface and the assessment of permeability of the subsurface.

- **Infiltration Rates:** the Infiltration Rates is the vertical intake of water into a soil surface and is an important parameter for selection of irrigation systems and soil management techniques. The double ring infiltrometer method was applied at three sites, with replicates 10 m apart from each other. The basic infiltration rate (IR) of valley floor soils ranges from 6.3 to 6.8 cm/hr whereas, soils on gently undulating areas ranges from 6.8 to 10.0cm/hr. Soils with high basic infiltration rates could be unsuitable for flood or furrow irrigation and the propsed system with a supply from subsurface pipes and hoses into the plots will reduce water losses. The improvement of soil fertility and organic matter should lead also to a reductuion of infiltration rates.

- **Hydraulic Conductivity Measurements**: The hydraulic conductivity technique is one method to measure the permeability (K) of a soil, whereby a known volume of water is passed through a unit cross-sectional area of soil in a given time and expressed in m/day. The measurement provides information on permeability and drainage characteristics to compare different soils. The tests were made using the 'inverse auger hole method' (water added to, in this case, moist soils). Tests are made in triplicate at modal profiles pits. It was found that the average hydraulic conductivity value varied from 0.1 to 3.63 m/day. Valley floor areas had lower hydraulic conductivity tests comparing to the gently undulating plain elevated of the upland areas.

3.5.5 Soil Moisture Characteristics

For the determination of bulk density, field capacity, permanent wilting point and soil moisture percentages, 68 undisturbed soil samples were collected from the field and analyzed in the National Soil testing Laboratory for BD, and soil moistuire status. Consecutively, and based on the determined moisture content of the soils, the available water holding capacity (AWC) and the total readily available water holding capacity (TRAWC) were calculated. A summary of water holding capacity data of the soils are given in Table 3.4. Full details are in Appendix B.

- **Bulk Density (BD):** Bulk density was determined by the dry weight of 100ml volume undisturbed core sample taken at field in a moist condition. The Bulk Density results are used as indicators of problems of root penetration and soil aeration in different soil horizons. The result shows that the value ranges from 1.2 to 1.5. Therefore, the overall BD values indicate that the soils in the study area are not compact and thus do not restrict root crops development and water movement.

- **Field Capacity (FC)**: The field capacity (0.3 atmospheres) of the soil is mostly a factor of soil texture and structure. Fine textured soils retain more water than coarse textured soils. The field capacity value of soils of study area varies from 12.6 to 42.3% / volume basis, with the average value equal to 27.8% / vol. The fine textured, valley floor area soils retain more water than gently undulating plain area soils.

- **Permanent Wilting Point (PWP)**: In the soil, water content gradually decreases through drainage and evapotranspiration, from a state of saturation through field capacity to permanent wilting point (asssesed as a suction of 15 atmospheres) where plants cannot meet their ETo requirement and suffer mositure stress. The Permanent Wilting Point for study area ranges from 8.2 to 27.7% on a volume basis and have an average value of 20.4% / vol.

- **Available water holding capacity (AWC)**: Available water holding capacity (AWC) is the volume of water retained between field capacity and permanent wilting point. Theoretically, all available moisture is not accessible to plants due to imperfect drainage, hydraulic conductivity of the soil and stage of plant growth. Total available water holding capacity value of any soil varies depending upon soil textural classes, organic matter and bulk density. The latter specially varies due to pore geometry of the soil. Soils with coarse texture classes have low AWC and those with fine texture classes have relatively high AWC. For the calculation of AWC of the soils the following formula was used: AWC = (FC-PWP) x Horizon depth x Bulk Density / 100. In the DBIP area the AWC data shows a range from 80.5 to 138 mm / m.

3.5.6 Soil Structure

Soil structure refers to the natural organization of soil particles into distinct soil units (aggregates or peds) that result from pedogenic processes. The aggregates are separated from each other by pores or voids. To describe soil structure of the project area grade, size & type of structure elements are recognized. Thus, based on field investigation result most of the valley floor area soils, vertisols are characterized by strong grade, coarse to medium size on the surface and moderate grade, medium size and platy to prismatic structure in sub-surface. Whereas the well drained gently undulating plain and hilly area soils have moderate to weak grade, medium size and granular structure in surface relatively and these soils have good workability condition.

3.5.7 Deep Borings

In order to check the depth of impervious horizon and to monitor fluctuation of water table of the soils of the study area deep borings were conducted at representative 11 sites. The auger hole deep boring tests were conducted mostly after 2m and in depth to the maximum depth of 5.8m at place where in situ physical tests have been conducted. Accordingly, in spite of impervious horizon, fluctuation of water table was not observed in all sites even to a maximum depth of 5.8m. The maximum test 5.8m was conducted on profile pit Dp39. On average the tests were investigated largely up to 3m depth. Consequently, 15 deep boring soil samples were collected from 11 sites for determinate of pH and EC of the soils. The deep boring soils have pH reaction ranges of 4.7 to 7.4 and the value for all the tests decrease gradually in depth. The neutral, 7.4 soil reaction was observed on Vertisol soils on profile pit DP 103. The pit site is found on seasonally wet valley floor, grass land units. The electrical conductivity value of all soils is also very low; maximum value (0.04 dS/m) was recorded similarly on DP 103 in depth 190- 300cm. All the samples indicate free of salinity. The excavations of deep borings were stopped in all sites due to lithic contact of the soils.

3.5.8 Effective Soil Depth

As it has been investigated in field, most of the project area soils in valley floor and gently undulating plain have very deep soil depth. Thus, effective soil depth is not a major limitation for irrigation development in these areas. To the contrary the soils, which are found on the strongly sloping and moderately steep areas, have moderate and shallow soil depth.

3.5.9 Infiltration

Infiltration rate refers to the measurement of vertical intake of water into a soil surface and it is important parameter for selection of irrigation systems and management techniques. For the determination of infiltration rate of the soils of survey area, in-situ infiltration tests were carried out. The investigations were undertaken mostly on deep and relatively potential areas which have extensive area occupation. Thus, mostly the measurements were undertaken on areas which have moderate slope. It was studied by using Double Ring Infiltrometer in triplicate which is 10m apart from each other. The basic infiltration rate (IR) of the soils of valley floor area ranges from 6.3 to 6.8cm/hr which is found to be suitable to marginally suitable level. Whereas, soils located on gently undulating areas have basic infiltration ranges of 6.8 to 10.0cm/hr, which is marginally suitable. In general, well drained & textured soils of the study area have relatively higher infiltration rates than the poorly drained soils. Soils with high basic infiltration rates may be unsuitable for flood or furrow irrigation and it may be preferable for overhead irrigation. Determined basic infiltration rates of model profile pits of the study area are shown in Table 3.8 and full data Appendix B.

3.5.10 Hydraulic Conductivity

The hydraulic conductivity (permeability) of the soil is a volume of water, which passes through a unit cross sectional area of the soil unit in a given time. It is expressed in m/day. Its measurements provide information on permeability and drainage characteristics of different soils. The measurements were undertaken in inverse auger hole method in triplicate at each representative model profiles sites. In general, the average hydraulic conductivity (HC) value of the survey area varies from 0.1 to 3.63m/day, which is found in the range of very slow to rapid. The test was under taken at the same place with infiltration measurements. As it is investigated in the field the soils that are located in valley floor areas have lower hydraulic conductivity tests comparing to the gently undulating plain elevated up land areas. Accordingly, on Vertisols, on DP9 and DP83 mapping units very slow hydraulic conductivity tests were recorded, while on well drained Nitosols and Acrisols soils relatively 3.63m/day (very rapid) and 2.4m/day (rapid) Hydraulic conductivity tests were recorded respectively. Summary results of the hydraulic conductivity measurements of each model profile pits are shown in Table 3.7 and full data in AppendixB.

Table 3.7: Summary : Mean Soil Physical and Chemical Properties, Dinger Bereha

Soil Mapping Unit	pH 1/2.5 Av.top 25cm.	EC dS/m 1/2.5 Av.Top. 100cm.	CEC meq/100g AV.Top 25cm.	TN (%) Av.top 25cm.	O.C (%) Av.top 25cm.	C:N Av.Top. 100cm.	ESP % Av.Top. 100cm.	P_2O5. ppm Av.Top. 25cm.	$CaCO_3$ % Av.Top. 100cm	B.D g/cm^3	AWC mm/m	Infiltration Rates cm/hr Measured	Infiltration Rates cm/hr FAO Meas	Hydraulic Conductivity m/day Meas.	Hydraulic Conductivity m/day FAO Stan
1	5.43	0.05	24.8	0.31	3.6	13	1	9.1	-	1.4	87.9	9.2	1.5	1.5	0.5
2	5.34	0.06	25.8	20.02	3.2	13	6.7	20.02	1.78	1.3	130.9	9.23	8	2.43	0.5
3	5.2	0.05	31.1	0.26	3.2	13	39.9	9.02	6.17	1.33	80.5	9.8	1.5	1.76	0.5
4	5.3	0.1	43.2	0.3	4	12	0.5	10.89	-	1.33	101.8	6.9	1.5	3.63	0.5
5	5.8	0.1	29.9	0.4	4.7	12	1.3	13.6	-	1.2	102.8	-	2	-	0.5
6	5.25	0.04	28.5	0.27	3.4	11.2	0.8	3.27	-	1.33	88.5	-	8-	-	1.5
7	4.96	0.06	15.5	0.4	3	9	1	52.75	-	1.3	102.8	-	8	-	0.5
8	6.3	0.09	31.4	0.4	4.4	11	0.6	45.9	-	1.2	130.4	-	2	-	0.5
9	5.1	0.09	39.1	0.2	2.5	10	0.7	12.7	2.24	1.3	138.3	6.5	0.8	0.4	0.1
10	5.2	0.03	35.6	0.3	4.59	15.6	0.6	3.36	-	1.3	130.3		0.8		0.1
11	6.45	0.2	22.8	0.31	3.1	11.25	0.7	53.125	5.33	1.3	95.6	9.7	2		0.5
12	-	-	-	-	-	-	-	-	--	-	-	-	-	-	-
13	-	-	-	-	-	-	-	-	--	-	-	-	-	-	-
14	-	-	-	-	-	-	-	-	--	-	-	-	-	-	-

Source: DBIP Soil Survey data, MCE-BRL, 2009. Note: – indicates no data; Also, no data is available for three former miscellaneous units, now renamed 12,13, 14.

Table 3.8: Basic Infiltration Rate of Model Profiles Pits at Dinger Bereha

No	Model Profile	Mapping Unit	Soil type (FAO-1998)	Basic Infiltration Rate (cm/hr)
1	DP2	G1b_2	Rhodic Nitisols (NTro)	6.9
2	DP3	G1b_1	Orthidystric Nitisols (NTdyo)	9.5
3	DP9	V1b_3	Mesotrophic Vertisols VRms)	6.8
4	DP12	G2d_1	Orthidystric Nitisols (NTdyo)	9.7
5	DP18	G2d_1	Orthidystric Nitisols (NTdyo)	9.9
6	DP52	Gb2_4	Hyperferric Acrisols (ACfrh)	10.0
7	DP65	V3c_8	Fluvic Cambisols (CMfv)	9.7
8	DP78	G1b_1	Orthidystric Nitisols (NTdyo)	9.2
9	DP83	V1b_3	Mesotrophic Vertisols VRms)	6.3
10	DP86	Gb2_4	Hyperferric Acrisols (ACfrh)	9.1
11	DP90	G1b_4	Hyperferric Acrisols (ACfrh)	8.6

4. LAND SUITABILITY EVALUATION

4.1 INTRODUCTION AND PURPOSE OF LAND SUITABILITY EVALUATION

The Land suitability assessment for Dinger Bereha has followed the 'Framework for Land Evaluation' given in FAO Soils Bulletin 32 (FAO, 1976), and the 'Guidelines : Land Evaluation for Irrigated Agriculture' (FAO, 1985). Land suitability assessment provides a method for defining the properties and areas of good, moderate and poor quality land for a specified use. The assessment is based on the analysis of a number of site and soil characteristics matched against the requirements of the intended land use. The best land has a favourable combination of characteristics, whilst the poor land has less favourable combinations. Land may have characteristics also that render it unsuitable for the intended use, and for each characteristic there is a minimum requirement or value to separate suitable from not suitable land. Land suitability is the appropriateness of land for a specified type of land use, the Land Utilisation Type (LUT), under a stated type of land management.

The FAO framework indicates that it is necessary to evaluate land and not just soils. Thus, the suitability of soils for irrigated crops is useful information but it is inadequate for making decisions about land use development. Therefore, all relevant land characteristics including soils, climate, topography, water resources, etc. and also socio-economic conditions and infrastructure have been considered to undertake suitability assessment of the project area. Some factors that affect land suitability are permanent (soil temperature, soil texture, depth to bedrock and macro topography) and others (eg salinity, sodicity, micro relief, soil nutrient status) can be changed, but at a certain cost.

Typical examples for permanent features are temperature, soil texture, depth to bedrock and macro topography. Changeable characteristics which may be altered deliberately or inadvertently, typical may include salinity depth to groundwater, micro relief, and some social and economic conditions.

Land suitability is assessed and classified with respect to a specified type of land use, in this case at Dinger Bereha a specific method for irrigation and its accompanying management. The irrigation and management requirements of different crops differ and thus the suitability of any soil mapping unit may be classed differently for the various uses. In the evaluation process for an LUT, the values of each land quality and characteristic are assessed or checked against the class limits of land use requirements for the type of irrigated agricultural development.

Thus, suitability assessments of the land unit are made for each land use requirements separately. The overall suitability of the land units are then determined on the basis of the suitability ratings, referred to as partial suitability of the individual land use requirements for the LUTs under consideration separately.

4.2 LAND SUITABILITY ORDERS AND CLASSES

The basis of the FAO land evaluation system are the land orders and the land classes, which are defined by calculated or inferred potential productivity levels (Table 4.1). There are two orders of land:

- Suitable land has favourable soil and site characteristics such that for the proposed LUT at least the recurrent investments will eventually be recouped through productivity. It is divided into three classes of suitabiity: highly, moderate, and marginally.

- Not Suitable land has characteristics that preclude sustained use because of an unacceptable level of recurrent or development inputs. The Not Suitable order of land is divided into two classes to differentiate land that is potentially suitable pending some major improvement (class N1) from land that is permanently unsuitable (class N2). Highly suitable land has no serious limitations for the proposed LUT.

Land is downgraded to suitability classes S2, S3 and N1 according to predicted reductions of productivity that are assumed to relate to the nature and severity of its limitations. In terms of land suitability, the soil survey allows an assessment of whether the land is primarily physically suitable or not suitable for the proposed LUT.

Table 4.1: Land Suitability Classes

Class	Designation	Definition
S1	Highly suitable	Land having no significant limitations to sustained application of a given use, or only minor limitations that will not significantly reduce productivity or benefits and will not raise inputs above an acceptable level.
S2	Moderately suitable	Land having limitations that, in aggregate, are moderately severe for sustained application of a given use. The limitations will reduce productivity or benefits and increase required inputs to the extent that the overall advantage to be gained from the use, although still attractive, will be appreciably inferior to that expected on Class S1 land.
S3	Marginally suitable	Land having limitations which, in aggregate, are severe for sustained application of a given use and will so reduce productivity or benefits, or increase required inputs, that this expenditure will be only marginally justified.
N1 [1]	Currently not suitable	Land otherwise suitable (S1 to S3) for sustained application of a given use but having a limitation(s) which, although possibly surmountable in time, cannot be corrected at currently acceptable cost. The limitation(s) is so severe as to preclude successful sustained use of the land in the given manner at present.
N2 [1]	Permanently not suitable	Land having limitations that appear so severe as to preclude any possibilities of successful sustained use of the land in the given manner.
Notes: 1		It is important to understand the difference between the two classes of unsuitable land. N1 land is not land intermediate in quality between S3 and N2 land. N1 land is, essentially, land suitable for the proposed use except for one (usually) limitation that is so severe that, until this limitation is removed, the land should not be developed. Further, it is expected that this overriding limitation could be removed in the foreseeable future, i.e. it is technically feasible and may be economically justifiable to so do. Saline or sodic land requiring reclamation, land needing terracing or land that has to be drained might warrant an N1 classification, for example. N2 land, on the other hand, is not and never will be suitable for the proposed use. It will never be technically feasible and/or economically justifiable to remove the limitations.

Source: FAO, 1976.

4.3 SOIL AND LAND REQUIREMENTS FOR IRRIGATED AGRICULTURE

For the Feasibility Study of the Dinger Bereha area a particular type of irrigation systen is being considered with subsurface piped networks. Here, where there are significant amounts of land with fairly steep slopes, and (deep) soils of moderate to poor quality, the view has been taken that if major land improvements are needed and are technically feasible - for example soil conservation measures and soil fertilisation programmes - then certain soil mapping units cannot be considered to be 'permanently not suitable' (class N2).

Until a statement is made to overturn the view, say, that there is no budget or intention to undertake the required improvement then the land remains class N1, the 'currently not suitable' class, and will only become suitable if the required improvement, is implemented.

The overall suitability of each soil mapping unit is then determined on the basis of the suitability ratings, with the suitability class defined according to the rating of the most limiting condition. These limitations are denoted by a letter suffix. In the Dinger Bereha area the principle limiting factors are soil drainage (d), risk of water erosion (e), risk of flooding (f), mechanization (k) and workability (w) problems, available water capacity limitations (m), inadequate soil depth and rooting depth (r), unfavourable topography (t), and soil factors such pH, texture, and nutrients (z). These are defined in Table 4.2.

Table 4.2: Land Suitability Limiting Factors

Sub- class/ suffixes	Description
d	Soil Drainage: Soil and Land units having soil drainage deficiencies such as poor soil drainage, high ground water table, flooding, slow infiltration, slow permeability, slow surface drainage (low physiographic position) or some combination of these. Sub-soiling, diversion ditches and subsurface drainage may be required.
e	Erosion hazard: Land having an increased water erosion risk under irrigation. Conservation practices and surface drainage control are required and must be employed.
f	Flooding hazard: Risk of land being flooded at different seasons from upstream or upslope influences.
k	Potential for mechanization: Land units having unfavorable slope steepness, rock hindrances, presence of large amount of surface stones and plastic heavy clays, which affects mechanized agricultural operations by any kind of implements.
m	Soil moisture availability: Soil and Land units having soil moisture deficiencies. There is a need for an increased amount and frequency of irrigation and/or selection of drought-resistant crop varieties.
r	Rooting condition: Soil and Land units with limited effective soil depth defined by occurrence of a high amount of gravels, hard pan, bedrock or toxic layers.
t	Topography: Land having topographic limitations ascribed to unfavorable slope angel, micro-relief coupled with excess rock out crops and denser vegetation covers, which needs a higher initial land development cost, requiring land leveling (or short channel lengths and drop structures), grading, terracing, clearances of rock hindrances and vegetation clearances.
w	Workability: Land units with poor workability, ascribed to massive clays, poor organic matter content, very firm consistence and occurrence of high amount of stones and gravels in the surface layers.
z	Soil Factors: Soils having a poor capacity to supply crops with nutrients mainly due to CEC, low organic matter, and low or high pH. Input will be required to conserve organic matter and improve soil structure and require fertilizer application. Elsewhere (not DB) soils with high stone content.

Source: FAO, 1985

Table 4.3 summarises the minimum soil and land characteristics needed for surface irrigated agriculture in the Dinger Bereha area. This is based on land suitability criteria as developed for Ethiopia. Land is suitable (S) if all the criteria are met but unsuitable (N1 or N2) if one or more of the criteria fail. We are not considering sprinkler nor drip irrigation in this study.

Sustainable surface irrigation demands the minimisation of water, uniform in-field water distribution and adequate drainage. For this, the critical land requirements are gentle and smooth slopes (<3%), water-retentive topsoils and deep, water-retentive but permeable subsoils. Soils that are coarse-textured and/or stony in the upper 0.5 m, which usually means that they are will have high infiltration rates (>90 mm/hr) are not suitable for surface irrigation as water will be quickly lost even in small basins.

For all irrigated agriculture in semi-arid areas where salinisation and/or a rising water table are a possibility, a minimum soil depth of 2.0m is required to allow leaching and drainage if necessary. This condition applies particularly to the flat plains, such as those of alluvial origin, but is less relevant for more sloping land that has natural drainage in the subsoil.

As slopes increase to 16% so too does the need for soil conservation measures to accompany irrigation; on slopes greater than 8% land-forming for surface irrigation is not viable and for sprinkler irrigation the soil and water conservation (SWC) needs are very high. The risks of erosion are potentially greater on increasingly sloping land so a sufficient minimum soil depth – 1.0m – must be maintained to allow maximum root and soil structural development and to enhance infiltration and reduce run-off. In the Dinger Bereha project, there are steep slopes but water will be delivered to the field by subsurface pipes. The rules for slope have been relaxed, but this can only be accepted if there are accompanying by SWC measures to protect the steeper slopes from soil erosion and water loss. Measures will include a high degree of land forming into small terraces and basins, very short furrows, and grass-banked risers on terraces. Vetiver grass is suggested for the grass banks.

Table 4.3: Suitability class limits for irrigated agriculture at Dinger Bereha

Limitation (*letter code*)	**S1**	**S2**	**S3**	**N1**
Topography (***t***)	Flat to slightly undulating lands of wetlands and alluvial valleys		Gently to moderately sloping lands	Undulating middle to upper slopes
% Slope (***t***)	0 – 2		3-8	8-20
Flooding (***f***)	No risk	Few events	Common events	Other, if flood protection is feasible
Soil depth in metres (***r***)	> 2		1 – 2	1-2
Topsoil (0-25 cm) stone, gravel (% vol) ***(z)***	< 10	10 – 25	26 – 40	
Topsoil (0-25 cm) texture ***(z)***	clay clay loam	vertic clay sandy clay silty clay silty clay loam	loam sandy clay loam silt loam	
Infiltration rate (cm/hr) [3] ***(m)***	1.0 – 3.5	0.5 – 1.0 3.5 – 6.5	0.3 – 0.5 6.5 – 9.0	
AWC (mm), top 0.6m. ***(m)***	> 100	80 – 100	60 – 80	
Hydraulic conductivity (permeability) rate (m/day) ***(m)***	1.4 – 1.9	0.5 – 1.4	0.2 – 0.5 2.0 – 3.0	< 0.2 if drainage is feasible
Soil drainage class [3] ***(d)***	well moderate	imperfect	poor	very poor, if drainage is feasible
Surface waterlogging ***(d)***	none	< 4 months	> 4 months	prolonged, if drainage is feasible
Water-table depth in wet season ***(d)***	> 10	> 4	> 2	< 2.0 if drainage is feasible
CEC, top 0.6 m ***(z)***	> 25	8 – 25	<8	
pH, top 0.6 m ***(z)***	6.0 – 7.7	5.1 – 5.9 7.8 – 8.3	4.5 – 5.0 8.4 – 8.7	< 4.5 if liming is feasible > 8.7 if not sodic or gypsum can be added
Organic C, top 0.6 m (%) ***(z)***	> 4	< 4		
ECe, top 0.6m (dS/m) ***(-)***	< 2	2 – 4	5 – 8	> 8 if reclamation is feasible
ESP, top 0.6m ***(-)***	< 8	8 – 15	16 – 25	> 25 if reclamation is feasible

Notes:

1. For ESP and EC the values found are low so these have not been used in the assessment.
2. The suitability classes are based on various assessments being developed on various projects in Ethiopia for irrigated land use within the MOWR and other agencies.

4.4 DETERMINATION OF LAND UTILIZATION TYPES (LUTS)

The main objective of this land evaluation study is to select the optimum LUT type for each soil maping unit / land unit identified in the study area. Land evaluation defines the suitability of a specific area of land for a specific LUT with particular management and inputs level.

In the Dinger Bereha area the major land use being considered for the evaluation is irrigated agricultural development in the command area, using surface gravity fed from strorage reservoirs through buried piped networks to the fields, where farmers will use flexible pipes to irrigate their land. This is an unusual method of irrigation for Ethiopia and will require considerable training of farmers so they can optimise the use of their lands without causing its degradation. There has been some suggestion that night irrigation could be a possibility. We think that this should not be considered on any slopes greater than 2% as it will be impossible to monitor water distribution and possible erosion during the night on sloping lands.

The Field Investigations examined the suitability of the soils for surface and overhead irrigation for onions, maize, sesame, beans and citrus. Overhead irrigation was later dropped by the FS as a not feasible option. In addition, the crops proposed by the FI did not cover the whole range of crops that the FS subequently was examining. It had been decided that the type of irrigation being proposed would be based on a system of subsurface pipes.

For the final report of the Feasibility Study four land utilization types (LUTs) were identified and defined in terms of their produce. The potential LUTs which have irrigation component and which are considered in the present land suitability assessment for the command are:

- A. Irrigated cereals (sorghum, maize, upland rice) and oil crops (sesame) Requirement is for at least moderately deep, well drained soils with appropriate SWC measures to be put in place. These crops are already being grown in the area under rainfed conditions.
- B. Irrigated Vegetables and Pulses. Requirement is for well to imperfectly drained soils, with appropriate SWC measures to be put in place. Some of this group are being grown successfully inthe area at present.
- C. Irrigated Citrus and Fruit Trees. Requirement is for deep well drained soils, with appropriate SWC measures to be put in place. Mango has been grown successfully on the convex slopes of the area on a local basis. There are some problems with termite control. Other fruit trees with deep roots will be suitable for the soils on the plateaux and slopes.
- D. Irrigated Wetland Rice. Requirement is for flat lands with heavy clays suitable for pudddling. Minor SWC measures to level lands will be required. This is not being grown at present but would appear to be well suited to the flat seasonally flooded areas in the valleys.

These four LUT groups, which have been used in the economic and financial analysis, are shown on Text Figures 6,7,8 and 9. These maps originally produced at a scale of 1:25,000 are also provided as a soft copy.

The Field Investigations examined the suitability of the soils for surface and overhead irrigation for onions, maize, sesame, beans and citrus. Subsequently the Feasibility Study decided that the type of irrigation being proposed would be based on a system of subsurface pipes. Furthermore, the suitability of crop were broadened and merged into a series of groups, as noted above. The Field Investigations work though is useful for study and comparison in the future and the results of the assessment are shown in Table 4.9. The Complementary Surveys' maps are given in the Final Report of the FI and are also provided in soft copy format on DVD.

4.5 RESULTS OF LAND SUITABILITY ASSESSMENT

Each soil mapping unit has been assessed for its suitability to the different LUTs. In the initial soil Complimentary Survey report on the Dinger Bereha area the land suitability assessments were made on the basis of overheard/ sprinkler and open surface irrigation systems. As such topographic constraints meant that large parts of the study area became unsuitable (N2): the FAO systems and land suitability requirements for Ethiopia required that such decisions be made.

Subsequently, an irrigation system has been devised that will be based neither on overheard nor open surface furrow type irrigations, but on a closed gravity system with irrigation water gravity fed from strorage reservoirs through buried piped networks to the fields, where farmers will use flexible pipes to irrigate their land. This is new and unproven in Ethiopia.

The proposed system can utilise much steeper slopes than other methods and thus the land suitability classification has been adopted to accommodate these requirements. This will not be without risk: the potential erodibility of the soils on the steeper slopes will require careful land management. The DBIP extension services will need to provide expert advice to farmers so that they fully understand the techniques that are most appropriate to this unusual (in Africa) type of irrigated farming.

In Table 4.4 the main constraints are shown against each soil mapping unit. Table 4.5 provides an assessment of land suitability for each soil mapping unit based on applying land suitability principles discussed above.

The area measurements for each suitability class within these mapping units are given in Table 4.6. Table 4.7 provides the areas of each land suitability unit within LUTs'.

In Table 4.8 are shown the percentages of land suitability calculated over the whole area for LUTs. Thus 92.3 % is S3 marginally suitable for LUTs A, B, C, but within the same area 15.4 % is also marginally suitable for rice.

Table 4.4: Suitability of Soil Units for Irrigation

Soil Mapping Unit	Main Constraints
1	Soil drainage and water holding capacity are moderate; for rice soils whilst the soils have high clay content they will not puddle easily and slope requirements too slow. Overall marginally suitable for LUTs A,B, C.
2	Soil drainage and water holding capacity are moderate; slopes are more unfavourable and SWC measures will be required. For rice soils whilst the soils have high clay content the lack of swelling clays mean they will not puddle properly. Marginally suitable for LUTs A,B,C.
3	These soils are on moderate steep slopes and are deep clays. They are leached but should react well to inputs and better management that has the potential to raise nutient levels. Marginally suitable for LUTs A,B,C.
4	These soils also occurr on moderate steep slopes and are deep leached clays. They should react well to inputs and better management that has the potential to raise nutient levels. Marginally suitable for LUTs A,B,C.
5	These soils occur on margins of rock outcrops, with slopes > 15% and are shallow to moderately deep. Lands from 15-20% if subjected to SWC can be utilised for LUTs A,B, C as Conditonally Suitable land (N1) with erosion and topographic constraints. Not suitable for D, rice. Those on steeper lands (>20%) are unsuitable for all crops.
6	These soils also occurr on moderate and steep slopes (5-8%) and are deep leached clays. They should react well to inputs and better management that has the potential to raise nutient levels. Marginally suitable for LUTs A,B,C.
7	These soils are moderately deep, well drained, clay loams, on middle to upper 5-8 % slopes on basaltic materials, stony below 70 cm. They have depth, soil and slope limitations which makes them marginal for LUTs A,B,C. They are not suitable for rice.
8	These are deep, moderately well drained, loams with clay subsoils, on hillside with slopes 8-15 %, and stony below 150 cm. Their limitations are steep slopes and erosion risk, which make them marginal for LUTs A, B, C. Unsuitable for rice.
9	These are deep, imperfectly drained, Vertisol clays, on 0-3 % lower slopes of seasonal flooded valleys, no stones. They are moderately suitable for rice, LUT D, with slight topographic limitation, and marginally suitable for other LUTs due to flood risks, drainage and workability.
10	These are deep, poorly drained, clays on valley floor, 0-2 % slopes, alluvium, no stones. They are moderately suitable for rice, LUT D, with and marginally suitable for other LUTs due to drainage and workability.
11	Includes the deep, moderately well drained, loams over clay loam / sandy clay loam, on colluvium of 2-4 % lower slopes in dissected valleys, may be gravelly > 1m. They are maginally suitable fro LUTs A, B, C and unsuitable for rice due slope and soil factors.
12	Shallow to rocky, reddish brown, sandy and skeletal soils on bedrock granite and basalt outcrops >5 % slopes. These soils are unsuitabnle (N2) for all LUTs and should not be developed.
13	The deep, poorly drained, clays and loams on 0-3 % valley floor alluvium are marginally suitable for all LUTs. The central incised strem bed will be demaracated with a 20m wide no- cultivation zone on each bank.
14	These are deep, clays / clay loams on undulating 4-8 % slopes under forest. They have drainage, workability and topographic limitations that makes them marginally suitable for LUTs A, B, C, and unsuitable for rice.

Table 4.5: Land Suitability Assessment for LUTs in Dinger Bereha

Soil Map Unit	LUT A	LUT B	LUT C	LUT D
1	S3dm	S3dm	S3dm	N2dmz
2	S3dtz	S3dtz	S3dt	N2dmz
3	S3mtz	S3mtz	S3mtz	N2dmtz
4	S3dtz	S3dmt	S3dkt	N2dmtz
5	N1et	N1et	N1et	N2dmtz
6	S3emt	S3t	S3t	N2tz
7	S3ktz	S3ktz	S3rt	N2tz
8	S3 det	S3et	S3et	N2tz
9	S3 dfw	S3 dfw	S3 dfw	S2t
10	S3 df	S3 df	S3 df	S2w
11	S3 dmk	S3mw	S3 d	N2tz
12	N2tz	N2tz	N2tz	N2tz
13	S3 df	S3 df	S3 df	S3et
14	S3 dtw	S3 dtw	S3 dtw	N2tz

Source : BRL / MCE, 2009.

Explanation of codes: d - soil drainage limitation; e - erosion risk; f - flooding risk; k - mechanization problems; m - available water capacity limitation; r - soil depth / rooting depth inadequate; t - topography of the land is unfavourable; w - workability of the soil; z - soil factors (pH, texture, nutrients).

Note: The 'Conditionally Suitable'category (N1) applies to lands with a range of soil conditions and is principally based on land where the slopes are 15-20% only. On some of these soils the slopes are >20% then these lands would be classed as N2et.

Table 4.6: Area Measurements and Suitability Class, Soil Map Units in LUT

Soil Map Unit	LUT A		LUT B		LUT C		LUT D	
1	1630.4	(S3)	1630.4	(S3)	1630.4	(S3)	0	(N2)
2	675.3	(S3)	675.3	(S3)	675.3	(S3)	0	(N2)
3	2430	(S3)	2430	(S3)	2430	(S3)	0	(N2)
4	242.4	(S3)	242.4	(S3)	242.4	(S3)	0	(N2)
5	787.5	(N1)	787.5	(N1)	787.5	(N1)	0	(N2)
6	387.5	(S3)	387.5	(S3)	387.5	(S3)	0	(N2)
7	152.5	(S3)	152.5	(S3)	152.5	(S3)	0	(N2)
8	958.7	(S3)	958.7	(S3)	958.7	(S3)	0	(N2)
9	1053.1	(S3)	1053.1	(S3)	1053.1	(S3)	1053.1	(S2)
10	30	(S3)	30	(S3)	30	(S3)	30	(S2)
11	200.2	(S3)	200.2	(S3)	200.2	(S3)	0	(N2)
12	0	(N2)	0	(N2)	0	(N2)	0	(N2)
13	1585.5	(S3)	1585.5	(S3)	1585.5	(S3)	1585.5	(S3)
14	130.4	(S3)	130.4	(S3)	130.4	(S3)	0	(N2)
Totals	1,263.5		9,476		9,476		2668.6	
Total S2	0		0		0		1083.1	
Total S3	9,476		9,476		9,476		1585.5	
Total N1	787.5		787.5		787.5		0	

4.6 LAND MANAGEMENT FOR PROPOSED PROJECT

4.6.1 Introduction

The results of the soil survey investigations have indicated that in considering the irrigation system that is proposed to be developed at Dinger Bereha, particular attention will be need to be made on land management, during both construction and implementation. The landscape at present is eroding at what appears to be a rapid rate under rainfed cultivation and this is likely to be accelerated unless appropriate measures are made. Characteristics of the soils are given in Table 4.10, and in the following sections particular aspects are discussed in brief. Land Management Characteristics for Soil Units

4.6.1.1 Soil Fertility

Based on the laboratory test results of the soil of the study area, the soils are low to medium in major nutrients such as phosphorous, nitrogen and organic carbon. This may be related to the fact that the soils are highly weathered and most cations leached downwards in the profile. Also relevant here is that the study area receives high rainfall (<1400mm) annually. The base saturation percentage confirms the same conclusion that the fertility level of the soils is low to medium, due to major cations - calcium, magnesium, potassium, and sodium - have been leached down and the sizable portion of the soil colloid appears to be occupied by aluminum cation.

4.6.1.2 Reclamation of Acidic Soils

The primary yield limiting factor of the area is believed to be acidity. Yields of any crop are limited mainly as a result of root damage because of aluminum toxicity. Such damage can be observed on cereals crop like maize and finger millet, and limits a plant’s ability to extract water and nutrients. Phosphorous is severely reduced. As the result, plants are very susceptible to drought and nutrient deficiencies. Therefore, all the analyzed soil samples for acidity test which have tested for pH less than 6 falls in strong acid category.

However, when it was tested for aluminum toxicity only five samples out of the suspected 40 samples confirm aluminum toxicity.

Importantly, the effects of acidity on crop yield may be significant. As has already been stated, maize and several other crops would not be expected to produce much of a yield on soils as acid as those collected from the study area, and optimally fertilized crops would not be expected to produce more than 50% of their potential. Immediate remedial action needs to be taken to improve the situation. One of the actions is use of agricultural lime to neutralize the soil acidity and to suppress any negative effect of aluminum toxicity. In addition to that, to maintain organic carbon and to increase organic matter of the soils, mulching of crop residues after harvesting should be practiced with application of manure and compost. Planting of tree species that are capable of fixing atmospheric nitrogen can improve soil fertility and reduce dependency on chemical fertilizer. In addition, improved agricultural practices such as crop rotation, alley cropping and the use of green manure provide additional nutrient for plant growth.

4.6.1.3 Soil Cultivation

Cultivation should be made to loosen compact soils and provide a favorable soil structure for seed emergence. At the same time, this will eliminate weeds and thusfavours growth of seedlings. Compared to other soils the Vertisols are hard and difficult to cultivate when dry and impossible to break to fine tilt, and when wet become very sticky and plastic. Therefore, these soils should be cultivated when the soil moisture content is not too high or too low. Furthermore, to use these soils properly for future agricultural development, Vertisols management technologies like, broad bed-maker (BBM) should be considered.

4.6.1.4 Soil Erosion Control

Most of the study areas soils are under severe sheet, rill and gully erosion. The risk of soil erosion is more considerable on the currently cultivated areas. During the study time the survey team has observed considerable deforestation in the project area and this is likely to lead to greater erosion on slopes. This kind of misuse of natural vegetations will bring a high ecological degradation. Therefore, to develop these areas properly and sustainably the prevailing deforestation action has to be stopped and proper management will have to be undertaken especially along the incised stream channels and gully cuts. Adding to that soil erosion control measures should be implemented.

4.6.1.5 Drainage

Soil drainage is often reflected by the colours of soil materials – blue colours reflect gleyed conditions; mottles indicate seasonal drying and wetting.. The heavy black clay Vertisols, located in valley floor areas pose a problem of poor drainage and workability. Comparing to other soil types they have relatively low infiltration and hydraulic conductivity rates and thus due to their natural states, they are subject to water logging during most rainy season. The drainage class of these soils falls under imperfect to poor drainage. Therefore, to use this area the surface drainage has to be undertaken.

4.6.2 Land Suitability Classes of Each Land Unit

Land suitability assessment has been made for a range of crops that are known to be suitable for the project area in terms of soil requirements and agro-climatology. . These selected crop groups are vegetables (example Onion), Pulses (example beans), fruit trees and citrus (example citrus), cereals (example maize); oil crops (example sesame); and wetland rice..

The results of matching of land use requirement of each selected crop with the condition of each land mapping unit has been discussed in this section.

The individual class determining factor of each land use requirement has been combined with each land unit and a tentative land suitability classification has been obtained. Summary of the land suitability classes, sub-classes rating of land units by LUTs with their area extent are shown in Table 4.7, 4.8, 4.9.

1. Land Mapping Unit 1 (G1b_1)

This mapping unit is found largely in the central part of the study area. It covers around 1,630.38 ha and constitutes about 15.46% of the study area. Due to nutrient availability, Drainage problem and erosion hazards the unit is rated as marginally suitable for both surface and overhead irrigated cultivation of onion, beans, citrus, maize and sesame.

2. Land Mapping Unit 2 (G1b_4)

The area extent of G1b_4 land unit is around 675.27 ha, which is about 6.4% of the study area. It is rated as marginally suitable due to nutrient availability and drainage for all selected land utilization types both for surface and overhead irrigated cultivations.

3. Land Mapping Unit 3 (G2d_1)

This unit covers around 2,429.96 ha or about 23.04% of the study area. It is rated as marginally suitable for onion, beans, citrus and maize both for surface and overhead irrigated cultivation, due to nutrient unavailability, drainage, workability and potential for mechanization limitations. But it is rated as currently unsuitable (N1z) for maize irrigated cultivation, having nutrent availability limitations for both, surface and overhead irrigated cultivation.

4. Land Mapping Unit 4 (G2d_2)

This land unit occupies 242.42 ha, which accounts 2.3 % of the study area. It is rated as marginally suitable for onion, beans, citrus, and sesame for surface and overhead irrigated cultivation. Nevertheless, it is down graded to currently unsuitable (N1z) due to nutrent availability limitations for surface and overhead irrigated maize cultivation.

5. Land Mapping Unit 5 (Sg_6)

This unit has an area extent of 787.51 ha of land and accounts about 7.47% of the study area. The land unit is rated as currently unsuitable (N1wk) for overhead irrigated cultivation of onion and beans, due to workability and rated as unsuitable for both surface and overhead irrigated cultivation of maize and sesame due to unsuitable for mechanization. Further more, it is rated as permanently unsuitable for surface irrigated cultivation of onion, beans and citrus, because of workability and unsuitable for mechanization.

6. Land Mapping Unit 6 (U1e_4)

It has an area extent of 387.45 ha which is about 3.67% of the study area. It is rated as currently unsuitable (N1kw) for surface irrigated cultivation of onion, beans, citrus and sesame. It is also reted as currently unsuitable for both surface and overhead irrigation of maize. Nevertheless, the land unit is rated as margenaly suitable for overehead irrigated cultivation of onion, beans, citrus and sesame.

7. Land Mapping Unit 7 (U1e_5)

U1e_5, land unit covers an area of 152.51 ha, which is about 1.45% of the study area. The unit is rated as permanently unsuitable (N2r) for surface and overhead irrigated cultivation of citrus, because of rooting condition limitation. It is also rated as currently unsuitable (N1k, N1zwk, N1z and N1zk) for both surface and overhead irrigated cultivation of beans, maize and sesame due to, workability, unsuitable for mechanization and nutrient unavailability limitations. Nevertheless, for overhead irrigated cultivation of onion it is rated as marginally suitable (S3k,) due to workability limitation

8. Land Mapping Unit 8 (U2f_9)

The extent of this mapping unit is relatively smaller than the others and it occupies about 958.68 ha (9.09%) of the study area. The unit is downgraded to currently unsuitable for surface and overhead irrigated cultivation of all land utilization types.

9. Land Mapping Unit 9 (V1b_3)

This land mapping unit occupies some 1,0531 ha or about 9.99 % of the study area. It is marginally suitable (S3zd[1], S3zrw, S3zr etc.) for surface and overhead irrigated cultivation of onion, beans and citrus, due to nutrient unavailability limitation it is also rated as currently unsuitable (N1z) because of nutrient unavailability for surface and overhead irrigated cultivation of maize.

10. Land Mapping Unit 10 (V2a_7)

The area extent of this land mapping unit is around 28.99 ha, about 0.27% of the study area. It is rated as currently unsuitable (N1d) for beans, citrus and maize due to drainage problem, but it is classified as marginally suitable because of drainage problem for both surface and overhead irrigated cultivation of onion and sesame.

11. Land Mapping Unit 11 (V3d_8)

This unit covers around 200.21 ha or about 1.9% of the study area. The unit is classified as marginally suitable (S3wk, S3d[1], S3wkd[1] etc.) For surface and overhead irrigated cultivation of all land utilization types (LUTs), the limitation is workability, unsuitable for mechanization.

12. Land Mapping Units 12 (G3d)

This land unit includes sloping lands on basement ridges (with shallow soils and boulders, stony). In terms of area they have an area extent of 67.3 ha, which is about 0.6% of the study area. Due to workability and unsuitable for mechanization they are rated as permanently unsuitable (N2) for all land utilization types.

13. Land Mapping Unit 13 (R)

These land units include slopping basement ridges (with shallow soils and boulders, stony) and incised river channels. In terms of area they have an area extent of 1,652.71 ha which is about 15.67% of the study area. Due to workability and unsuitable for mechanization they are rated as permanently unsuitable (N2/r/t) for all land utilization types.

14. Land Mapping Unit 14 (F)

These land units covers around ha or about % of the study area. They are described by forest areas, therefore due their occupation, workability and unsuitable for mechanization they are rated as currently unsuitable for irrigation development. It is likely these lands will be cleared by the settlers however.

15. Land Mapping Units ST

These land units covers around ha or about % of the study area. They are settlements and due their use are rated as unsuitable for irrigation development.

Table 4.7: Land Suitability Classes in LUTs

Land Suitability Class	Area in LUT A - ha	Area in LUT B - ha	Area in LUT C - ha	Area in LUT D - ha
S1	0	0	0	0
S2t	0	0	0	1,053.1
S2w	0	0	0	30
S3d	0	0	200.2	0
S3det	958.7	0	0	0
S3df	1615.5	1615.5	1,615.5	0
S3dfw	1053.1	1053.1	1,053.1	0
S3dkt	0	0	242.4	0
S3dm	1630.4	1630.4	0	0
S3dmk	200.2	0	0	0
S3dmt	0	242.4	0	0
S3dt	0	0	675.3	0
S3dtw	130.4	130.4	130.4	0
S3dtz	917.7	675.3	0	0
S3et	0	958.7	958.7	1,585.5
S3emt	387.5	0	0	0
S3ktz	152.5	152.5	0	0
S3mw	0	200.2	0	0
S3mtz	2,430	2430	2430	0
S3rt	0	0	152.5	0
S3t	0	387.5	387.5	0
N1et	0	0	787.5	0
N2dmz	0	0	0	0
N2dmz	0	0	0	0
N2dmtz	0	0	0	0
N2z	0	0	0	0
Totals	9,476	9,476	9,476	2,668.6

Table 4.8: Summary of Totals by Land Suitability Class

Land Suitability Class	**Total Area ha (10,263.5 ha)**	**% of total area (10,263.5 ha)**
S1. Highly Suitable	0	0
S2. Moderately Suitable	1,083.1 (LUT D - rice)	10.6
S3. Marginally Suitable	9,476 (LUT A, B, C)	92.3
S3. Marginally Suitable	1,585.5 (LUT D - rice)	15.4
N1. Conditionally Suitable	787.5 (LUT A, B, C)	7.7
N2. Permanently Unsuitable	67.3 (mapping units with all LUT)	0.7
Other - Settlements	216	

Table 4.9: Field Investigations: Summary of land suitability classes - surface & overhead irrigation

Land	Onion		Beans		Citrus		Maize		Sesame	
Suitability	Surface	O.head	Surface	O.head	Surface	O.head	Surface	O.head	Surface	O.head
Class	Ha	ha	Ha	ha	ha	ha	ha	ha	ha	ha
S2	none	none	none	none	none	none	none	none	none	none
S3	6260.33	7371.52	6017.91	6405.36	5988.92	6376.37	2505.86	2505.86	6260.33	6647.8
Sub-Total Suitable	6260.33	7371.52	6017.91	6405.36	5988.92	6376.37	2505.86	2505.86	6260.33	6647.8
N1	1844.99	1521.31	2874.92	2487.47	1963.89	1576.44	6386.97	6386.97	2632.5	2245.1
N2	2440.22	1652.71	1652.71	1652.71	2592.73	2592.73	1652.71	1652.71	1652.71	1652.7
Sub -Total Unsuitable	4285.21	3174.02	4527.63	4140.18	4556.62	4169.17	8039.68	8039.68	4285.21	3897.7
Total	10544.5	10545.5	10545.5	10545.5	10545.5	10545.5	10545.5	10545.5	10545.5	10545.5

Table 4.10: Physical Descriptions & Identified Soil & Land Management Interventions

Map. Unit	FAO- 1998 Soil Type	Land Cover / Use	Major Constraint	Potential	Management Interventions (Major)		
					Fertility Improvement	Soil Erosion Control	Liming
1	Orthidystric Nitisols	Intensively Cultivated land mainly; ▪ Sorghum ▪ Haricot beans ▪ Sesame & Rice	▪ Moderately acidic soil ▪ Low organic carbon, ▪ Very low available P & (AWC)	▪ High CEC & BSP ▪ High Nitrogen ▪ Deep & Well drained Soil	√	√ Soil & stone bund	√ Dolomitic/ Calictic Lime
2	Hyperferric Acrisols	Moderately Cultivated land Mainly; ▪ Sorghum & ▪ Rice	▪ Very acidic soil ▪ Low OC, BSP & ▪ Low Available P	▪ Medium AWC, ▪ High CEC & Nitrogen ▪ Deep & Well drained Soil	√	√ Soil & stone bund	√ Dolomitic/ Calictic Lime
3	Orthidystric Nitisols	Intensively cultivated land Mainly; ▪ Sorghum ▪ Rice &	▪ Moderately acidic soil ▪ Low Organic C, ▪ V. low Available P & ▪ Low-BSP & AWC	▪ High CEC & Nitrogen ▪ Deep & Well drained Soil	√	√	√ Dolomitic lime
4	Rhodic Nitisols	Intensively cultivated land Mainly; ▪ Sorghum	▪ Moderately Acidic soil ▪ Low OC Very low ▪ Av. P & ▪ Low BSP & AWC	▪ High CEC, Nitrogen, ▪ Deep & Well drained soils	√	√	√ Dolomitic/ Calictic Lime
5	Orthieutric Leptosols	Scattered cultivation Shrub & Bushed land Dominant Crops; ▪ Maize & ▪ Sorghum	▪ Moderately steep land >15%, ▪ Stony, Rocky & Shallow soil & ▪ Excessive drainage	▪ Slightly acidic soil ▪ Very high Av P & N ▪ High CEC, BSP & ▪ Moderate Fertility & ▪ Somewhat exe.dr		√ Terraces Contour ploughing	√ Dolomitic lime
6	Hyperferric Acrisols	Predominantly cultivated land mainly; ▪ Sorghum	▪ Strongly sloping land 5-8% ▪ Moderately acidic soil ▪ Low Av. Phosphorous, ▪ Low BSP, OC & AWC.	▪ High CEC & TN ▪ Deep & Well drained Soil	√	Contour ploughing, Soil & stone bund	√ Dolomitic/ Calictic Lime

Table 4.10 Physical Descriptions & Identified Soil & Land Management Interventions (contd.)

Map. Unit	FAO- 1998 Soil Type	Land Cover / Use	Major Constraint	Potential	Management Interventions (Major)		
					Fertility Improvement	Soil Erosion Control	Liming
7	Orthidystric Cambisols	Moderately cultivated mainly; ▪ Sorghum ▪ Sesame & ▪ Rice	▪ Strongly sloping land ▪ 5-8% ▪ Moderately deep soil, ▪ Stony and Rocky soil ▪ Moderately acidic soil ▪ Low BSP & OC.	▪ High Ava. P ▪ Medium CEC, ▪ Well drained soils,	√	Contour ploughing, Soil & stone bund & Terraces	√ Dolomitic/ Calictic Lime
8	Hypereutric Cambisols	Sparsely cultivated, Shrub and Bush land Dominant Crop; ▪ Maize	▪ Strongly sloping 8-15%, ▪ Rock & stony land,	▪ Slightly acidic soil ▪ High Ava. P ▪ CEC, BSP ▪ Medium OC& High N ▪ Well drainage.	√	√ Contour ploughing, Soil & stone bund	√ Dolomitic/ Calictic Lime
9	Mesotrophic Vertisols	Seasonally wet land ▪ Used for grazing	▪ Poor drainage, ▪ Heavy soil texture, ▪ Moderately acidic soil	▪ Medium Available P. ▪ High CEC, BSP & N, ▪ Medium OC, ▪ Level land	√	√ Gully Control	√ Dolomitic/ Calictic Lime
10	Gelic Gleysols	Seasonally swamp land ▪ Perennial crop, ▪ sugarcane	▪ Poor drainage, ▪ Heavy soil texture, ▪ Moderately Acidic soil ▪ Low BSP, Ava. P	▪ High CEC, Nitrogen, ▪ Level land	Drainage	-	√ Calictic Lime
11	Fluvic Cambisols	Sparsely cultivated land ▪ Dominant Crops; ▪ Sorghum, Maize ▪ Sesame & Rice	▪ Moderately dissected land	▪ Neutral soil reaction , ▪ High CEC, BSP. ▪ Ava. P & Nitrogen, ▪ Well drainage,	√	√ Soil & stone bund -	√ Dolomitic/ Calictic Lime
12	Basement Ridges	Exposed Rock out crop	▪ Very Shallow, ▪ Rocky and stony land	▪ Settlement	-	Ruioff and coarse debris	-
13	Incised Stream Channel	Riverine disturbed high forest area	▪ Deep soils with waterloggiing	▪ As for unit 9, 10	-	Gully Control	-
14	Forest Area	▪ Dense mixed high forest	▪ Undulating to convex slopes ▪ Varied soilsd	▪ -variable soil conditions	-	Risk if cleared	
ST	Settlement Area	▪ Settlement	▪ Gently sloping lands on free darining sites	▪ -not surveyed	-	-	-

5. SUMMARY AND CONCLUSIONS

5.1 SUMMARY

The soils study of of the proposed Dinger Bereha Irrigation Project was carried out at a detailed level of soil survey over 10,546ha of land. The survey has showed that out of the total surveyed area, about 6,260ha (59%) of land is characterized by gently undulating plains and valley floor landforms with a slope range of 0-5%, which are expected to be a potential area for irrigation development.

Using survey methods of topographic maps, study of erial photographic interpretation, reviewing previous studies and conducting field survey, a soil map of 1:10,000 scale and a narrative soil report were produced. In the course of the study soil/land mapping units were verified and representative soil samples collected to determine chemical and physical properties of the soils. A total of 1,243 auger holes were described. In addition, 103 profile pits were studied and sampled. Taking on an average 4 samples from each profile pit, 303 samples were collected and analyzed at the Water works Design & Supervision Enterprise Laboratory Serves. In-situ infiltration and hydraulic conductivity tests were also studied on 11 representative model profile pits.

The data from soil sites pertaining to the profiles and auger holes including their location coordinates have been recorded with the help of GPS. Slope percentages were recorded with clinometer. Land forms, land use/cover, presence of stoniness, soils drainage, and erosion hazards have also been studied in the field. Internal soil characteristics such as soil depth, texture, structure, mineral nodules and depth to ground water were noted on each auger hole description.

Based on the investigation results, most of the gently undulating plain with convex interfluve area soils have loam to clay loam on surface and clay texture in subsurface. The Vertisols, which are situated in the valley floor area, have clay to clay loam soil texture, and the infiltration rate and hydraulic conductivity measurements are found to be at moderate level. Due to relatively low topographic features and high clay contents of the area, the soils have imperfect to poor drainage characteristics. This makes some soils well suited to rice cultivation.

Cation Exchange Capacity (CEC) and the derived base saturation percentage (BS %) that are important for soil classification, and can be used as indicator for ranking soil fertility assessment are found low to medium. Regarding the total nitrogen percentages the value ranges from medium to very high. On the other hand comparing the organic carbon content with nitrogen content it is found constantly higher for almost all soils.

Subsequently, based on significant information, soils of the project area were classified based on FAO-ISSS, ISRIC 1998 Guidelines. Six major soil types were identified, which include, Nitisols (NT), Acrisols (AC), Vertisols (VR), Cambisols (CM), Gleysols (GL) and Leptosols (LP). The most extensive soils of the project area are found to be Nitisols which is followed by Acrisols and Cambisols. In area wise Nitisols occupy around 4,303ha, which is about 41% of the study area. Whereas, 1,311ha (12.4%) and 1,063ha (10.1%) are occupied by Acrisols and Cambisols respectively. The remaining area is occupied by Vertisols 1,053ha (10.0%), Leptosols 788ha (7.5%) and Gleysols 29ha (0.3%) correspondingly.

With regard to fertility status based on the laboratory test results detailed assessment has been carried out. Accordingly, fertility status of most of the soils of the study area is found to be low to medium for major nutrients like Phosphorous, Nitrogen and Organic Carbon.

The base saturation percentage of the study area is also confirms the same conclusion that the fertility level of the soils is found to be low to medium. For most of the soils samples its value is observed to be low to medium with an average value of 50 % which indicate that the soils major cations like calcium, magnesium, potassium, and sodium have been leached down and the sizable portion of the soil colloid is covered by Aluminum cation.

In addition to that, most of the analyzed soil samples for acidity test fall in high acidic category based on pH tests. However, when it is tested for aluminum toxicity only six samples out of the suspected 40 samples confirm aluminum toxicity.

The laboratory results for electrical conductivity (EC) of all soils of the study area have an average value of 0.1 dS/m, which is very low. It is far below the threshold critical values and therefore, salinity will not be causing any restriction on plant growth of soil of the study area.

Similarly, the average value of the exchangeable sodium percentage (ESP) within the 100cm depth of the soils is also low (2). These levels of exchangeable sodium of the soils do not cause any adverse effect for both plant nutrition and physical properties of the soils.

5.2 RECOMMENDATIONS

5.2.1 Soils

1. The main constraint for agriculture production in the project area is believed to be acidity. Yields of any crops are limited mainly as a result of root damage because of aluminum toxicity. Such damage can be observed on maize. As soon as the plant root is damaged the plant's ability to extract water and nutrients such as phosphorous is severely reduced. As the result plants are very susceptible to drought and are prone to nutrient deficiencies. The sampled area has an acidity potential that will hinder crop production unless or else, immediate remedial action is taken to improve the situation. One of the actions to be taken is the use of agricultural lime to neutralize the soil acidity and to suppress the negative effect of aluminum toxicity in the area.

2. The average available phosphorous for most of the soils of the study area is found to be at a moderate level. The response of soil to phosphorus fertilizer for the time being is not required but, in the near future applications of phosphorous fertilizer is likely to be required.

3. The valley floor of the study area is covered with Vertisols and they have area coverage of 1,053.1ha. During the wet season the clays of these soils swell and cause pressure in the sub-soil. Therefore, to use these soils properly for future agricultural development, Vertisols management technologies like, broad bed-maker (BBM) should be considered or practiced.

4. During the survey time high deforestation action has been observed in the project area. This kind of misuse of natural vegetations will have brought high ecological disparity. Therefore, to develop these areas properly and sustainably the prevailing deforestation action has to be stopped and proper management will have to be undertaken especially along the incised stream channels and gully areas.

5. Laboratory results indicated very low of organic carbon having over all an average value of 3.7%. Therefore, to increase the organic matter of the soils of the study area mulching activity has to be. The positive effect of high organic matter content in the soil is, at the same time, increasing the cation exchange capacity of the soils. Therefore, ploughing back of the crop residues and mulching should be encouraged to raise the very low carbon levels and to improve the structure of the top soils.

6. The amount of lime needed to neutralize soil acidity mostly depends on the crop type, soils, and the effective calcium carbonate equivalent (ECCE) or effective neutralizing value (ENE) of the liming materials. In view of that, when magnesium deficiencies is occur in the acidic soil dolomitic lime that, containing $MgCO_3$ is particularly advantageous for liming.

In the case of soils of the study area as it is learned from laboratory results the Ca: Mg ratio for all identified soil types found to be between 3:1 to 4.1, which is optimum for most of the crops and deficiencies of Mg is not observed. Therefore, with this value ranges to correct soil acidity of the project area calcitic lime ($CaCO_3$) or dolomitic lime ($MgCO_3$) materials can be used. For that matter both agricultural limes are available from lime crushers at Guder and Degen area.

5.2.2 Land Suitability Classification

Following the TOR, Land evaluation assessment for irrigation development has been conducted based on the methodology outlined in the FAO Soil Bulletin No. 55, Guideline for Land Evaluation for Irrigated Agriculture (FAO, 1985) and FAO, Soil Bulletin No. 32, Land Evaluation Framework.

As part of land resources study the land evaluation assessment aims to translate land resources data into an expression of suitability of land units (land units map) for a defined use. The soil report and map are the main land resource database for the anticipated land evaluation assessment. The main objective of the land evaluation is to select possible relevant land use types for which kinds of development land should be classified. The land evaluation assessments of the irrigation area identified a number of land utilization types (LUTs) and defined in terms of their climatic adaptability, economic viability and food preferences.

The Field Investigations selected 5 land utilization types for onions, beans, citrus, maize and sesame. The Feasibility Study, which followed the FI work decided to broaden this into a series of land utilization types which reflect more the types of crops that the Project had decided to concentrate on. These included cereals and sesame (oil crops) as LUT-A; Vegetables and Pulses as LUT-B; Citrus and Fruit Crops as LUT-C; and wetland rice as LUT-D.

For all of these the overall suitability of the land units were then determined on the basis of the suitability ratings. The evaluation assessments were made assuming moderately to high inputs of management, and high labor intensity.

To undertake the land evaluation assessment the land use requirements of these LUTs were determined. The Land use requirements are described by the land characteristics grouped to land qualities needed for the required sustained irrigated agriculture production for the LUTs considered. Based on land characteristics 15 land mapping units have been identified for the study area. After considering various factors namely: agronomic, environmental requirements and conservation, the relevant class determining factors were defined as variables that affect the performance of LUTs on a land unit. Subsequently, individual class determining factor of each land use requirement has been combined (matching) with each land unit and a tentative land suitability classification has been obtained.

The Field Investigations made land suitability maps for selected crops with surface and overhead irrigation as part of the report. The Feasibility Study did not consider overhead irrigation as the chosen method for the project will be based on subsurface pipes.

In general, most soils that have been identified in the Dinger Bereha irrigation project found to be marginally suitable for surface (and overhead) irrigated agriculture. The limitations are moisture and oxygen unavailability, workability and unsuitability for mechanization. It should also be emphasized that the present land suitability evaluation results are guidelines for future agricultural developments activities.

5.2.3 Soil and Water Conservation

The proposed DBIP will adopt and implement a novel type of irrigation system, using buried pipes that supply water directly to small fields. We have developed the land suitability classification to cover the steeper and more erodible lands, so that the irrigation system can cover the command area. It must be stressed that this is a tremendous risk, as the technology is unproven in Ethiopia and especially amongst these farmers.

Although the farming community have some experience of irrigation, most are rainfed farmers. In addition, the study area is being eroded by lack of soil and water conservation (SWC) practices. The introduction of a new irrigation system will require an immense effort to train the new irrigators so that the project can be sustained. This is the risk and the challenge

It must be stressed therefore that the DBIP will be as much a soil conservation project as an irrigation project, for several reasons:

- The watershed above the command area must be protected. It will require protection so that the gallery forests continue to exist and supply waters to the downstream users in the community as good drinking water supply, and the forest ecosystems in the gallery forests, and that the / any excess water discharge will continue to pass into the Didessa and hence to the Abbay. Unless these basic rules of watershed management are heeded then there will be an unsatisfactory degradation of this area. The Chaweka community should not assume that they can continue to deforest the catchment and utilise every drop of water, and still hope to be able to continue to utilise the valley soils for forest products and obtain a water supply that is currently being recharged and runs throughout the year.

- The continued destruction of gallery forest within and upslope of the command area will lead to an infilling with coarser materials of the wetlands schedule to become rice lands and lead to unsuitable soils in these areas. This is not wanted.

- The soils in the development area on the sloping lands already show very onsiderable susceptibility to water erosion. During rain events, rills and sheet erosion deposit coarser materials in the valley floors - the wetlands and stream beds. There is no control over this by farnmers and almost no SWC meaasures to reduce water erosion. A few attempts, though very feeble, are lines of crop sorghum stalk residues that are placed along the contour in some of the more sandy areas. But, despite good intentions, these have minimal impact. Without improvements put in place soon, and whilst the lands remain as rainfed, the soils of the project area will become more degraded. This could change the land suitability classification as it is now assessed, but in a downwards spiral of degradation.

Much of the work to make this successfull will fall on the agricultural services of the Chaweka Woreda to implement SWC measures in the coming seasons, in the rainfed lands and also inthe catchment. It has good well qualified staff, who can take on these tasks, but they will need suppoprt. It is recommended that mitigation to protect the catchment and command areas from erosion and ecosystem degradation are now implemented with the greatest speed and determination.

The lessons provided by Hudson (1991) on the success or failure of soil and water conservation projects provide a sober reading for all interested in these matters, and should be examined very carefully by all concerned with final planning for this potentially useful project.

Bibliography

BCEOM, 1998. Abbay Basin Master Plan. Ministry of Irrigation and Water Resources. Addis Ababa.

De Data, S.K. 1981. Principles and practice of rice production. p618. Wiley, Chichester.

Dent, D and Young, A., 1981. Soil survey and land evaluation. George Allen and Unwin Ltd., London.

Driessen, P.M. and Dudal, R. (eds) 1989. Geography, Formation, Properties and Use of Major Soils of the World. Wagnengen, Netherlands, and Leuven, Belgium.

FAO, 1972. Trace Elements in soils and agriculture. FAO Soil Bulletin No. 17. FAO, Rome.

FAO, 1976 (reprinted 1981). A framework for land evaluation. Soils Bulletin 32. Food and Agricultural Organization (FAO), Rome.

FAO, 1979. Soil survey investigations for irrigation. Soils Bulletin 42, Food and Agricultural Organization (FAO), Rome.

FAO, 1985. Guidelines: land evaluation for irrigated agriculture. Soils Bulletin 55, Food and Agricultural Organization (FAO), Rome.

FAO, 1990. Guidelines for Soil Description. 3rd edition. Rome.

FAO, 2006. Guidelines for Soil Description. 4th edition. Rome.

FAO, ISRIC and ISSS. 1998. World Reference Base for Soil Resources (WRB) –World Soil Report No. 84. Editors: J.A. Deckers, O.C. Spaargaren, F. O. Nachtergaele (ISSS), L.R. Oldeman, R (ISRIC), Brinkman (FAO). FAO, Rome.

FAO, ISSS and ISRIC, 1998. World Reference Base for Soil Resources, Rome.

Grist, D.H. 1983. Rice. 5th edition. Longman, London

Hudson, N.W., 1991. A study of the reasons for success or failure of soil conservation projects. FAO soils bulletin 64. Rome: FAO. (available online from WAICENT, FAO)

Landon J.R, 1991. Booker Tropical Soil Manual, a Handbook for Soil Survey and Agricultural Land Evaluation in the Tropics and Sub-Tropics. Longman, London.

LUPRD, 1984. Geomorphology and soil Map of Ethiopia. FAO, Rome.

Richards, L.A. 1954. Diagnosis and improvement of saline and alkali soils. Handbook 60, USDA, Washington DC, (available online from website of the Riverside laboratory, Ca.)

Sillanpää, M. 1990. Micronutrient assessment at the country level: an international study. FAO Soils Bulletin, 63. Rome: FAO.

Smyth, A.J. 1970. The preparationof soil survey reports. FAO Soils Bulletin No. 9. Rome: FAO.

Sogreah, 1979. Lower Didessa Project. Ministry of Irrigation and Water Resources.

USBR, 1964. Land and Water Resources Study of the Blue Nile Basin. Addis Ababa.

WWDSE, In Association of MCE and WAPCOS, 2002, “Soil Survey Guideline “Soil Description, Sampling and Coding for Soil Data Base, Addis Ababa.

Appendix A : Chemical Analyses

Table A1. Dinger Bereha Chemical Analysis from Profile Pits

Profile	Depth	Texture <2 mm fraction				pH(1:2.5)			EC	Total N	Org C	C/N	Avail P	Exchange Cations (meq/100gm soil)					CEC	Base Satn	ESP	Ca/ Mg	availFe	avail Mn	avail Cu	avail Zn
SMU	cm	Sand	Silt	Clay	Class	H2O	KCl	ΔPH	dS/m	%	%		ppm	Na	K	Ca	Mg	Sum	meq/g	%	%		mg/ kg soil (ppm)			
DP1	0-20	33.7	14.7	51.6	C	5.3	4.6	-0.7	0.0	0.5	3.4	7.2	1.6	0.2	0.4	8.2	1.8	10.7	39.2	27.3	0.6	4.5	47.3	20.3	1.8	1.4
SMU 1	20-62	25.0	16.9	58.1	C	4.8	4.0	-0.8	0.0	0.1	1.2	12.6	Trace	0.2	0.1	6.4	2.7	9.5	23.8	39.8	0.9	2.3				
	62-140	14.8	12.6	72.5	C	4.8	4.4	-0.4	0.0	0.1	0.7	7.4	10.9	0.2	0.1	6.4	1.8	8.5	9.9	86.0	1.8	3.5				
	140-200	10.6	10.5	78.8	C	4.9	4.2	-0.7	0.0	0.2	1.7	7.3	Trace	0.2	0.2	5.4	1.8	7.6	27.5	27.5	0.6	3.0				
DP2	0-15	36.7	23.6	39.7	CL	5.4	4.5	-0.9	0.1	0.3	3.2	11.0	0.7	0.2	0.3	9.0	2.7	12.2	40.8	30.0	0.5	3.3	37.2	78.8	2.1	1.2
SMU 4	15-41	17.9	17.1	65.0	C	5.1	4.2	-0.9	0.0	0.2	1.7	6.8	0.3	0.1	0.1	4.0	1.4	5.7	43.2	13.2	0.3	2.8				
	41-92	5.0	14.9	80.1	C	4.9	4.2	-0.8	0.0	0.2	1.2	7.5	Trace	0.2	0.1	4.5	3.6	8.4	24.1	34.8	0.7	1.3				
	92-180	2.3	12.7	84.9	C	7.8	4.9	-2.9	0.0	0.2	1.4	7.1	Trace	0.1	0.1	3.6	1.4	5.2	49.6	10.4	0.2	2.7				
DP3	0-30	30.8	34.1	35.1	CL	5.3	4.7	-0.6	0.1	0.3	2.6	8.8	3.6	0.2	0.4	10.8	2.7	14.2	35.4	40.0	0.5	4.0	25.6	73.8	1.8	1.3
SMU 3	30-113	25.0	4.2	70.8	C	4.7	4.5	-0.2	0.0	0.1	0.9	7.5	0.3	0.6	0.2	4.5	0.9	6.1	34.4	17.9	1.7	5.0				
	113-200	10.6	10.5	78.9	C	4.9	4.2	-0.7	0.0	0.1	1.4	9.8	Trace	0.2	0.2	3.6	1.8	5.8	21.6	26.7	0.8	2.0				
	200-300	8.8	8.4	82.9	C	5.2	4.4	-0.8	0.0	0.2	1.3	7.1	0.3	0.2	0.2	7.2	0.9	8.5	19.7	43.2	0.9	8.0				
	300-337	10.5	8.4	81.0	C	4.9	4.2	-0.7	0.0	0.2	1.4	8.8	Trace	0.2	0.1	3.6	0.9	4.8	22.1	21.8	0.7	4.0				
DP4	0-14	41.1	15.0	43.9	C	5.0	3.8	-1.2	0.1	0.1	1.1	7.6	1.3	0.2	0.4	18.1	0.9	19.6	42.3	46.4	0.6	20.0	75.4	51.5	2.3	1.0
SMU 9	14-61	34.6	15.0	50.4	C	5.0	3.5	-1.5	0.0	0.1	0.7	7.6	Trace	0.3	0.2	13.4	2.7	16.6	36.5	45.6	0.8	5.0				
	61-114	28.3	11.0	60.6	C	5.4	3.5	-1.9	0.0	0.1	0.5	7.9	Trace	0.6	0.2	23.3	2.7	26.8	44.3	60.5	1.3	8.7				
	114-200	39.0	8.9	52.1	C	6.1	4.6	-1.5	0.0	0.1	1.6	17.5	0.3	0.6	0.3	31.4	13.4	45.7	44.3	103.2	1.5	2.3				
DP7	0-17	37.5	23.3	39.2	CL	5.0	4.3	-0.7	0.2	0.3	2.3	7.1	3.0	0.2	0.7	11.6	5.4	17.9	39.0	45.9	0.5	2.2	26.1	73.7	1.5	0.4
SMU 3	17-64	21.8	17.1	61.1	C	4.3	4.0	-0.3	0.0	0.2	1.8	10.5	2.0	0.2	0.3	3.6	0.9	5.0	32.6	15.2	0.5	4.0				
	64-200	8.9	12.9	78.2	C	4.3	4.1	-0.3	0.0	0.1	1.2	8.7	2.6	0.2	0.2	5.4	0.9	6.7	21.9	30.4	0.7	6.0				

Profile	Depth	Texture <2 mm fraction				pH(1:2.5)			EC	Total N	Org C	C/N	Avail P	Exchange Cations (meq/100gm soil)					CEC	Base Satn	ESP	Ca/ Mg	availFe	avail Mn	avail Cu	avail Zn
SMU	cm	Sand	Silt	Clay	Class	H2O	KCl	∆PH	dS/m	%	%		ppm	Na	K	Ca	Mg	Sum	meq/g	%	%		mg/ kg soil (ppm)			
DP9	0-13	47.4	20.0	32.6	Sacl	5.3	4.1	-1.3	0.0	0.2	1.5	7.1	13.8	0.3	0.7	6.3	2.7	9.9	26.8	36.8	0.9	2.3	372.0	55.0	2.9	1.0
SMU 9	13-46	43.7	27.6	28.7	CL	5.1	4.5	-0.6	0.0	0.1	0.9	7.6	32.9	0.2	0.2	8.9	4.4	13.7	21.7	63.3	1.0	2.0				
	46-88	44.4	18.2	37.4	CL	4.9	4.5	-0.4	0.0	0.1	0.7	7.7	2.0	0.3	0.2	15.2	0.9	16.6	29.7	56.0	0.9	17.0				
	88-200	37.7	24.1	38.3	CL	6.5	5.5	-1.0	0.1	0.1	1.4	13.0	0.7	0.6	0.3	24.2	0.9	26.0	41.9	62.0	1.4	27.0				
DP10	0-15	33.9	16.0	50.1	C	5.5	4.5	-1.0	0.1	0.3	3.1	10.1	3.6	0.2	1.0	15.2	1.8	18.3	39.4	46.3	0.5	8.5	48.8	11.9	2.3	2.3
SMU 3	15-35	43.4	8.5	48.0	C	4.9	3.8	-1.1	0.0	0.2	1.5	7.0	1.7	0.2	0.2	5.4	1.8	7.6	10.2	73.9	1.5	3.0				
	35-69	17.0	21.6	61.4	C	5.0	4.0	-1.0	0.0	0.1	0.9	7.3	Trace	0.1	0.2	5.4	1.8	7.5	31.2	24.1	0.4	3.0				
	69-160	17.7	9.7	72.5	C	5.1	4.1	-0.9	0.0	0.2	1.8	10.5	Trace	0.2	0.2	3.6	1.8	5.8	21.4	27.0	0.9	2.0				
DP11	0-16	38.5	10.4	51.0	C	5.3	4.2	-1.1	0.1	0.2	3.3	16.6	85.7	0.2	0.2	5.4	1.8	7.6	21.4	35.3	0.8	3.0	43.2	52.5	1.8	0.3
SMU 3	16-46	37.3	15.7	47.0	C	4.7	3.9	-0.7	0.0	0.1	2.0	21.8	0.7	0.2	0.1	5.4	1.8	7.5	21.9	34.3	1.0	3.0				
	46-132	30.1	12.5	57.4	C	4.7	4.0	-0.7	0.0	0.1	1.1	12.9	0.3	0.1	0.1	7.2	0.9	8.3	16.6	50.2	0.8	8.0				
	132-200	24.1	12.5	63.4	C	4.6	4.1	-0.5	0.0	0.1	0.8	10.3	0.4	0.2	0.1	4.5	2.7	7.4	16.6	44.9	0.9	1.7				
DP12	0-14	32.5	13.7	53.8	C	5.4	4.3	-1.1	0.1	0.2	3.8	15.3	3.6	0.2	0.4	10.7	3.6	14.8	28.5	52.1	0.7	3.0	56.8	76.5	1.8	1.1
SMU 3	14-35	35.5	16.9	47.6	C	4.9	4.0	-0.9	0.0	0.1	2.3	16.8	1.0	0.2	0.2	7.2	0.9	8.4	24.8	34.0	0.7	8.0				
	35-59	29.2	14.8	56.0	C	4.8	3.9	-0.9	0.0	0.2	1.7	10.9	0.9	0.2	0.2	3.6	0.9	4.9	21.9	22.3	0.9	4.0				
	59-180	16.4	12.7	70.9	C	4.9	4.1	-0.8	0.0	0.1	1.0	12.5	1.9	0.2	0.2	3.6	0.9	4.8	16.9	28.4	1.1	4.0				
DP13	0-17	32.6	41.7	25.7	Loam	5.0	4.3	-0.6	0.1	0.3	3.5	10.8	5.9	0.2	0.4	9.9	1.8	12.2	38.0	32.2	0.4	5.5	32.7	137.7	2.1	1.0
SMU 3	17-51	21.7	23.6	54.7	C	5.1	4.2	-0.9	0.0	0.2	2.1	11.3	0.9	0.2	0.3	4.5	0.9	5.9	26.8	21.9	0.7	5.0				
	51-180	11.7	16.2	72.2	C	4.9	4.0	-0.9	0.0	0.1	1.2	8.6	3.9	0.1	0.3	3.6	0.9	5.0	56.0	9.0	0.2	4.0				
DP14	0-16	49.3	26.9	23.8	SCL	6.4	5.6	-0.8	0.1	0.3	3.3	10.6	12.1	0.1	0.6	13.3	2.7	16.6	21.7	76.6	0.4	5.0	40.2	42.4	1.5	0.1
SMU 1	16-77	48.3	18.3	33.5	SCL	6.4	5.2	-1.2	0.0	0.1	1.3	14.3	50.5	0.1	0.3	7.6	2.7	10.7	17.5	61.1	0.4	2.8				
	77-102	38.7	18.7	42.6	C	6.1	6.0	-0.1	0.0	0.7	0.0	19.0	1.4	0.1	0.4	8.7	6.4	15.5	22.3	69.6	0.5	1.4				

Profile	Depth	Texture <2 mm fraction				pH(1:2.5)			EC	Total N	Org C	C/N	Avail P	Exchange Cations (meq/100gm soil)					CEC	Base Satn	ESP	Ca/ Mg	Avail Fe	avail Mn	avail Cu	avail Zn
SMU	cm	Sand	Silt	Clay	Class	H2O	KCl	ΔPH	dS/m	%	%		ppm	Na	K	Ca	Mg	Sum	meq/g	%	%		mg/ kg soil (ppm)			
DP15	0-15	37.8	35.4	26.8	L	6.7	5.9	0.1	0.1	0.6	7.8	14.2	112.0	0.1	1.7	27.4	6.8	36.0	37.7	95.6	0.3	4.0	24.1	105.0	3.5	8.9
SMU 8	15-52	33.9	24.5	41.6	C	6.4	5.7	0.1	0.1	0.2	1.5	6.9	42.9	0.1	0.9	21.7	14.5	37.2	30.5	122.0	0.5	1.5				
	52-100	24.3	21.3	54.4	C	6.6	5.8	-0.8	0.1	0.1	1.1	7.3	7.9	0.1	0.8	16.3	11.3	28.5	31.4	90.6	0.3	1.4				
DP17	0-15	25.5	11.7	62.8	C	5.7	4.6	-1.1	0.1	0.3	3.5	10.3	5.3	0.2	0.9	4.5	4.5	10.1	37.3	27.1	0.4	1.0	47.8	30.3	1.5	0.9
SMU 3	15-37	21.1	7.5	71.4	C	4.6	3.7	-0.9	0.1	0.2	2.8	13.7	4.3	0.1	0.4	6.3	1.8	8.6	31.4	27.4	0.4	3.5				
	37-68	15.8	9.6	74.6	C	5.1	4.2	-0.9	0.0	0.1	1.6	11.5	2.0	0.1	0.2	2.7	1.8	4.9	28.0	17.4	0.4	1.5				
	68-200	9.5	10.6	79.9	C	4.9	4.5	-0.4	0.0	0.1	0.8	7.2	0.7	0.2	0.2	3.6	0.9	4.9	21.1	23.2	0.9	4.0				
DP18	0-20	10.9	38.7	50.5	C	4.9	4.2	-0.8	0.1	0.4	3.3	8.4	6.6	0.2	0.6	9.0	3.6	13.4	36.8	36.5	0.5	2.5	66.9	84.4	2.6	1.8
SMU 3	20-42	27.7	17.3	55.0	C	4.6	3.7	-0.8	0.0	0.3	2.6	8.7	3.3	0.2	0.3	7.2	1.8	9.5	33.9	27.9	0.5	4.0				
	42-180	17.0	10.8	72.3	C	4.7	3.9	-0.8	0.0	0.2	1.4	8.2	5.3	0.2	0.2	3.6	0.9	4.9	26.0	19.0	0.8	4.0				
	200-280					5.4	4.4	-1.0	0.1																	
DP19	0-20	34.8	12.0	53.3	C	5.1	4.0	-1.0	0.1	0.2	2.9	14.5	8.9	0.2	0.4	19.9	8.1	28.7	43.7	65.5	0.4	2.4	222.7	50.0	2.3	0.6
SMU 9	20-55	25.6	8.9	65.5	C	5.1	4.1	-1.0	0.0	0.1	1.3	9.3	2.9	0.3	0.3	22.6	4.5	27.7	44.2	62.7	0.7	5.0				
	55-200	1.9	30.8	67.3	C	6.5	4.7	-1.8	0.1	0.0	0.5	15.8	3.2	0.4	0.4	31.4	9.0	41.2	54.1	76.2	0.8	3.5				
DP20	0-12	46.8	20.9	32.3	SCL	5.4	4.4	-0.9	0.1	0.2	3.3	13.2	4.7	0.1	1.0	9.0	2.7	12.8	28.7	44.5	0.4	3.3	20.1	65.7	1.2	0.1
SMU 3	12--35	36.8	17.9	45.3	C	4.8	3.8	-1.0	0.0	0.2	2.2	11.6	1.7	0.1	0.2	3.6	0.9	4.9	31.7	15.3	0.4	4.0				
	32-115	38.0	14.7	47.3	C	5.0	4.2	-0.8	0.0	0.2	1.1	7.4	1.4	0.2	0.2	3.6	0.9	4.9	21.4	22.8	0.9	4.0				
	115-176	33.5	19.0	47.5	C	4.9	4.5	-0.4	0.0	0.1	1.1	7.6	1.9	0.2	0.3	4.5	1.8	6.7	23.9	28.2	0.7	2.5				
	176-200	40.0	16.8	43.1	C	4.9	4.3	-0.6	0.0	0.2	0.2	0.6	1.4	0.1	0.3	2.7	1.8	4.9	29.7	16.7	0.5	1.5				
DP21	0-13	38.6	40.9	20.5	L	5.2	4.4	-0.8	0.2	0.5	5.4	11.3	7.9	0.2	0.3	17.0	3.6	21.1	52.6	40.1	0.3	4.8	42.2	104.3	2.3	1.4
SMU 4	13-30	38.3	41.1	20.6	L	5.1	4.2	-0.9	0.1	0.3	4.2	12.9	2.2	0.2	0.2	8.9	3.6	12.8	52.6	24.4	0.4	2.5				
	30-53	17.1	36.6	46.3	C	5.3	4.2	-1.1	0.0	0.2	3.3	14.2	1.1	0.2	0.2	7.2	1.8	9.3	66.7	14.0	0.3	4.0				
	53-200	7.2	14.9	77.9	C	5.2	4.7	-0.6	0.0	0.1	1.1	10.1	1.9	0.2	0.2	8.1	3.6	12.0	26.8	44.8	0.7	2.3				

Profile	Depth	Texture <2 mm fraction				pH(1:2.5)			EC	Total N	Org C	C/N	Avail P	Exchange Cations (meq/100gm soil)					CEC	Base Satn	ESP	Ca/ Mg	Avail Fe	avail Mn	avail Cu	avail Zn
SMU	cm	Sand	Silt	Clay	Class	H2O	KCl	ΔPH	dS/ m	%	%		ppm	Na	K	Ca	Mg	Sum	meq/g	%	%		mg/ kg soil (ppm)			
DP22	0-15	43.1	12.4	44.5	C	4.8	4.0	-0.8	0.2	0.3	2.6	8.9	4.7	0.2	0.6	6.3	1.8	8.8	25.3	34.9	0.8	3.5	67.9	61.4	1.2	0.2
SMU 3	15-30	48.0	17.7	34.3	SCL	4.8	3.9	-0.9	0.0	0.1	2.2	16.2	1.4	0.3	0.3	3.6	0.9	5.1	25.3	20.1	1.2	4.0				
	30-50	39.5	21.9	38.6	Cl	4.8	4.0	-0.8	0.0	0.1	1.7	11.9	1.7	0.3	0.3	2.7	0.9	4.2	32.1	13.2	1.0	3.0				
	50-200	30.3	15.6	54.1	C	4.9	4.2	-0.7	0.0	0.1	0.8	6.9	11.1	0.3	0.3	3.6	2.7	6.8	14.6	46.9	2.1	1.3				
DP23	0-15	47.7	17.8	34.5	SCL	5.1	4.1	-1.0	0.1	0.2	2.4	11.0	9.5	0.2	0.4	10.8	7.2	18.5	30.7	60.3	0.8	1.5	107.6	12.1	2.1	2.0
SMU 9	15-30	34.8	12.8	52.4	C	4.8	4.0	-0.8	0.0	0.2	1.5	10.1	3.2	0.2	0.2	6.3	2.7	9.3	34.1	27.4	0.6	2.3				
	30-200	45.7	6.4	47.9	SC	5.2	3.6	-1.7	0.0	0.0	0.5	11.8	2.9	0.3	0.2	10.8	5.4	16.6	28.7	57.9	0.9	2.0				
DP24	0-21	51.7	26.7	21.6	SCL	6.5	5.7	-0.9	0.1	0.3	7.3	23.3	25.6	0.1	0.8	15.7	2.2	18.8	34.6	54.4	0.3	7.0	43.7	21.8	3.2	26.9
SMU -	21-45	48.6	18.9	32.5	SCL	5.4	4.1	-1.3	0.0	0.2	2.2	12.4	58.2	0.1	0.2	2.7	1.8	4.8	16.4	29.2	0.8	1.5				
	45-80	42.9	12.5	44.6	C	5.2	4.0	-1.2	0.0	0.2	1.4	7.3	3.1	0.1	0.2	2.6	1.8	4.7	14.3	32.9	0.9	1.5				
DP25	0-20	44.8	27.1	28.1	CL	6.0	5.9	-0.1	0.2	0.5	4.1	9.0	29.6	0.2	0.5	17.0	3.6	21.4	38.0	56.2	0.6	4.8	42.7	73.4	1.8	2.2
SMU 2	20-50	51.3	12.4	36.3	SC	6.5	5.7	-0.7	0.0	0.2	2.0	11.6	11.1	0.2	0.4	11.1	2.2	13.9	15.4	89.9	1.2	5.0				
	50-75	56.8	5.1	38.1	SC	6.5	5.3	-1.2	0.1	0.1	0.7	9.5	62.3	0.1	0.4	6.3	2.7	9.4	15.6	60.5	0.6	2.3				
DP26	0-22	51.2	15.3	33.6	SC	5.4	4.3	-1.1	0.0	0.1	1.8	20.2	4.2	0.2	0.2	4.5	3.6	8.4	16.1	52.5	1.3	1.3	29.7	28.3	0.6	1.5
SMU 3	22-50	50.2	10.2	39.6	SC	5.1	4.1	-1.0	0.0	0.1	1.8	13.1	2.2	0.2	0.1	3.6	0.9	4.7	11.1	42.8	1.7	4.0				
	50-75	46.3	14.2	39.5	SC	4.9	4.0	-0.9	0.0	0.1	0.7	9.0	0.9	0.2	0.1	2.7	0.9	3.9	15.1	25.6	1.2	3.0				
	75-200	46.0	10.2	43.8	SC	4.9	3.9	-1.0	0.0	0.0	0.3	21.7	1.3	0.2	0.2	3.6	0.9	4.9	22.4	21.7	1.0	4.0				
DP27	0-17	38.8	22.8	38.4	C	4.8	3.9	-0.9	0.1	0.2	2.7	13.7	4.2	0.2	0.2	4.6	1.8	6.8	22.8	29.8	1.0	2.5	45.2	40.2	0.9	0.4
SMU 3	17-40	29.3	26.0	44.7	C	4.7	4.3	-0.4	0.0	0.2	2.0	13.3	2.4	0.2	0.1	2.7	0.9	4.0	24.8	16.0	0.8	3.0				
	40-78	32.7	18.6	48.7	C	4.7	4.3	-0.4	0.0	0.1	1.6	17.0	1.6	0.2	0.1	2.7	1.8	4.9	18.3	26.7	1.1	1.5				
	78-128	26.6	21.3	52.1	C	4.8	4.5	-0.2	0.0	0.1	1.2	13.5	1.9	0.2	0.1	1.8	1.8	3.9	17.7	22.3	1.1	1.0				
	128-200	33.3	3.2	63.5	C	5.0	4.3	-0.7	0.0	0.1	0.9	8.0	0.7	0.2	0.2	2.7	2.7	5.8	17.2	33.7	1.3	1.0				

Profile	Depth	Texture <2 mm fraction				pH(1:2.5)			EC	Total N	Org C	C/N	Avail P	Exchange Cations (meq/100gm soil)					CEC	Base Satn	ESP	Ca/ Mg	Avail Fe	avail Mn	avail Cu	avail Zn
SMU	cm	Sand	Silt	Clay	Class	H2O	KCl	ΔPH	dS/ m	%	%		ppm	Na	K	Ca	Mg	Sum	meq/g	%	%		mg/ kg soil (ppm)			
DP30	0-26	29.6	23.1	47.3	C	5.2	4.0	-1.2	0.1	0.3	4.2	14.2	13.6	0.3	0.6	15.4	6.3	22.6	52.6	42.9	0.5	2.4				
SMU 9	26-53	21.3	17.7	60.9	C	5.0	4.0	-0.9	0.1	0.2	1.8	10.6	3.9	0.3	0.3	15.4	11.8	27.7	46.7	59.3	0.6	1.3				
	53-71	27.0	5.5	67.5	C	5.1	3.8	-1.3	0.1	0.2	1.4	9.3	3.3	0.3	0.3	19.0	10.8	30.5	39.3	77.5	0.8	1.8				
	71-114	30.6	11.9	57.5	C	5.4	4.2	-1.1	0.0	0.1	0.7	9.9	1.9	0.3	0.4	18.1	9.0	27.8	48.6	57.1	0.6	2.0				
DP31	0-18	17.9	48.2	33.9	SiCL	6.1	5.1	-1.0	0.1	0.3	4.0	14.4	10.3	0.1	1.5	15.8	3.2	20.6	47.2	43.7	0.2	5.0	40.2	72.7	1.2	0.9
SMU 3	18-43	6.8	30.7	62.5	C	4.9	3.8	-1.1	0.1	0.2	2.6	11.9	1.3	0.2	0.7	6.3	6.3	13.6	37.8	36.0	0.6	1.0				
	43-175	20.4	4.4	75.3	C	5.0	4.1	-1.0	0.0	0.1	1.4	14.8	1.1	0.3	0.3	4.5	4.5	9.6	37.8	25.3	0.7	1.0				
	175-200	33.6	6.5	59.8	C	4.9	4.0	-0.9	0.0	0.1	1.0	7.3	1.8	0.2	0.2	5.4	3.6	9.5	29.0	32.8	0.7	1.5				
DP32	0-25	36.1	34.0	29.9	CL	7.0	6.1	-0.9	0.1	0.3	3.7	10.6	73.3	0.1	0.8	14.3	2.7	18.0	26.8	67.1	0.4	5.3	38.2	68.7	1.5	0.9
SMU -	25-50	32.7	20.7	46.6	C	6.8	5.6	-1.2	0.1	0.1	1.5	16.2	219.5	0.1	0.6	8.4	2.2	11.4	13.5	84.2	1.0	3.8				
	50-80	34.1	18.3	47.7	C	6.5	5.5	-1.0	0.1	0.1	1.1	14.3	108.9	0.1	0.5	5.8	2.7	9.1	15.1	60.5	0.6	2.2				
DP33	0-25	47.5	24.7	27.8	SCL	4.9	4.0	-1.0	0.0	0.2	2.9	13.6	15.7	0.1	0.2	1.8	0.9	2.9	13.6	21.6	0.7	2.0	29.2	25.0	2.6	0.2
SMU 3	25-50	42.3	14.7	43.0	C	4.8	3.9	-0.9	0.0	0.2	2.2	10.3	11.8	0.1	0.1	1.8	0.9	2.9	13.6	21.3	0.7	2.0				
	50-90	38.8	16.6	44.6	C	4.8	8.9	4.1	0.0	0.1	1.6	12.9	3.8	0.1	0.1	1.8	0.9	2.9	12.7	22.6	0.8	2.0				
	90-125	38.1	10.5	51.4	C	4.8	3.9	-0.9	0.0	0.1	1.2	9.7	3.5	0.1	0.1	1.8	0.9	2.9	12.7	22.9	0.9	2.0				
DP34	0-20	37.1	18.6	44.3	C	5.1	3.8	-1.2	0.0	0.3	4.2	13.5	30.4	0.3	0.6	9.0	2.7	12.5	24.8	50.5	1.3	3.3				
SMU 3	20-45	34.8	10.4	54.9	C	5.3	3.7	-1.6	0.0	0.2	2.2	12.4	14.2	0.2	0.4	14.3	3.6	18.5	26.8	69.1	0.9	4.0				
	45-100	36.1	6.1	57.8	C	7.3	5.9	-1.3	0.2	0.1	0.7	11.7	28.9	0.3	0.4	26.4	2.7	29.9	33.6	88.8	1.0	9.8				
	100-125	28.2	14.4	57.4	C	7.6	6.2	-1.4	0.2	0.1	0.6	10.1	100.8	0.4	0.8	29.1	6.7	37.0	38.5	96.1	0.9	4.3				
DP37	0-14	35.4	38.1	26.5	L	5.5	4.3	-1.1	0.1	0.3	4.9	14.3	1.7	0.2	0.9	10.8	7.2	19.2	33.4	57.5	0.6	1.5	45.7	139.5	2.9	1.1
SMU 3	14-32	12.6	43.7	43.7	SiC	5.0	4.1	-0.9	0.0	0.2	2.3	10.8	1.5	0.2	0.2	4.5	4.5	9.4	28.7	32.7	0.7	1.0				
	32-95	4.1	33.0	62.9	C	5.1	4.3	-0.8	0.0	0.2	2.0	13.1	2.9	0.2	0.2	4.5	1.8	6.6	38.0	17.5	0.5	2.5				
	95-132	5.3	17.0	77.7	C	5.0	4.0	-1.1	0.0	0.1	0.8	8.2	1.4	0.2	0.2	3.6	2.7	6.7	32.6	20.5	0.7	1.3				

Profile	Depth	Texture <2 mm fraction				pH(1:2.5)			EC	Total N	Org C	C/N	Avail P	Exchange Cations (meq/100gm soil)					CEC	Base Satn	ESP	Ca/ Mg	Avail Fe	avail Mn	avail Cu	avail Zn
SMU	cm	Sand	Silt	Clay	Class	H2O	KCl	ΔPH	dS/m	%	%		ppm	Na	K	Ca	Mg	Sum	meq/g	%	%		mg/ kg soil (ppm)			
DP38	0-14	44.5	27.2	28.3	CL	5.5	4.6	-0.9	0.1	0.3	4.6	13.5	0.8	0.2	0.6	9.0	8.1	17.8	33.1	53.8	0.6	1.1	58.8	17.3	2.3	0.4
SMU 3	14-36	31.8	29.4	38.8	CL	4.8	3.8	-1.0	0.0	0.1	3.0	21.7	0.6	0.2	0.2	4.5	2.7	7.5	28.7	26.3	0.7	1.7				
	36-65	27.8	20.9	51.3	C	4.7	3.8	-0.9	0.0	0.2	2.3	13.9	2.9	0.2	0.2	4.5	1.8	6.7	17.5	38.0	1.3	2.5				
	65-150	14.0	14.9	71.1	C	4.7	4.1	-0.7	0.0	0.2	1.4	9.3	0.6	0.2	0.1	2.7	1.8	4.8	19.0	25.2	0.9	1.5				
DP39	0-29	24.8	45.8	29.4	CL	5.9	5.0	-0.9	0.1	0.4	6.7	15.4	2.4	0.2	0.2	22.2	8.9	31.5	50.2	62.8	0.4	2.5	20.1	58.3	2.3	0.0
SMU 4	29-47	10.6	30.2	59.2	C	5.3	4.6	-0.7	0.0	0.2	2.8	14.0	0.6	0.2	0.1	9.0	6.3	15.6	33.6	46.3	0.6	1.4				
	47-75	10.9	21.5	67.7	C	5.5	4.7	-0.7	0.0	0.1	1.7	12.4	0.9	0.2	0.1	5.4	5.4	11.1	32.1	34.5	0.7	1.0				
	75-200	9.1	12.8	78.1	C	5.2	5.3	0.1	0.0	0.1	0.9	14.8	0.8	0.2	0.1	6.3	3.6	10.2	24.8	41.2	0.9	1.8				
	200-300					5.5	5.2	-0.3	0.0																	
	300-400					5.0	4.5	-0.5	0.0																	
	400-580					4.9	4.2	-0.6	0.0																	
DP41	0-19	25.3	51.9	22.7	SiL	6.0	5.1	-0.9	0.1	0.5	6.2	13.5	12.0	0.2	1.3	17.9	9.9	29.3	54.1	54.2	0.4	1.8	54.3	49.8	2.9	2.0
SMU 2	19-34	13.2	27.9	58.9	C	5.3	4.3	-1.0	0.1	0.2	2.4	9.8	0.9	0.2	0.3	8.1	5.4	13.9	34.1	40.8	0.6	1.5				
	34-62	11.0	19.3	69.7	C	5.3	4.4	-0.9	0.0	0.1	1.4	20.3	1.1	0.2	0.2	5.4	6.3	12.1	36.0	33.5	0.6	0.9				
	62-127	10.1	16.1	73.8	C	5.2	4.6	-0.6	0.0	0.1	1.1	19.6	1.8	0.2	0.2	4.5	4.5	9.4	26.3	35.6	0.7	1.0				
	127-200	7.5	12.8	79.8	C	5.3	4.9	-0.4	0.0	0.1	1.0	12.8	3.2	0.2	0.2	4.4	4.4	9.3	21.2	43.7	1.0	1.0				
	200-300					5.0	4.6	-0.4	0.0																	
	300-400					5.0	4.6	-0.4	0.0																	
DP45	0-10	40.1	16.8	43.1	C	5.1	4.5	-0.7	0.1	0.4	4.0	10.8	2.9	0.2	0.2	6.2	5.3	12.0	25.6	47.0	0.9	1.2	72.4	102.3	1.5	0.1
SMU 1	10--25	35.6	11.6	52.8	C	5.1	4.2	-0.9	0.0	0.3	3.5	11.9	0.8	0.2	0.1	4.5	2.7	7.5	25.8	29.0	0.8	1.7				
	25-60	29.9	22.3	47.8	C	5.0	4.2	-0.8	0.0	0.2	2.7	11.5	10.8	0.2	0.1	3.6	3.6	7.5	29.2	25.6	0.7	1.0				
	60-80	33.5	19.0	47.5	C	4.8	4.1	-0.7	0.0	0.2	2.2	10.1	0.3	0.2	0.1	3.6	0.9	4.9	29.2	16.7	0.8	4.0				

Profile	Depth	Texture <2 mm fraction				pH(1:2.5)			EC	Total N	Org C	C/N	Avail P	Exchange Cations (meq/100gm soil)					CEC	Base Satn	ESP	Ca/ Mg	availFe	avail Mn	avail Cu	avail Zn
SMU	cm	Sand	Silt	Clay	Class	H2O	KCl	ΔPH	dS/ m	%	%		ppm	Na	K	Ca	Mg	Sum	meq/g	%	%		mg/ kg soil (ppm)			
DP47	0-12	38.0	18.9	43.1	C	5.2	4.2	-1.0	0.1	0.4	4.4	11.8	3.8	0.2	0.3	9.1	7.3	16.9	28.7	58.9	0.8	1.3	63.8	45.1	1.8	1.3
SMU 1	40177.0	17.0	6.3	76.7	C	5.2	4.2	-1.0	0.0	0.2	2.2	9.0	0.9	0.2	0.2	4.6	3.6	8.6	26.3	32.8	0.9	1.3				
	30-65	15.0	10.5	74.5	C	5.0	4.2	-0.8	0.0	0.2	2.0	13.1	0.9	0.2	0.1	1.8	1.8	4.0	20.1	19.6	1.0	1.0				
	65-200	10.8	8.4	80.8	C	5.0	4.3	-0.7	0.0	0.1	0.8	11.0	0.3	0.2	0.1	2.7	1.8	4.8	28.5	16.8	0.6	1.5				
DP50	0-19	45.1	8.3	46.6	SCL	5.4	4.4	-1.0	0.1	0.3	3.0	10.1	3.2	0.2	0.7	5.4	3.6	9.9	26.0	38.0	0.8	1.5	24.1	56.6	1.2	1.0
SMU 3	19-50	40.6	12.5	46.9	C	4.7	3.9	-0.8	0.0	0.2	1.9	11.2	0.3	0.2	0.2	2.7	1.8	4.9	19.2	25.5	1.0	1.5				
	50-110	31.8	12.6	55.6	C	4.8	3.9	-1.0	0.0	0.1	1.3	10.6	0.3	0.2	0.2	2.7	1.8	4.9	24.1	20.2	0.7	1.5				
	110-200	34.0	14.7	51.3	C	4.9	3.9	-0.9	0.0	0.1	0.8	10.2	0.5	0.2	0.2	3.6	0.9	4.9	20.6	23.5	0.9	4.0				
DP51	0-25	59.6	16.6	23.8	SCL	6.4	6.0	-0.4	0.1	0.7	7.3	10.5	50.6	0.1	0.8	19.9	2.3	23.0	30.5	75.7	0.5	8.8	73.4	98.7	2.6	2.7
SMU 1	25-48	59.0	12.3	28.7	SCL	6.5	6.0	-0.6	0.1	0.4	4.6	11.4	27.6	0.1	0.3	5.9	1.4	7.6	26.5	28.8	0.4	4.3				
	48-78	58.0	8.2	33.8	SCL	6.6	5.2	-1.4	0.0	0.2	1.3	8.6	8.4	0.3	0.9	15.4	7.2	23.8	28.0	85.0	0.9	2.1				
DP54	0-13	39.2	26.2	34.6	CL	5.7	4.8	-0.9	0.1	0.4	4.8	12.5	4.2	0.9	0.7	10.8	4.5	16.9	25.8	65.4	3.6	2.4	50.8	62.6	1.5	0.1
SMU 5	13-40	38.5	18.8	42.7	C	4.8	3.9	-1.0	0.0	0.2	2.6	12.8	3.3	0.2	0.1	4.5	1.8	6.6	20.0	33.0	0.9	2.5				
	40-70	21.9	20.8	57.3	C	4.7	4.0	-0.7	0.0	0.2	1.6	9.7	0.8	0.2	0.1	5.4	1.8	7.4	17.5	42.4	1.0	3.0				
DP52	0-20	51.9	24.1	24.1	SL	5.1	4.2	-0.9	0.1	0.3	3.7	13.4	5.7	0.1	0.1	3.2	3.6	7.0	29.0	24.1	0.5	0.9	26.1	51.5	1.2	0.0
SMU 2	20-43	55.0	23.0	22.0	SL	4.7	4.1	-0.6	0.1	0.2	3.1	12.6	1.4	0.2	0.1	2.7	0.9	4.0	23.6	16.9	1.0	3.0				
	43-120	33.1	17.8	49.2	C	4.4	4.1	-0.4	0.1	0.1	1.3	9.4	0.8	0.2	0.1	1.8	0.9	2.9	20.5	14.4	0.9	2.0				
	120-200	20.2	10.4	69.4	C	4.2	3.9	-0.3	0.0	0.1	1.2	10.9	0.8	0.2	0.1	3.6	2.7	6.6	18.5	35.4	0.9	1.3				
	200-300					4.7	3.9	-0.8																		
	300-400					4.7	3.9	-0.8																		
DP56	0-23	48.7	29.3	22.0	L	6.8	6.0	-0.8	0.2	0.7	6.8	10.2	33.3	0.1	1.3	26.0	3.6	31.1	43.8	70.9	0.3	7.3	28.7	44.0	0.6	1.7
SMU 5	23-60	44.8	20.8	34.4	CL	6.8	6.0	-0.8	0.1	0.2	1.6	7.3	5.6	0.2	0.6	16.1	5.4	22.3	25.8	86.2	0.7	3.0				

Profile	Depth	Texture <2 mm fraction				pH(1:2.5)			EC	Total N	Org C	C/N	Avail P	Exchange Cations (meq/100gm soil)					CEC	Base Satn	ESP	Ca/ Mg	Avai Fe	avail Mn	avail Cu	avail Zn
SMU	cm	Sand	Silt	Clay	Class	H2O	KCl	ΔPH	dS/m	%	%		ppm	Na	K	Ca	Mg	Sum	meq/g	%	%		mg/ kg soil (ppm)			
DP55	0-23	53.6	18.6	27.9	SCL	6.4	5.6	-0.9	0.1	0.4	3.6	8.8	14.7	0.1	0.4	9.8	2.7	12.9	21.2	61.0	0.7	3.7	68.4	16.3	1.2	2.9
SMU 2	23-50	42.7	12.5	44.8	C	6.6	5.4	-1.2	0.0	0.2	1.6	9.3	4.1	0.1	0.4	9.9	3.6	13.9	17.0	81.8	0.6	2.8				
	50-90	38.5	10.4	51.1	C	6.8	5.9	-0.9	0.1	0.1	1.1	7.6	3.8	0.1	0.4	9.9	3.6	14.0	16.1	87.1	0.7	2.8				
	90-150	34.2	12.5	53.3	C	6.4	5.8	-0.6	0.0	0.1	0.8	10.8	3.5	0.1	0.4	7.6	3.6	11.7	16.6	70.8	0.8	2.1				
	150-200	32.1	12.5	55.4	C	6.2	5.4	-0.7	0.1	0.1	0.8	8.8	4.2	0.2	0.4	7.6	3.6	11.7	17.0	68.9	0.9	2.1				
DP58	0-17	43.3	12.4	44.3	C	4.5	3.8	-0.8	0.1	0.3	3.1	10.1	4.5	0.1	1.3	26.0	3.6	31.1	43.8	70.9	0.3	7.3	35.7	73.3	1.2	0.0
SMU 3	17-60	52.4	17.6	30.0	SCL	4.4	4.0	-0.4	0.0	0.2	2.3	11.5	0.6	0.2	0.6	16.1	5.4	22.3	25.8	86.2	0.7	3.0				
	60-200	29.5	15.5	54.9	C	4.3	3.9	-0.3	0.1	0.2	1.5	8.7	3.2	0.2	0.1	4.5	1.8	6.6	21.9	30.1	0.9	2.5				
DP-60	0-16	59.0	19.5	21.5	SCL	5.7	4.8	-0.8	0.1	0.4	4.9	13.3	16.0	0.1	0.7	12.5	2.7	16.1	43.8	36.7	0.3	4.7	50.3	65.9	0.6	0.6
SMU -	16-40	57.9	20.5	21.6	SCL	5.8	4.9	-0.9	0.1	0.4	4.3	10.8	8.4	0.2	0.6	10.8	2.7	14.2	22.9	62.0	0.7	4.0				
	40-90	43.4	10.3	46.3	C	5.0	4.3	-0.7	0.0	0.2	1.8	7.2	8.2	0.1	0.3	2.7	0.9	4.0	16.1	25.0	0.7	3.0				
DP63	0-13	52.4	23.8	23.8	SCL	6.4	6.1	-0.4	0.1	0.5	5.5	11.1	31.5	0.1	1.0	17.9	3.6	22.6	28.7	78.7	0.5	5.0	47.8	60.6	1.8	2.8
SMU 8	13-38	53.7	18.5	27.8	SCL	6.5	5.8	-0.8	0.1	0.3	2.3	8.4	3.2	0.1	0.4	9.8	3.6	13.8	17.4	79.7	0.6	2.8				
	38-65	47.4	14.4	38.2	SCL	6.5	5.6	-0.8	0.1	0.4	2.5	7.2	3.0	0.1	0.4	9.0	3.6	13.1	18.0	72.8	0.6	2.5				
DP65	0-21	47.6	24.7	27.8	SCL	6.6	6.3	-0.2	0.4	0.5	4.5	9.5	23.9	0.2	1.4	15.7	4.0	21.3	24.8	85.9	0.8	3.9	35.2	59.2	2.1	1.1
SMU 11	21-55	44.3	15.5	40.2	C	6.4	5.2	-1.2	0.2	0.2	1.8	7.1	3.4	0.1	0.8	9.8	2.2	12.9	15.9	81.1	0.8	4.4				
	55-69	44.3	9.3	46.4	C	6.6	5.7	-0.8	0.4	0.2	1.3	8.4	5.4	0.1	3.3	6.3	1.3	11.1	16.6	66.8	0.8	4.7				
	69-175	32.7	14.5	52.8	C	6.4	5.9	-0.5	0.2	0.1	1.0	8.2	9.8	0.1	1.2	6.3	2.7	10.3	15.1	68.1	1.0	2.3				
DP67	0-14	45.6	28.2	26.2	L	5.4	4.4	-1.0	0.1	0.3	4.0	12.1	4.6	0.2	0.4	9.1	4.6	14.3	34.7	41.1	0.6	2.0	33.7	55.9	3.5	0.4
SMU 6	14-45	46.8	18.8	34.5	SCL	5.1	4.3	-0.8	0.0	0.2	2.8	12.9	1.9	0.2	0.1	4.6	1.8	6.7	22.3	30.1	0.8	2.5				
	45-80	28.0	25.0	47.0	C	5.1	4.3	-0.8	0.0	0.2	1.5	8.4	1.9	0.2	0.1	4.6	1.8	6.6	17.3	38.3	0.9	2.5				
	80-160	25.8	14.6	59.5	C	5.0	4.3	-0.7	0.0	0.1	1.1	7.4	Trace	0.2	0.1	4.5	1.8	6.6	14.7	44.8	1.1	2.5				

Profile	Depth	Texture <2 mm fraction				pH(1:2.5)			EC	Total N	Org C	C/N	Avail P	Exchange Cations (meq/100gm soil)					CEC	Base Satn	ESP	Ca/ Mg	Avail Fe	avail Mn	avail Cu	avail Zn
SMU	cm	Sand	Silt	Clay	Class	H2O	KCl	ΔPH	dS/m	%	%		ppm	Na	K	Ca	Mg	Sum	meq/g	%	%		mg/ kg soil (ppm)			
DP68	0-19	53.8	20.5	25.7	SCL	5.6	4.6	-1.0	0.1	0.2	2.6	16.8	10.7	0.3	0.2	9.0	4.5	14.0	22.1	63.5	1.2	2.0	108.6	21.2	1.5	0.7
SMU 8	19-46	43.5	16.4	40.1	C	5.5	4.2	-1.2	0.0	0.1	1.5	10.7	6.5	0.3	0.1	7.2	3.6	11.2	17.7	63.6	1.4	2.0				
	46-120	26.3	21.8	52.0	C	5.7	4.3	-1.4	0.0	0.1	0.8	7.8	2.4	0.3	0.2	9.0	3.6	13.2	14.7	89.6	2.3	2.5				
DP69	0-20	41.0	36.9	22.1	L	6.5	5.7	-0.9	0.1	0.6	7.1	11.8	27.5	0.1	1.4	13.6	4.5	19.6	39.3	50.0	0.4	3.0	42.7	152.7	2.9	3.2
SMU 8	20-64	34.2	25.1	40.7	C	6.5	5.5	-0.9	0.1	0.3	3.0	10.8	7.3	0.1	0.3	13.1	2.7	16.3	26.5	61.5	0.6	4.8				
	64-160	22.1	12.5	65.4	C	6.7	7.8	1.1	0.1	0.0	0.7	15.2	49.3	0.1	0.5	7.2	3.6	11.5	16.7	68.6	0.7	2.0				
DP71	0-12	48.7	11.3	40.0	SC	5.7	4.7	-1.1	0.0	0.2	2.9	14.3	4.3	0.2	0.4	6.3	2.7	9.7	21.1	45.7	0.8	2.3	29.2	5.6	1.2	1.1
SMU 2	12--34	41.3	8.2	50.5	C	5.1	4.3	-0.8	0.0	0.2	1.9	9.4	3.1	0.2	0.1	3.6	1.8	5.7	13.3	43.2	1.3	2.0				
	34-70	42.2	15.5	42.3	C	5.0	4.3	-0.7	0.0	0.1	1.6	17.7	2.5	0.2	0.1	3.6	2.7	6.6	13.3	50.0	1.3	1.3				
	70-160	41.0	8.3	50.7	C	4.9	4.2	-0.7	0.0	0.1	0.9	11.4	5.6	0.2	0.1	2.7	2.7	5.7	12.3	46.4	1.3	1.0				
DP73	0-11	67.5	11.2	21.3	SCL	5.9	5.0	-0.9	0.1	0.2	2.0	11.5	7.4	0.2	0.4	7.2	3.6	11.3	17.0	66.4	0.9	2.0	26.6	31.6	0.9	0.6
SMU 2	11--34	58.0	8.2	33.8	SCL	5.6	4.3	-1.2	0.0	0.1	1.9	17.9	3.7	0.2	0.2	4.5	3.6	8.4	16.6	51.0	1.2	1.3				
	34-80	53.8	8.2	38.0	SCL	5.3	4.2	-1.1	0.0	1.4	0.1	0.1	1.3	0.2	0.2	5.4	4.5	10.2	12.2	84.1	1.3	1.2				
	80-155	47.5	10.3	42.2	SCL	5.3	4.2	-1.0	0.0	0.7	0.1	0.1	0.9	0.2	0.2	3.6	1.8	5.7	13.6	42.1	1.3	2.0				
DP75	0-24	48.6	31.5	19.9	L	7.1	6.5	-0.7	0.2	0.6	4.9	8.2	29.7	0.1	0.8	22.4	6.7	30.1	36.0	83.4	0.4	3.3	29.7	89.1	1.5	3.5
SMU -	24-50	47.1	20.8	32.2	SCL	7.1	6.2	-0.9	0.1	0.2	1.8	7.3	7.1	0.1	0.7	13.4	4.9	19.2	21.4	89.7	0.6	2.7				
	50-114	38.2	10.5	51.4	C	5.9	6.0	0.2	0.1	0.1	1.0	11.2	5.1	0.2	0.7	11.6	3.6	16.2	17.5	92.2	1.2	3.3				
DP77	0-17	34.9	11.6	53.6	C	5.4	4.7	-0.8	0.1	0.3	4.4	13.7	3.6	0.2	0.2	9.8	3.6	13.8	29.0	47.5	0.7	2.8	58.3	91.7	1.2	0.7
SMU 1	17-57	15.8	9.5	74.8	C	5.2	4.4	-0.9	0.0	0.2	2.2	13.1	1.3	0.2	0.1	4.5	2.7	7.4	24.3	30.6	0.7	1.7				
	57-140	3.1	9.5	87.4	C	4.9	4.2		0.0	0.1	1.2	11.4	3.6	0.2	0.1	3.6	2.7	6.5	15.1	43.2	1.0	1.3				

Profile	Depth	Texture <2 mm fraction				pH(1:2.5)			EC	Total N	Org C	C/N	Avail P	Exchange Cations (meq/100gm soil)					CEC	Base Satn	ESP	Ca/ Mg	Avail Fe	avail Mn	avail Cu	avail Zn
SMU	cm	Sand	Silt	Clay	Class	H2O	KCl	ΔPH	dS/ m	%	%		ppm	Na	K	Ca	Mg	Sum	meq/g	%	%		mg/ kg soil (ppm)			
DP78	0-18	32.0	10.5	57.5	C	5.6	4.5	-1.0	0.1	0.3	4.1	12.5	2.7	0.2	0.4	10.8	3.6	15.0	28.7	52.1	0.7	3.0	50.3	58.4	1.2	1.5
SMU 1	18-43	27.9	12.5	59.6	C	4.8	3.8	-1.0	0.0	0.1	2.4	19.5	0.9	0.2	0.2	3.6	2.7	6.6	27.3	24.3	0.6	1.3				
	43-85	27.8	8.4	63.9	C	5.1	4.2	-0.9	0.0	0.1	1.6	12.7	0.4	1.9	0.2	4.5	3.6	10.2	20.0	51.3	9.8	1.3				
	85-200	15.9	8.4	75.7	C	5.0	4.0	-1.0	0.0	0.1	0.6	7.3	1.0	0.2	0.1	3.6	2.7	6.6	15.6	42.3	1.1	1.3				
	200-300					5.4	4.8	-0.7																		
	300-400					5.3	4.5	-0.8																		
DP79	0-10	45.0	14.5	40.4	SC	4.7	4.2	-0.5	0.1	0.3	3.7	11.8	6.1	0.2	0.3	4.5	2.7	7.6	22.4	33.9	0.8	1.7	79.9	26.8	1.9	0.7
SMU 2	10--43	47.7	15.6	40.7	C	4.9	4.2	-0.7	0.0	0.1	2.4	17.5	2.8	0.2	0.1	2.7	1.8	4.7	8.3	57.3	2.1	1.5				
	43-100	36.9	16.6	46.6	C	5.0	4.3	-0.6	0.0	0.1	1.8	19.2	0.7	0.2	0.1	2.7	1.8	4.7	7.7	60.6	2.3	1.5				
	100-200	34.0	54.7	11.4	C	4.7	4.3	-0.5	0.0	0.0	1.0	21.2	0.9	0.2	0.1	2.7	1.8	4.7	12.7	37.3	1.2	1.5				
	200-300					5.1	4.4	-0.7																		
	300-350					4.9	4.2	-0.7																		
DP80	15-40	41.0	20.0	39.0	CL	4.9	4.2	-0.8	0.0	0.2	2.6	13.1	1.8	0.2	0.1	3.6	0.9	4.7	29.2	16.2	0.5	4.0	49.8	72.0	1.8	2.6
SMU 1	40-96	24.4	15.8	59.9	C	5.2	4.2	-1.0	0.0	0.2	1.7	8.5	0.1	0.2	0.1	1.8	0.9	3.0	21.4	13.8	0.8	2.0				
	96-200	17.8	8.1	74.1	C	4.9	4.2	-0.7	0.0	0.1	1.0	10.7	0.6	0.2	0.1	1.8	0.9	3.0	19.8	15.1	0.8	2.0				
DP81	0-13	59.0	10.3	30.8	SCL	5.7	4.7	-0.9	0.1	0.3	3.2	11.5	8.0	0.2	0.5	7.3	4.6	12.5	16.9	74.4	1.2	1.6	56.3	48.6	2.1	0.6
SMU 11	13-35	48.6	9.2	42.1	SC	4.9	4.1	-0.8	0.3	0.1	1.7	14.0	1.5	0.1	0.1	3.6	0.9	4.8	14.9	32.5	0.9	4.0				
	35-66	51.7	4.1	44.2	SC	4.8	3.7	-1.1	0.0	0.1	1.0	15.4	1.2	0.1	0.1	3.6	1.8	5.6	15.7	35.9	0.8	2.0				
	66-160	46.5	12.6	40.9	SC	5.0	4.2	-0.8	0.0	0.0	0.7	21.2	0.6	0.2	0.2	5.4	3.6	9.4	14.7	63.7	1.3	1.5				

Profile	Depth	Texture <2 mm fraction				pH(1:2.5)			EC	Total N	Org C	C/N	Avail P	Exchange Cations (meq/100gm soil)					CEC	Base Satn	ESP	Ca/ Mg	Avail Fe	avail Mn	avail Cu	avail Zn
SMU	cm	Sand	Silt	Clay	Class	H2O	KCl	∆PH	dS/ m	%	%		ppm	Na	K	Ca	Mg	Sum	meq/g	%	%		mg/ kg soil (ppm)			
DP82	0-15	49.2	29.1	21.8	L	5.2	4.3	-0.9	0.2	0.4	4.6	12.6	4.3	0.2	0.2	9.0	3.6	13.1	28.0	46.7	0.6	2.5	46.2	40.9	1.5	0.6
SMU 1	15-37	46.5	16.8	36.7	SC	5.0	4.2	-0.8	0.0	0.2	2.8	12.2	0.9	0.2	0.1	2.7	1.8	4.8	21.6	22.2	0.7	1.5				
	37-77	29.6	16.8	53.6	C	4.9	4.3	-0.7	0.0	0.1	1.6	12.9	0.3	0.2	0.1	1.8	0.9	3.0	24.1	12.4	0.7	2.0				
	77-200	16.8	12.6	70.6	C	4.6	4.0	-0.6	0.0	0.1	1.1	17.2	0.4	0.1	0.1	1.8	0.9	2.9	19.7	15.0	0.7	2.0				
DP83	0-23	31.5	21.1	47.4	C	5.5	4.2	-1.3	0.1	0.3	4.6	13.7	9.2	0.2	0.4	21.7	8.1	30.4	51.6	59.0	0.5	2.7	402.1	101.3	4.7	0.2
SMU 9	23-70	29.9	10.5	59.6	C	5.5	4.0	-1.5	0.0	0.1	1.7	14.0	2.8	0.3	0.2	19.0	9.0	28.6	42.3	67.6	0.7	2.1				
	70-160	28.9	5.2	65.9	C	7.9	7.1	-0.8	0.3	0.0	0.5	17.8	0.6	0.8	0.3	52.0	10.4	63.5	57.0	111.4	1.4	5.0				
DP84	0-12	47.6	5.2	47.1	SC	5.6	4.6	-1.0	0.1	0.3	4.4	13.6	4.3	0.2	0.4	6.3	1.8	8.7	22.1	39.5	0.7	3.5	61.3	21.8	0.9	0.6
SMU 1	12--40	21.2	4.2	74.6	C	4.9	3.9	-1.0	0.0	0.1	2.4	18.2	0.9	0.1	0.1	2.7	2.7	5.6	11.3	49.9	1.0	1.0				
	40-75	14.9	6.3	78.8	C	5.0	4.1	-0.8	0.0	0.1	1.7	12.1	0.6	0.2	0.1	3.6	0.9	4.7	17.5	26.8	0.9	4.0				
	75-190	22.9	7.1	70.0	C	5.0	4.4	-0.6	0.0	0.1	0.9	14.4	0.1	0.2	0.1	2.7	0.9	3.8	17.5	21.8	1.0	3.0				
DP86	0-16	36.4	9.2	54.3	C	4.9	3.9	-1.0	0.1	0.3	4.0	13.0	4.5	0.2	0.1	5.4	3.6	9.3	29.2	31.7	0.6	1.5	52.3	28.3	1.2	0.4
SMU 2	16-42	33.2	10.3	56.5	C	4.9	4.1	-0.8	0.0	0.1	2.1	19.9	0.6	0.1	0.1	3.6	0.9	4.7	23.4	20.1	0.6	4.0				
	42-80	21.8	7.2	71.0	C	4.9	4.2	-0.7	0.0	0.1	1.0	19.2	0.9	0.1	0.1	2.7	1.8	4.7	19.5	24.1	0.7	1.5				
	80-200	19.3	4.2	76.5	C	5.3	4.4	-1.0	0.0	0.1	0.8	13.7	0.4	0.2	0.1	3.6	2.7	6.5	14.6	44.6	1.1	1.3				
DP88	0-13	50.5	27.8	21.7	SCL	5.7	4.7	-1.0	0.1	0.3	3.8	13.0	3.1	0.2	0.7	6.3	1.8	8.9	21.9	40.6	0.8	3.5	58.3	75.4	1.5	0.7
SMU 3	13-50	45.1	12.4	42.4	SC	5.5	4.5	-1.0	0.0	0.2	1.9	12.5	1.5	0.1	0.1	2.7	1.8	4.7	14.5	32.5	0.9	1.5				
	50-94	41.2	11.2	47.7	C	5.7	4.7	-0.9	0.0	0.1	1.4	14.9	1.1	0.1	0.2	5.4	1.8	7.5	7.8	96.0	1.8	3.0				
	94-170	31.3	10.3	58.4	C	5.6	4.8	-0.8	0.0	0.1	1.0	12.5	3.1	0.1	0.3	4.5	4.5	9.4	13.1	71.5	1.0	1.0				

Profile	Depth	Texture <2 mm fraction				pH(1:2.5)			EC	Total N	Org C	C/N	Avail P	Exchange Cations (meq/100gm soil)					CEC	Base Satn	ESP	Ca/ Mg	Avail Fe	avail Mn	avail Cu	avail Zn
SMU	cm	Sand	Silt	Clay	Class	H2O	KCl	ΔPH	dS/ m	%	%		ppm	Na	K	Ca	Mg	Sum	meq/g	%	%		mg/ kg soil (ppm)			
DP89	0-14	50.7	27.7	21.6	C	6.2	5.7	-0.5	0.0	0.4	5.0	13.5	7.9	0.2	1.2	16.1	5.4	22.9	31.2	73.5	0.6	3.0	31.7	56.8	1.2	1.0
SMU 2	14-67	42.4	25.7	31.9	SCL	5.8	4.9	-0.9	0.0	0.2	2.1	13.5	1.5	0.1	0.4	7.2	1.8	9.5	20.9	45.4	0.7	4.0				
	67-106	33.9	18.9	47.2	CL	5.6	4.9	-0.7	0.0	0.1	1.3	14.5	1.7	0.2	0.3	5.4	1.8	7.7	16.1	47.8	1.3	3.0				
	106-200	30.5	12.5	57.1	C	5.4	4.4	-1.0	0.0	0.0	0.8	20.5	1.8	0.1	0.3	3.6	1.8	5.8	16.1	35.9	0.8	2.0				
DP90	0-12	48.6	23.1	28.3	SCL	5.1	4.2	-0.9	0.1	0.3	3.9	14.2	6.1	0.2	0.3	5.4	1.8	7.6	31.7	24.1	0.5	3.0	64.8	41.7	2.1	0.4
SMU -	12--70	25.4	50.4	24.2	SiL	4.6	4.2	-0.5	0.0	0.2	2.7	16.2	2.1	0.1	0.1	1.8	0.9	2.9	27.8	10.6	0.5	2.0				
	70-200	35.8	6.3	57.9	C	4.5	4.2	-0.3	0.1	0.1	1.8	14.3	0.8	0.1	0.1	2.7	1.8	4.7	18.0	26.2	0.6	1.5				
DP91	0-42	31.5	19.0	49.5	C	5.2	3.9	-1.3	0.0	0.3	4.6	15.3	3.4	0.2	0.3	11.6	4.5	16.6	35.5	46.6	0.5	2.6	196.0	16.3	2.3	17.1
SMU 10	42-68	26.8	15.7	57.5	C	5.3	3.9	-1.5	0.0	0.1	1.7	15.9	1.4	0.2	0.2	12.4	3.6	16.4	27.0	60.5	0.6	3.5				
	68-159	27.9	10.5	61.7	C	5.3	4.0	-1.4	0.0	0.1	1.0	13.4	1.1	0.3	0.2	14.3	2.7	17.6	28.2	62.2	1.1	5.3				
	159-184	59.2	8.4	32.5	SCL	5.4	3.8	-1.6	0.0	0.0	0.9	60.5	21.8	0.2	0.1	5.4	2.7	8.4	20.0	42.3	1.2	2.0				
DP92	0-14	48.5	50.5	1.1	SiL	6.9	6.0	-0.8	0.1	0.3	4.3	14.5	9.3	0.1	1.0	13.3	2.7	17.1	28.0	61.1	0.3	5.0	15.1	37.7	2.1	Trace
SMU -	14-43	35.9	29.4	34.7	CL	6.7	5.5	-1.2	0.1	0.1	1.9	13.6	3.4	0.1	0.5	7.6	1.8	10.0	16.1	62.0	0.5	4.3				
	43-160	54.4	12.2	33.5	SCL	6.5	6.1	-0.4	0.1	0.1	1.1	14.3	1.2	0.1	0.6	6.7	1.8	9.2	14.6	63.0	0.7	3.8				
DP93	0-13	64.1	20.5	15.4	SL	4.5	3.7	-0.7	0.2	0.2	3.6	14.6	4.4	0.1	0.2	4.6	1.8	6.7	23.8	28.2	0.5	2.5	31.7	70.8	1.8	58.6
SMU 2	13-54	45.5	16.4	38.0	SC	5.2	4.2	-1.0	0.1	0.2	2.5	14.7	2.4	0.1	0.1	2.7	0.9	3.9	18.8	20.5	0.6	3.0				
	54-102	31.1	12.3	56.6	C	4.4	3.9	-0.5	0.0	0.2	1.8	10.2	0.6	0.1	0.1	2.7	0.9	3.8	18.8	20.4	0.6	3.0				
	102-200	25.6	10.5	64.0	C	4.5	4.2	-0.3	0.0	0.3	2.5	7.8	0.5	0.1	0.1	1.8	0.9	2.9	16.2	18.1	0.8	2.0				
DP94	0-14	48.5	14.7	36.8	SC	5.3	4.3	-1.0	0.1	0.6	3.9	7.1	77.9	0.2	0.5	2.7	2.7	6.1	16.7	36.7	1.1	1.0	35.2	31.8	2.1	37.4
SMU 7	14-38	36.1	18.3	45.6	C	4.6	4.0	-0.6	0.0	0.2	2.0	8.3	27.6	0.1	0.1	1.8	0.9	2.9	14.2	20.7	0.8	2.0				
	38-70	43.6	16.4	40.0	CL	4.8	4.0	-0.8	0.0	0.1	1.4	11.7	4.4	0.1	0.1	1.8	0.9	3.0	13.8	21.6	1.0	2.0				

Profile	Depth	Texture <2 mm fraction				pH(1:2.5)			EC	Total N	Org C	C/N	Avail P	Exchange Cations (meq/100gm soil)					CEC	Base Satn	ESP	Ca/ Mg	availFe	avail Mn	avail Cu	avail Zn
SMU	cm	Sand	Silt	Clay	Class	H2O	KCl	ΔPH	dS/ m	%	%		ppm	Na	K	Ca	Mg	Sum	meq/g	%	%		mg/ kg soil (ppm)			
DP95	0-12	62.0	14.4	23.6	SCL	6.4	5.5	-0.9	0.1	0.3	3.3	11.4	21.1	0.1	0.5	9.5	1.8	11.9	17.2	69.1	0.6	5.2	28.7	26.8	2.9	18.4
SMU -	12--42	53.7	14.4	31.9	SCL	5.4	4.2	-1.2	0.0	0.1	1.8	13.0	0.9	0.2	0.2	4.5	1.8	6.7	13.3	50.6	1.3	2.5				
	42-111	42.3	14.7	43.0	C	5.1	4.3	-0.8	0.0	0.1	1.3	17.3	0.2	0.1	0.1	2.7	1.8	4.8	16.2	29.5	0.8	1.5				
DP96	0-16	52.6	25.8	21.7	SCL	5.8	4.9	-0.9	0.1	0.3	3.6	12.5	2.9	0.2	0.3	9.9	3.6	14.0	24.1	58.4	0.7	2.8	48.8	56.1	4.7	35.8
SMU -	16-46	48.2	19.7	32.1	SCL	5.2	4.1	-1.1	0.0	0.1	1.8	13.0	4.9	0.2	0.1	5.4	2.7	8.4	18.2	46.3	0.9	2.0				
	46-116	40.2	14.2	45.6	C	5.2	4.5	-0.7	0.0	0.1	0.9	13.9	213.1	0.2	0.1	7.2	2.7	10.2	15.2	67.1	1.0	2.7				
DP98	0-10	58.0	26.7	15.4	SL	6.9	6.4	-0.5	0.4	0.6	6.6	11.9	126.7	0.1	1.4	31.6	2.3	35.4	41.8	84.8	0.3	14	42.2	32.6	0.9	8.3
SMU 2	10--25	55.8	24.7	19.5	SL	6.4	6.2	-0.2	0.1	0.4	3.0	7.8	144.4	0.1	1.1	17.9	2.7	21.8	30.2	72.1	0.3	6.7				
	25-75	41.4	18.5	40.1	C	7.1	5.8	-1.3	0.1	0.1	1.5	11.1	9.8	0.1	0.9	9.6	2.3	12.9	24.3	52.9	0.4	4.2				
	75-85+	65.4	8.4	26.2	SCL	6.9	5.7	-1.1	0.1	0.0	0.7	19.4	7.2	0.1	0.5	4.6	1.4	6.5	10.9	59.9	0.6	3.3				
DP99	0-15	73.0	15.6	11.4	SL	6.4	5.4	-1.0	0.1	0.3	3.2	12.1	88.7	0.1	0.5	7.7	2.7	11.0	15.2	72.1	0.6	2.8	34.7	1.7	1.5	25.0
SMU -	15-33	69.6	14.7	15.7	SL	5.4	4.3	-1.1	0.0	0.2	2.2	12.9	80.8	0.2	0.2	1.8	0.9	3.0	14.1	21.4	1.1	2.0				
	33-145	53.8	13.7	32.6	SCL	5.1	3.9	-1.1	0.0	0.1	1.2	8.4	16.3	0.1	0.2	1.8	1.8	4.0	14.4	27.5	0.8	1.0				
DP100	0-15	44.2	25.3	30.5	CL	5.3	4.4	-1.0	0.1	0.3	2.9	9.9	16.2	0.1	0.6	9.0	4.5	14.3	15.2	93.8	0.9	2.0	56.8	54.5	2.6	47.5
SMU 1	15-40	43.1	16.8	40.0	C	5.0	3.7	-1.3	0.0	0.2	2.8	12.2	8.2	0.1	0.1	2.7	1.8	4.8	19.7	24.2	0.6	1.5				
	40-75	46.7	12.6	40.8	SC	5.1	4.1	-1.0	0.0	0.1	2.2	18.0	2.0	0.1	0.1	3.6	1.8	5.6	16.6	33.9	0.8	2.0				
	75-175	32.0	11.0	57.0	C	4.8	3.9	-0.8	0.0	0.1	1.3	20.8	15.9	0.1	0.1	2.7	1.8	4.7	6.9	68.8	1.4	1.5				
DP102	0-15	59.0	14.0	27.0	SCL	6.0	5.0	-1.0	0.1	0.3	3.9	14.6	17.7	0.1	1.1	9.0	2.7	12.9	27.5	47.0	0.4	3.3	177.9	16.8	2.1	40.9
SMU -	15-40	61.1	14.7	24.2	SCL	5.0	3.9	-1.1	0.0	0.1	1.8	19.2	7.5	0.1	0.1	2.7	1.8	4.7	15.1	31.4	0.9	1.5				
	40-100	52.7	12.6	34.7	SCL	5.1	3.8	-1.3	0.0	0.0	0.7	18.8	0.9	0.2	0.1	3.6	1.8	5.7	17.0	33.3	0.9	2.0				
	100-200	54.4	8.1	37.5	SCL	5.5	4.0	-1.5	0.0	0.0	0.2	16.0	1.4	0.2	0.2	4.5	2.7	7.6	18.0	42.1	1.2	1.7				

Profile	Depth	Texture <2 mm fraction				pH(1:2.5)			EC	Total N	Org C	C/N	Avail P	Exchange Cations (meq/100gm soil)					CEC	Base Satn	ESP	Ca/ Mg	availFe	avail Mn	avail Cu	avail Zn
SMU	cm	Sand	Silt	Clay	Class	H2O	KCl	ΔPH	dS/ m	%	%		ppm	Na	K	Ca	Mg	Sum	meq/g	%	%		mg/ kg soil (ppm)			
DP103	0-20	27.0	32.0	41.0	C	5.5	4.1	-1.4	0.0	0.4	4.3	12.2	43.7	0.2	0.3	14.5	8.1	23.2	48.1	48.1	0.5	1.8	408.2	26.5	5.6	41.5
SMU 9	20-50	25.0	26.0	49.0	C	5.5	3.9	-1.6	0.0	0.2	1.7	9.6	10.7	0.3	0.2	13.6	9.0	23.1	30.0	77.0	0.9	1.5				
	50-160	29.0	16.5	54.5	C	6.4	4.5	-1.9	0.0	0.1	0.8	12.3	23.2	0.9	0.3	19.3	9.4	29.9	39.9	74.8	2.2	2.0				
	160-190	67.5	10.5	22.0	SCL	7.5	5.9	-1.6	0.1	0.0	0.4	16.4	218.5	0.6	0.1	9.9	4.9	15.5	21.9	70.9	2.8	2.0				
	190-300	84.3	6.3	9.4	SL	7.4	5.7	-1.6	0.0	0.0	0.2	10.1	141.7	0.3	0.1	6.7	2.2	9.3	13.5	68.8	2.6	3.0				
DP104	0-10	8.7	17.6	73.7	C	4.9	4.0	-0.9	0.0	0.1	1.4	15.2	5.3	0.1	0.1	2.7	1.8	4.8	24.1	19.7	0.5	1.5	50.3	121.1	5.3	79.2
SMU 4	10--30	29.8	27.3	43.0	C	5.4	4.3	-1.1	0.0	0.2	2.9	11.9	22.3	0.1	0.1	6.3	3.6	10.2	31.9	31.9	0.4	1.8				
	30-200	48.5	33.6	17.9	L	5.8	5.0	-0.8	0.2	0.4	5.2	14.0	18.3	0.1	0.4	15.4	9.9	25.8	35.9	72.0	0.4	1.5				
DP105	0-22	54.7	25.3	20.0	SCL	7.1	5.3	-1.8	0.1	0.3	4.9	15.3	152.5	0.1	1.3	19.0	5.4	25.8	39.8	64.8	0.3	3.5	106.6	21.2	1.8	79.2
SMU -	22-75	60.0	20.0	20.0	SCL	5.4	4.3	-1.2	0.0	0.2	2.6	15.2	129.5	0.2	0.2	4.5	3.6	8.4	24.8	34.0	0.6	1.3				
	75-123	35.2	17.8	47.1	C	5.4	4.3	-1.1	0.0	0.1	0.9	10.4	147.9	0.2	0.3	7.2	2.7	10.4	25.1	41.6	0.6	2.7				
DP106	0-19	61.3	23.0	15.7	SL	7.0	6.4	-0.6	0.2	0.5	7.2	14.4	78.9	0.2	2.0	27.8	5.4	35.3	41.9	84.3	0.5	5.2	39.2	61.4	1.8	2.0
SMU -	19-70	38.2	18.8	42.9	C	6.3	5.0	-1.3	0.0	0.4	2.6	7.1	6.4	0.1	0.7	15.2	2.7	18.7	71.6	26.1	0.1	5.7				
	70-124	22.2	17.9	59.9	C	5.8	4.7	-1.0	0.0	0.2	1.2	7.7	123.7	0.3	1.0	9.0	2.7	12.9	20.5	62.9	1.3	3.3				
DP107	0-13	56.9	21.0	22.1	C	6.3	5.5	-0.8	0.2	0.4	4.4	10.7	100.0	0.2	1.0	25.5	7.2	33.9	47.7	71.0	0.3	3.6	48.3	53.2	11.4	52.0
SMU 8	13-60	53.0	14.6	32.4	SCL	6.5	5.1	-1.4	0.1	0.2	1.8	11.6	10.5	0.1	0.2	11.2	4.0	15.5	22.4	69.2	0.5	2.8				
DP109	0-25	69.6	18.8	11.5	SL	6.0	5.1	-0.9	0.1	0.4	6.7	15.4	42.0	0.2	0.5	17.0	17.0	34.8	50.2	69.3	0.4	1.0	47.8	26.8	2.1	0.7
SMU 4	25-55	33.8	23.1	43.1	C	5.3	4.3	-1.1	0.0	0.2	2.6	15.4	4.0	0.2	0.1	5.4	3.6	9.2	35.5	26.0	0.4	1.5				
	55-90	8.6	18.9	72.5	C	5.2	4.5	-0.6	0.0	0.1	1.0	12.9	4.1	0.2	0.1	4.5	1.8	6.5	29.2	22.4	0.5	2.5				
	90-200	10.7	15.2	74.1	C	5.3	4.7	-0.6	0.0	0.0	0.6	20.6	19.8	0.2	0.1	4.5	3.6	8.4	19.0	44.0	0.9	1.3				

Profile	Depth	Texture <2 mm fraction				pH (1:2.5)			EC	Total N	Org C	C/N	Avail P	Exchange Cations (meq/100gm soil)					CEC	Base Satn	ESP	Ca/ Mg	Avail Fe	avail Mn	avail Cu	avail Zn
SMU	cm	Sand	Silt	Clay	Class	H2O	KCl	ΔPH	dS/m	%	%		ppm	Na	K	Ca	Mg	Sum	meq/g	%	%		mg/ kg soil (ppm)			
DP110	0-21	41.6	47.2	11.3	L	4.7	3.9	-0.8	0.3	0.3	4.3	13.9	15.0	0.2	0.3	13.4	4.5	18.5	42.9	43.1	0.5	3.0	103.6	45.7	2.3	1.3
SMU 9	21-38	41.4	20.5	38.0	CL	4.6	3.7	-0.9	0.3	0.2	2.0	9.8	10.1	0.2	0.3	9.0	5.4	14.8	32.6	45.4	0.7	1.7				
	38-70	37.3	14.4	48.3	C	4.8	3.8	-1.0	0.3	0.1	1.1	8.7	4.4	0.3	0.3	14.3	3.6	18.5	41.4	44.7	0.6	4.0				
	70-200	29.7	8.4	61.9	C	6.2	4.7	-1.5	0.1	0.1	0.8	13.5	4.4	0.3	0.4	35.8	6.7	43.3	63.8	67.8	0.5	5.3				

Source: MCE laboratory analyses, 2009; SMU = soil mapping unit.

Texture codes: SC - Sandy Clay; SL - Sandy Loam; SCL - Sandy Clay Loam; SiL - Silt Loam; L - Loam; CL - Clay Loam; sIcl - Silty Clay Loam

Note: Values have been rounded off for presentation; calculations (eg C/N) are based on laboratory values that are available as Excel files.

Table A.2: Summary of Laboratory Results of Major Soil Types (FAO Classification)

Nitisols (NT)-Surface

Value	PH(1:2.5)			EC	TN	OC	C/N	Av.P	Cations (meq/100gm soil					CEC	BSP	ESP	Ca/Mg	Ca+Mg/ K	Micronutrient mg/kg			
	H2O	KCl	ΔPH	dS/m	%	%	N	ppm	Na	K	Ca	Mg	Sum	meq/100g	%	%			Fe	Mn	Cu	Zn
Aver.	5.3	4.4	-0.9	0.07	0.3	3.5	12.7	8.0	0.2	0.4	8.5	3.5	12.6	30.4	41.9	0.7	3.0	35.9	49.9	59.7	1.7	3.4
Maxi.	6.4	6.0	-0.4	0.20	0.7	7.3	21.8	85.7	0.3	1.3	26.0	17.0	34.8	54.1	93.8	1.5	8.8	136.5	177.9	139.5	2.9	47.5
Min.	4.5	3.7	-1.3	0.01	0.1	1.5	2.7	0.3	0.1	0.1	1.8	0.9	2.9	10.2	13.2	0.3	1.0	9.6	20.1	11.9	0.6	0.0

Nitisols (NT) - Subsurface

Value	PH(1:2.5)			EC	TN	OC	C/N	Av.P	Cations (meq/100gm soil					CEC	BSP	ESP	Ca/Mg	Ca+Mg/ K	Micronutrient mg/kg			
	H2O	KCl	ΔPH	dS/m	%	%	N	ppm	Na	K	Ca	Mg	Sum	meq/100g	%	%			Fe	Mn	Cu	Zn
Aver.	5.1	4.4	-0.7	0.02	0.1	1.4	11.5	5.3	0.2	0.2	5.0	2.2	7.6	23.6	34.5	1.0	2.7	40.9				
Maxi.	7.8	8.9	4.1	0.17	0.7	4.6	21.8	100.8	1.9	0.9	29.1	7.2	37.0	66.7	96.1	9.8	9.8	110.5				
Min.	4.3	3.7	-2.9	0.01	0.01	0.02	0.04	0.62	0.1	0.1	1.8	0.9	2.9	6.9	9.0	0.2	0.9	10.8				

Vertisols (VR) - Surface

Value	PH(1:2.5)			EC	TN	OC	C/N	Av.P	Cations (meq/100gm soil					CEC	BSP	ESP	Ca/Mg	Ca+Mg/ K	Micronutrient mg/kg			
	H2O	KCl	ΔPH	dS/m	%	%	N	ppm	Na	K	Ca	Mg	Sum	meq/100g	%	%			Fe	Mn	Cu	Zn
Aver.	5.1	4.0	-1.1	0.1	0.2	2.9	11.4	12.8	0.2	0.4	13.5	5.4	19.5	40.5	47.5	0.6	4.0	51.5	241.6	48.9	3.2	6.8
Maxi.	5.5	4.2	-0.8	0.3	0.4	4.6	14.5	43.7	0.3	0.7	21.7	8.1	30.4	52.6	65.5	0.9	20.0	80.4	408.2	101.3	5.6	41.5
Min.	4.6	3.7	-1.4	0.01	0.1	1.1	7.1	1.3	0.2	0.2	6.3	0.9	9.3	26.8	27.4	0.4	1.5	13.7	75.4	12.1	2.1	0.2

Vertisols (VR) - Subsurface

Value	PH(1:2.5)			EC	TN	OC	C/N	Av.P	Cations (meq/100gm soil					CEC	BSP	ESP	Ca/Mg	Ca+Mg/ K	Micronutrient mg/kg			
	H2O	KCl	∆PH	dS/m	%	%	N	ppm	Na	K	Ca	Mg	Sum	meq/100g	%	%			Fe	Mn	Cu	Zn
Aver.	5.7	4.4	-1.3	0.1	0.1	1.0	11.6	18.7	0.4	0.3	20.9	6.8	28.4	40.9	68.2	1.1	5.2	100.5				
Maxi.	7.9	7.1	-0.4	0.3	0.2	1.8	17.8	218.5	0.9	0.4	52.0	13.4	63.5	63.8	111.4	2.8	27.0	215.3				
Min.	4.8	3.5	-1.9	0.01	0.02	0.4	7.6	0.3	0.2	0.1	8.9	0.9	13.7	21.7	44.7	0.5	1.3	52.0				

Acrisols (AC)-Surface

Value	PH(1:2.5)			EC	TN	OC	C/N	Av.P	Cations (meq/100gm soil					CEC	BSP	ESP	Ca/Mg	Ca+Mg/ K	Micronutrient mg/kg			
	H2O	KCl	∆PH	dS/m	%	%	N	ppm	Na	K	Ca	Mg	Sum	meq/100g	%	%			Fe	Mn	Cu	Zn
Aver.	5.5	4.8	-0.7	0.1	0.3	3.6	12.5	25.6	0.2	0.5	9.7	3.1	13.5	27.1	48.3	4.6	3.4	26.8	41.9	43.2	1.6	6.7
Maxi.	6.9	6.4	-0.1	0.4	0.6	6.6	17.9	144.4	0.2	1.4	31.6	5.4	35.4	41.8	84.8	56.2	14.0	26.7	79.9	73.4	3.5	58.6
Min.	4.5	3.7	-1.2	0.02	0.1	1.9	7.8	3.1	0.1	0.1	3.2	1.8	5.7	13.3	24.1	0.3	0.9	61.1	26.1	5.6	0.9	0.0

Acrisols (AC)-Subsurface

Value	PH(1:2.5)			EC	TN	OC	C/N	Av.P	Cations (meq/100gm soil					CEC	BSP	ESP	Ca/Mg	Ca+Mg/ K	Micronutrient mg/kg			
	H2O	KCl	∆PH	dS/m	%	%	N	ppm	Na	K	Ca	Mg	Sum	meq/100g	%	%			Fe	Mn	Cu	Zn
Aver.	5.2	4.4	-0.7	0.03	0.2	1.6	13.0	4.6	0.2	0.2	4.1	1.8	6.3	16.9	40.5	6.3	2.4	30.5				
Maxi.	7.1	5.8	-0.3	0.07	1.4	3.1	21.2	62.3	0.2	0.9	11.1	4.5	13.9	27.8	89.9	89.9	5.0	17.2				
Min.	4.2	3.9	-1.3	0.01	0.04	0.1	0.1	0.4	0.1	0.1	1.8	0.9	2.9	7.7	10.6	0.4	1.0	39.4				

Cambisols (CM)-Surface

Value	PH(1:2.5)			EC	TN	OC	C/N	Av.P	Cations (meq/100gm soil)					CEC	BSP	ESP	Ca/Mg	Ca+Mg/ K	Micronutrient mg/kg			
	H2O	KCl	ΔPH	dS/m	%	%	N	ppm	Na	K	Ca	Mg	Sum	meq/100g	%	%			Fe	Mn	Cu	Zn
Aver.	6.3	5.5	-0.8	0.1	0.4	4.7	11.4	60.4	0.1	0.9	15.9	4.5	21.5	30.7	66.3	0.6	3.4	21.7	52.0	66.5	3.0	19.1
Maxi.	7.1	6.5	0.1	0.2	0.6	7.8	16.8	152.5	0.3	2.0	27.8	7.2	36.0	47.7	95.6	1.2	5.3	17.8	108.6	152.7	11.4	79.2
Min.	4.6	4.0	-1.8	0.03	0.2	2.0	7.1	3.2	0.1	0.1	1.8	0.9	2.9	14.2	20.7	0.3	1.0	23.4	24.1	21.2	1.5	0.7

Cambisols (CM)-Subsurface

Value	PH(1:2.5)			EC	TN	OC	C/N	Av.P	Cations (meq/100gm soil)					CEC	BSP	ESP	Ca/Mg	Ca+Mg/ K	Micronutrient mg/kg			
	H2O	KCl	ΔPH	dS/m	%	%	N	ppm	Na	K	Ca	Mg	Sum	meq/100g	%	%			Fe	Mn	Cu	Zn
Aver.	6.1	5.3	-0.8	0.05	0.2	1.6	10.4	54.5	0.2	0.5	10.0	4.3	15.0	23.7	67.6	0.9	2.7	28.2				
Maxi.	7.1	7.8	1.1	0.14	0.4	3.0	16.2	219.5	0.3	1.0	21.7	14.5	37.2	71.6	122.0	2.3	5.7	37.9				
Min.	4.8	4.0	-1.4	0.01	0.05	0.7	6.9	2.4	0.1	0.1	1.8	0.9	3.0	13.5	21.6	0.1	1.3	23.4				

Gleysols (GL)-Surface

Value	PH(1:2.5)			EC	TN	OC	C/N	Av.P	Cations (meq/100gm soil)					CEC	BSP	ESP	Ca/Mg	Ca+Mg/ K	Micronutrient mg/kg			
	H2O	KCl	ΔPH	dS/m	%	%	N	ppm	Na	K	Ca	Mg	Sum	meq/100g	%	%			Fe	Mn	Cu	Zn
Aver.	5.2	3.9	-1.3	0.04	0.3	4.6	15.3	3.4	0.2	0.3	11.6	4.5	16.6	35.5	46.6	0.5	2.6	58.5	196.0	16.3	2.3	17.1
Maxi.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Min.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Gleysols (GL)- Sub-surface

Value	PH(1:2.5)			EC	TN	OC	C/N	Av.P	Cations (meq/100gm soil)					CEC	BSP	ESP	Ca/Mg	Ca+Mg/ K	Micronutrient mg/kg			
	H2O	KCl	∆PH	dS/m	%	%	N	ppm	Na	K	Ca	Mg	Sum	meq/100g	%	%			Fe	Mn	Cu	Zn
Aver.	5.4	3.9	-1.5	0.02	0.1	1.2	29.9	8.1	0.2	0.2	10.7	3.0	14.1	25.1	55.0	1.0	3.6	74.7				
Maxi.	5.4	4.0	-1.4	0.02	0.1	1.7	60.5	21.8	0.3	0.2	14.3	3.6	17.6	28.2	62.2	1.2	5.3	82.0				
Min.	5.3	3.8	-1.6	0.02	0.0	0.9	13.4	1.1	0.2	0.1	5.4	2.7	8.4	20.0	42.3	0.6	2.0	58.5				

Leptosols (LP)-Surface

Value	PH(1:2.5)			EC	TN	OC	C/N	Av.P	Cations (meq/100gm soil)					CEC	BSP	ESP	Ca/Mg	Ca+Mg/ K	Micronutrient mg/kg			
	H2O	KCl	∆PH	dS/m	%	%	N	ppm	Na	K	Ca	Mg	Sum	meq/100g	%	%			Fe	Mn	Cu	Zn
Aver.	5.8	4.9	-0.9	0.1	0.4	4.7	11.8	13.6	0.4	0.7	13.7	3.3	18.2	29.9	56.4	1.6	4.1	23.4	39.7	53.3	1.0	0.9
Maxi.	6.8	6.0	-0.8	0.2	0.7	6.8	12.8	33.3	0.9	1.3	26.0	4.5	31.1	43.8	70.9	3.6	7.3	22.7	50.8	62.6	1.5	1.7
Min.	4.8	3.9	-1.0	0.01	0.2	2.6	10.2	3.3	0.1	0.1	4.5	1.8	6.6	20.0	33.0	0.3	2.4	45.5	28.7	44.0	0.6	0.1

Leptosols (LP)- Sub-surface

Value	PH(1:2.5)			EC	TN	OC	C/N	Av.P	Cations (meq/100gm soil)					CEC	BSP	ESP	Ca/Mg	Ca+Mg/ K	Micronutrient mg/kg			
	H2O	KCl	∆PH	dS/m	%	%	N	ppm	Na	K	Ca	Mg	Sum	meq/100g	%	%			Fe	Mn	Cu	Zn
Aver.	5.7	5.0	-0.7	0.04	0.2	1.6	8.5	3.2	0.2	0.3	10.8	3.6	14.8	21.7	64.3	0.8	3.0	43.0				
Maxi.	6.8	6.0	-0.7	0.06	0.2	1.6	9.7	5.6	0.2	0.6	16.1	5.4	22.3	25.8	86.2	1.0	3.0	37.4				
Min.	4.7	4.0	-0.8	0.01	0.2	1.6	7.3	0.8	0.2	0.1	5.4	1.8	7.4	17.5	42.4	0.7	3.0	78.0				

Source: MCE, laboratory analyses, 2009

Table A.3: Physical Characterstics of Major FAO Soil Types

No	Soil Type	Depth	Texture	Drainage	CaCO3	AWC	Infiltration	H.C	Area	
		cm.	Class	Class	%	mm/m	cm/hr	m/day	ha	%
1	Nitisols (NT)	>180	Clay loam -Clay	WD	6.17	98.9	8.63	2.29	4302.76	41.61
2	Acrisols (AC)	>160	Loam –Sandy clay loam	WD	1.78	122.42	9.23	2.43	1062.72	10.17
3	Leptosols (LP)	>60	Loam –Clay loam	SWED	-	-	-	-	787.51	7.54
4	Cambisols (CM)	>70	Loam –Sandy clay loam	WD	5.33	95.05	-	-	1311.40	12.56
5	Vertisols (VR)	>200	Clay	ID	2.24	138.3 5	6.50	0.1	1053.10	10.08
6	GLeysols (GL)	>184	Clay	PD	-	130.40	-	-	28.99	0.28

APPENDIX A. TABLE A. 4. In-situ pH Measurements

No.	Local code	UTM_Easting	UTM_Northing	Depth (cm)	pH Reading
1	D40/30	189200	987400	25-100	5.17
2	D40/30	189200	987400	0-25	5.30
3	D40/32	190000	987400	25-100	5.52
4	D40/32	190000	987400	0-25	5.58
5	D43/29	188800	988200	0-25	5.57
6	D43/29	188800	988200	0-100	5.58
9	D60/21	195600	992000	0-25	5.99
10	D63/21	195600	992000	0-25	5.98
11	D64/10	181200	992200	0-25	5.67
12	D64/9	180800	992200	0-25	5.34
13	D64/9	180800	992200	25-100	5.74
15	D65/34	190800	992400	25-100	6.27
16	D65/34	190800	992400	0-25	6.65
17	D67/3	182400	992800	0-25	5.81
18	D67/35	194200	992800	25-100	5.77
20	D67/35	180000	999600	0-25	6.44
21	D67/35	182400	992800	25-100	5.49
22	D72/31	189600	993800	0-25	6.49
23	D72/31	189600	993800	25-100	6.17
24	D73/26	187600	994000	25-100	6.08
25	D73/26	187600	994000	0-25	5.80
26	D76/14	182800	994600	0-25	5.06
27	D76/14	182800	994600	0-100	5.24
29	D76/17	181485	998027	25-100	5.70
30	D76/17	184000	994600	0-25	5.15
31	D77/19	184800	994800	0-25	5.59
32	D77/8	180400	994900	0-25	4.99
33	D77/8	180400	994800	25-100	6.25
35	D78/25	187200	995000	0-25	6.52
36	D79/19	184800	995200	0-25	5.92
37	D79/23	186400	995200	0-25	6.09
38	D81/15	183200	995600	0-25	6.23
39	D81/15	183200	995600	0-100	6.67

APPENDIX A. TABLE A. 4. In-situ pH Measurements (contd.)

No.	Local code	UTM_Easting	UTM_Northing	Depth (cm)	pH Reading
40	D82/20	185200	995800	0-25	5.24
41	D82/20	185200	995600	25-100	5.31
42	D83/20	185200	996000	0-25	5.50
43	D83/20	185200	996000	0-100	5.24
44	D90/11	181600	997400	0-25	5.19
45	D90/11	181600	997400	0-100	5.32
46	D90/14	182800	997400	0-25	6.07
47	D93/18	184400	998000	0-25	6.11
49	D95/17	184000	998400	0-25	6.00
50	D95/17	184000	998400	25-100	6.06
51	D96/8	180400	998600	0-25	6.68
52	D96/8	180400	998600	25-100	5.68
53	DP93/18	184400	998000	0-25	6.00
54	DP50/48	189864	989465	0-25	6.23
55	DP40/19	184800	989400	0-25	6.33
56	DP40/19	184800	989400	25-100	6.14
57	DP48/32	189864	989435	0-25	5.50
58	DP49/31	189407	988588	0-25	5.55
59	DP49/31	189407	988588	25-50	5.21
60	DP53/22	185970	992000	25-100	5.60
61	DP53/22	185970	992000	0-25	5.79
62	DP62/10	181489	992610	0-25	6.31
63	DP62/10	181489	992600	25-100	6.20
64	DP87/16	183544	995905	25-100	5.86
65	DP87/16	183544	995905	0-25	6.17
66	DP89/15	183200	997200	25-100	5.75
67	DP89/15	183200	997200	0-25	5.81
68	DP97/12	181485	998027	0-39	6.37

Source: Field Investigations, 2009

Appendix A.5: Exchangeable Acidity Test Results on Selected Soil Samples which have pH less than 5

No	Profile Pit & Depth		Av. P	K	Ca	Mg	Al+H	CEC	BSP	Exchange.	pH	OC	Texture %	
	N0	(cm.)	ppm	meq/100gm soil					%	Acidity %	H2O	%	Clay	Class
1	DP1	20-62	Trace	0.14	6.4	2.7	0.77	23.8	39.8	7.7	4.8	1.2	58.1	clay
2	DP7	0-17	3.0	0.7	11.6	5.4	0.36	39.0	45.9	2.0	5.0	2.3	39.2	C.L
3	DP7	17-64	2.0	0.3	3.6	0.9	1.57	32.6	15.2	24.7	4.3	1.8	61.1	Clay
4	DP10	15-35	1.7	0.2	5.4	1.8	1.49	10.2	73.9	16.8	4.9	1.5	48.0	clay
5	DP11	16-46	0.7	0.1	5.4	1.8	0.92	21.9	34.3	11.2	4.7	2.0	47.0	clay
6	DP12	14-35	1.0	0.2	7.2	0.9	0.54	24.8	34.0	6.1	4.9	2.3	47.6	clay
7	DP13	0-17	5.9	0.4	9.9	1.8	0.45	38.0	32.2	3.6	5.0	3.5	25.7	Loam
8	Dp17	15-37	4.3	0.4	6.3	1.8	0.85	31.4	27.4	9.1	4.6	2.8	71.4	clay
9	DP18	0-20	6.6	0.6	9.0	3.6	0.36	36.8	36.5	2.6	4.9	3.3	50.5	clay
10	DP18	20-42	3.3	0.3	7.2	1.8	2.39	33.9	27.9	20.4	4.6	2.6	55.0	clay
11	Dp20	12--35	1.7	0.2	3.6	0.9	1.55	31.7	15.3	24.7	4.8	2.2	45.3	clay
12	DP22	0-15	4.7	0.6	6.3	1.8	0.29	25.3	34.9	3.2	4.8	2.6	44.5	clay
13	DP22	15-30	1.4	0.3	3.6	0.9	1.42	25.3	20.1	22.9	4.8	2.2	34.3	Sacl
14	DP23	15-30	3.2	0.2	6.3	2.7	2.88	34.1	27.4	24.0	4.8	1.5	52.4	clay
15	DP27	0-17	4.2	0.2	4.6	1.8	0.77	22.8	29.8	10.5	4.8	2.7	38.4	Cl
16	DP27	17-40	2.4	0.1	2.7	0.9	1.42	24.8	16.0	27.3	4.7	2.0	44.7	clay
17	DP31	18-43	1.3	0.7	6.3	6.3	1.57	37.8	36.0	10.5	4.9	2.6	62.5	clay
18	DP38	14-36	0.6	0.2	4.5	2.7	1.45	28.7	26.3	16.5	4.8	3.0	38.8	Cl
19	DP50	19-50	0.3	0.2	2.7	1.8	1.65	19.2	25.5	26.0	4.7	1.9	46.9	clay
20	DP52	20-43	1.4	0.1	2.7	0.9	3.26	23.6	16.9	**46.5**	4.7	3.1	22.0	Sal
21	DP54	13-40	3.3	0.1	4.5	1.8	1.45	20.0	33.0	18.4	4.8	2.6	42.7	clay
22	DP58	0-17	4.5	1.3	26.0	3.6	1.80	43.8	70.9	5.5	4.5	3.1	44.3	clay
23	Dp77	0-17	3.6	0.2	9.8	3.6	0.12	29.0	47.5	0.9	5.4	4.4	53.6	clay
24	DP78	18-43	0.9	0.2	3.6	2.7	1.26	27.3	24.3	16.3	4.8	2.4	59.6	clay
25	DP79	0-10	6.1	0.3	4.5	2.7	0.89	22.4	33.9	10.7	4.7	3.7	40.4	Sac
26	DP79	10--43	2.8	0.1	2.7	1.8	3.37	8.3	57.3	**42.4**	4.9	2.4	40.7	clay
27	DP80	15-40	1.8	0.1	3.6	0.9	3.39	29.2	16.2	**42.5**	4.9	2.6	39.0	Cl
28	DP81	13-35	1.5	0.1	3.6	0.9	1.45	14.9	32.5	23.6	4.9	1.7	42.1	Sac
29	DP82	15-37	0.9	0.1	2.7	1.8	1.46	21.6	22.2	24.0	5.0	2.8	36.7	Sacy
30	DP83	0-23	9.2	0.4	21.7	8.1	1.88	51.6	59.0	5.9	5.5	4.6	47.4	clay
31	DP84	12-40	0.9	0.1	2.7	2.7	0.73	11.3	49.9	11.7	4.9	2.4	74.6	clay
32	DP86	0-16	4.5	0.1	5.4	3.6	0.69	29.2	31.7	7.0	4.9	4.0	54.3	clay
33	DP86	16-42	0.6	0.1	3.6	0.9	2.80	23.4	20.1	**38.0**	4.9	2.1	56.5	clay
34	DP90	12--70	2.1	0.1	1.8	0.9	5.87	27.8	10.6	**67.7**	4.6	2.7	24.2	SiL
35	DP93	0-13	4.4	0.2	4.6	1.8	1.26	23.8	28.2	16.1	4.5	3.6	15.4	SaL

Appendix A.5: Exchangeable Acidity Test Results. On Selected Soil Samples which have pH less than 5 (contd.)

No	Profile Pit & Depth		Av. P	K	Ca	Mg	Al+H	CEC	BSP	Exchange.	pH	OC	Texture %	
	N0	(cm.)	ppm	meq/100gm soil					%	Acidity %	H2O	%	Clay	Class
36	DP94	14-38	27.6	0.1	1.8	0.9	2.06	14.2	20.7	**42.1**	4.6	2.0	45.6	clay
37	DP96	0-16	2.9	0.3	9.9	3.6	0.04	24.1	58.4	0.3	5.8	3.6	21.7	Sacl
38	DP100	15-40	8.2	0.1	2.7	1.8	1.65	19.7	24.2	26.2	5.0	2.8	40.0	clay
39	DP104	10-30	22.3	0.1	6.3	3.6	0.68	31.9	31.9	6.3	5.4	2.9	43.0	clay
40	DP110	0-21	15.0	0.3	13.4	4.5	0.77	42.9	43.1	4.0	4.7	4.3	11.3	Loam

Appendix B : Soil Physical Tests

Table B.1 Basic Infiltration Rates, Dinger Bereha Area

Test No	Model Profile	Mapping Unit Final Map Code	Mapping Unit Old map Code (Draft Field Investigations)	Basic Infiltration Rate (cm/hr)	Soil Classification (FAO-1998)
1	DP2	4	G2d_2	6.9	Rhodic Nitisol
2	DP3	3	G2d_1	9.5	Orthidystric Nitisol
3	DP9	9	V1b_3	6.8	Mesotrophic Vertisol
4	DP12	3	G2d_1	9.7	Orthidystric Nitisol
5	DP18	3	G2d_1	9.9	Orthidystric Nitisol
6	DP52	2	G1b_4	10.0	Hyperferric Acrisol
7	DP65	7	U1e_5	9.7	Fluvic Cambisol
8	DP78	1	G1b_1	9.2	Orthidystric Nitisol
9	DP83	9	V1b_3	6.3	Mesotrophic Vertisol
10	DP86	2	G1b_4	9.1	Hyperferric Acrisol
11	DP90	2	G1b_4	8.6	Hyperferric Acrisol

Table B.2 Hydraulic Conductivity Tests, Dinger Bereha

Test No	Profile	Mapping Unit Final Map Code	Mapping Unit Old Map Code	Replicate Rate K (m/day)	Average Rate K (m/day)	Soil Classification (FAO 1998)
1	DP2	4	G2d_2	6.59		
				2.09	3.63	Rhodic Nitisol
				2.2		
2	DP3	3	G2d_1	0.58		
				1.06	1.3	Orthidystric Nitisol
				2.27		
3	DP9	9	V1b_3	0.36		
				0.56	0.04	Mesotrophic Vertisol
				0.28		
4	DP12	3	G2d_1	4.51		
				4.43	3.6	Orthidystric Nitisol
				1.87		
5	DP18	3	G2d_1	0.50		
				0.25	0.38	Orthidystric Nitisol
				0.39		
6	DP52	2	G1b_4	1.92		
				2.44	2.4	Hyperferric Acrisol
				2.85		
7	DP65	7	U1e_5	0.88		
				1.32	1.40	Fluvic Cambisol
				1.99		
8	DP78	1	G1b_1	2.10		
				1.00	1.50	Orthidystric Nitisol
				1.38		
9	DP83	9	V1b_3	0.51		
				0.18	0.10	Mesotrophic Vertisol
				0.21		
10	DP86	2	G1b_4	2.22		
				5.83	2.95	Hyperferric Acrisol
				0.81		
11	DP90	2	G1b_4	4.10		
				1.50	1.96	Hyperferric Acrisol
				0.28		

Table B.3 Comparison of Basic Infiltration Rates & Hydraulic Conductivity Tests

Test No	Mapping Unit Final Code	Mapping Unit Old Soil Code (Field Investigations draft report)	Soil Texture	Basic Infiltration (cm/hr)	Hydraulic Conductivity K (m/day)
1	4	G2d_2	Clay Loam	6.9	3.63
2	3	G2d_1	Clay Loam	9.5	1.30
3	9	V1b_3	Clay Loam	6.8	0.40
4	3	G2d_1	Clay	9.7	3.60
5	3	G2d_1	Clay	9.9	0.38
6	2	G1b_4	Sandy Loam	10.0	2.40
7	7	U1e_5	Sandy Clay Loam	9.7	1.40
8	1	G1b_1	Clay	9.2	1.50
9	9	V1b_3	Clay	6.3	0.10
10	2	G1b_4	Clay	9.1	2.95
11	2	G1b_4	Sandy Clay Loam	8.6	1.96

Note : Test Site Nos. are the same as in Table B 2.

Table B 4 Soil Moisture Analyses at Dinger Bereha

Profile No.	Horizon cm	Depth (mm)	Textural Class	FC % vol	PWP % vol	BD gm/cm^{-3}	AWC cm/m	Horizon cm/m	AWC mm/m	TRAWC mm/m	FAO Soil Unit 1988
DP2	0-30	300	CL	32.7	23.8	1.3	11.5	34.6			Rhodic Nitisol
	30-70	700	Clay	33.5	26.3	1.4	10.0	70.1	105	62.9	
DP3	0-50	500	CL	32.8	24.9	1.3	10.4	51.9			Orthidystric Nitisol
	50-100	500	Clay	34.8	26.4	1.3	10.9	54.6	107	63.9	
DP9	0-30	300	SCL	22.5	16.4	1.4	8.2	24.7			
	30-70	400	CL	23.2	16.4	1.3	8.9	35.5			
	70-100	300	CL	25.1	17.1	1.3	10.4	31.2	91	54.8	
DP11	0-16	160	Clay	21.4	16.1	1.3	6.8	11.0			Orthidystric Nitisol
	16-46	300	Clay	23.9	18.3	1.3	7.1	21.4			
	46-132	540	Clay	23.9	19.2	1.2	5.8	31.1	63	38.0	
DP12	0-40	400	Clay	29.3	21.8	1.3	9.3	37.1			Orthidystric Nitisol
	40-70	300	Clay	29.8	23.4	1.4	8.6	25.8			
	70-100	300	Clay	30.1	23.0	1.5	10.3	30.9	94	56.2	
DP18	0-40	400	Clay	31.8	24.7	1.2	8.6	34.6			Orthidystric Nitisol
	40-70	300	Clay	33.2	25.9	1.2	8.9	26.8			
	70-100	300	Clay	33.4	26.3	1.4	9.8	29.3	91	54.4	
DP20	0-12	120	SCL	21.0	15.5	1.4	7.3	8.8			Orthidystric Nitisol
	12_32	200	Clay	23.1	18.3	1.3	6.1	12.2			
	32-115	680	Clay	23.3	19.0	1.3	5.5	37.7	59	35.2	
DP26	0-22	220	SCL	13.2	9.0	1.3	5.6	12.4			Orthidystric Nitisol
	22-50	280	SCL	12.6	8.7	1.3	5.2	14.6			
	50-75	500	SCL	12.8	8.2	1.3	6.0	30.2	57	34.3	
DP39	0-29	290	CL	34.5	25.7	1.3	11.6	33.6			Rhodic Nitisol
	29-47	180	Clay	34.2	26.8	1.2	8.8	15.9			
	47-75	530	Clay	34.7	27.7	1.3	9.3	49.4	99	59.3	
DP41	0-19	190	SiL	31.7	25.0	1.4	9.1	17.3			Orthidystric Nitisol
	19-34	150	Clay	32.4	26.0	1.2	7.7	11.6			
	34-62	280	Clay	32.9	26.3	1.4	9.3	26.1			
	62-127	380	Clay	33.5	26.4	1.4	10.1	38.3	93	56.0	
DP47	0-12	120	Clay	26.6	19.5	1.4	9.8	11.8			Orthidystric Nitisol
	12_30	180	Clay	28.5	21.6	1.5	10.1	18.1			
	30-65	700	Clay	30.9	23.1	1.5	11.3	79.4	109	65.6	

Table B 4, Cont.

Profile No.	Horizon cm	Depth (mm)	Texture Class	F.C % vol	P.W.P % vol	Bd gm/cm-3	AWC cm/m	Horizon cm/m	AWC mm/m	TRAWC mm/m	FAO Soil Classification 1998
DP65	0-50	500	SCL	22.1	14.4	1.4	10.6	52.8			Fluvic Cambisol
	50-100	500	Clay	23.4	16.8	1.3	8.6	42.8	96	57.3	
DP52	0-40	400	SL	28.6	20.1	1.4	11.8	47.3			HyperferricAcrisol
	40-70	300	SL	28.4	20.6	1.3	9.8	29.3			
	70-100	300	Clay	27.8	21.1	1.3	8.6	25.7	152	91.4	
DP67	0-14	140	L	27.0	19.6	1.4	10.2	14.3			HyperferricAcrisol
	14-45	310	SCL	26.9	20.3	1.3	8.9	27.7			
	45-80	550	Clay	29.1	22.4	1.3	8.5	46.6	89	53.1	
DP69	0-20	200	L	32.9	23.5	1.4	13.1	26.1			Hypereutric Cambisol
	20-.64	440	Clay	28.3	21.4	1.3	8.8	38.8			
	64-160	360	Clay	29.8	23.9	1.4	8.2	29.5	95	56.7	
DP77	0-17	170	Clay	28.3	21.0	1.3	9.2	15.6			Orthidystric Nitisol
	17-57	400	Clay	29.1	22.3	1.3	8.6	34.2			
	57-140	430	Clay	30.9	24.3	1.3	8.5	36.7	87	51.9	
DP78	0-40	400	Clay	27.9	20.3	1.2	9.5	37.9			Orthidystric Nitisol
	40-70	300	Clay	28.9	22.0	1.4	9.5	28.5			
	70-100	300	Clay	30.2	22.5	1.4	10.4	31.3	98	58.7	
DP83	0-50	500	Clay	38.2	24.4	1.3	17.4	87.0			Mesotrophic Vertisol
	50-100	500	Clay	42.3	26.3	1.2	19.7	98.3	185	111.2	
DP86	0-50	500	Clay	32.1	22.3	1.3	12.3	61.4			HyperferricAcrisol
	50-100	500	Clay	31.4	22.6	1.3	11.3	56.6	118	70.8	

Table B 4, Cont.

Profile No.	Horizon (cm)	Depth (mm)	Texture Class	FC % vol	PWP % vol	BD gm/cm-3	AWC cm/m	Horizon cm/m	AWC mm/m	TRAWC mm/m	FAO Soil Classification 1998
DP90	0-40	400	SCL	32.4	22.2	1.4	14.0	55.8			HyperferricAcrisol
	40-70	300	SiL	33.7	23.3	1.4	14.1	42.3			
	70-100	300	Clay	33.9	24.3	1.2	11.8	35.5	134	80.2	
DP91	0-40	400	Clay	29.0	18.4	1.3	13.4	53.6			Gelic Gleysol
	40-68	280	Clay	25.1	15.9	1.2	11.3	31.7			
	68-159	320	Clay	30.6	19.0	1.2	14.1	45.1	130	78.2	
DP93	0-30	300	SL	24.6	17.3	1.4	10.5	31.4			Hyperferric Acrisol
	30-54	240	SCL	28.0	19.9	1.3	10.7	25.7			
	54-102	460	Clay	31.7	20.7	1.2	13.6	62.5	120	71.7	

Notes: Field Capacity (FC), Permanent Wilting Point (PWP), Available Water Holding Capacity (AWC), Bulk Density (BD), TRAWC (Total Readily Available Water Capacity - Landon, 1991 noted that the TRAWC is about 50-70% of the AWC) ; SCL: Sandy Clay Loam; CL: Clay Loam ; SL: Sandy Loam ; L: Loam; SiL: Silt Loam

APPENDIX C1 : SOIL & LAND USE REQUIREMENTS FOR SELECTED LUTs

1. Irrigated Vegetables Cultivation. Example: Onion (Allium cepa)

Onion is vegetable best suited for small scale irrigation mainly along river terraces, but where cooler temperature prevails. Onion grows on a wide variety of soils, provided they are well aerated and friable as long as sufficient water can be retained. Fertile, loams textured soils are most suitable. The maximum rooting depth of the crop is 50cm. EC values of 1.8 ds/m may cause 10% of yield reduction, and 2.8 ds/m may cause 25% yield reduction. Sodicity affects the productions of onion and 50% yield reduction takes place at exchangeable ESP of 35%. Onion is not grown in the lowland humid tropics. Cool conditions with an adequate moisture supply are most suitable for the early growth of onion, warm and drier conditions are required at maturation and harvesting stages. Optimum pH range is 6.0-7.5, although alkaline soils area also suitable up pH 8.2. Soils with CEC contents of above 16 meq/100g soils, more than 50% base saturation and over 2% organic carbon content are most suited for optimum requirement of onion. Onion requires uniform moisture supply throughout the growing season. The total growing period requirement ranges between 130 and 175 days including nursery management.

Germination takes place in the temperature range of 20-35^{0}C. Optimum temperatures for the plant growth is between 13 and 24^{0}C. Flowering and consequent low yields are observed at temperatures less than13^{0}C. Early maturity and low yields occur at temperatures greater than 24^{0}C. The optimal precipitation for onion is 350 – 600mm/growing cycle. Low air humidity and low temperatures lead to flowering. Onion is sensitive to day length: 12-13 hours of day length are required in the yield formation period.

2. Irrigated Pulses. Example: Beans

Climate: Beans are not grown in the low land, humid tropics. Beans can grow in regions that are characterized by air temperature between 18 and 30^{0}C. The optimum temperature range is 15 - 20^{0}C. The crop is sensitive to temperature above 30^{0}C, especially at flowering and seed set. The soil temperature for germination should be more than 15^{0}C. They are sensitive to frost; flowers are damped at 5^{o}C. Moisture stress should be avoided in the flowering and setting periods and dry weather is required at harvest. Excessive rain causes flower drop and diseases. An annual precipitation of 400 - 500mm is adequate for growing beans. Beans prefer a medium to high relative air humidity, especially at flowering. Dry winds affect pollination and therefore, the yield. Strong winds damage the crop.

Soils: The maximum rooting depth of the crop is between 1.0 and 1.5m. The minimum soil depth is about 0.5m and the optimum being 0.75m. However, soils that show surface capping should be avoided. They can be grown on soils with a texture ranging from loamy sand to clay; best are loam to clay loam textures. Soils, with moderately to well drained are most suitable. The crop is sensitive to water logging, surface water standing for only a few hours damages the crop. The pH range is between 5.2 and 8.2 and the optimum is between 6.0 and 7.0.

3. Irrigated Citrus and Fruit Trees. Example Citrus spp.

Climate: It is mostly grown in sub-tropical countries below 600m.a.s.l. Citrus do not do well on the equator bellow 1800m.a.s.l. It performs well in the temperatures range of 13-39^{0}C, but it prefers air temperatures of 22-30^{0}C. Among citrus spp. grapefruits can withstand long hot periods than other citrus spp.

The required average total rainfall should be >800mm unless irrigated. High wind speed can cause much damage and consideration should be given to the provision of windbreaker. Flowers and young fruits are sensitive to frost. Citrus is intolerant to high humidity, but mandarins can tolerate wetter conditions than other citrus spp.

Soils: Citrus roots have a high oxygen requirement, thus the soil should be well aerated, well drained and not too heavy in textures. The most suited soil textures are light sands to medium loams. It can be grown on poor, sandy soils that are extremely low in natural fertility. An excess of phosphorus can cause micronutrient deficiency and impair nitrogen use. It is also susceptible to magnesium, deficiency caused by excess of calcium and/or potassium. Dolomite and limestone should be used for liming acid soils. The crop is sensitive to water logging and the pH range should be between 5.5 and 7.6.

4. Irrigated Cereals. Example: Maize (Zea mays)

Maize is a demanding crop, yielding higher than other cereals if climate and soils are favorable.

Climate: Maize has a wide range of tolerance to environmental conditions, but growing season must be frost-free. It grows in temperature that ranges from 14-40^{0}C. The growth of the crop is optimal at temperatures between 18^{0}C and 32^{0}C. The mean maximum temperature should be in the range of 26-29^{0}C, the mean minimum temperature should be in the range of 12-24^0 C, and germination is reduced at 13^{0}C and fails at temperatures below 10^{0}C. It is most sensitive to moisture stress from the beginning of flowering until the end of grain formation.

Soils: Maize can grow on many types of soils. It requires well-drained, well-aerated, deep loam and silt soils, with adequate organic matter. The maximum rooting depth is about 2m, but the majority of the water and nutrient uptake roots are in the top 90cm of the soil. Shallow soils depress yields, both because of increased drought hazard and lower nutrient supplies.

Land units with substantial drainage impediment as shown by mottling within 1m depth from the surface should be avoided, unless installation of artificial drainage is planned. It can't stand water logging in the first 5 weeks after sowing. From the 6th week onwards, water logging for 1 to 2 days may not kill the crop. On soils with low moisture retention capacity, or in areas of low rainfall, a low plant density should be used to avoid competition for water and nutrients. Yield increases with planting density on irrigated plot, but the reverse may occur on rain fed plots. The preferred pH requirement of maize can range from 5.5 to 8.0; however, it can grow in the pH range of 5.2 to 8.2, with proportional yield reduction, but this can be rectified. Strongly acid soils or alkalin soils (PH <5.2 and >8.5), however are unsuitable. It has high nutrient requirement, thus soils having a higher CEC are more suitable. Nitrogen is the most important nutrient. Young maize has difficulty in taking up phosphorous from the less available phosphate forms in the soil. Potassium removal is very high in maize harvested for silage: 200-300kg/ha are removed at harvest time.

To produce some 6ton grain/ha, nutrient removal of 165, 24 and 112 (kg/ha/growing cycle) of N, P_2O_5 and K_2O takes place respectively. The soils of the study area are of moderate to low fertility level, and all have moderate levels of organic matter. Fertilizer application range required to produce about 4ton grains/ha will be 60-100, 50-100, and 30-60 (kg/ha/ growing cycle) for N, P_2O_5 and K_2O respectively. Traditional smallholder yield range is between 0.5 to 1.5ton grain/ha, but good commercial yield under irrigation range between 6 to 9ton grain/ha and 80ton fodder/ha.

Excess of salts: Maize is moderately sensitive to salinity, no yield reduction at an electrical conductivity (EC) of <1.7 dS/m, the yield reduction is 10% at 1.7 to 2.5; 25% at 3.6, 50% at 5.9, and 100% at 10 dS/m. Thus, ECe values requirement for maize ranges from 2.5 to 5.9 with proportional yield reduction. The ESP requirement for maize ranges from 15 to 25, with proportional yield decrease. The optimum ESP levels are below 15; maize can suffer by progressively stunted growth at ESP levels above 15 and about 50% yield reduction is observed at an ESP of 15%. The higher ESP levels can be mitigated by gypsum application to lower at the required level.

5. Irrigated Oil Crops. Example: Sesame (Sesamum Indicum L. Syn.)

Sesame is an adaptable crop to the hotter, less fertile environments of the country, because of its drought resistance, ease of management, adaptability to poor soils and suitability for intercropping. It is therefore, appropriate for cropping in the lowland region, from 0m to 1600m altitude. These areas have a tropical wet and dry or a semiarid climate (Koppen, Aw and Bsh) with a mean annual rainfall of 600-800mm. Although sesame is drought resistant it is very sensitive to excess soil moisture. The best soils are freely drained sandy loams with a pH of 5.5-7.0, but sesame is not exacting in its soil requirements and does reasonably well on poor soils.

Growth habit: An annual erect herb 30-200m tall, with stem longitudinally furrowed and densely hairy. It has a long (90cm) tap root and a dense surface mat of feeding roots. There are a large number of cvs, differing in duration, season of planting, degree of branching, number of flowers per axil, etc. Basically the cvs are classified into two groups, being either shattering or non-shattering according to whether the seed capsules open on drying.

Land preparation: Since sesame seed is small (300 seeds to 1g), it should be planted shallowly on a firm but mellow seedbed. All living weeds should be killed and trash removes or ploughed under since this crop is usually grown in areas of limited rainfall, land preparation should run across the slope to aid in water retention and to minimize run-off.

Planting practices: Seeds are frequently sown broadcast at the rate of 5-8 kg/ha. They are often mixed with sand or with an associated crop such as sorghum before sowing in order to achieve an even spread. If sown mechanically in lines, or if thinning is done, the seed should be sown 2cm deep at an optimum plant population of 200,000ha in rows about 50cm apart, with one seed to 6-12cm of row. Where seedling emergency may be hampered by heavy soil the seedling rate should be increased and the desired stand of plants achieved by thinning after emergence.

Fertilizer application: Sesame is usually not fertilized, but fertilizer experiments have shown good response to N and K; 30-50kg/ha N. 10-20 kg/ha P_2O_5 and 30-40 kg/ha K_2O are generally recommended.

6. Irrigated Wetland (paddy) Rice (Oryza sativa)

Wetland (paddy) rice tolerates a very wide range of climatic conditions from sea level to high elevation and from temperate latitudes to the hot tropics. It requires long periods of sunshine and an average temperature of between 20-38 degrees C during the growing period.

Paddy rice requires soils that have low infiltration rates. This can be achived on various soils by puddling the surface with a mechanical tool, often drawn by oxen, sometimes by hand. Maintaining the low infiltration rate on loamy and even sandier soils is difficult and time consuming and the optimum soils are clays that are easy to seal. The layer of clay over, for example, more sandy materials can be, though, quite thin as rice tolerates a shallow rooting depth. The soils for rice can be of poor structure, as the wetted surface soil is artifically puddled but paddy rice has low drought resistance and maintenance of the wetted zone is important.

Soils suitable for rice should have rates of <0.1 cm h^{-1}. With puddling these can be reduced to 0.02 cmh $^{-1}$, or less. Rice is semi-tolerant of sodium and a 50% yield loss wil be experienced if the ESP is at 15-25%. In the DB area the ESP is very low. Rice also is semi-tolerant of salinity, and lies within the medium group of tolerance (ECe 4-12 mS cm^{-1}) (Richards, 1954): the low salinities in DB ensure that plant growth wil not be affected by salinity. Rice nutrition can be a problem at higher pH in soils, where ferrous iron is absorbed by rice roots following oxidation to insoluble forms: in DB with low pH soils this will not be an issue. It has a low requirement for calcium and soil pH that rice tolerates ranges from 4 to 8 and is in gernal tolerant of high acidity. Fertiliser requirements are high especially for nitrogen. Due to the anaerobic conditions that develop ion the puddled layer decomposition of organic matte ris slow and N fixation takes place by Azotobacter and blue-green algae. With wetland rice good management is more important than an ideal soil or climate. Useful references: Landon 1991 ; De Data, 1981 ; Grist, 1983 ; IRRI publications on rice are available online.

APPENDIX C2. LAND USE REQUIREMENTS FOR SURFACE IRRIGATED AGRICULTURE DEVELOPMENT – TABLES

Source: Dinger Bereha Field Investigations, 2009

Appendix C2-1: – Land use requirements for surface irrigated onion (Allium sp.) cultivation, moderate to high input level

Land use requirements			Unit	Factor Ratings/Range of suitability/level of yield				
Land Quality/diagnostic factors		Land Characteristics		S1	S2	S3	N1	N2
Description	Sub class Suffix		100	85	60	40	25	0
Crop requirement								
Climate	c	Mean air temperature for growing cycle	^{0}C	13-24	22–23 13–16	23–55 10– 13	–	>25 <10
		Relative humidity	%	24–80	80–90 20–24	<20 >90	–	–
Moisture availability	m	AWC	Mm/m	>150	130-150	100-130	<100	<60
Oxygen availability	d	Soil Drainage	Class	W- M.W,	ID,SD	Poor and aeric	V.Poor	Poor not drainable
		Flooding	duration /depth	FO	–	F1	–	F2+
Nutrient retention	n	Organic carbon	% (25 cm)	> 1.2	1.2– 0.8	< 0.8	–	–
		CEC	Meq/ 100g soil (50cm)	>16	<16	<16	–	–
Nutrient Availability	z	Soil reaction	pH (25cm)	6.0–7.5	5.5 – 6 7.5 – 8	5.0- 5.5 8.0– 8.2	< 5.5	> 8.2
		Texture / Structure	Class	CL,L,SiCl,Si,SiC ,Co,C<60s,LS, LfS	C>60s,C< 60v,LS, LfS	C>60v,Fs, LcS, cS	–	Cm,SiCcm
Rooting condition	r	Effective soil depth	Cm	>100	75–50	75–50		<50
		Stones and rocks	%	no	<15	15–35	15–35	>35
		Texture / Structure/	Class	CL,L,SiCl,Si,SiC ,Co,C<60s,LS, LfS	C>60s,C< 60v,LS, LfS	C>60v,fS, LcS, cS	–	Cm,SiCcm
		Compaction (Db)	g/cm^{-3}	<1.6	<1.6	<1.6	>1.6	>1.6
		Organic carbon	%	> 1.2	1.2– 0.8	< 0.8	–	–
Toxicity	x	$CaCo_3$	%	0–5	5–10	10–20		>20

Appendix C2-1: – Land use requirements for surface irrigated onion (cont.)

Land development and Management requirement								
Workability	w'	Slope	%	0-2	2-4	4-6		>6
		Stones & rocks	Class	<15	15–35			>35
		Organic carbon	% (25 cm)	> 1.2	< 0.8		–	–
		Texture / Structure	Class	CL,L,SiCl,Si,SiC,Co,C<60s,LS,LfS	C>60s,C<60v,LS,LfS	C>60v,fS,LcS	–	Cm,SiCm
Potential for mechanization	k	Slope	%	0-2	2-4	4-6		>6
		Stones & rocks	Class	no	<15	15–35	15–35	>35
		Texture / Structure	Class	CL,L,SiCl,Si,SiC,Co,C<60s,LS,LfS	C>60s,C<60v,LS,LfS	C>60v,fS, LcS, cS	–	Cm,SiCm
Drainage	d’	Infiltration	cm/h	0.7-3.5	0.3-0.7 3.5-6.5	0.1-0.3 6.5-12.5-15		<0.1 >12.5
		Depth to ground water	M	>3	1.5– 3	0.5–1.5		<0.5
		Hydraulic conductivity	M/day	1.0–3	0.5–1.0	0.2–0.5	0.1-0.2	<0.2 >3
Flood hazard	f	Flooding	Duration /depth	Protection feasible	Protection feasible	Protection feasible	Protection feasible	Protection not feasible
Conservation requirement								
Erosion hazard	e	Sheet	Class	No	Moderate			Strong
		Slope	%	0-2	2-4	4-6		>6
		Gully	Class	None	Slight		–	Moderate strong

Appendix C2-2: - Land use requirements for surface irrigated beans (phaseolus vulgaris) cultivation, moderate to high input level

Land use requirements			Unit	Factor Ratings /Range of Suitability /level of yield				
Land Quality/diagnostic factors		Land Characteristics	100	S1 85	S2 60	S3 40	N1 25	N2 0
Crop requirement								
Climate	^0c	Mean air temperature for growing cycle	^0C	12-24	24-27 10-12	27-30 10-8	-	>30 <8
		Relative humidity	%	42-75	42-36 75-90	36-30 >90	--	<30
Moisture availability	m	AWC	mm/m	>180	180-120	120-60	-	<60
Oxygen availability	d	Soil Drainage	Class	W-M	I	P	P	P
		Flooding	Duration /depth	Protection feasible	Protection feasible	Protection feasible	Protection feasible	Protection not feasible
Nutrient retention	n	Organic carbon	% (25 cm)	> 1.2	1.2-0.8	<0.8	-	-
		CEC	Meq/ 100g soil (50cm)	>16	<16 (-)	<16 (+)	-	-
Nutrient Availability	z	Soil reaction	pH (25cm)	6.5-5.6 6.5-7.6	5.6-5.4 7.6-8.0	5.4-5.2 8.0-8.2	< 5.2	> 8.2
		Texture / Structure	Class	C<60s, Co, SiCs, SiCL, CL, Si, SiL C>60s, SC, C<60v, L, SCL	C>60v, SCL, LfS, LS	LCS, fS, S		Cm, SiCm, CS
Rooting condition	r	Effective soil depth	Cm	>75	75-50	50-20		<20
		Stones and rocks	%	<15	15-35	35-55		>55
		Compaction (Db)	g/cm^{-9}	<1.6	<1.6	<1.6	>1.6	>1.6
		Organic carbon	%	> 1.2	1.2-0.8	<0.8	-	-
Toxicity	*x*	$CaCo_3$	%	0–6	6–15	15–25	–	>25

Appendix C2-2: - Land use requirements for surface irrigated beans (phaseolus vulgaris) cultivation, moderate to high input level (cont.)

Land development and Management requirement								
Workability	w'	Slope	%	0-2	2-4	4-6		>6
		Stones & rocks	Class	<15	15-35	35-55		>55
		Organic carbon	% (25 cm)	> 1.2	1.2-0.8	<0.8	-	-
		Texture / Structure	Class	C<60s, Co, SiCs, SiCL, CL, Si, SiL C>60s, SC, C<60v, L, SCL	C>60v, SCL, LfS, LS	LCS, fS, S		Cm, SiCm, CS
Potential for mechaniza- tion	k	Slope	%	0-2	2-4	4-6		>6
		Stones & rocks	Class	<15	15-35	35-55		>55
				C<60s, Co, SiCs, SiCL, CL, Si, SiL C>60s, SC, C<60v, L, SCL	C>60v, SCL, LfS, LS	LCS, fS, S		Cm, SiCm, CS
		Texture / Structure	Class	C<60s, Co, SiCs, SiCL, CL, Si, SiL C>60s, SC, C<60v, L, SCL	C>60v, SCL, LfS, LS	LCS, fS, S		Cm, SiCm, CS
Drainage	d'	Infiltration	Cm/h	0.7-3.5	0.3-0.7 3.5-6.5	0.1-0.3 6.5-12.5		<0.1 >12.5
		Depth to ground water	M	>3	1.5- 3	0.5-1.5		<0.5
		Hydraulic conductivity	M/day	1.4-3	0.5-1.4	0.2-0.5	-	<0.2 >3
Flood hazard	f	Flooding	Duration /depth	Protection feasible	Protection feasible	Protection feasible	Protection feasible	Protection not feasible
Conservation requirement								
Erosion hazard	e	Sheet	Class	No	Slight	Moderate		Strong
		Slope	%	0-2	2-4	4-6		>6
		Gully	Class	None	None	Slight	-	Moderate strong

Appendix C2-3: - Land use requirements for surface irrigated citrus cultivation, moderate to high input level

Land use requirements			Unit	Factor Ratings /Range of Suitability /level of yield				
Land Quality/diagnostic factors		Land Characteristics		S1	S2	S3	N1	N2
Description	Sub class Suffix		100	85	60	40	25	0
Crop requirement								
Climate	^0c	Mean air temperature for growing cycle	^0C	19-33	33-36 19-16	36-39 16-13	-	<39 <13
		Relative humidity	%	< 60	60-90	>90	-	-
Moisture availability	m	AWC	mm/m	>180	180-120	120-60	-	<60
Oxygen availability	d	Soil Drainage	Class	W	M	I	P	P
		Flooding	Duration /depth	Protection feasible	Protection feasible	Protection feasible	Protection feasible	Protection not feasible
Nutrient retention	n	Organic carbon	% (25 cm)	> 1.5	1.5-0.8	< 0.8	-	-
		CEC	Meq/ 100g soil (50cm)	>16	<16 (-)	<16 (+)	-	-
Nutrient Availability	z	Soil reaction	pH (25cm)	6.5-5.5 6.5-7.6	5.5-5.2 7.6-8.0	5.2-5.0 8.0-8.2	< 5.0	> 8.2
		Texture / Structure	Class	L, SCL, SL, SiCl, SiL, Si, CL, LS, LfS,	C<60s, SiCs, SC, S, fS, Co	C<60v, C>60s		Cm, SiCm, C>60v
Rooting condition	r	Effective soil depth	Cm	>150	150-100	100-75		<75
		Stones and rocks	%	< 15	15-35	35-55		>55
		Texture	Class	L, SCL, SL, SiCl, SiL, Si, CL, LS, LfS,	C<60s, SiCs, SC, S, fS, Co	C<60v, C>60s		Cm, SiCm, C>60v
		Compaction (Db)	g/cm^{-9}	<1.6	<1.6	<1.6	>1.6	>1.6
		Organic carbon	%	> 1.5	1.5-0.8	< 0.8	-	-
Toxicity	*x*	*$CaCo_3$*	%	0–6	6–15	15–25	–	>25

Appendix C2-3: - Land use requirements for surface irrigated citrus cultivation, moderate to high input level (cont.)

Land development and Management requirement								
Workability	w'	Slope	%	0-2	2-4	4-6		>6
		Stones & rocks	Class	< 15	15-35	35-55		>55
		Organic carbon	% (25 cm)	> 1.5	1.5-0.8	< 0.8	-	-
		Texture / Structure	Class	L, SCL, SL, SiCl, SiL, Si, CL, LS, LfS,	C<60s, SiCs, SC, S, fS, Co	C<60v, C>60s		Cm, SiCm, C>60v
Potential for mechaniza-tion	k	Slope	%	0-2	2-4	4-6		>6
		Stones & rocks	Class	< 15	15-35	35-55		>55
		Texture / Structure	Class	L, SCL, SL, SiCl, SiL, Si, CL, LS, LfS,	C<60s, SiCs, SC, S, fS, Co	C<60v, C>60s		Cm, SiCm, C>60v
Drainage	d'	Infiltration	Cm/h	0.7-3.5	0.3-0.7 3.5-6.5	0.1-0.3 6.5-12.5		<0.1 >12.5
		Depth to ground water	M	>3	1.5- 3	0.5-1.5		<0.5
		Hydraulic conductivity	M/day	1.4-3	0.5-1.4	0.2-0.5	-	<0.2 >3
Flood hazard	f	Flooding	Duration /depth	Protection feasible	Protection feasible	Protection feasible	Protection feasible	Protection not feasible
Conservation requirement								
Erosion hazard	e	Sheet	Class	No	Slight	Moderate		Strong
		Slope	%	0-2	2-4	4-6		>6
		Gully	Class	None	None	Slight	-	Moderate strong

Appendix C2-4: Land use requirements for surface irrigated maize cultivation, moderate to high input level

Land use requirements			Unit	Factor Ratings /Range of Suitability /level of yield				
Land Quality/diagnostic factors		Land Characteristics		S1	S2	S3	N1	N2
Description	Sub class Suffix		100	85	60	40	25	0
Crop requirement								
Climate	°c	Mean air temperature for growing cycle	°C	18 – 32	16–18 32–35	14–16 35–40	–	<14 >40
		Relative humidity	%	24–75	20–24 75–90	<20 >90	–	–
Moisture availability	m	AWC	Mm/m	>180	120–180	60–120	–	<60
Oxygen availability	d	Soil Drainage	Class	W–Mw	Ip	Poor and aeric	Poor, and drainable	Poor, not drainable
		Flooding	Duration /depth	Protection feasible	Protection feasible	Protection feasible	Protection feasible	Protection not feasible
Nutrient retention	n	Organic carbon	% (25 cm)	> 1.2	0.8 – 1.2	< 0.8	–	–
		CEC	Meq/ 100g soil (50cm)	>16	<16	<16	–	–
Nutrient Availability	z	Soil reaction	pH (25cm)	6 –7. 6	5.6 – 6.0 7.6 – 8.0	5.5 – 5.6 8 – 8.2	–	< 5.5 >8.2
		Texture / Structure	Class	C<60s,CO,SiC,SiCL,Si,SiL,CL,SC,SCL,C<60v,C>60s	C>60v,SL,LfS,LS	fS,S,LcS,cS	–	Cm, SiCm ,
Rooting condition	r	Effective soil depth	Cm	>75	75–50	50–20	–	<20
		Stones and rocks	%	<15	15–35	15–35	–	>35
		Texture / Structure/	Class	C<60s,CO,SiCSiCL, Si, SiL, CL,SC,SCL,C<60v,C>60s	C>60v,SL, LfS, LS	fS, S, LcS, cS	–	Cm, SiCm ,
		Compaction (Db)	G/cm^{-3}	<1.6	<1.6	<1.6	>1.6	>1.6
		Organic carbon	%	>0.8	0.8–0.5	<0.5	–	–
Toxicity	x	$CaCo_3$	%	0–15	15–25	25–35	–	>35

Appendix C2-4: Land use requirements for surface irrigated maize cultivation, moderate to high input level (Cont.).

Land development and Management requirement								
Workability	w'	Slope	%	0-2	2-4	4-6		>6
		Stones & rocks	Class	<15	15–35	15–35		>35
		Organic carbon	% (25 cm)	>0.8	0.8–0.5	<0.5	–	–
		Texture / Structure	Class	C<60s,CO,SiC,SiCL,Si,SiL,CL,SC,SCL,C<60v,C>60s	C>60v,SL,LfS,LS	fS,S,LcS,cS	–	Cm, SiCm ,
Potential for mechaniza-tion	k	Slope	%	0-2	2-4	4-6		>6
		Stones & rocks	Class	<15	15–35	15–35		>35
		Texture / Structure	Class	C<60s,CO, SiC, SiCL, Si, SiL, CL, SC, SCL, C<60v,C>60s	C>60v,SL,LfS,LS	fS,S,LcS,cS	–	Cm, SiCm
Drainage	d'	Infiltration	cm/h	0.7–3.5	0.3–0.7 3.5–6.5	0.1–0.3 6.5–12.5	–	<0.1 >12.5
		Depth to ground water	M	>3	1.5– 3	0.5–1.5		<0.5
		Hydraulic conductivity	M/day	1.4–3	0.5–1.4	0.2–0.5	–	<0.2 >3
Flood hazard	f	Flooding	Duration /depth	Protection feasible	Protection feasible	Protection feasible	Protection feasible	Protection not feasible
Conservation requirement								
Erosion hazard	e	Sheet	Class	No	Slight	Moderate		Strong
		Slope	%	0-2	2-4	4-6		>6
		Gully	Class	None	None	Slight	–	Moderate strong

Appendix C2-5: Land use requirements for surface irrigated sesame cultivation, moderate to high input level

Land use requirements			Unit	Factor Ratings /Range of Suitability /level of yield				
Land Quality/diagnostic factors		Land Characteri tics		S1	S2	S3	N1	N
Description	Sub class Suffix		100	85	60	40	25	0
Crop requirement								
Climate	°c	Mean air temperature for growing cycle	°C	20-28	28-30 20-18	30-38 18-16	<16, >38	<14 >38
		Relative humidity	%	<56	65-75	75-85	–	–
Moisture availability	m	AWC	Mm/m	>180	120–180	60–120	–	<60
Oxygen availability	d	Soil Drainage	Class	W–Mw	Sw. ex. – Imperfe.	Poor and aeric	Poor& drainable	Poor not drainable
Nutrient retention	n	Organic carbon	% (25 cm)	> 1.2	0.8 – 1.2	< 0.8	–	–
		CEC	Meq/ 100g soil (50cm)	>16	>16, <16	<16	–	–
Nutrient Availability	z	Soil reaction	pH (25cm)	5.8-7.0	5.5 – 5.8 7.0 – 7.5	5.2 – 5.5 7.5 – 8.2	<5.2, >8.2	< 5.5 >8.2
		Texture / Structure	Class	L, SCL, SiL, CL,Si,CL, SiC SC,	Cs, ,Ls,	C>60s,S	–	Cm, SiCm CS ,
Rooting condition	r	Effective soil depth	Cm	>75	75-50	30-50	–	<30
		Stones and rocks	%	0-15	15–35	15–35	–	>35
		Texture / Structure/	Class	L, SCL, SL, CL,SiCL. SiCs, SiL,SC	Cs,Co,LS	C>60s,S	–	Cm, SiCm ,
		Compaction (Db)	G/cm^{-3}	<1.6	<1.6	<1.6	>1.6	>1.6
		Organic carbon	%	> 1.2	0.8 – 1.2	< 0.8	–	–
Toxicity	x	$CaCo_3$	%	0–5	5–10	10-25	–	>25

Appendix C2-5: Land use requirements for surface irrigated sesame cultivation, moderate to high input level (Cont.)

Land development and Management requirement								
Workability	w'	Slope	%	0-2	2-4	4-6	4-6	>6
		Stones & rocks	Class	<15	15–35	15–35		>35
		Organic carbon	% (25 cm)	>0.8	0.8–0.5	<0.5	–	–
		Texture / Structure	Class	L, SCL, SL, CL,SiCL. SiCs, SiL,SC	Cs,Co,LS	C>60s,S	–	Cm, SiCm ,
Potential for mechaniza- tion	k	Slope	%	0-2	2-4	4-6	4-6	>6
		Stones & rocks	Class	<15	15–35	15–35		>35
		Texture / Structure	Class	L, SCL, SL, CL,SiCL. SiCs, SiL,SC	Cs,Co,LS	C>60s,S	–	Cm, SiCm
Drainage	d'	Infiltration	cm/h	0.7–3.5	0.3–0.7 3.5–6.5	0.1–0.3 6.5–12.5	–	<0.1 >12.5
		Depth to ground water	M	>3	1.5– 3	0.5–1.5		<0.5
		Hydraulic conductivity	M/day	1.4–3	0.5–1.4	0.2–0.5	–	<0.2 >3
Conservation requirement								
Erosion hazard	e	Sheet	Class	No	Slight	Moderate		Strong
		Slope	%	0-2	2-4	4-6		>6
		Gully	Class	None	None	Slight	–	Moderate strong

APPENDIX D: Partial Suitability Classes for Dinger Bereha Irrigation Area (Field Investigations)

Appendix D. Table 1 Land suitability for surface irrigated onion (Allium espa l) cultivation

Land qualities or land characteristics/ Suffixes	FACTOR RATING																														
	c		m	x	d		n		Z		r					w				k			t		d'			f	e		
	Climate		Moisture availability	Toxicity	Oxygen availability		Nutrient retention		Nutrient availability		Rooting condition					Workability				Potential for mechanization			Land preparation & clearance		Drainage			Flood hazard	Erosion hazard		Final suitability class and sub class
Land units	t °C	R. H	AWC (mm/m)	$CaCO_3$	S.DC	Flo.	OC	CEC	PH	Texture	Depth	Stones	Texture	Com.	OC	Slope	Stones	OC	Texture	Slope	Stones	Texture	Stones	Texture	I.N	D.G.W	H. C	Flo.	Sheet	Slope	
G1b-1	S2	S1	N1	-	S1	S1	S1	S1	S3	S2	S1	S1	S2	S1	S1	S2	S1	S1	S2	S2	S1	S2	S1	S2	S3	S1	S1	S1	S3	S2	**S3zd[1]**
G1b-4	S2	S1	S2	S1	S1	S1	S1	S1	S3	S1	S1	S2	S1	S1	S1	S2	S2	S1	S1	S2	S2	S1	S2	S1	S3	S1	S1	S1	S3	S2	**S3 zd[1]**
G2d-1	S2	S1	N1	S2	S1	S1	S1	S1	S3	S2	S1	S1	S2	S1	S1	S3	S1	S1	S2	S3	S1	S2	S1	S2	S3	S1	S1	S1	S3	S3	**S3z wk**
G2d-2	S2	S1	S3	-	S1	S1	S1	S1	S3	S2	S1	S3	S2	S1	S1	S3	S3	S1	S2	S3	S3	S2	S3	S2	S3	S1	S1	S1	S3	S3	**S3zwk**
Sg-6	S2	S1	S3	-	S1	S1	S1	S1	S2	S1	S2	S3	S1	S1	S1	N2	S3	S1	S1	N2	S3	S1	S3	S1	S2	S1	S2	S1	N1	N2	**N2wk**
U1e-4	S2	S1	N1	-	S1	S1	S1	S1	S3	S1	S1	S2	S1	S1	S1	N1	S2	S1	S1	N1	S2	S1	S2	S1	S3	S1	S1	S1	S3	N1	**N1kw**
U1e-5	S2	S1	S3	-	S1	S1	S1	S2	S3	S1	S2	S1	S1	S1	S1	N1	S1	S1	S1	N1	S1	S1	S1	S1	S3	S1	S1	S1	S3	N1	**N1k**
U2f-9	S2	S1	N1	-	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	N1	S1	S1	S1	N1	S1	S1	S1	S1	S1	S1	S1	S1	N1	N1	**N1wk**
V1b-3	S2	S1	S2	S1	S2	S1	S1	S1	S3	S2	S1	S1	S2	S1	S1	S1	S1	S1	S2	S1	S1	S2	S1	S2	S1	S1	S3	S1	S1	S1	**S3zd[1]**
V2a-7	S2	S1	S2	-	S3	S1	S1	S1	S3	S2	S1	S1	S2	S1	S1	S1	S1	S1	S2	S1	S1	S2	S1	S2	S1	S2	S3	S1	S1	S1	**S3zdd[1]**
V3c-8	S2	S1	N1	S2	S1	S1	S1	S1	S1	S2	S1	S1	S2	S1	S1	S3	S1	S1	S2	S3	S1	S2	S1	S2	S3	S1	S1	S1	S3	S3	**S3wk**
G3d	S2	S1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	N2	-	-	-	N2	-	N2	-	-	-	-	-	-	-	**N2wk**
R	S2	S	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**N2w**
F&St	S	S	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**N1w**

Source: Field Investigations, 2009

Appendix D Table 2 : Land suitability for surface irrigated beans cultivation

Land qualities or land characteristics/ Suffixes	FACTOR RATING																														Final suitability class and sub class
	c		m	x	d		n		z		r					w				k			t		d'			f	e		
	Climate		Moisture availability	Toxicity	Oxygen availability		Nutrient retention		Nutrient availability		Rooting condition					Workability				Potential for mechanization			Land preparation & clearance		Drainage			Flood hazard	Erosion hazard		
Land units	t 0c	R. H	AWC	$CaCO_3$	S.DC	Flo.	OC	CEC	PH	Texture	Depth	Stones	Texture	Com.	OC	Slope	Stones	OC	Texture	Slope	Stones	Texture	Stones	Texture	I.N	D.G.W	H. C	Flo.	Sheet	Slope	
G1b-1	S1	S2	S3	-	S1	S1	S1	S1	S2	S1	S1	S1	S1	S1	S1	S2	S1	S1	S1	S2	S1	S1	S1	S1	S3	S1	S1	S1	S3	S2	**S3d[1]e**
G1b-4	S1	S2	S2	S1	S1	S1	S1	S1	S3	S1	S1	S2	S1	S1	S1	S2	S2	S1	S1	S2	S2	S1	S2	S1	S3	S1	S1	S1	S3	S2	**S3zd[1]**
G2d-1	S1	S2	S3	S2	S1	S1	S1	S1	S3	S1	S1	S1	S1	S1	S1	S3	S1	S1	S1	S3	S1	S1	S1	S1	S3	S1	S1	S1	S3	S3	**S3zwk**
G2d-2	S1	S2	S3	-	S1	S1	S1	S1	S3	S1	S1	S3	S1	S1	S1	S3	S3	S1	S1	S3	S3	S1	S3	S1	S3	S1	S1	S1	S3	S3	**S3zwk**
Sg-6	S1	S2	S3	-	S1	S1	S1	S1	S1	S1	S2	S3	S1	S1	S1	N2	S3	S1	S1	N2	S3	S1	S3	S1	S1	S1	S2	S1	N1	N2	**N2wk**
U1e-4	S1	S2	S3	-	S1	S1	S1	S1	S3	S1	S1	S2	S1	S1	S1	N1	S2	S1	S1	N1	S2	S1	S2	S1	S3	S1	S1	S1	S3	N1	**N1wk**
U1e-5	S1	S2	S3	-	S1	S1	S1	S2	N1	S1	S2	S1	S1	S1	S1	N1	S1	S1	S1	N1	S1	S1	S1	S1	S3	S1	S2	S1	S3	N1	**N1zwk**
U2f-9	S1	S2	S3	-	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	N1	S1	S1	S1	N1	S1	S1	S1	S1	S1	S1	S2	S1	N1	N1	**N1wk**
V1b-3	S1	S2	S2	S1	S3	S1	S1	S1	S3	S3	S1	S1	S3	S1	S1	S1	S1	S1	S3	S1	S1	S3	S1	S3	S1	S1	S3	S1	S1	S1	**S3zrw**
V2a-7	S1	S2	S2	-	N1	S1	S1	S1	S3	S3	S1	S1	S3	S1	S1	S1	S1	S1	S3	S1	S1	S3	S1	S3	S1	S1	S3	S1	S1	S1	**N1d**
V3c-8	S1	S2	S3	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S3	S1	S1	S1	S3	S1	S1	S1	S1	S1	S1	S3	S1	S3	S3	**S3wkd[1]**
G3d	S1	S2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	N2	-	-	-	N2	-	N2	-	-	-	-	-	-	-	**N2wk**
R	S1	S2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**N2w**

Source: Field Investigations, 2009

Appendix D. Table 3. Land suitability for surface irrigated citrus cultivation

Land qualities or land characteristics/ Suffixes	FACTOR RATING																														Final suitability class and sub class
	c		m	x	d		n		z		r					w				k			t		d'			f	e		
	Climate		Moisture availability	Toxicity	Oxygen availability		Nutrient retention		Nutrient availability		Rooting condition					Workability				Potential for mechanization			Land preparation & clearance		Drainage			Flood hazard	Erosion hazard		
Land units	t 0c	R. H	AWC	$CaCO_3$	S.DC	Flo.	OC	CEC	PH	Texture	Depth	Stones	Texture	Com.	OC	Slope	Stones	OC	Texture	Slope	Stones	Texture	Stones	Texture	I.N	D.G.W	H. C	Flo.	Sheet	Slope	
G1b-1	S1	S2	S3	-	S1	S1	S1	S1	S2	S1	S1	S1	S1	S1	S1	S2	S1	S1	S1	S2	S1	S1	S1	S1	S3	S1	S1	S1	S3	S2	**S3d^{1}e**
G1b-4	S1	S2	S2	S1	S1	S1	S1	S1	S2	S1	S1	S2	S1	S1	S1	S2	S2	S1	S1	S2	S2	S1	S2	S1	S3	S1	S1	S1	S3	S2	**S3d^{1}e**
G2d-1	S1	S2	S3	S2	S1	S1	S1	S1	S2	S1	S1	S1	S1	S1	S1	S3	S1	S1	S1	S3	S1	S1	S1	S1	S3	S1	S1	S1	S3	S3	**S3mwk**
G2d-2	S1	S2	S3	-	S1	S1	S1	S1	S2	S1	S1	S3	S1	S1	S1	S3	S3	S1	S1	S3	S3	S1	S3	S1	S3	S1	S3	S1	S3	S3	**S3wk**
Sg-6	S1	S2	S3	-	S1	S1	S1	S1	S1	S1	N2	S3	S1	S1	S1	N2	S3	S1	S1	N2	S3	S1	S3	S1	S1	S1	S1	S1	N1	N2	**N2rwk**
U1e-4	S1	S2	S3	-	S1	S1	S1	S1	S2	S1	S1	S2	S1	S1	S1	N1	S2	S1	S1	N1	S2	S1	S2	S1	S3	S1	S1	S1	S3	N1	**N1kw**
U1e-5	S1	S2	S3	-	S1	S1	S1	S2	S3	S1	N2	S1	S1	S1	S1	N1	S1	S1	S1	N1	S1	S1	S1	S1	S3	S1	S1	S1	S3	N1	**N2r**
U2f-9	S1	S2	S3	-	S1	S1	S1	S1	S1	S1	S2	S1	S1	S1	S1	N1	S1	S1	S1	N1	S1	S1	S1	S1	S1	S1	S1	S1	N1	N1	**N1wk**
V1b-3	S1	S2	S2	S1	S3	S1	S1	S1	S3	S3	S1	S1	S3	S1	S1	S1	S1	S1	S3	S1	S1	S3	S1	S3	S2	S1	S3	S1	S1	S1	**S3zwk**
V2a-7	S1	S2	S2	-	N1	S1	S1	S1	S3	S3	S1	S1	S3	S1	S1	S1	S1	S1	S3	S1	S1	S3	S1	S3	S1	S3	S1	S1	S1	S1	**N1d**
V3c-8	S1	S2	S2	S1	S1	S1	S1	S1	S1	S1	S2	S1	S1	S1	S1	S3	S1	S1	S1	S3	S1	S1	S1	S1	S3	S1	S1	S1	S3	S3	**S3wk**
G3d	S1	S2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	N2	-	-	-	N2	-	N2	-	-	-	-	-	-	-	**N2wk**
R	S1	S2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**N2w**
F&St	S1	S2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**N1w**

Source: Field Investigations, 2009

Appendix D. Table 4. Land suitability for surface irrigated maize cultivation

Land qualities or land characteristics/ Suffixes	FACTOR RATING																													Final suitability class and sub class
	c		m	x	d		n		z		r					w				k			t		d'			f	e	
	Climate		Moisture availability	Toxicity	Oxygen availability		Nutrient retention		Nutrient availability		Rooting condition					Workability				Potential for mechanization			Land preparation & clearance		Drainage			Flood hazard	Erosion hazard	
Land units	t 0c	R. H	AWC	$CaCO_3$	S.DC	Flo.	OC	CEC	PH	Texture	Depth	Stones	Texture	Com.	OC	Slope	Stones	OC	Texture	Slope	Stones	Texture	Stones	Texture	I.N	D.G.W	H. C	Flo.	Sheet	Slope	
G1b-1	S1	S2	S3	-	S1	S1	S1	S1	S3	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S3	S1	S1	S1	S3	S1	**S3md[1]**
G1b-4	S1	S2	S2	S1	S1	S1	S1	S1	S3	S1	S1	S2	S1	S1	S1	S1	S2	S1	S1	S1	S2	S1	S2	S1	S3	S1	S1	S1	S3	S1	**S3z d[1]**
G2d-1	S1	S2	S3	S1	S1	S1	S1	S1	N1	S1	S1	S1	S1	S1	S1	S3	S1	S1	S1	S3	S1	S1	S1	S1	S3	S1	S1	S1	S3	S3	**N1z**
G2d-2	S1	S2	S3	-	S1	S1	S1	S1	N1	S1	S1	S3	S1	S1	S1	S3	S3	S1	S1	S3	S3	S1	S3	S1	S3	S1	S1	S1	S3	S3	**N1z**
Sg-6	S1	S2	S3	-	S1	S1	S1	S1	S2	S1	S2	S3	S1	S1	S1	N1	S3	S1	S1	N1	S3	S1	S3	S1	S1	S1	S1	S1	N1	N1	**N1wk**
U1e-4	S1	S2	S3	-	S1	S1	S1	S1	N1	S1	S1	S2	S1	S1	S1	N1	S2	S1	S1	N1	S2	S1	S2	S1	S3	S1	S1	S1	S3	N1	**N1zk**
U1e-5	S1	S2	S3	-	S1	S1	S1	S1	N1	S1	S2	S1	S3	S1	S1	N1	S1	S1	S3	N1	S1	S3	S1	S3	S3	S1	S1	S1	S3	N1	**N1zk**
U2f-9	S1	S2	S3	-	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	N1	S1	S1	S1	N1	S1	S1	S1	S1	S1	S1	S1	S1	N1	N1	**N1wk**
V1b-3	S1	S2	S2	S1	S2	S1	S1	S1	N1	S2	S1	S1	S2	S1	S1	S1	S1	S1	S2	S1	S1	S2	S1	S2	S1	S1	S3	S1	S1	S1	**N1z**
V2a-7	S1	S2	S2	-	S3	S1	S1	S1	N1	S2	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S2	S3	S1	S1	S1	**N1z**
V3c-8	S1	S2	S2	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S3	S1	S1	S1	S3	S1	S1	S1	S1	S3	S1	S1	S1	S3	S3	**S3wk**
G3d	S1	S2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	N2	-	-	-	N2	-	N2	-	-	-	-	-	-	-	**N2wk**
R	S1	S2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**N2w**
F&St	S1	S2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**N1w**

Source: Field Investigations, 2009

Appendix D. Table 5. Land suitability for surface irrigated sesame cultivation

Land qualities or land characteristics/ Suffixes	FACTOR RATING																													Final suitability class and sub class
	c		m	x	d		n		z		r					w				k			t		d'			f	e	
	Climate		Moisture availability	Toxicity	Oxygen availability		Nutrient retention		Nutrient availability		Rooting condition					Workability				Potential for mechanization			Land preparation & clearance		Drainage			Flood hazard	Erosion hazard	
Land units	t 0c	R. H	AWC	$CaCO_3$	S.DC	Flo.	OC	CEC	PH	Texture	Depth	Stones	Texture	Com.	OC	Slope	Stones	OC	Texture	Slope	Stones	Texture	Stones	Texture	I.N	D.G.W	H. C	Flo.	Sheet	Slope	
G1b-1	S1	S2	S3	-	S1	S1	S1	S1	S3	S1	S1	S1	S1	S1	S1	S2	S1	S1	S1	S2	S1	S1	S1	S1	S3	S1	S1	S1	S3	S2	**S3zd[1]**
G1b-4	S1	S2	S2	S1	S1	S1	S1	S1	S3	S1	S1	S2	S1	S1	S1	S2	S2	S1	S1	S2	S2	S1	S2	S1	S3	S1	S1	S1	S3	S2	**S3zd[1]**
G2d-1	S1	S2	S3	S2	S1	S1	S1	S1	S3	S1	S1	S1	S1	S1	S1	S3	S1	S1	S1	S3	S1	S1	S1	S1	S3	S1	S1	S1	S3	S3	**S3zwd[1]**
G2d-2	S1	S2	S3	-	S1	S1	S1	S1	S3	S1	S1	S3	S1	S1	S1	S3	S3	S1	S1	S3	S3	S1	S3	S1	S3	S1	S3	S1	S3	S3	**S3zwk**
Sg-6	S1	S2	S3	-	S1	S1	S1	S1	S2	S1	S3	S3	S1	S1	S1	N1	S3	S1	S1	N1	S3	S1	S3	S1	S1	S1	S2	S1	N1	N1	**N1wk**
U1e-4	S1	S2	S3	-	S1	S1	S1	S1	S3	S1	S1	S2	S1	S1	S1	N1	S2	S1	S1	N1	S2	S1	S2	S1	S3	S1	S1	S1	S3	N1	**N1wk**
U1e-5	S1	S2	S3	-	S1	S1	S1	S2	N1	S1	S3	S1	S1	S1	S1	N1	S1	S1	S1	N1	S1	S1	S1	S1	S3	S1	S2	S1	S3	N1	**N1zwk**
U2f-9	S1	S2	S3	-	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	N1	S1	S1	S1	N1	S1	S1	S1	S1	S1	S1	S2	S1	N1	N1	**N1wk**
V1b-3	S1	S2	S2	S1	S2	S1	S1	S1	S3	S2	S1	S1	S2	S1	S1	S2	S1	S1	S2	S2	S1	S2	S1	S2	S1	S1	S3	S1	S1	S2	**S3zd[1]**
V2a-7	S1	S2	S2	-	S3	S1	S1	S1	S3	S2	S1	S1	S2	S1	S1	S1	S1	S1	S2	S1	S1	S2	S1	S2	S1	S2	S3	S1	S1	S1	**S3dd[1]**
V3c-8	S1	S2	S2	S2	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S3	S1	S1	S1	S3	S1	S1	S1	S1	S3	S1	S2	S1	S3	S3	**S3wkd[1]**
G3d	S1	S2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	N2	-	-	-	N2	-	N2	-	-	-	-	-	-	-	**N2wk**
R	S1	S2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**N2w**
F&St	S1	S2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	N1w

Source: Field Investigations, 2009

APPENDIX E

INTERPRETATIVE RATINGS

[USED IN DINGER BEREHA FIELD INVESTIGATIONS (SOILS) AND ADOPTED BY THE FEASIBILITY STUDY]

Table E.1 Analytical Data Interpretation

Description	Very Low	Low	Medium	High	Very High
Total Nitrogen %	<0.05	0.05-0.125	0.125-0.225	0.225-0.3	>0.3
Organic carbon %	<2	2-4	4-10	10-20	>20
CEC (meq/100g soil)	<5	5-15	15-25	25-40	>40
Exch. Ca (meq/100g soil)	<2	2-5	5-10	10-20	>20
Exch. Mg (meq/100g soil)	<0.5	0.5-1.5	0.5-3	3-8	>8
Exch. K(meq/100g soil)	<0.1	0.1-0.3	0.3-0.6	0.6-1.2	>1.2
Exch. Na (meq/100g soil)	<0.1	0.1-0.3	0.3-0.7	0.7-2.0	>2.0
Sodicity (ESP)	<2	2-8	8-15	15-27	>27
Available P (ppm) Olsen Method	<5	5-8	8-12	12-20	>20
pH	<5.3 Very acid	5.3-6 M. Acid	6-7 Slightly Acid	7-8.5 M. Alkaline	>8.5 V. Alkaline
ESP	<2	2-8	8-15	15-27	>27
C:N		<10 Good	10-14 Medium	>14 Poor	

Source: B. Frank 1990 (Adopted from Illaco Agricultural Compendium; FAO ; and Booker TSM)

Table E.2 Bulk Density in Relation to Textural Class

No.	Soil texture class	Bulk density (gm/cc^3)
1	Clay, clay loam and Silty loam (surface soil)	1.0-1.6
2	Sand and sandy loams	1.2-1.8
3	Recently cultivated soils	0.9-1.2
4	Soils showing root restriction	
4.1	Sand and loams	> 1.75
4.2	Silts	1`.4-1.6
4.3	Clays	> 1.3
5	Compacted sub-soils	> 2.0

Source: Taylor et al. 1966; De Geus, 1973

Table E.3 Ranking Infiltration Rate for Surface Irrigation Development

No.	(cm/hr)	Suitability for surface Irrigation
1	<0.1	Unsuitable (too slow) but suitable for Rice
2	0.1-0.3	Marginally suitable (too slow) & marginally for Rice
3	0.3-0.7	Suitable; but unsuitable for Rice
4	0.7-3.5	Optimum
5	3.5-6.5	Suitable
6	6.5-12.5	Marginally suitable (too rapid); small basins is needed
7	12.5-25.0	Unsuitable only under special conditions; Very small basins needed
8	>25	Unsuitable (too rapid) overhead irrigation methods only

Table E. 4 Infiltration Rates in Relation to Soil Texture

No.	Soil texture	Representative IR (cm/h)	Normal IR Rang (cm/h)
1	sand	5	2 - 5
2	Sandy loam	2	1 - 8
3	Loam	1	1 - 2
4	Clay loam	0.8	0.2 – 1.5
5	Silty clay	0.2	0.03 – 0.5
6	Clay	0.05	< 0.1 – 0.8

Table E.5. Hydraulic Conductivity Value Rating

No.	Hydraulic Conductivity Class	K (Cm/h)	K (m/ day)
1	Very slow	< 0.8	< 0.2
2	Slow	0.8 – 2.0	o.2 – 0.5
3	Moderate	2.0 – 6.0	0.5 – 1.4
4	Moderately rapid	6.0 – 12.5	1.9 – 3.0
5	Rapid	8.0 – 12.5	1.9 – 3.0
6	Very Rapid	> 12.5	> 3.0

Source: FAO (1963)

Table E.6 Approximate Relationship between soil Texture and Hydraulic Conductivity

No	Texture Class	K (Cm/h)	K (m/ day)
1	Loamy Sand & Fine sand	12-25	3-6
2	Sandy loam	6-12	1.5-3
3	Clay Loam,Silt, Silty Loam	2-6	0.5-1.5
4	Silty Clay,Sandy Clay,Silty Clay,Loam,Clay Loam,Silty Loam, Silty Sandy Clay Loam	0-5-2	0.1-0.5
5	Clay Loam,Silty Clay,Clay, Sandy Clay Loam	0.25-0.5 <0.25	0.1-0.5 <0.05
6	Clay, heavy clay	<0.25	<0.05

Source FAO-1979

Table E.7 Available Water Holding Capacity Rating for Irrigation Suitability

Rating for irrigation suitability	AWC (mm/m)
Low	<120
Medium	120-180
High	>180

Table E.8 Electrical Conductivity (EC) (mS/cm)

Approximate value	Rating	Interpretation
0-2	Salt free	Salinity effects are negligible except for most sensitive
4-8	Slightly saline	Yields of many crops restricted.
8-15	Moderately Saline	Only tolerant crops restricted
>15	Strongly saline	Only very tolerant crops yield satisfactory.

Table E.9 Cation Exchange Capacity (CEC)

(me/100g soil)	Rating	Interpretation
>40	Very high	Normal good agricultural soils
25-40	High	As above only small amounts of lime and K fertilizer needed
12-25	Medium	Satisfactory for agriculture given fertilizer.
5-15	Low	Moderate to poor response to Fertilizer
<5	Very low	Few nutrient reserves. Marginal for sustainable and rain fed agriculture unsuitable for irrigation.

Table E.10 Base Saturation Percentage (BSP)

%	Rating	Interpretation
<20	Low	Less fertile soil
20-60	Medium	Moderately fertile soil
>60	High	More fertile soil soil

Table E.11 Exchangeable Cation Ratio

Cation Ratio	Approximate Value	Effects	
Ca:Mg	>5:1	Mg increasingly unavailable with increasing Ca and P availability may be reduced	
	3:1 to 4:1	Approximate optimum range for most crops	
	< 3:1	Available P up take may be inhibited (Yates, 1964)	
	1:1	Suggested lowest acceptable limit (Fauck et al.1969). With lower values. Ca Availability slightly reduced	
K:Mg	>2:1	Mg uptake may be inhibited	
	<3:2	Field crops recommended levels (Doll and Lucas1973)	
	<1:1	Vegetables and Sugar beet	
	<3:5	Fruit and greenhouse crops	
(Ca+Mg)/K	>40	Very high	Overdose Ca +Mg or lack of K.
	25-40	High.	Fertilizer response no need
	15-25	Optimal.	Fertilizer response unlikely
	0-15	Lack of Ca or Mg (see ca/Mg).	Fertilizer response probable
	<5	Low	Fertilizer response most likely

Table E.12 Carbonate%

Range	Interpretation
<15	Low to Medium
15-40	Calcic
>40	Extremely calcareous

Table E.13 Indicative Level of Micronutrient in the Soils & Their Value Rating

Category (ppm)	Iron (Fe)	Manganese (Mn)	Copper (Cu)	Zinc (Zn)	Source
Low	0-3	0-0.5	0-0.2	0-0.9	*
Marginal	3.1-5	0.6-1	0.3-0.5	1-1.5	*
Adequate	>5	>1	>0.5	>1.5	*
Approximate mean in soil		200	30	90	Fairbridge & Finkl, 1979
Usual rang in soil	10-1000	20-300	2-100	10-100	
Toxic	>1000	>300	>100	>100	

Source: * = Soil analytical hand book for reference method by Soil and Plant Analysis Council INC-1992. Extracting solution is DTPA.

Table E. 14. Exchangeable Aluminum Level in the soil & its effects

Exchangeable Al %	Effects	Source
30	-Sensitive crops may be affected	
60	▪ Generally toxic only very low Al concentrations expected ▪ 60% tolerated by sugar cane	Nye etal (1961) Evans - 1965
85	May be tolerated by some crops in some condition tea, rubber, cassava, Pineapple & legumes are notably Al tolerant	Scacher 1976

APPENDIX F : MODAL SOIL PROFILES – DESCRIPTIONS & ANALYSES

[From Field Investigations]

SOIL PROFILE DESCRIPTION	**Field No: DP2**	Map Sheet: 0836A1
Location: N-W of Illuharar town	Region: Oromiya, Zone: Illuababora, Wereda: Chewaka	
Mapping Unit: G2d-2		
Author: Zelealem S/Mariam	Date: 07/05/09	
FAO - Soil Type: Rhodic Nitisols (NTro)	Coordinate (UTM)	N: 989140
Agro-Climatic Zone: Kolla	Elevation (m)1248	E:186500
Land form: Middle & lower part of gently undulating plains with convex interfluves	Slope Class: Gently slope	Slope: Position: Medium
Slope Aspect: South-North direction	Slope Length: 1.5km	Slope Form: Uniform
Micro - Topography: Termite	Coverage%:	
Parent Material :	Soil depth cm.: 180	Rocky outcrop:
Surface Fragment coverage :	Surface Crack:	Sealing:
Flooding	Water table cm: > 180	
Drainage - External Well	Internal: Well drained	
Human influence: vegetation disturbed/clearing		Moisture condition: Moist
Land Cover: Predominantly cultivated land		
Land Use: Rain fed arable cultivation		
Major Crop Type: sorghum, maize, rice sesame	Fertilizer Type: Applies for maize	
Type of erosion: sheet & splash erosion	Area affected:10-25%	
Activity: Active at present	Degree of dissection: Slight	
Remarks:		

0-15cm: Dark reddish brown (5YR 3/4) color moist, loam texture, moderate, coarse, granular structure, slightly hard dry and slightly stick/slightly plastic consistency when wet, few, fines roots and many to common pores.
15-41cm: Red (2.5YR 4/6) color moist, clay texture, strong, medium to coarse, sub-angular blocky structure, firm moist and stick / plastic consistency when wet, few, fine roots and few, fine pores.
41-92cm: Dark red (2.5YR3/6) color moist, clay texture, strong, medium to coarse sub-angular blocky structure, sticky/ plastic consistency when wet, moderately cemented, platy, clay cementation, few, fine roots and few, fine pores.
92-180cm: Dark red (2.5YR3/6) color moist, clay loam texture, strong, coarse, sub-angular blocky structure, firm moist and stick/plastic consistency when wet, moderately cemented, platy, clay cementation.

	Profile DP2				SMU : G2_d2									Soil Type : Rhodic Nitisols (Ntro)									
Depth	Texture <2 mm. fraction				pH (1:2.5)			EC	T N	OC	C/N	Avail P	CaCO3	Ex. Cations (meq/100gm soil)					CEC	BS	ESP	Ca/	Ca+Mg/
cm	Sand	Silt	Clay	Class	H2O	KCl	∆pH	dS/m	%	%		ppm		Na	K	Ca	Mg	Sum	meq/g	%	%	Mg	K
0-15	36.7	23.6	39.7	CL	5.4	4.5	-0.9	0.09	0.3	3.2	11	0.7		0.2	0.3	9.0	2.7	12.2	40.8	30	0.5	3	39
15-41	17.9	17.1	65.0	C	5.1	4.2	-0.9	0.02	0.2	1.7	7	0.3		0.1	0.1	4.0	1.4	5.7	43.2	13	0.3	3	43
41-92	5.0	14.9	80.1	C	4.9	4.2	-0.8	0.01	0.2	1.2	8	Trace		0.2	0.1	4.5	3.6	8.4	24.1	35	0.7	1	88
92-180	2.3	12.7	84.9	C	7.8	4.9	-2.9	0.02	0.2	1.4	7	Trace		0.1	0.1	3.6	1.4	5.2	49.6	10	0.2	3	57

Micronutrients mg/kg soil (ppm)

Depth (cm)	Fe	Mn	Cu	Zn
0-15	37.2	78.8	2.1	1.2

Source: MCE laboratory analyses, 2009; DP = Dinger Profile Pit; SMU = Soil Mapping Unit. Note: Values have been rounded off for presentation;
Texture codes: SC - Sandy Clay; SL - Sandy Loam; SCL - Sandy Clay Loam; SiL - Silt Loam; L - Loam; CL - Clay Loam; SICl - Silty Clay Loam

SOIL PROFILE DESCRIPTION	**Field No:DP3**	Map Sheet: 0836A1
Location: N-W of ILLUHARAR	Region: Oromiya, Zone: Illuababora, Wereda: Chewaka	
Mapping Unit: 3 (G2d-1)		
Author: Zelealem S/Mariam	Date: 07/05/09	
FAO - Soil Type: Orthidystric Nitisol (NTdyo)	Coordinate (UTM)	N: 987085
Agro-Climatic zone: Kolla	Elevation (m): 1253	E: 186469
Land form: Upper part of gently undulating plain with convex interfluves	Slope Class: Strongly sloping	Slope: Position : Medium
Slope Aspect: West-East	Slope Length: 1km	Slope Form: Convex /Uniform
Micro - Topography: Termite	Coverage%: 3	
Parent Material : Volcanic ash/Colluvial deposit	Soil depth cm.: 200	Rock outcrop:
Surface Fragment coverage:	Surface Crack:	Sealing:
Flooding	Water table cm: >200	
Drainage - External Well	Internal – Well drained	
Human influence: New settlement		Moisture condition: Moist
Land Use: Rain fed arable cultivation;	Land cover: Predominantly cultivated	
Major crop Type : sorghum	Fertilizer Type	
Type of Erosion : Sheet & Splash erosion	Area Affected: 5-10%	
Activity: Active at present	Degree of dissection: Slight to medium	
Remarks:		

0-30cm: Dark reddish brown (5YR3/4) color, moist, loam texture, weak, medium to coarse, sub-angular blocky structure, firm moist and slightly stick /slightly plastic consistency when wet, patchy /broken, distinct, pressure faces cutanic feature, few to common, medium to fine roots, and many to medium pores.

30-113cm: Red (2.5YR4/6) color, moist, clay loam texture, moderate, medium to fine, sub-angular block structure, firm moist and stick / plastic consistency when wet, few, fine roots and very few, medium to coarse pores.

113-200cm: Dark reddish brown (5YR3/4) color moist, clay loam texture, moderate, medium to coarse, sub-angular blocky structure, firm moist and stick /plastic consistency when wet, few, fine roots and very few, coarse pores.

	Profile DP3				SMU: *** (G2d_1)								Soil Type:Orthidystric Nitisols (Ntdyo)									
Depth	Texture <2 mm. fraction				pH (1:2.5)			EC	T N	OC	C/N	Avail P	Ex. Cations (meq/100gm soil)					CEC	BS	ESP	Ca/	Ca+Mg/
cm	Sand	Silt	Clay	Class	H2O	KCl	ΔpH	dS/m	%	%		ppm	Na	K	Ca	Mg	Sum	meq/g	%	%	Mg	K
0-30	30.8	34.1	35.1	CL	5.3	4.7	-0.6	0.07	0.3	2.6	9	3.6	0.2	0.4	10.8	2.7	14.2	35.4	40	0.5	4	33
30-113	25.0	4.2	70.8	C	4.7	4.5	-0.2	0.02	0.1	0.9	8	0.3	0.6	0.2	4.5	0.9	6.1	34.4	18	1.7	5	36
113-200	10.6	10.5	78.9	C	4.9	4.2	-0.7	0.01	0.1	1.4	10	Trace	0.2	0.2	3.6	1.8	5.8	21.6	27	0.8	2	31
200-300	8.8	8.4	82.9	C	5.2	4.4	-0.8	0.01	0.2	1.3	7	0.3	0.2	0.2	7.2	0.9	8.5	19.7	43	0.9	8	44
300-337	10.5	8.4	81.0	C	4.9	4.2	-0.7	0.01	0.2	1.4	9	Trace	0.2	0.1	3.6	0.9	4.8	22.1	22	0.7	4	33

Micronutrients mg/kg soil (ppm)

Depth (cm)	Fe	Mn	Cu	Zn
0-30	25.6	73.8	1.8	1.3

Source: MCE laboratory analyses, 2009; DP = Dinger Profile Pit; SMU = Soil Mapping Unit. Note: Values have been rounded off for presentation;
Texture codes: SC - Sandy Clay; SL - Sandy Loam; SCL - Sandy Clay Loam; SiL - Silt Loam; L - Loam; CL - Clay Loam; SICl - Silty Clay Loam

SOIL PROFILE DESCRIPTION	**Field No:DP15**	Map Sheet: 0836A1
Location: W of village # 7	Region: Oromiya, Zone: Illuababora, Wereda: Chewaka	
Mapping Unit: 8 (U2f-9)		
Author: Zelealem S/Mariam	Date:- 10/05/09	
FAO -Soil Type : Hypereutric Cambisol (CMeuh)	Coordinate (UTM)	N: 992348
Agro-Climatic zone: Kolla	Elevation (m): 1207/09	E: 189879
Land form : Strongly steep hill/ ridge side	Slope Class: Strongly slope	Slope: Position medium
Slope Aspect: E-W	Slope Length: 600m	Slope Form: Convex
Micro- Topography:	Coverage %:	
Parent Material : Volcanic ash	Soil depth cm: 100	Rock outcrop:
Surface Fragment coverage :	Surface Crack:	Sealing:
Flooding	Water table cm. >100cm	
Drainage - External Slow	Internal – Rapid	
Human influence : New settlement area		Moisture condition: Moist
Land Cover : Sparsely cultivated	Land use: Rain fed arable cultivation	
Major crop Type : maize	Fertilizer Type	
Type of Erosion: Sheet & Splash erosion	Area Affected: 10-25%	
Activity: Active at present	Degree of dissection: Slight to moderate	

Remarks: After 100cm stones and gravel is observed. The area is highly raged and irregular surface feature

---

0-15cm: Dark brown (10YR3/3) color, moist, clay loam texture, common, coarse to medium structure, slightly sticky and plastic when consistency when wet, many roots and coarse to medium pores.
15-52cm: Dark yellowish red (10YR3/4) color moist, clay loam texture, few, fine roots and many to common, fine medium pores.
52-100cm: Dark yellowish red (10YR3/4) color, moist, clay loam texture, many to common, fine to medium coarse fragment, strong to moderate, medium to coarse, sub-angular blocky structure, firm when moist and stick/plastic consistency when wet and few, fine pores.

	Profile DP15							SMU : U2f_9					Soil Type : Hypereutric Cambisols (CMeuh)									
Depth	Texture <2 mm. fraction				pH (1:2.5)			EC	T N	OC	C/N	Avail P	Ex. Cations (meq/100gm soil)					CEC	BS	ESP	Ca/	Ca+Mg/
cm	Sand	Silt	Clay	Class	H2O	KCl	ΔpH	dS/m	%	%		ppm	Na	K	Ca	Mg	Sum	meq/g	%	%	Mg	K
0-15	37.8	35.4	26.8	C	6.7	5.9	0.1	0.13	0.6	7.8	14	112.0	0.1	1.7	27.4	6.8	36.0	37.7	96	0.3	4	20
15-52	33.9	24.5	41.6	C	6.4	5.7	0.1	0.14	0.2	1.5	7	42.9	0.1	0.9	21.7	14.5	37.2	30.5	122	0.5	2	41
52-100	24.3	21.3	54.4	C	6.6	5.8	-0.8	0.05	0.1	1.1	7	7.9	0.1	0.8	16.3	11.3	28.5	31.4	91	0.3	1	34

Micronutrients mg/kg soil (ppm)

Depth (cm)	Fe	Mn	Cu	Zn
0-15	24.1	105.0	3.5	8.9

Source: MCE laboratory analyses, 2009; DP = Dinger Profile Pit; SMU = Soil Mapping Unit. Note: Values have ben rounded off for presentation;
Texture codes: SC - Sandy Clay; SL - Sandy Loam; SCL - Sandy Clay Loam; SiL - Silt Loam; L - Loam; CL - Clay Loam; SICl – Silty Clay Loam

SOIL PROFILE DESCRIPTION **Field No :DP56** Map Sheet : 0836A1

Location : N of Illuharar Region : Oromiya, Zone : Illuababora, Wereda : Chewaka

Mapping Unit : 5 (Sg-6)

Author :- Zelealem S/M Date :- 08/05/09

FAO –Soil Type : Orthieutric Leptosol (Lpeou) Coordinate (UTM) N : 995602

Agro-Climatic zone : Kolla Elevation (m) :1187 E : 187193

Land form : Moderately steep side of hill / ridge. Slope Class : Gently slope Slope : Position : Medium

Slope Aspect : North –South Slope Length : 70m Slope Form : Uniform

Micro- Topography : Termite Coverage % :2

Parent Material : Volcanic ash Soil depth cm. : 60 Rock outcrop :

Surface Fragment coverage : Surface Crack : Sealing :

Flooding Water table cm. :> 60

Drainage -External rapid /medium Internal –well

Human influence :New settlement area Moisture condition : moist

Land Cover : Predominantly cultivated/ Intensively cultivated land ; Land Use : Rain fed arable cultivativation

Major Crop Type :sorghum ,maize ,rice ,haricot bean ,sesame Fertilizer Type

Type of erosion : Sheet & Splash erosion Area Affected : 5-10%

Activity : Active at present Degree of dissection : Slight

Remarks: Deforestation is high .After 60cm the oi lis stony & gravelly.

0-23cm : Dark reddish brown (5YR3/2) color, moist, loam texture, few, fine coarse fragment, strong, coarse, angular block/ sub-angular blocky structure, hard dry, slightly stick /slightly plastic consistency when wet, common, fine to medium roots and common, medium to coarse pores.

23-60cm : Reddish brown (5YR4/3) color, moist, clay loam texture, common, fine to medium coarse fragment, strong, coarse sub-angular blocky structure, slightly stick/slight plastic consistency when wet, few, black, hard, manganese mineral nodules, few, fine roots and common, fine to medium pores.

	Profile DP56							SMU : Sg-6						Soil Type: Orthieutric Leptosols (Lpeoul)									
Depth	Texture <2 mm. fraction				pH (1:2.5)			EC	T N	OC	C/N	Avail P	CaCO3	Ex. Cations (meq/100gm soil)					CEC	BS	ESP	Ca/	Ca+Mg/
cm	Sand	Silt	Clay	Class	H2O	KCl	∆pH	dS/m	%	%		ppm		Na	K	Ca	Mg	Sum	meq/g	%	%	Mg	K
0-23	48.7	29.3	22.0	L	6.8	6.0	-0.8	0.24	0.7	6.8	10	33.3	1.23	0.1	1.3	26.0	3.6	31.1	43.8	71	0.3	7	22
23-60	44.8	20.8	34.4	CL	6.8	6.0	-0.8	0.06	0.2	1.6	7	5.6	0.56	0.2	0.6	16.1	5.4	22.3	25.8	86	0.7	3	37

Micronutrients mg/kg soil (ppm)

Depth (cm)	Fe	Mn	Cu	Zn
0-23	28.7	44.0	0.8	1.7

Source: MCE laboratory analyses, 2009; DP = Dinger Profile Pit; SMU = Soil Mapping Unit. Note: Values have ben rounded off for presentation;
Texture codes: SC - Sandy Clay; SL - Sandy Loam; SCL - Sandy Clay Loam; SiL - Silt Loam; L - Loam; CL - Clay Loam; SICl = Silty Clay Loam

SOIL PROFILE DESCRIPTION	**Field No: DP65**	Map Sheet: 0836A1
Location : 6.5 km NE of Illu Harer	Region : Oromiya, Zone: Illuababora, Wereda: Chewaka	
Mapping Unit: 11 (V3c-8)		
Author:- Zelealem S/M	Date:- 08/05/09	
FAO -Soil Type : Fluvic Cambisols (CMfv)	Coordinate (UTM)	N: 991896
Agro-Climatic zone: Kolla	Elevation (m):1222	E:191038
Land form : Seasonally Wet Valley Floor	Slope Class :	Slope: Position : Low
Slope Aspect: West -East	Slope Length: 100m	Slope Form: Convex
Micro- Topography: Termite	Coverage 2%	
Parent Material : Volcanic ash	Soil depth cm.: 175	Rock outcrop:
Surface Fragment coverage :	Surface Crack:	Sealing:
Flooding	Water table cm. : >175	
Drainage -External	Rapid	Internal –Well drained
Human influence: New settlement area		Moisture condition: Moist
Land Cover : Predominantly cultivated land;	Land Use: Rain fed arable cultivate	
Major Crop Type :sorghum, maize, sesame, rice, pepper	Fertilizer Type	
Type of erosion : Sheet & Splash erosion	Area Affected : 10-25%	
Activity :Active at present	Degree of dissection: Slight to Medium	

Remarks: At the valley bottom there are large trees like bedessa , harabo local name, sample is taken from wet land.

0-21cm: Dusky red (2.5YR3/3) color, moist, loam texture, strong, coarse and sub-angular blocky structure, hard dry, and slightly stick/ plastic consistency when wet, common, fine to medium roots and many to common, medium to fine pores.

21-55cm: Dusky red(2.5YR3/3) color, moist, clay loam texture, few, fine coarse fragment, strong, medium to coarse, sub-angular blocky structure, stick/plastic consistency wet, common, red, slightly hard, iron mineral nodules, few, fine roots, and common, fine pores.

55-69cm: Dusky red(2.5YR3/3) color, moist, clay loam texture, few, fine coarse fragment, strong, medium to coarse, sub-angular blocky structure, stick/plastic consistency when wet, common, red, soft, iron mineral nodules, common, medium pores.

69-175cm: Reddish brown (2.5YR4/4) color, moist, clay loam texture.

	Profile DP65							SMU : V3c_8					Soil Type:Fluvic Cambisols (CMfv)									
Depth	Texture <2 mm. fraction				pH (1:2.5)			EC	T N	OC	C/N	Avail P	Ex. Cations (meq/100gm soil)					CEC	BS	ESP	Ca/	Ca+Mg/
cm	Sand	Silt	Clay	Class	H2O	KCl	∆pH	dS/m	%	%		ppm	Na	K	Ca	Mg	Sum	meq/g	%	%	Mg	K
0-21	47.6	24.7	27.8	SCL	6.6	6.3	-0.2	0.41	0.5	4.5	10	23.9	0.2	1.4	15.7	4.0	21.3	24.8	86	0.8	4	14
21-55	44.3	15.5	40.2	C	6.4	5.2	-1.2	0.18	0.2	1.8	7	3.4	0.1	0.8	9.8	2.2	12.9	15.9	81	0.8	4	15
55-69	44.3	9.3	46.4	C	6.6	5.7	-0.8	0.39	0.2	1.3	8	5.4	0.1	3.3	6.3	1.3	11.1	16.6	67	0.8	5	2
69-175	32.7	14.5	52.8	C	6.4	5.9	-0.5	0.17	0.1	1.0	8	9.8	0.1	1.2	6.3	2.7	10.3	15.1	68	1.0	2	8

Micronutrients mg/kg soil (ppm)

Depth (cm)	Fe	Mn	Cu	Zn
0-21	35.2	59.2	2.1	1.1

Source: MCE laboratory analyses, 2009; DP = Dinger Profile Pit; SMU = Soil Mapping Unit. Note: Values have ben rounded off for presentation;
Texture codes: SC - Sandy Clay; SL - Sandy Loam; SCL - Sandy Clay Loam; SiL - Silt Loam; L - Loam; CL - Clay Loam; SICl = Silty Clay Loam

SOIL PROFILE DESCRIPTION	**Field No: DP67**	Map Sheet: 0836A1
Location : Barjk Anani	Region : Oromiya, Zone: Illuababora, Wereda: Chewaka	
Mapping Unit: 6 (U1e-4)		
Author:- Kumsa	Date:- 09/05/09	
FAO -Soil Type : Hyperferric Acrisol (ACfrh)	Coordinate (UTM)	N: 995438
Agro-Climatic Kolla	Elevation (m) :1237	E:181318
Land form : Strongly sloping valley side	Slope Class: Sloping	Slope: Position :Medium
Slope Aspect: North-South	Slope Length: >200m	Slope Form: Concave
Micro- Topography: Terracing /Termite	Coverage %:1	
Parent Material : In suite weathered residual	Soil depth cm.: 160	Rock outcrop:
Surface Fragment coverage :	Surface Crack:	Sealing:
Flooding	Water table cm. :>160	
Drainage -External Well	Internal –Well drained	
Human influence :Burning, clearing ,terracing;	Land Cover : Intensively cultivated land	Moisture condition: Moist
Land Use: Rain fed arable cultivated		
Major Crop Type :sorghum	Fertilizer Type	
Type of erosion : Sheet & Splash erosion	Area Affected : >50%	
Activity : Active at present	Degree of dissection: Slight	
Remarks: Deep soil and 7% Slope		

0-14cm: Dark reddish brown (5YR3/2) color moist, clay loam texture, weak, fine to medium, sub-angular blocky structure, firm, stick/plastic consistency when wet, many, fine roots and many, fine pores.
14-45cm: Dark reddish brown (5YR3/4) color moist, clay texture, moderate, fine to medium, sub-angular blocky structure, firm moist and stick/plastic consistency when wet, common, fine to medium and roots many, fine pores.
45-80cm: Dark reddish brown (2.5YR3/4) color moist, clay texture, moderate, fine to medium, sub-angular blocky structure, firm, stick/plastic consistency when wet, few, fine to medium and roots, many, fine pores.
80-160cm: dark red (2.5YR3/6) color moist, clay texture, moderate, fine to medium, sub-angular blocky structure, firm moist and stick/plastic consistency when wet, few, fine roots, and many, fine pores.

	Profile DP67							SMU: Ue1_4					Soil Type: Hyperferric Acrisols (Acrh)									
Depth	Texture <2 mm. fraction				pH (1:2.5)			EC	T N	OC	C/N	Avail P	Ex. Cations (meq/100gm soil)					CEC	BS	ESP	Ca/	Ca+Mg/
cm	Sand	Silt	Clay	Class	H2O	KCl	∆pH	dS/m	%	%		ppm	Na	K	Ca	Mg	Sum	meq/g	%	%	Mg	K
0-14	45.6	28.2	26.2	L	5.4	4.4	-1.0	0.10	0.3	4.0	12	4.6	0.2	0.4	9.1	4.6	14.3	34.7	41	0.6	2	35
14-45	46.8	18.8	34.5	SCL	5.1	4.3	-0.8	0.02	0.2	2.8	13	1.9	0.2	0.1	4.6	1.8	6.7	22.3	30	0.8	3	46
45-80	28.0	25.0	47.0	C	5.1	4.3	-0.8	0.01	0.2	1.5	8	1.9	0.2	0.1	4.6	1.8	6.6	17.3	38	0.9	3	61
80-160	25.8	14.6	59.5	C	5.0	4.3	-0.7	0.01	0.1	1.1	7	Trace	0.2	0.1	4.5	1.8	6.6	14.7	45	1.1	3	55

Micronutrients mg/kg soil (ppm)

Depth (cm)	Fe	Mn	Cu	Zn
0-14	33.7	55.9	3.5	0.4

Source: MCE laboratory analyses, 2009; DP = Dinger Profile Pit; SMU = Soil Mapping Unit. Note: Values have been rounded off for presentation;
Texture codes: SC - Sandy Clay; SL - Sandy Loam; SCL - Sandy Clay Loam; SiL - Silt Loam; L - Loam; CL - Clay Loam; SICl = Silty Clay Loam

SOIL PROFILE DESCRIPTION	**Field No:DP78**	Map Sheet: 0836A1
Location: 6 Km NW of Illu Harer	Region : Oromiya, Zone: Illuababora, Wereda: Chewaka	
Mapping Unit: : 1 (G1b-1)		
Author:- Zelealem S/M	Date:- 06/05/09	
FAO -Soil Type : Orthidystric Nitisol (NTdyo)	Coordinate (UTM)	N: 991975
Agro-Climatic Zone: Kolla	Elevation (m): 1250	E:184396
Land form : Upper part of Gently undulating Plains with Convex Interfluves	Slope Class: Nearly level	Slope: Position : Medium
Slope Aspect: North -South	Slope Length: 400m	Slope Form: Uniform
Micro- Topography: Termite	Coverage % :	
Parent Material : Volcanic ash	Soil depth cm: 200	Rock outcrop:
Surface Fragment coverage :	Surface Crack:	Sealing:
Flooding	Water table cm. >200	
Drainage -External Well	Internal – Well drained	
Human influence: Clearing		Moisture condition:
Land Cover : Predominantly cultivated land;	Land Use : Rain fed arable cultivate	
Major Crop Type : sorghum, sesame, haricot bean &Maize	Fertilizer Type	
Type of Erosion : Sheet & splash erosion	Area Affected :5-10%	
Activity : Active at present	Degree of dissection: Slight	
Remarks : Scattered big trees occupy nearly 20% of the area		

0-18cm: Dark reddish brown (5YR3/2) color moist, clay loam texture, moderate, medium/coarse, sub-angular blocky structure, stick/plastic consistency when wet, few, fine roots and many, coarse to medium pores.

18-43cm: Dark reddish brown (5YR3/4) color moist, clay loam texture, moderate, medium, sub-angular blocky structure, stick /plastic consistency when wet, very few roots and many, medium pores.

43-85cm: Dark reddish (2.5YR3/6) color moist, clay texture, moderate, very medium, sub-angular blocky structure, stick/plastic consistency when wet, many/few, medium to fine pores.

85-200cm: Dark reddish (2.5YR3/6) color moist, loam texture, moderate to weak, very medium, granular consistency when wet and few, fine pores.

	Profile DP78								SMU : G1b_1				Soil Type:Orthidystric Nitisols (Ntdyo)									
Depth	Texture <2 mm. fraction				pH (1:2.5)			EC	T N	OC	C/N	Avail P	Ex. Cations (meq/100gm soil)					CEC	BS	ESP	Ca/	Ca+Mg/
cm	Sand	Silt	Clay	Class	H2O	KCl	∆pH	dS/m	%	%		ppm	Na	K	Ca	Mg	Sum	meq/g	%	%	Mg	K
0-18	32.0	10.5	57.5	C	5.6	4.5	-1.0	0.07	0.3	4.1	13	2.7	0.2	0.4	10.8	3.6	15.0	28.7	52	0.7	3	34
18-43	27.9	12.5	59.6	C	4.8	3.8	-1.0	0.02	0.1	2.4	20	0.9	0.2	0.2	3.6	2.7	6.6	27.3	24	0.6	1	34
43-85	27.8	8.4	63.9	C	5.1	4.2	-0.9	0.02	0.1	1.6	13	0.4	1.9	0.2	4.5	3.6	10.2	20.0	51	9.8	1	35
85-200	15.9	8.4	75.7	C	5.0	4.0	-1.0	0.01	0.1	0.6	7	1.0	0.2	0.1	3.6	2.7	6.6	15.6	42	1.1	1	42
200-300					5.4	4.8	-0.7	0.01														
300-400					5.3	4.5	-0.8	0.01														

Micronutrients mg/kg soil (ppm)

Depth (cm)	Fe	Mn	Cu	Zn
0-18	50.3	58.4	1.2	1.5

Source: MCE laboratory analyses, 2009; DP = Dinger Profile Pit; SMU = Soil Mapping Unit. Note: Values have ben rounded off for presentation;
Texture codes: SC - Sandy Clay; SL - Sandy Loam; SCL - Sandy Clay Loam; SiL - Silt Loam; L - Loam; CL - Clay Loam; SIC - Silty Clay Loam

SOIL PROFILE DESCRIPTION	**Field No: DP83**	Map Sheet: 0836A1
Location: Jegene	Region : Oromiya, Zone: Illuababora, Wereda: Chewaka	
Mapping Unit: 9 (V1b_3)		
Author:- Kumsa B	Date:- 06/05/09	
FAO -Soil Type : Mesotrophic Vertisol (VRms)	Coordinate (UTM)	N: 992161
Agro-Climatic Zone:Kolla	Elevation (m):1243m	E: 183590
Land form: Seasonally Wet Valley Floor	Slope Class: Nearly level	Slope: Position : Medium
Slope Aspect: West-East	Slope Length: >300m	Slope Form: Uniform
Micro- Topography: Gilgai	Coverage % : 20	
Parent Material: Fluvial deposition	Soil depth cm.: 160	Rock outcrop:
Surface Fragment coverage:	Surface Crack:	Sealing:
Flooding	Water table cm. >160	
Drainage - External Rapid	Internal – Imperfectly drained	
Human influence:		Moisture condition: Moist
Land Cover: Grass land;; Land Use: Communal Grazing land		
Major Crop Type	Fertilizer Type	
Type of Erosion	Area Affected	
Activity	Degree of dissection:	

remarks: Deep soil, seasonal water logging, wide cracks, slope 2% formation of carbonic horizon in the lower layer

0-23cm: Very dark brown (10RY3/1) color moist, many, yellowish red, distinct mottle, clay texture, moderate, fine/medium, sub-angular blocky structure, firm moist, very stick/very plastic consistency when wet, many, fine roots and many, fine pores.
23-70cm: Dark gray (10YR4/1) color moist, many, yellowish red, distinct mottle, clay texture, moderate, medium/coarse, wedge–shaped structure, very firm moist, very stick /very plastic consistency when wet, many, fine roots and many, fine pores.
70-160cm: Dark gray (10YR4/1) color moist, few mottle, clay texture, common, medium coarse fragment, moderate, medium /coarse, wedge-shaped structure, very stick /very plastic consistency when wet, few, fine roots and common, fine pores.

	Profile DP83							SMU : V1b_3						Soil Type : Mesotrophic vertisols (VRsm)									
Depth	Texture <2 mm. fraction				pH (1:2.5)			EC	T N	OC	C/N	Avail P	CaCO3	Ex. Cations (meq/100gm soil)					CEC	BS	ESP	Ca/	Ca+Mg/
cm	Sand	Silt	Clay	Class	H2O	KCl	∆pH	dS/m	%	%		ppm		Na	K	Ca	Mg	Sum	meq/g	%	%	Mg	K
0-23	31.5	21.1	47.4	C	5.5	4.2	-1.3	0.05	0.3	4.6	14	9.2		0.2	0.4	21.7	8.1	30.4	51.6	59	0.5	3	80
23-70	29.9	10.5	59.6	C	5.5	4.0	-1.5	0.03	0.1	1.7	14	2.8		0.3	0.2	19.0	9.0	28.6	42.3	68	0.7	2	121
70-160	28.9	5.2	65.9	C	7.9	7.1	-0.8	0.30	0.0	0.5	18	0.6	2.24	0.8	0.3	52.0	10.4	63.5	57.0	111	1.4	5	215

Micronutrients mg/kg soil (ppm)

Depth (cm)	Fe	Mn	Cu	Zn
0-23	402.1	101.3	4.7	0.2

Source: MCE laboratory analyses, 2009; DP = Dinger Profile Pit; SMU = Soil Mapping Unit. Note: Values have ben rounded off for presentation;
Texture codes: SC - Sandy Clay; SL - Sandy Loam; SCL - Sandy Clay Loam; SiL - Silt Loam; L - Loam; CL - Clay Loam; SICl - Silty Clay Loam

SOIL PROFILE DESCRIPTION	**Field No: DP90**	Map Sheet: 0836A1
Location: Burka Anani	Region: Oromiya, Zone: Illuababora, Wereda: Chewaka	
Mapping Unit : 2 (G1b_4)		
Author:- Zeleam S/Mariam	Date:- 07/05/09	
FAO -Soil Type: Hyperic Acrisol (ACfrh)	Coordinate (UTM)	N: 994577
Agro-Climatic Zone: Kolla	Elevation (m): 1256	E : 181927
Land form: Upper part of Gently undulating Plains with Convex Interfluves	Slope Class: 06	Slope: Position : Lowest
Slope Aspect: South -North	Slope Length: 200m	Slope Form: Concave
Micro- Topography: Terracing	Coverage % : 0.2	
Parent Material: In situ weathered	Soil depth cm: 200	Rock outcrop:
Surface Fragment coverage :	Surface Crack:	Sealing:
Flooding:	Water table cm. >200	
Drainage - External Well	Internal – Well drained	
Human influence: Burning, Clearing, Terracing		Moisture condition:
Land Cover: Intensively cultivated Land;	Land Use: Rain fed arable cultivation	
Major Crop Type: sorghum		Fertilizer Type
Type of Erosion: Sheet & Splash erosion		Area Affected: >50%
Activity: Active at present		Degree of Dissection: Slight
Remarks: Deep soil >200cm, slope 7%		

0-12 cm:-Dark red (2.5YR3/2) color, clay loam texture, weak fine/medium, sub-angular blocky structure, firm moist and stick/plastic consistency when wet, patchy, distinct, clay cutanic, feature, common, fine and medium roots, many and fine/medium pores.
12-70cm:-Dark reddish brown (2.5YR3/4) color, clay texture, moderate fine/medium, sub-angular blocky structure, firm moist and stick/plastic consistency wet, patchy, distinct, clay cutanic feature few, fine and medium roots and many, fine/medium pores.
70-200cm:-Dark red (2.5YR3/6) color, clay texture, moderate fine/medium, sub-angular blocky structure, firm moist and stick/plastic consistency when wet, few, medium roots and common, fine pores.

	Profile DP90							SMU : G1b_4					Soil Type : Hyperferric Acrisols (Acfrh)									
Depth	Texture <2 mm. fraction				pH (1:2.5)			EC	T N	OC	C/N	Avail P	Ex. Cations (meq/100gm soil)					CEC	BS	ESP	Ca/	Ca+Mg/
cm	Sand	Silt	Clay	Class	H2O	KCl	∆pH	dS/m	%	%		ppm	Na	K	Ca	Mg	Sum	meq/g	%	%	Mg	K
0-12	48.6	23.1	28.3	SCL	5.1	4.2	-0.9	0.10	0.3	3.9	14	6.1	0.2	0.3	5.4	1.8	7.6	31.7	24	0.5	3	23
12--70	25.4	50.4	24.2	SiL	4.6	4.2	-0.5	0.03	0.2	2.7	16	2.1	0.1	0.1	1.8	0.9	2.9	27.8	11	0.5	2	23
70-200	35.8	6.3	57.9	C	4.5	4.2	-0.3	0.05	0.1	1.8	14	0.8	0.1	0.1	2.7	1.8	4.7	18.0	26	0.6	2	39

Micronutrients mg/kg soil (ppm)

Depth (cm)	Fe	Mn	Cu	Zn
0-12	64.8	41.7	2.1	0.4

Source: MCE laboratory analyses, 2009; DP = Dinger Profile Pit; SMU = Soil Mapping Unit. Note: Values have been rounded off for presentation;
Texture codes: SC - Sandy Clay; SL - Sandy Loam; SCL - Sandy Clay Loam; SiL - Silt Loam; L - Loam; CL - Clay Loam; SICl - Silty Clay Loam

SOIL PROFILE DESCRIPTION	**Field No: DP91**	Map Sheet: 0836A1
Location: N-W of Illuharar	Region: Oromiya, Zone: Illuababora, Wereda: Chewaka	
Mapping Unit: 10 (V2a-7)		
Author:- Zeleam S/Mariam	Date:-	
FAO -Soil Type: Gelic Gleysol (GLge)	Coordinate (UTM)	N: 9956634
Agro-Climatic Zone: Kolla	Elevation (m): 1244	E : 182903
Land form: Permanently Wet Valley Floor	Slope Class: Gently slope	Slope: Position : Lowest
Slope Aspect: North- South	Slope Length: 1.5km	Slope Form: Irregular
Micro- Topography: gilgai	Coverage % :	
Parent Material: Fluvial deposit	Soil depth cm. 184	Rock outcrop:
Surface Fragment coverage :	Surface Crack:	Sealing:
Flooding: Annually	Water table cm. >184	
Drainage - External Moderately drained	Internal – Poorly drained	
Human influence: Vegetation disturbed		Moisture condition: Moist / Wet
Land Cover: Seasonal marsh;	Land Use: Animal production	
Major Crop Type:	Fertilizer Type	
Type of Erosion: Gully erosion	Area Affected: 10-25%	
Activity: Active at present	Degree of Dissection: Moderate/ Slight	

Remarks: Profile pit is taken from gully cut, surrounding land is covered with hyperemia grasses along the stream & gully. Currently the area is used for grazing, it is communal land.

0-42cm: Black (10YR2/1) color moist, clay texture, moderate, medium, sub-angular blocky structure, firm moist and sticky/ plastic consistency when wet, many, fine/medium roots, few, and fine/medium pores.

42-68cm: Very dark gray (10YR3/1) color moist, many, yellowish red, distinct mottle, Clay texture, few, fine coarse fragment, moderate, medium, sub-angular blocky structure, firm moist and stick/plastic consistency when wet, few, fine/medium roots and few, fine pores.

68-159cm: Dark grayish brown (10YR4/2) color moist, many, yellowish red, prominent mottle, clay texture, many fine coarse fragment, firm moist and stick /plastic consistency when wet, few, brownish, soft, moderate mineral nodules, few, fine roots.

159-184 cm: Very dark gray (10YR3/1) color moist, few, yellowish red, faint mottle, clay texture, many, fine coarse fragment, firm moist and stick/plastic consistency when wet.

	Profile DP91							SMU : V2b_7					Soil Type : Gelic Gleysols (Glge)										
Depth	Texture <2 mm. fraction				pH (1:2.5)			EC	T N	OC	C/N	Avail P	Ex. Cations (meq/100gm soil)					CEC	BS	ESP	Ca/	Ca+Mg/
cm	Sand	Silt	Clay	Class	H2O	KCl	∆pH	dS/m	%	%		ppm	Na	K	Ca	Mg	Sum	meq/g	%	%	Mg	K
0-42	31.5	19.0	49.5	C	5.2	3.9	-1.3	0.04	0.3	4.6	15	3.4	0.2	0.3	11.6	4.5	16.6	35.5	47	0.5	3	59
42-68	26.8	15.7	57.5	C	5.3	3.9	-1.5	0.02	0.1	1.7	16	1.4	0.2	0.2	12.4	3.6	16.4	27.0	61	0.6	4	83
68-159	27.9	10.5	61.7	C	5.3	4.0	-1.4	0.02	0.1	1.0	13	1.1	0.3	0.2	14.3	2.7	17.6	28.2	62	1.1	5	78
159-184	59.2	8.4	32.5	SCL	5.4	3.8	-1.6	0.02	0.0	0.9	61	21.8	0.2	0.1	5.4	2.7	8.4	20.0	42	1.2	2	59

Micronutrients mg/kg soil (ppm)

Depth (cm)	Fe	Mn	Cu	Zn
0-42	196.0	16.3	2.3	17.1

Source: MCE laboratory analyses, 2009; DP = Dinger Profile Pit; SMU = Soil Mapping Unit. Note: Values have been rounded off for presentation;
Texture codes: SC - Sandy Clay; SL - Sandy Loam; SCL - Sandy Clay Loam; SiL - Silt Loam; L - Loam; CL - Clay Loam; SICl - Silty Clay Loam

SOIL PROFILE DESCRIPTION	**Field No: DP94**	Map Sheet: 0836A1
Location: 2 km NW of Sire Guda	Region : Oromiya, Zone: Illuababora, Wereda: Chewaka	
Mapping Unit: 7 (U1e_5)		
Author:- Zelealem S/Mariam		
FAO -Soil Typ : Orthidystric Cambisol (CMdyo)	Coordinate : UTM	N: 996968
Agro-Climatic Zone: kola	Elevation (m): 1253	E : 181653
Land form: Strongly sloping upper part of hill / ridges	Slope Class: Gently slope	Slope: Position :
Slope Aspect: East –West	Slope Length: 400m	Slope Form: Uniform
Micro- Topography: Termite	Coverage % : 2	
Parent Material: Volcanic ash/ In situ weathered	Soil depth cm: 70	Rock /outcrop:
Surface Fragment coverage :	Surface Crack:	Sealing:
Flooding	Water table cm.: >70cm	
Drainage - External Rapid	Internal – Well Drained	
Human influence Vegetation disturbed, clearing		Moisture condition:
Land cover: Moderately Cultivated land;	Land use: Rain fed arable cultivation	
Major crop Type: Sorghum, Sesame, Rice, Haricot bean	Fertilizer Type	
Type of erosion: Sheet & splash erosion	Area Affected: 5-10%	
Activity: Active at present	Degree of dissection: slight	

Remarks: Previously the area was under forest vegetation cover, now most of the vegetation is cleared, at the bottom the soil is gravelly & stony.

0-14cm: Brown (7.5YR4/4) color moist, loam texture, few, fine coarse fragment, moderate, medium, angular blocky structure, hard dray, slightly stick/ slight plastic consistency when wet , very few, fine roots, many, medium to fine pores.

14-38cm: Strong brown (7.5YR4/6) color moist, clay loam texture, few, fine coarse fragment, moderate, medium/coarse, sub-angular blocky structure, very firm moist and stick/plastic consistency when wet, cemented, prominent cementation, common, yellowish brown, soft, iron/manganese mineral nodules and common, medium to fine pores.

38-70cm: Strong brown (7.5YR4/6) color moist, clay loam texture, many, fine & medium coarse fragment, moderate, medium, sub-angular blocky structure, very firm moist and stick /plastic consistency when wet, cemented, prominent cementation, many, yellowish brown, soft, manganese mineral nodules.

	Profile DP94				SMU : U1e_5								Soil Type:Orthidystric Cambisols (Cmdyo)									
Depth	Texture <2 mm. fraction				pH (1:2.5)			EC	T N	OC	C/N	Avail P	Ex. Cations (meq/100gm soil)					CEC	BS	ESP	Ca/	Ca+Mg/
cm	Sand	Silt	Clay	Class	H2O	KCl	∆pH	dS/m	%	%		ppm	Na	K	Ca	Mg	Sum	meq/g	%	%	Mg	K
0-14	48.5	14.7	36.8	SC	5.3	4.3	-1.0	0.12	0.6	3.9	7	77.9	0.2	0.5	2.7	2.7	6.1	16.7	37	1.1	1	10
14-38	36.1	18.3	45.6	C	4.6	4.0	-0.6	0.03	0.2	2.0	8	27.6	0.1	0.1	1.8	0.9	2.9	14.2	21	0.8	2	23
38-70	43.6	16.4	40.0	CL	4.8	4.0	-0.8	0.02	0.1	1.4	12	4.4	0.1	0.1	1.8	0.9	3.0	13.8	22	1.0	2	23

Micronutrients mg/kg soil (ppm)

Depth (cm)	Fe	Mn	Cu	Zn
0-14	35.2	31.8	2.1	37.4

`

Source: MCE laboratory analyses, 2009; DP = Dinger Profile Pit; SMU = Soil Mapping Unit. Note: Values have been rounded off for presentation;
Texture codes: SC - Sandy Clay; SL - Sandy Loam; SCL - Sandy Clay Loam; SiL - Silt Loam; L - Loam; CL - Clay Loam; SICl = Silty Clay Loam

APPENDIX G
Keys for Auger and Profile descriptions at Dinger Bereha

SITE DESCRIPTION

Major land form		**Slope %**	**Rock out crops**			
W	Flat / Wet land	0_2	N	None	0	%
F	Flat almost flat	2_4	V	Very few	0-2	%
E	Flat Elevated flat land	2_4	F	Few	2-5	%
G	Gently Undulating Plain	4_6	C	Common	5-15	%
V	Valley floor	0-2	M	Many	15-40	%
U	Strongly sloping side	5_15	A	Abundant	40-80	%
S	Moderately steep hill side	>15	D	Dominant	>80	%

Parent materials, unconsolidated

FL	Fluvial deposits
AL	Alluvial deposits
VA	Volcanic ash
OR	Organic deposits
CO	Colluvial deposits
WE	In situ weathered, residual
U	Unknown

Slope

Percentage	Clinometer measurement
Aspect	Direction of Slope
Length	Length of slope breaks

Form of slope

U	Uniform
C	Concave
V	Convex
I	Irregular

Drainage Classes

E. Excessively drained. Water is removed from the soil very rapidly. The soils are commonly very coarse textured or rocky. Shallow or on steep slopes.
S. Somewhat excessively drained. Water is removed from the soil rapidly. The soils are commonly sandy and very pervious.
W. Well drained. Water is removed from the soil readily but not rapidly. The soils commonly retain optional amounts of moisture, but wetness does not inhibit the growth of roots for significant periods.
M. Moderately well drained. Water is removed from the soil somewhat slowly during some periods of the year. The soils are wet for short periods within the rooting depth. They commonly have an almost impervious layer, or periodically receive heavy rainfall
I. Imperfectly drained. Water is removed slowly so that the soils are wet at shallow depth for significant periods. The soils commonly have an almost impervious layer, a high water table, additions of water by seepage, or very frequent rainfall.
P. Poorly drained. Water is removed so slowly that the soil is wet at a shallow depth for considerable periods The soils commonly have a shallow water table which is usually the result of an almost impervious layer seepages or very frequent rainfall.

V. very poorly drained. Water is removed to slowly that the soils are wet at a shallow depth for long periods. The soil have a very shallow water table and are commonly in level or depressed sites or have very high rainfall most days.

External Drainage

E. Extremely slow: Water ponds at surface. Large parts waterlogged for over 30 days
S. Slow: Water drains slowly, most of terrain is not waterlogged for more than 30 days continuously.
W. Well: Water drains well but not excessively; nowhere does terrain remain waterlogged for a continuous period of >48 hours.
R. Rapid: Excess water drains rapidly, even during periods of prolonged rainfall.
V. Very Rapid: Excess water drains rapidly; the terrain does not support growth of short-rooted plants, even if there is sufficient rainfall.

Microtopography

GI. Gilgai. Micro- relief produced by expansion and contraction of montmorillonitic clay with changes in moisture; found in Vertisols; in nearly level areas a succession of micro-basins and micro-knolls; on sloping and micro-valleys and micro- ridges parallel to the direction of the slope.
GL. Low Gilgai. Height difference (within 10m) <20 cm
GM. Medium Gilgai. Height difference (within 10m) 20-40 cm
GH. High Gilgai. Height difference (within 10m) >40 cm
AT. Animal tracks.
AB. Animal burrows.
H. Hummocks. Meso-relief (2.5-2.5m) showing a very complex pattern of slopes, extending from somewhat rounded depressions of Various sizes to irregular conical knolls or knobs.
R. Ridges. Coverage at least 5 & by parallel, sub parallel, or intersecting usually sharp- crested ridges or elongated narrow elevations
T. Terraced. Level areas <2% slope bounded on one side by a steep slope >2.5m high with flat surface above it.

Surface coarse fragments (cm)

F	Fine gravel 0.2-0.6
M	Medium gravel 0.6-2.0
C	Coarse gravel 2-10
S	Stones 10-20
B	Boulders 20-60
L	Large boulders 60-200
FM	Fine and medium gravel
MC	Medium and coarse gravel
FC	Fine to coarse gravel
SB	Stones and boulders

Type of erosion

N.	None
B.	River bank erosion
C.	Undercutting
S.	Sheet and splash
R.	Rill
G.	Gully
T.	Tunnel
U.	Unknown.

Other Erosion and Deposition

P.	Deposition
A.	Active erosion
W.	Water and wind
R.	Active in recent past
H.	Active in historical times
U.	Period of activity unknown

Area affected by erosion

1. 0-5%
2. 5-10%

3.	10-25%
4.	25-50%
5.	>50%

Soil Depth

Vd	0_25	Very Shallow
S	25_50	Shallow
M	50_100	Deep
D	100_125	Very Deep

Mottling

Abundance

N	None	0	%
V	Very few	0-2	%
F	Few	2-5	%
C	Common	5-15	%
M	Many	15-40	%
A	Abundant	40-80	%
D	Dominant	>80	%

Size

V	Very fine	<2	mm
F	Fine	2-6	mm
M	Medium	6-20	mm
C	Coarse	>20	mm

Contrast

F	Faint	The mottles are evident only on close examination. Soil colors in both the matrix and mottles have closely related hues, chromas and values.
D	Distinict	Although not striking, the mottles are ready seen. The hue chroma or values of the matrix are easily distinguished from those of the mottles.
P	Prominent	The mottles are conspicuous and mottling is one of the outstanding features of the horizon.

Boundary

S	Sharp	0-0.5	mm
C	Clear	0.5-2	mm
D	Diffuse	>2	mm

Colours: as per Munsell colour charts

Soil Textural Classes

C	Clay
L	Loam
CL	Clay Loam
SL	Sandy Loam
SIC	Silty Clay
SICL	Silty Clay Loam
SIL	Silt Loam
SC	Sandy Clay
SCL	Sandy Clay Loam
SL	Sandy Loam
FSL	Fine Sandy Loam
LS	Loamy Sand
LVFS	Loamy very Fine Sand
LFS	Loamy fine Sand
VFS	Very Fine sand

FS	Fine sand
MS	Medium Sand
CS	Coarse sand
US	Unsorted sand
S	Unspecified sand

Consistence when dry

LO.	Loose
SO.	Soft
SHA.	Slightly hard
HA.	Hard
VHA.	Very hard
EHA.	Extremely hard
SSH.	Soft to slightly hard
SHH.	Slightly hard to hard

Consistence when Moist

LO.	Loose
VFR.	Very friable
FI.	Firm
VFI.	Very firm
EFI.	Extra firm
FVF.	Firm to very firm
VFF.	Very friable to firm
FRF.	Friable to firm

Consistence when wet

NST.	Non sticky
SST.	Slightly sticky
ST.	Sticky
VST.	Very sticky
SSS.	Slightly sticky to sticky
SVS.	Sticky to very sticky

Plasticity

NPL.	Non-plastic
SPL.	Slightly plastic
PL.	Plastic
VPL.	Very plastic
SSP.	Slightly plastic to plastic
PVP.	Plastic to very plastic

Soil Cutanic Features

Abundance

N	None	
P	Patchy	Small scattered patches of cutan
B	Broken	Cutans cover much but not all pore or ped faces
C	Continuous	Cutans cover entire ped faces or line pores and channels

Contrast

F	Faint	Surface of cutan shows little contrast in colour, smoothness or any other property to the adjacent surface. Any lamellae are <2 mm thick.
D	Distinct	Surface of cutan is distinctly smoother or different in colour than the adjacent different in colour than the adjacent different in colour tha the adjacent surface. Any lamellae are between 2 & 5 mm thick.
P	Prominent	Surface of cutan contrast strongly in smoothness or colour with adjacent surface. Outlines of the sand grains are not visible. Any lamellae are > 5mm.

Nature of Cutans

C	Clay cutans	Coating of clay. Field criteria are observed thickness, an abrupt boundary between the coating and the interior of the ped, as seen in cross section on a broken surface and a waxy luster when observed in reflected light
PF	Pressure faces	Pressure faces or stress cutans are formed when peds press against each other during soil wetting. Ped surface is smooth. When peds press against each other during and coating has no observable thickness.
S	Slickensides	Special type of stress cutan. A slickenside is is smoothed surface with parallel striae and grooves
SF	Shiny faces	(as in nitic properties)

Carbonates

N	Non- calacareous	No detectable or audible effervescence
SL	Slightly calcareous	Audible effervescence but not visible
MO	Moderately calcareous	Visible effervescence
ST	Strongly calcareous	Strong visible effervescence (bubbles)
EX	Extremely calacareous	Extremely strong reaction (thick loam)

Cementation and Compaction

Grade

N	Non-cemented and non-compacted; neither cementation nor compaction observed (slakes in water)
Y	Compacted: compacted mass is appreciably harder or more brittle than other comparable soil mass (slakes in water).
W	Weakly cemented: cemented mass is brittle and hard, but can be broken in the hands.
M	Moderately cemented: cemented mass cannot be broken in the hands - but is discontinuous (less than 90% of soil mass).
C	Cemented: cemented mass cannot be broken in the hands & is discontinuous (>90% soil mass)

Structure

N	None	The structure is massive without recognizable orientation.
P	Platy	The compacted or cemented parts are plate- like and have a K K (sub)horizontal orientation
V	Vesicular	The layer has large, equidimensional voids which may be filled with uncemented material
P	Pisolithic	Thelayer is constructed from cemented speherical nodules.
D	Nodular	The layer is largely constructed from cemented bodies or irregular shape.

Pores. Abundance (Per dm^2)

		Very fine/fine	Medium/coarse
N	None	0	0
V	Very few	1-20	1-2
F	Few	20-50	2-5
C	Common	50-200	5-20
M	Many	> 200	>20

Size (diameter) for elongate or tubular voids

F	Fine
M	Medium
C	Coarse
FM	Fine and medium
MC	Medium and coarse
FC	Fine to coarse

Mineral Nodules: Abundance by volume as class for Mottling

Colour: as for mottling

Classes: as for mottling

Hardness

H	Hard	Can not be broken in the fingers.
S	Soft	Can be broken between forefinger and thumb nail.
B	Both hard and soft	

Nature

Mineral classes as for cementation

Kind

C	Concretion	A discrete body with a concentric internal structure.
S	Segregation	Differs from the surrounding soil mass in color and composition but is easily separated as a discrete body.
N	Nodule	A discrete body without any internal organization.

Horizon Boundary

Width			**Code**	**Topography**
A	Abrupt	Boundary less than 2cm	**S**	Smooth
C	Clear	Boundary 2_5cm	**W**	Wavy
G	Gradual	Boundary 5_12	**I**	Irregular
D	Diffuse	Boundary >12cm	**B**	Broken

LAND COVER & LAND USE

LAND COVER

Major class	**Sub-Class**	**Code**
SETTLEMENT	Village Tukul	**ST**
CULTIVATED LAND		**CL**
	Intensively cultivated land	**CL2**
	Predominantly cultivated	**CL3**
	Moderately cultivated	**CL4**
	Sparsely cultivated	**CL5**
	Perennial crop cultivated	**CL6**
FOREST LAND		**FL**
	Dense coniferous high forest	**FL1**
	Dense mixed high forest	**FL2**
	Disturbed high forest	**FL3**
WOOD LAND		**WL**
	Dense Woodland	**WL1**
	Open Woodland	**WL2**
RIPARIAN WOOD LANDS		**RL**
BUSH LANDS		**BL**
	Dense bush land	**BL1**
	Open bush land	**BL2**
SHRUB LANDS		**SL**
	Dense shrub land	**SL1**
	Open shrub land	**SL2**
GRASS LANDS		**GL**
	Open grass land	**GL1**
	Bushed shrub grass land	**GL2**
	Wood grass land	**GL3**
WET LANDS		**WEL**
	Perennial swamp	**WEL1**
	Perennial marsh	**WEL2**
	Seasonal swamp	**WEL3**
	Seasonal marsh	**WEL4**
BARELAND		**BA**
	Exposed rock surface	**BA1**
	Exposed sand and soil surface	**BA2**
	Exposed sand and soil surface	**BA3**
WATER BODY		**WB**
Other (specify)	If there is any observation	**OB**

LAND USE

Major class	**Sub-Class**	**Code**
SETTLEMENT		**ST**
	Shifting cultivation	**CA1**
	Fallow sys. cultivation	**CA2**
	Lay system cultivation	**CA3**
	Rain fed arable cultivation	**CA4**
	Wet rice cultivation	**CA5**
	Irrigated cultivation	**CA6**
	Non- Irrigated	**CP1**
	Irrigated tree crop cultivation	**CP2**
ANIMAL	Nomadic	**HE1**
HUSBANDRY	Semi-nomadic	**HE2**
	Ranching	**HE3**
	Animal production	**HH**
FORESTRY	Exploitation of natural forest	**F**
MIXED FARMING		**MF**
EXTRACTION	Timber production	**EX1**
	Wood collection	**EX2**
	Charcoal production	**EX3**