

CHARACTERIZATION OF AGRICULTURAL SOILS IN  
CASCAPE INTERVENTION WOREDAS IN EASTERN REGION

Final Report

By

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## List of Acronyms and Abbreviations

ADLI	Agriculture Development Led Industrialization
ATA	Agricultural Transformation Agency
BD	Bereda Kebele
BL	Bilisuma Kebele
BO	Bekelcha Oromia Kebele
CASCADE	Capacity Building for Scaling up of Evidence Based Best Practices in Agricultural Production in Ethiopia
CEC	Cation Exchange Capacity
CL	Chelenko Lola Kebele
DAP	Di-ammonium Phosphate
DB	Dursitu Bilisuma Kebele
DJ	Damota Jalala Kebele
EG	Egu kebele
EthioSIS	Ethiopian Soil Information System
FAO	Food and Agriculture Organization of the United Nations
FI	Finkile Kebele
GG	Garbi Gobe
GPS	Geographic Positioning System
GRW	Gurawa Woreda
ha	Hectare
HB	Hawi Bilisuma Kebele
HC	Haro Chercher Kebele
HE	East Hararghe
HMY	Haramaya Woreda
HRO	Habro Woreda
HW	West Hararghe
IF	Ifa Oromia Kebele
IJ	Ifa Jiru
ISRIC	International Soil Reference and Information Centre
KJ	Kuro Jalala Kebele
KK	Kakali Kebele
KOM	Kombolcha Woreda
LH	Lencha Kebele
LT	Lafto Ila Tatesa Kebele
MoA	Ministry of Agriculture (Ethiopia)
MTA	Meta Woreda
NCU	National Coordination Unit of CASCADE
ONRS	Oromia National Regional State
PRA	Participatory Research Appraisal
RJ	Rasa Janata Kebele

## List of Acronyms and Abbreviations (Continued...)

RSG	Reference Soil Group
UJ	Ula Janata Kebele
WM	Were Mahamed Kebele
WRB	World Reference Base for Soil Resources

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## 1. INTRODUCTION

The soil resources of Hararghe region, due to complex interaction of soil forming factors and processes, are extremely diverse in their nature. Within a short distance, both lateral and horizontal, different types of soils can be found. Furthermore, the majority of these soils, due to continuous intensive cultivation for many years, are highly degraded, being degraded, and prone to degradation. The population these resources support, on the other hand, is extremely large, arguably among the most densely populated regions in the country. Soils failed to give goods and services to the expected level means the livelihood of these communities is put under threat. As a result of this heinous degradation and soil fertility depletion, significant number of households, from both east and west Hararghe regions, have been moved to new settlement areas in other parts of the country. Still many others residing on steep and highly degraded areas are begging for the same program.

Furthermore, agriculture remains the most important sector in Ethiopia's economy, for it is central for the country's food security and the livelihoods of nearly 85% of its people rely on this sector. But most importantly, it is the engine for the country's Agriculture Development Led Industrialization (ADLI) strategy, a strategy expected to take the country's economic development to a new high level. It is important to put on a high note that soil is the prime resource on which the success of this sector depends. Characterization, classification and mapping of soils is crucial for identifying problems and potentials, knowing the identity of soils for sharing knowledge among experts, and indicate the spatial distribution of soils in a given geographic area. Doing these will help in guiding decisions on the sustainable use of soil resources through making site-specific and effective management interventions. Soil resources related undertakings in this

country are needed for significant improvements to soil fertility and fertilizer applications that take into account Ethiopia's varied agro-ecologies, soil, and climate and ultimately meet aspirations of higher crop yields.

CASCAPE has entered into a collaboration agreement with the Government of Ethiopia (MoA/ATA) to assist the Ethiopian Soils Information System (EthioSIS) in various ways including a soil characterization study conducting detailed soil profile studies and classification of major agricultural soils in all 5 CASCAPE intervention woredas in East and West Hararghe regions of Oromia National Regional State (ONRS). The five woredas included in this study are Haramaya, Kombolcha, Meta, and Gurawa from East Hararghe region, and Habro from West Hararghe region.

The CASCAPE soil characterization and classification effort stands at the forefront of the country's effort aimed at identifying the potentials and limitations of its soil resources. Needless to say, this remains the most important task to sustain the recently observed rapid growth and transformation of the country's agriculture. This is especially important in the study woredas where there is high diversity of soils, high population density, and highly degraded soils, but with high potential as well. This report, therefore, presents the soil characterization and classification results for the five CASCAPE intervention woredas in Hararghe region.

## General Objectives

The goal of the conducted study was to characterize and understand the qualities and behaviour of the major agricultural soils occurring in the 5 CASCAPE intervention woredas based on properly observed and measured soil morphological, physical and chemical properties. This will be the basis for developing site-specific and functional soil information that would guide soil fertility management decisions by smallholder farmers. Moreover, this will help in scaling up and extrapolating soil-based results of experiments.

The study also contributes to the development of the national/regional soil information database under EthioSIS by the generated locally specific soil information.

#### Specific objectives

The study was conducted with the following specific objectives:

- To survey soil variability and identify major soil types in each woreda (4 kebeles per woreda) through auger observations and soil pits,
- To characterize and classify the major agricultural soils following the FAO-WRB (2006) classification system, and
- Based on problems identified, to develop management recommendations.

#### Scope of the study

The study was conducted on the agricultural lands of 20 kebeles in the five (5) CASCAPE intervention woredas in East and West Hararghe regions of ONRS (Figure 1). The study has been carried out by Dr. Kibebew Kibret, Haramaya University. The scope of this report is the results of the soil characterisation and classification study of Haramaya, Kombolcha, Meta, Gurawa, and Habro woredas conducted by Haramaya University.

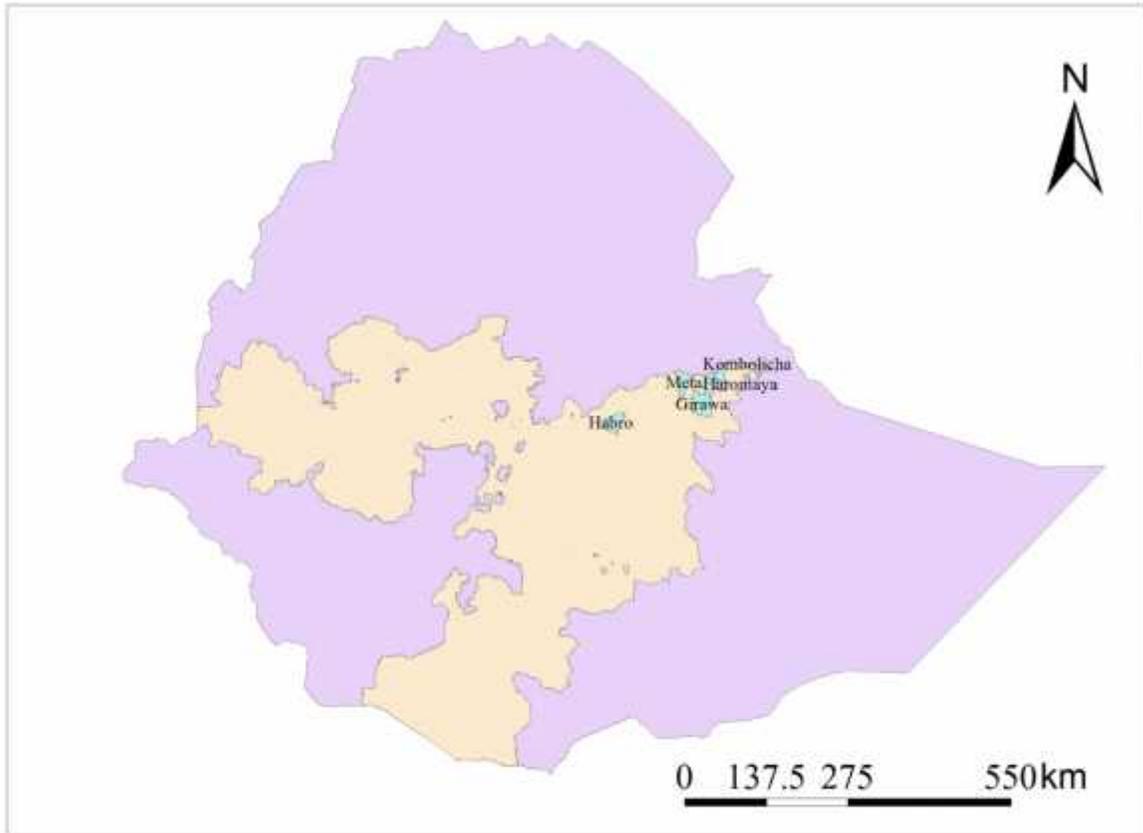


Figure 1. Location map of the CASCAPE intervention Woredas in East and West Hararghe regions.

## 2. MATERIALS AND METHODS

The whole process, including production of this report, involved three phases: preparation, field work, and report writing.

### i. The preparation phase

This phase involved the collection of relevant secondary information for the preparation of base maps for each kebele in each woreda. Spatial information about each kebele in each intervention woreda was obtained from the original soils and geomorphology map of Ethiopia (FAO, 1984) at 1:1000,000 scale and topographic map (1:50,000 scale) obtained from

Ethiopian Mapping Authority and used for the preparation of the base map. Shape files of the 5 woredas in combination with the scanned copies of the 1984 soil map of the country were supplied by ISRIC. Furthermore, other relevant information about the study woredas was obtained from different sources including, but not limited to, Haramaya University's CASCAPE office (PRA results), relevant Woreda level bureaus, and websites.

## ii. The field work phase

After the base map is produced, the field work was started. The field work involved two major tasks: field auger and pit descriptions. To locate the representative auguring points, an exploratory survey was conducted through each and every agricultural land in the kebeles. Using the base map and the extensive walking guided by development agents working in the kebeles, augering points were decided and auger pits opened. During the walking, features such as road cuts, gully cuts, exposed rock outcrops, surface texture and soil color were used to observe soil type differences. Eight auger points per kebele were opened to a depth of 120 cm unless restricted by hard rock or impenetrable layer. Accordingly, a total of 160 auger points were opened in the 20 kebeles in the 5 woredas. All the auger points were georeferenced using GPS (GARMIN GPS 60) and described according to the standard description form and following the guidelines for soil profile description (FAO, 2006). Soft copy of the auger description form was provided by ISRIC. The auger description led to the identification of the major agricultural soils in each kebele.

The second major field activity involved detailed characterization of pedons that are representative for the distinguished major soil types on agricultural lands. Following the exploratory soil survey and the identified major soil types, representative point locations for detailed observation were identified, georeferenced by GPS and opened as pedons. The opened soil pedons were described in detail according to the standard description form provided by

WUR following the guidelines for soil profile description (FAO, 2006), designating master horizons with subordinate characteristics to a depth of at least 180 cm (bedrock permitting), for on average 7 pedons per woreda (minimally 5, maximally 10). The locations of the pedons were not necessarily evenly distributed over all the 4 kebeles but over all major soil types. Pedons opened per kebele ranged from 1 to 4. Following this, a total of 38 pedons were opened in the 20 kebeles of the 5 woredas.

Two to five samples of at least 1 kg were collected from the designated genetic horizons of each pedon for laboratory analysis. The samples were properly labelled and transported to Haramaya University for air drying. Up on arrival at Haramaya University, the sample bags were opened, and air dried before they were submitted to the Water Works and Design Supervision Soil Laboratory in Addis Ababa for laboratory analysis of relevant soil properties. A total of 158 samples, together with 4 hidden duplicates, were submitted to the same. Soil colour (dry) using the Munsell color chart and soil consistence (dry) were determined on dried sub-samples at Haramaya University.

### iii. Data processing and write-up phase

The auger pit (site data and morphological properties) and pedons (soil site information, morphological, chemical and physical properties on genetic horizon basis) data were compiled in a database using format provided by ISRIC. Accordingly, two data tables one each for site and horizon were produced. In the process, error checking of the data was done, particularly comparison of the results obtained from the hidden duplicates and original samples was made immediately after collecting the laboratory analysis results.

The analytical data were used to verify the preliminary soil classifications made during the field description and final classification of the soils of the pedons was made according to the WRB (2006) classification system.

After completing the data processing, a report was written per woreda. The report includes a detailed description of the pedon site characteristics (major land forms, geology, land uses, etc) of the major soil types identified in the woreda. It also includes a full characterization of the representative soil pedons, including a summary of the whole profile, a description of the profile site and morphology and tables of morphologic and analytical data, with reference to the classified major soil types. Auger profile descriptions, including GPS readings, were also annexed with reference to the corresponding major soil types identified. Maps that show the distribution of the major soil types in the four kebeles of each woreda were also produced.

Agronomic observations and main management implications of the soil properties were discussed for each soil type, with emphasis on the relevance for making soil type-specific soil fertility management recommendations.

The match/mismatch between farmers' traditional soil classifications and classification of soils with scientific classification was explored and discussed in order to recommend appropriate management strategies.

### 3. RESULTS

#### 3.1. Description of the Environment

The five CASCAPE intervention woredas are found in East and West Hararghe regions of the Oromia National Regional State in eastern Ethiopia. A general description of major features of each of these intervention woredas is given below.

##### Haramaya Woreda

Located in East Hararghe zone of Oromia National Regional State, the Haramaya woreda shares boundaries with Kurfa Chale on the South, Kersa on the west, Dire Dawa Administrative Council in the north, Kombolcha on the east, and Harari National Regional State on the southeast.

The altitude of this Woreda ranges from 1400 to 2340 meters above sea level, with Dof and Jeldo the highest points. A survey of the land in Haramaya (released in 1995/96) shows that, from the total land area, 36.1% is arable or cultivable, 2.3% pasture, 1.5% forest, and the remaining 60.1% is considered built-up, degraded or otherwise unusable. According to the 2007 National Census, the Woreda has an estimated total population of 271,018 of whom 138,282 were men and 132,736 were women (CSA, 2007). According to the same report, about 81% of the population lives in rural areas where agriculture is the main source of livelihood.

The administrative capital of the woreda is Haramaya town which is located at 42°3' E longitude, 9°26' N latitude and at an altitude of 1980 meters above sea level. This puts the area into the category of Ethiopian highlands. It is situated in the semi-arid tropical belt of eastern Ethiopia. The mean annual rainfall, as recorded from meteorology station located in Haramaya University, received ranges from 600 to 1260 mm and is bimodal. The Woreda is representative of a sub-humid mid-altitude agro-climatic zone.

The short rainy season locally, called Badheessa, usually starts in March and extends to May, while the main/long rainy season, called Ganna, stretches from end of June to September. Minimum and maximum annual temperatures range from 6 to 12 and 17 to 25 °C, respectively.

Although water is arguably the most critical resource in the woreda, there are no perennial rivers. However, there are seasonal streams, the major one being the Amaresa stream. The other major water bodies include Lake Tinike, Lake Kuro, Part of Lake Adele, and also part of the extinct Lake Haramaya, which is showing some signs of rehabilitation. Furthermore, there exists good groundwater potential, particularly in the Haramaya watershed. Its development is, however, still based on traditional practices through hand dug wells.

The major farming system is mixed crop-livestock production system. The major food crops grown are cereals (mainly maize and sorghum), pulses (haricot bean), vegetables such as onion, potato, carrot, cabbage, shallot, and pepper, and occasional horticultural crops such as peach grown mostly around homesteads. Intercropping and alley cropping are common practices. Khat (*Catha edulis* F.) is the dominant cash crop grown in the woreda. Farmers living near valleys are also growing vegetables as cash crops during off-season by small-scale irrigation.

#### Kombolcha Woreda

Kombolcha is one of the woredas in East Hararghe zone of Oromia region. It is bordered on the south by the Harari region, on the southwest by Haramaya woreda, on the northwest by Dire Dawa Administrative Council, on the north by the Ethiopia-Somali region, and on the east by Jarso woreda. Melka Rafu is the administrative center of the Woreda.

The altitude of this Woreda ranges from 1200 to 2460 meters above sea level and Were Mucha, Babo and Lalu are amongst the highest points. The Haramaya University CASCAPE PRA report indicates that the Woreda is characterized by valleys and rugged topography. This was observed during the field work as well. A significant northern part of the Woreda is hilly with steep slopes. These geographical features limit accessibility to some of the Kebeles in the Woreda. A survey of the land in Kombolcha shows that 16.8% is arable or cultivable, 1.7% pasture, 3.9% forest, and the remaining 77.6% is considered built-up, degraded or otherwise unusable. The 2007 national census reported a total population for this Woreda of 140,080, of whom 70,967 were men and 69,113 were women. As per this census, about 90.99% of the total population lives in the rural areas of the Woreda. The settlement pattern of the Woreda population is dense, reaching as high as 234.9 persons per square kilometer.

Lowland and midland agro-ecological zones characterize the Woreda's climate. The Woreda receives a mean annual rainfall of 600-900 mm, which is bimodal and erratic in distribution. The small rainy season starts in February/March and extends to mid-May, while the main rainy season stretches between July and August. The mean annual minimum and maximum temperatures are 13.8 and 24.4 °C, respectively.

In terms of water resources, Kombolcha woreda is relatively better and has the Yerer and Fefra rivers. Furthermore, lots of perennial springs originating from under the hills are very common. As a result, irrigation is commonly practiced in the valleys during the off-season.

The farming system is dominantly crop farming mixed with livestock husbandry. The major crops grown in the Woreda include sorghum, maize, vegetables such as tomato, potato, cabbage, onion, and carrot, khat,

groundnut, coffee and sweet potato. Fenugreek is also produced. Khat, fruits and vegetables are important cash crops.

### Meta Woreda

Meta woreda is located in East Hararghe zone of Oromia region. Meta is bordered to the southwest by Deder woreda, to the northwest by Goro Gutu woreda, to the north by the Somali regional state, to the northeast by Kersa woreda, and to the southeast by Bedeno woreda. The administrative capital of the Woreda is Chelenko.

The total population of the Woreda is estimated at 252,269, of whom 127,371 were men and 124,898 were women (CSA, 2007). About 93.97% of the population lives in rural areas. The Woreda is characterized by valleys in pocket areas, and rugged topography with many hills.

There are some permanent rivers in the Woreda. Notable among these is the river that supplies water to the town of Chelenko. Besides, there are many perennial springs originating from below the mountains and crossing the valleys. One lake is also found. Groundwater resources are always there.

Mixed crop production and livestock rearing characterize the farming system of the Woreda. The major crops produced in the Woreda include sorghum, maize, wheat, haricot bean, vegetables of different kinds and fruit trees.

Although there is no meteorological station for recording rainfall, the rainfall pattern in the Woreda is bimodal. Like in the other CASCAPE intervention woredas, the small rainy season starts around February/March and extends to May, whereas the main rainy season stretches from end of June to September.

## Gurawa Woreda

Gurawa woreda is found in East Hararghe zone of Oromia region. It shares borders with Gola Odana Meyumuluke to the south, Bedeno to the west, Kurfa Chele to the north, and Fedis to the east. The administrative center of the Woreda is Gurawa town.

The altitude of this Woreda ranges from 500 to 3230 meters above sea level where Geyle and Mount Gara Muleta are among the highest peaks. Of the total land area of Gurawa, 54.3% is arable or cultivable, 4.4% pasture, 1.2% forest, 21.8% built-up, and the remaining 18.3% is considered degraded or otherwise unusable. Like the other highlands of Hararghe region, Gurawa Woreda is also characterized by rugged topography with very steep slopes and some valleys in limited areas. The 2007 national census estimates the total population of the Woreda at 240,173. The information released by the Central Statistical Agency shows significant proportion (97.55%) of the total population is living in the rural areas, which means the major source of livelihood is agriculture.

Gurawa Woreda is relatively a high rainfall area. The mean annual rainfall, based on data obtained from meteorological station located at Gurawa town, is 931.0 mm and has a bimodal distribution. The short rainy season starts in February/March and extends to May, while the long/main rainy season begins in June and stretches to September. The rainfall peaks in the months of July and August. Due to the presence of many peaks, Gurawa is relatively cold. The annual mean minimum and maximum temperatures, as recorded at Gurwa town situated at 41°49.8' longitude and 9°7.8' latitude at an altitude of 2250 meters above sea level, are 10.3 and 18.9 °C, respectively.

Like in many other areas in Hararghe region, water is the most critical resource in Gurawa Woreda as well. Even the administrative center, Gurawa, is suffering from chronic water shortage for domestic consumption.

However, there are many springs originating from under the peaks but not developed for better benefit to the community. If these are tapped, they can benefit the community to a greater extent.

Mixed crop and livestock production are the common farming practices in the Woreda. Due to chronic shortage of animal feed, nevertheless, the livestock component is not that strong. Fattening by cut and carry is the common practice to overcome the problem of limited grazing land. The dominant crops produced include sorghum, maize, wheat, barley, Irish potato, and other vegetables. Khat and coffee, in addition to fruits and vegetables, are the major cash crops grown in the Woreda. Production of sugarcane at small-scale in pocket areas and some fruits like banana are also common in areas where there is water for irrigation. Inter-cropping and relay cropping with intensive soil and crop management practices are common.

#### Habro Woreda

Habro woreda, situated at 8°30´ N to 8°59´N latitude, 40°21´ E to 40°43´ E longitude at altitudes ranging from 1500 to 2000 meters above sea level, is located in West Hararghe zone of Oromia National Regional state. The Woreda is bordered on the south by Darolebu, on the west and north by Guba Koricha, on the northeast by Kuni, and on the southeast by Boke woreda. The administrative center of the Woreda is Gelemso town.

The Woreda consists of mid-highland (Weynadega) (57%), lowland (Kola) (25%), and highland (Dega) (18%) agro-climatic zones. In terms of topography, 45% of the Woreda is mountainous and undulating, while the remaining 55% is composed of plains and gentle slope. The existing land use system of the Habro Woreda consists of 33.7% cultivated area of which 10.3% is under perennial crops, 22.9% pasture, and 1.7% forest and shrub and bush lands, while the rest is accounted for barren, settlement area and others.

Thirteen (13) years (1980-2006) data obtained from Gelemso meteorological station indicates that the study area receives a mean annual rainfall of 975.4 mm. The rainfall pattern in the area is bimodal with high amount of rainfall occurring during the main rainy season between June to September (Kiremt) and the short rainy season stretching from March to May (Belg). The highest rainfall is received in August. The annual mean temperature ranges from 10-27.9 °C with the hottest months being February, March, April, May and June.

The water resource of Habro woreda is relatively better than most other areas in Hararghe region. Perennial rivers, intermittent streams, springs and lakes (e.g. the re-emerged Lake Chercher) are found within this Woreda. As a result, production of cash crops by irrigation during the off-season is quite common in the Woreda.

Mixed agriculture is a common farming system in the study area. The main crops grown in the area are cereals such as teff (*Eragrostis tef*), maize (*Zea mays*), wheat (*Triticum aestivum*), barley (*Hordeum vulgare*), haricot bean (*Phaseolus vulgaris*) and sorghum (*Sorghum bicolor*) and cash crops such as coffee (*Coffea arabica*), chat (*Catha edulis*), pepper (*Capsicum species*) and onion (*Allium cepa* L.). Intercropping is a common practice in the Woreda. Common bean and maize are often intercropped to increase yields and maximize land use. Growing maize and sorghum in Khat alleys is also another common practice.

## 3.2. Results of Preparation and Review of Existing Information

### 3.2.1. Preparation

Relevant data collected during the preparation phase were compiled in GIS files using spatial databases. These include:

- Geographic coordinates of the four kebeles boundaries in each woreda
- Geographic coordinates of soil types in each kebele as extracted from the 1984 soil map of Ethiopia
- Geographic coordinates of the woreda boundaries

### 3.2.2. Base map

Based on the information collected, base maps of the four kebeles in each woreda were produced showing the dominant main mapping units in each kebele. The following base map units were produced:

Table 1. Base mapping units of Haramaya Woreda

Soil name	Code	Soil name	Code
Rendzic Leptosols	LPrz	Luvisols (Chromic	LVcr
Lithic Leptosol	LPli	Haplic Vertisols	VRha
Umbric Nitisols	NTum		

The mapping units were then delineated and projected upon the topographic map as in Figure5 2-6 below:

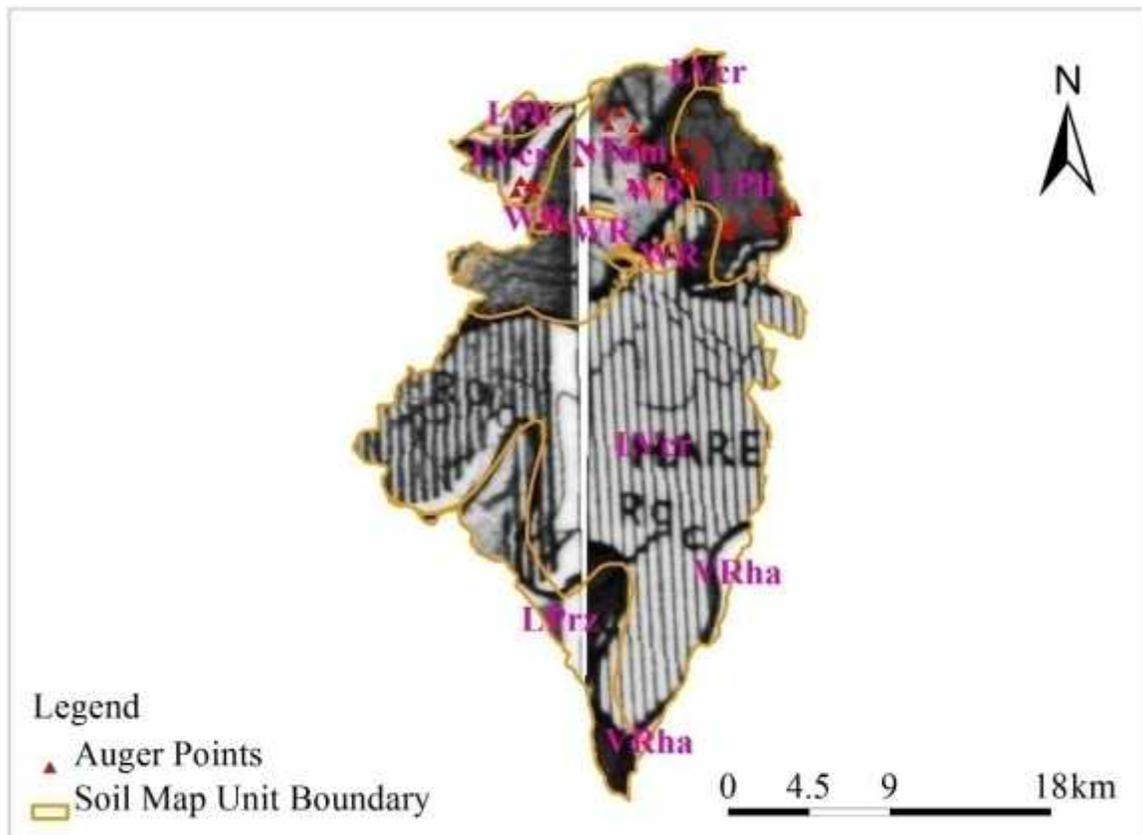


Figure 2. Base map showing the mapping units identified in Haramaya woreda.

Table 2. Base mapping units of Kombolcha Woreda

Soil name	Code
Lithic Leptosol	LPli
Luvisols (Chromic	LVcr

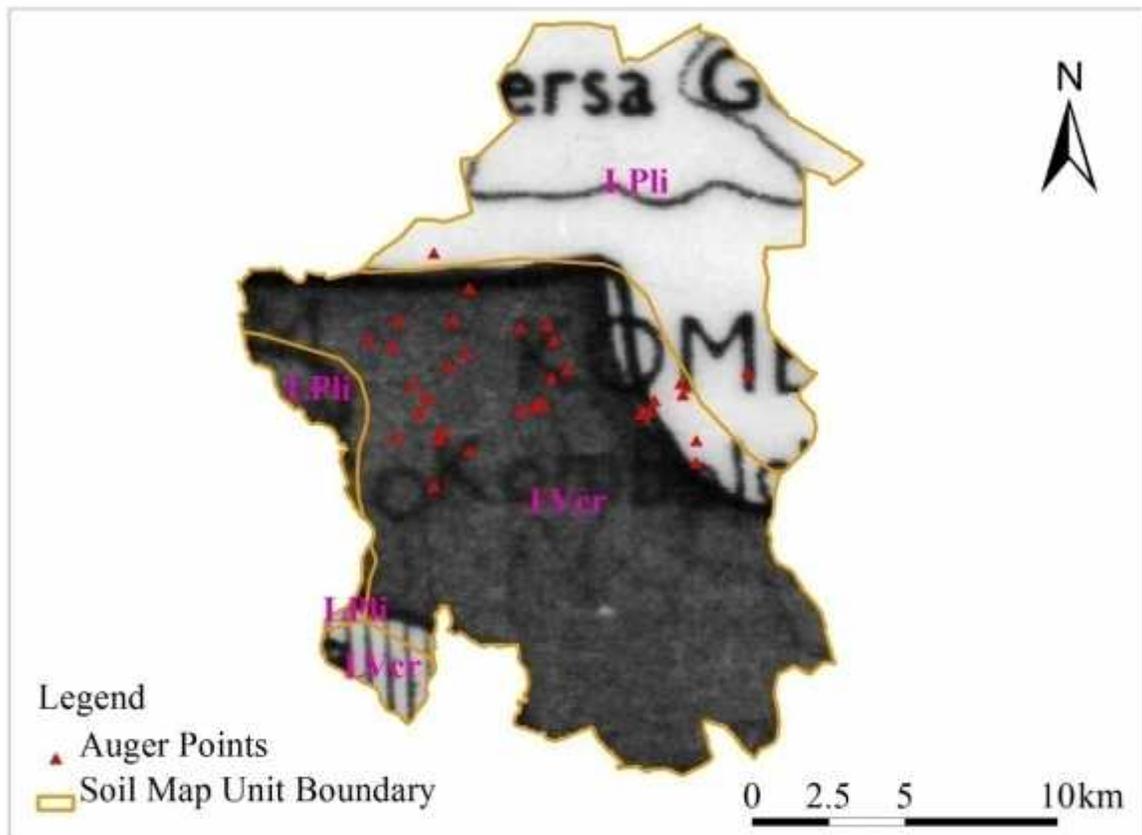


Figure 3. Base map showing the mapping units identified in Kombolcha woreda.

Table 3. Base mapping units of Meta Woreda

Soil name	Code	Soil name	Code
Lithic Leptosol	LPli	Rendzic Leptososs	LPrz
Leptosols (Eutric)	LPeu	Umbric Nitisol	NTum

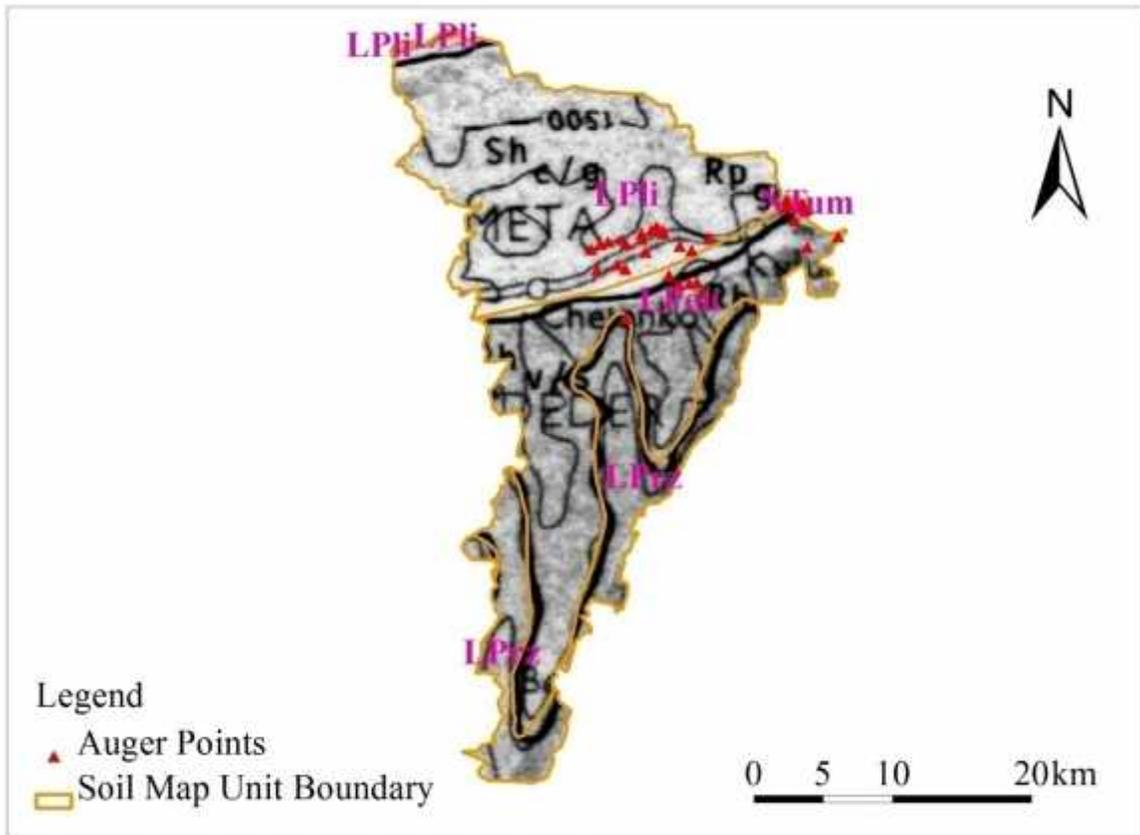


Figure 4. Base map showing the mapping units identified in Meta woreda.

Table 4. Base mapping units of Gurawa Woreda

Soil name	Code	Soil name	Code
Rendziz Leptosols	LPrz	Luvisols (Chromic)	LVcr
Leptosols (Eutric)	LPeu	Haplic Vertisols	VRha

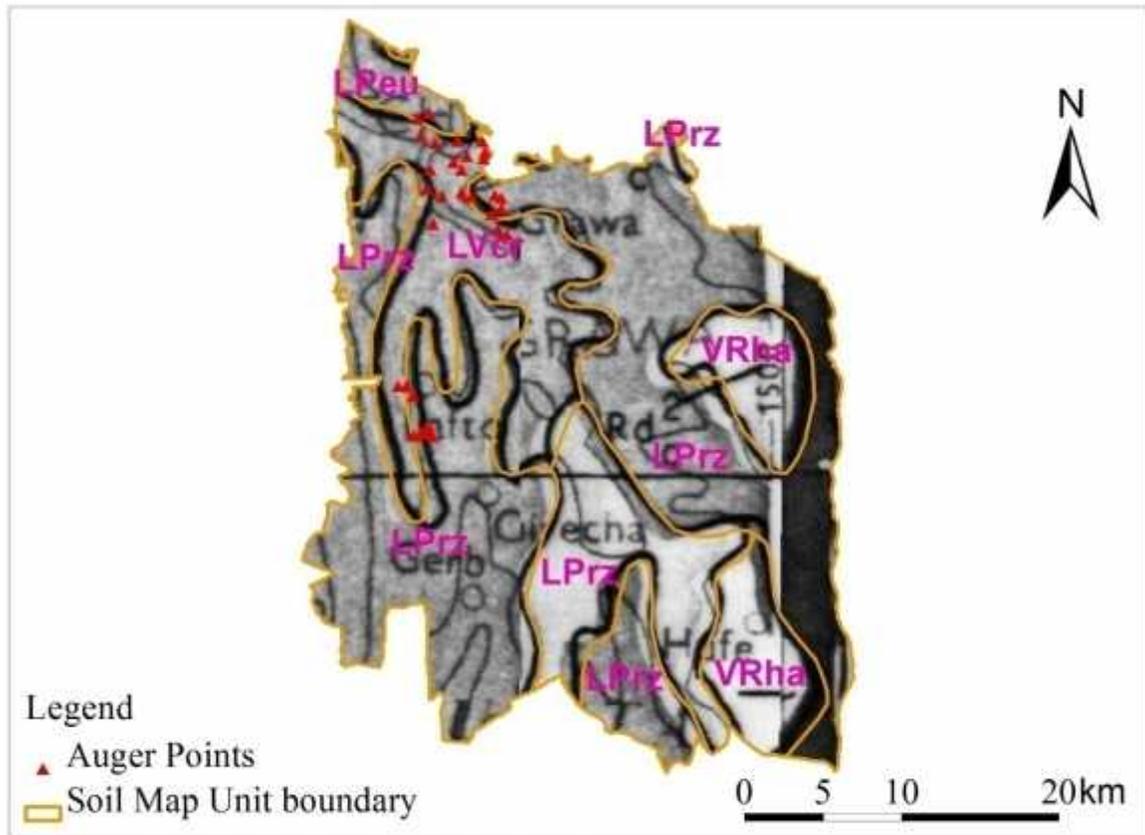


Figure 5. Base map showing the mapping units identified in Gurawa woreda.

Table 5. Base mapping units of Habro Woreda

Soil name	Code
Lithic Leptosols	LPl
Rendzic Leptosols	LPrz
Umbric Nitisols	NTum

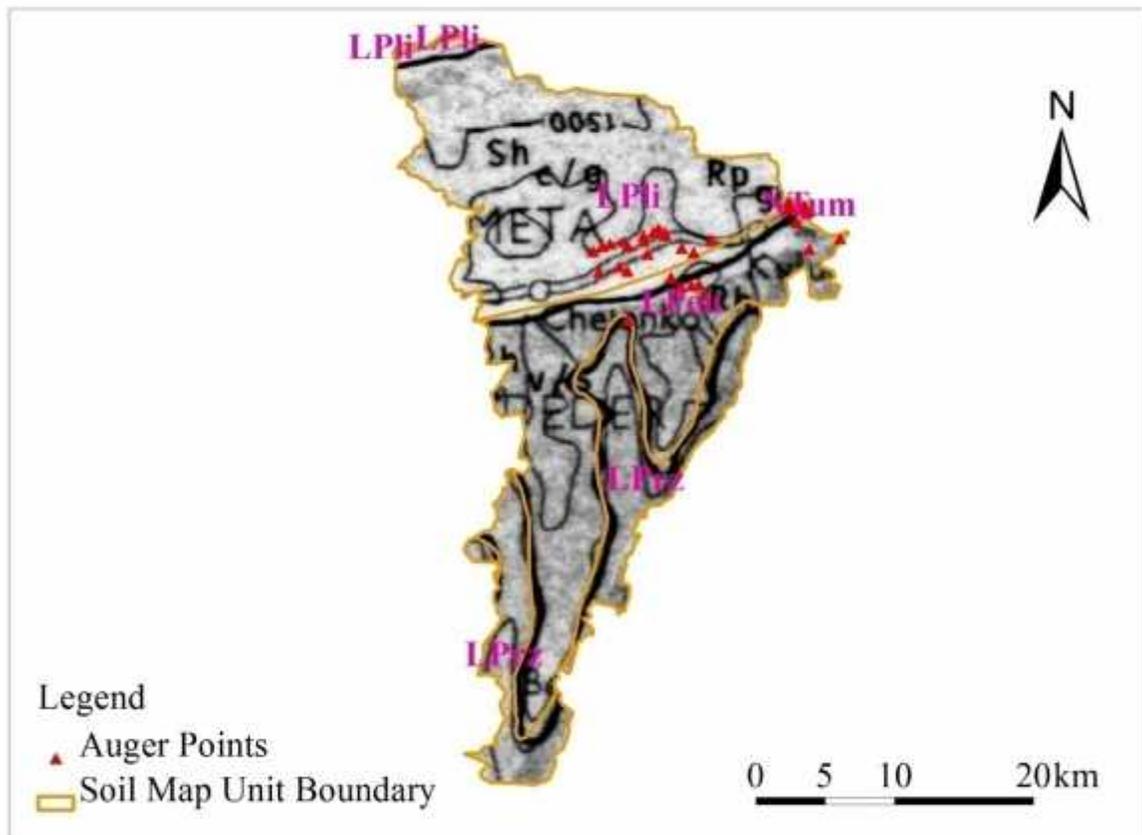


Figure 6. Base map showing the mapping units identified in Habro woreda.

### 3.3. Results of Field Work and Data Processing

#### 3.3.1. Field work

##### i. Exploratory soil survey in the 4 CASCAPE kebeles

Following the base map, 8 augers per kebele were described. A total of 160 augers were described in the 5 woredas. See Figures 2-6 for a visualization of the auger locations, projected upon the base map. The auger ID's, with reference to the corresponding major soil type and soil-landscape (mapping) unit, are provided in table format in Annex 1.

Following the exploratory soil survey, the delineations of the mapping units were adapted where necessary and the different major soil types, and their respective proportions, were identified per mapping unit and per kebele.

ii. Detailed characterization of soil profiles representative for the distinguished major soil types

Following the exploratory soil map, 38 representative soil pedons were characterized in detail, according to the agreed upon procedures. The location of the soil pits, projected upon the exploratory soil map is shown for each kebele in each woreda. The profile descriptions are also given for the respective woredas separately in the sections that follow.

Following the detailed soil profile descriptions, the profiles were sampled and the samples were labeled and administrated according to the agreed upon procedures. The sample identifiers are specified hereunder in the detailed soil profile descriptions and the sample administration is also summarized in Annex 2.

### 3.3.2. Office work

i. Administration of soil samples

Batch of 158 administrated soil samples were submitted to the soil laboratory at Water Works and Design Supervision Enterprise in Addis Ababa. See Annex 2 for the sample administration shared with the NCU. The samples were prepared by the lab and analyzed for the key soil parameters. The results were collected from the lab, and the results shared with NCU, and given in Annex 3.

### Data processing

The profile data collected from augers and soil pits (site data and morphological, chemical and physical horizon data) were compiled in a

database. The format of the data base was provided by ISRIC (tailored version of Africa Soil Profiles database).

Data compilation was followed by data analysis including error checking [and possibly revisit of the laboratory]. Some descriptive statistics, such as coefficient of variation, was used to evaluate the level of variability of a parameter among soils of the kebeles in the respective woredas. Preliminary soil classifications were verified against analytical data and the profiles are classified according to WRB (2006). Finally, a report was written per woreda.

### 3.4. Soils of CASCAPE Intervention Kebeles in Haramaya Woreda

#### 3.4.1. The Soil-landscape in Haramaya Woreda

##### 3.4.1.1. Geology

According to the geological map of Ethiopia, first published in 1973 and edited in 1996 at a scale of 1:2000,000, the geology of the Woreda is dominantly covered by Adigrat formation constituted by sandstones and the Hamanlei formation that contains Oxfordian limestone and shale formed during the early Triassic to middle Jurassic periods.

The work of Mohr (1964), on the other hand, indicates that the Hararghe highlands, where Haramaya Woreda forms a part, lie over the crystalline bed-rock of pre-historic Gondwana continent which became fractured at a much later time. The hard rocks of this Continent were granite and gneiss, which were formed during the Pre-Cambrian period. These rocks lie as peneplains below sea level for a long period, which then resulted in the deposits of very ancient sedimentary rocks. These ancient sedimentary rocks were mainly limestones and sandstones, which began to be laid down during the Triassic when the sea again covered the eastern part and the Jurassic and Cretaceous periods. The sandstones were formed in the deeper areas of the sea, while the limestones were deposited in the shallower parts. The last small deposits were formed at the end of Miocene.

However, in many places, the most recently formed rocks have been eroded and those of the original rocks exposed once more. The Pre-Cambrian rocks, such as granite, and to a lesser extent gneiss and micaschists, are particularly exposed throughout Haramaya and many other places (Mohr, 1964; Tamir, 1974). This was also observed during the field work in most parts of the kebeles. In Damota Jalala Kebele, for instance, limestone is exposed all throughout the slopes of the hills and on most of the plateau. At

the bottom of the hills, layers of soft red and white sands are exposed. On some of the lower and higher elevations where both limestone and sandstone are completely eroded, granite rock is exposed on the surface.

The location of the Kebeles, as was observed during the field work and also described by Tamir et al. (1986), is site of numerous sink-hole lakes (the reviving Lake Haramaya, Lake Tinike, Lake Kuru, and Lake Adele) and represent some of the typical examples of Kharst topography regions in Ethiopia. These Lakes are formed in sink-holes produced through the dissolution of the thicker beds of limestone in the area. Common characteristics of all of these lakes is that all of them have internal drainage and are surrounded by saucer-shaped landscape with steeper slopes and hills of highly erosion susceptible orthoclase-rich rotten granite rocks, their saprolites and shallow soils formed from these rocks.

#### 3.4.1.2. The Landscape

On a coarser scale, the land form of the Woreda is dominantly a plateau. Nevertheless, at the scale of the studied kebeles (local scale), the topography varies from nearly level land, which represents the plains and plateau areas, to moderately steep and undulating land that characterizes the medium to high gradient hills. In the four CASCAPE intervention kebeles, the landform is highly dissected with many drainage networks. As a result, there are many mini-watersheds that have their own peculiar characteristics in terms of hydrology, geology and, thus, major types of soils. All these mini-watersheds, however, drain to a common convergent point at the plains and small valleys. Accordingly, the different mini-watersheds in Finkile and Kuro Jalala Kebeles converge at Lake Tinike, which by itself drains to Lake Haramaya when it overflows. These two Kebeles, together with other neighbouring kebeles, form a saucer-shaped landscape that drains towards

Lake Tinike. On the other hand, the different mini-watersheds in Damota Jalala Kebele drain to an intermittent river that flows to Lake Haramaya. The many mini-watersheds in Ifa Oromia also converge and drain to Lake Adele. The contour and elevation map of the four kebeles is indicated in Figure 7.

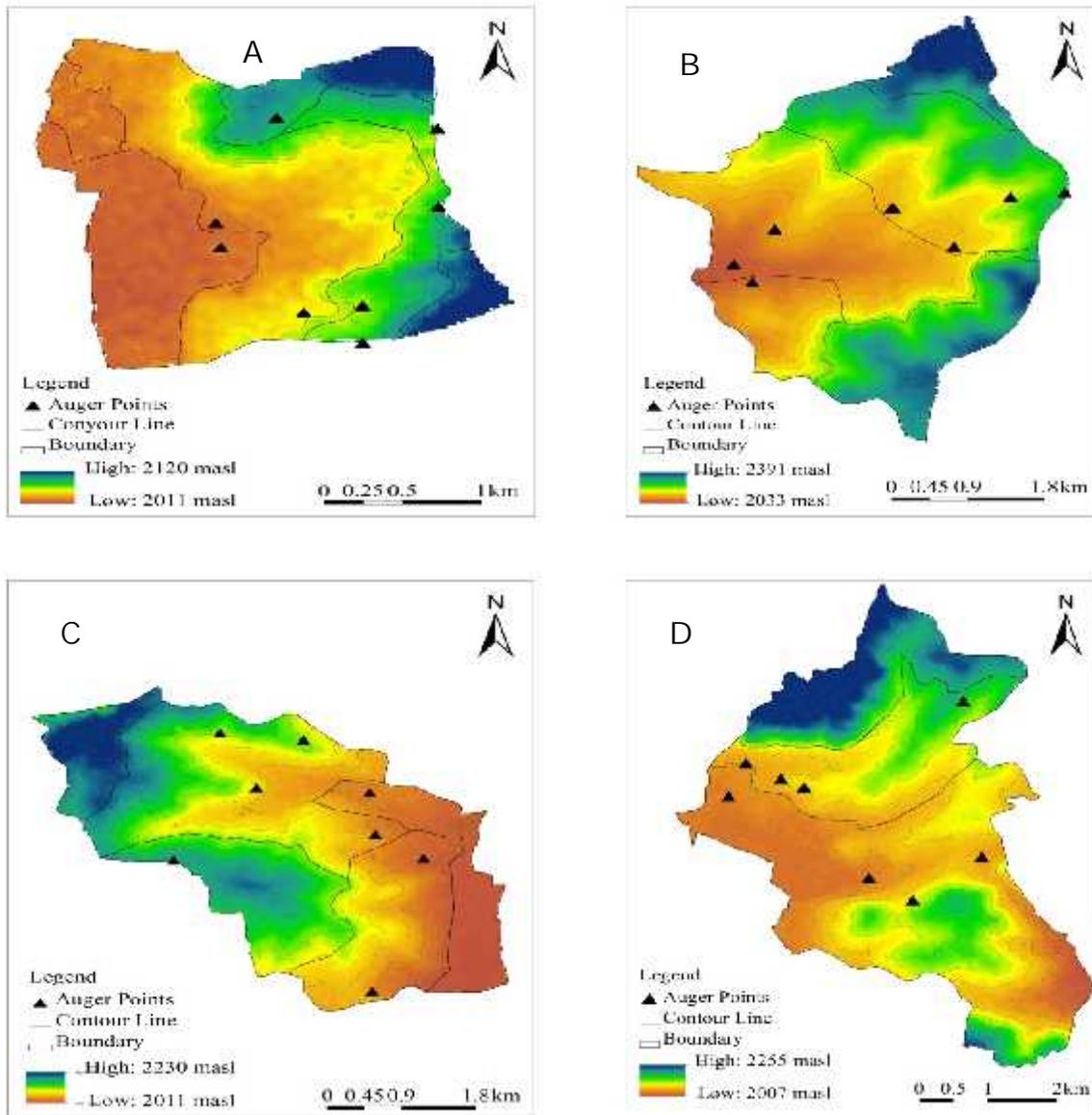


Figure 7. Contour and elevation map of and location of auger points in the four CASCAPE intervention kebeles in Haramaya Woreda: (A) Finkile, (B) Damota Jalala, (C) Kuro Jalala, and (D) Ifa Oromia.

### 3.4.1.3. Land Use

Most of the steep slopes are highly degraded and covered by shrubs, bushes, and rock outcrops. The vegetation in most places is dominantly *Lanthana camara*, cactus, and small stature *Acacia abyssinica*. At a few places, remnants of *Juniperus procera*, *Podocarpus nubigenus* and *Olea europaea* are present on the slopes and border areas. Around homesteads, eucalyptus trees, such as *Eucalyptus globules* and *Eucalyptus camaldulensis* are found. Some agro-forestry tree species, such as *Acacia abyssinica*, and *Croton macrostachyus*, were also observed in some farms. By and large, the study kebeles are characterized by a highly disturbed vegetation cover.

Very deep and wide gully, formed probably many years back, that shows the existence of a material that looks like a buried soil, but highly indurated, was also observed. Because of the prevalence of excessive erosion from these steep to very steep landforms for many years, the soils on these steep and rocky slopes are shallow soils (Leptosols). These soils are not deep enough to support successful crop production. As a result, crop stands (mainly sorghum and maize intercropped with khat) observed on these soils during the field work were poor and stunted with distinct nutrient deficiency symptoms.

Although the farming system is commonly mixed crop production and livestock husbandry, the livestock component is a weak link in the farming system. The overriding reason for this is lack of grazing land that supports livestock. The average per capita land holding in the four kebeles, based on the observation made and discussions held with farmers and development agents, is not more than 0.25 ha. As a solution, most farmers are using the cut and carry system (usually crop residues, weeds, sorghum and maize tillers) to feed the few numbers of livestock they possess. The only free grazing lands observed are the dried parts of Lakes Haramaya, Tinike, and Adele.

The middle, lower and toe slopes are intensively used for agriculture. The major rainfed field crops grown are sorghum (*Sorghum bicolor* L.) and maize (*Zea mays* L.) often intercropped with common bean (*Phaseolus vulgaris*), sweet potato, and khat (*Catha edulis* Forsk). Because of small size of land holding per capita and relatively large average family size, one time production using rainfall is not enough to produce sufficient food. Because of this, production more than twice per year is a must for majority of the farmers. Where there is water, therefore, irrigation is commonly practiced during the off-season, while sometimes supplementary irrigation is also used. Water is a key resource throughout the study kebeles, as a result. During the off-season, vegetables, such as potato, carrot, shallot, onion, garlic, pepper (*Capsicum* species), cabbage, lettuce, spinach and others are produced mainly as cash crops. Khat is the major cash crop planted on almost all farms. This non-food crop is heavy consumer of water during the off-season.

Regardless of crop and soil types, farmers are applying nitrogen and phosphorus fertilizers using blanket recommendation of about 100 kg ha<sup>-1</sup> each. There are no other chemical fertilizer types being used. However, every farmer is advised to prepare compost of his own and apply to his field. The attempts have been observed during the field work. The major concern, nevertheless, remains the impact this very small amount of organic matter may have on the soil fertility and health. Inputs of organic materials for the preparation of compost itself are very much limited. This is because materials that can be used as inputs are most of the time used as animal feed (e.g., crop residues). On top of this, no crop residue, particularly of sorghum and maize, is returned to the soil. Instead, they are used as animal feed starting from the early stage of growth, fuel wood, construction material, and as source of income.

#### 3.4.1.4. Soil-landscape (Exploratory Survey Results)

From the exploratory surveys made across the four kebeles, different soils types formed from different parent materials and occurring on different topographic positions are indentified (See Section 3.4.1.5 for the details). The major soil mapping units and their areal coverage is presented in Table 6. Furthermore, Plate 1 below shows the different soil types occurring on different landforms. The soil maps of the exploratory survey are also indicated in Figure 8.

Table 6. Major soil mapping units and their areal coverage in the four CASCAPE intervention kebeles

Kebele	Soil type	Soil code	Area (ha)	%
Finkile	Lithic Leptosols	LP-li	51	8
	Cambisols	CM	59	9
	Luvisols	LV	94	15
	Calcic Vertisols	VR-cc	283	45
	Fluvisols	FL	146	23
Damota Jalala	Lithic Leptosols	LP-li	431	25
	Regosols	RG	177	11
	Cambisols	CM	532	31
	Vertisols	VR	562	33
Kuro Jalala	Leptosols	LP	148	10
	Luvisols	LV	648	44
	Vertisols	VR	363	25
	Calcic Vertisols	VR-cc	314	21
Ifa Oromia	Nitisols	NT	529	21
	Luvisols (Chromic)	LV-cr	446	18
	Calcic Vertisols	VR-cc	1498	61

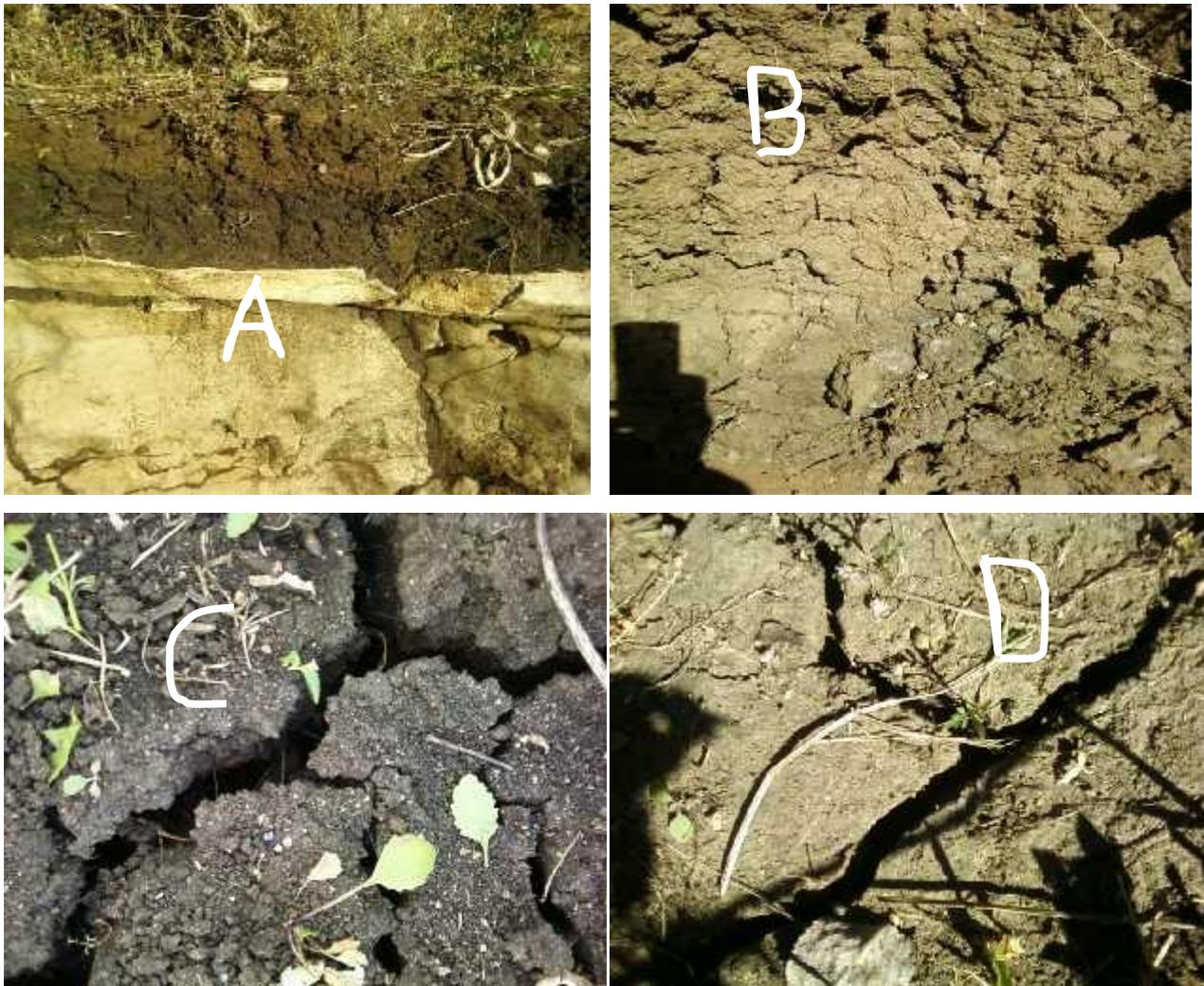


Plate 1. Mosaic of soils in the four CASCAPE intervention kebeles in Haramaya Woreda. The plates indicate the soil types that dominantly occupy the different slope positions in a typical toposequence: (A) iron-rich Leptosols/Cambisols, (B) well drained and free iron-rich Vertisols, (C) and (D) wide cracks formed in Vertisols high and low in clay content, respectively.

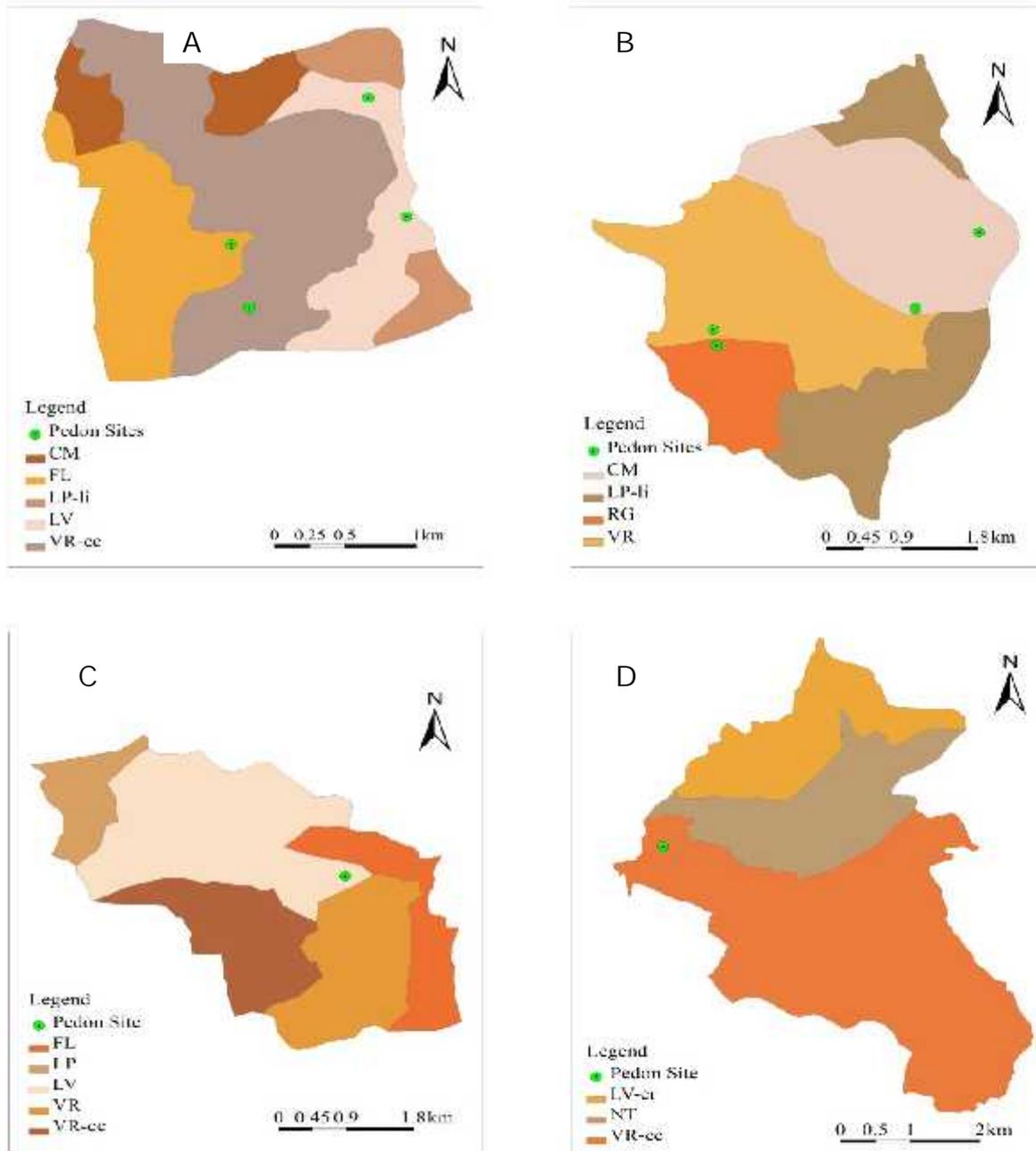


Figure 8. Exploratory (auger based) soil map and location of pedon sites in the four CASCAPE intervention kebeles in Haramaya Woreda.

#### 3.4.1.5. The Soil-landscape (Final)

The major soil mapping units, the landform on which they occur and their area coverage is depicted in Table 7. The results indicate that the soil mapping units identified in the four kebeles are very much affected by parent material and landform.

The Leptosols generally occur on the steepest parts of the sloping interspersed hills and are developed mainly on granitic and limestone parent materials. Those developed on granitic materials are coarser in texture, while those developed from limestone are finer in texture. Similarly, the Regosols also occur on sloping lands where the parent materials are weathering (unconsolidated) granite and sandstones. The Haplic Regosols (Eutric, Skeletic), for instance, occur on the lower slopes of the sloping hill in Damota Jalala Kebele and are developed from a mixed parent material of granite and sand. The upper parts of this hill are covered by granite while the lower slopes are covered by mixed granite and sandstone.

The Haplic Cambisols (Eutric, Clayic, Rhodic) in Finkile Kebele and the Haplic Cambisols (Eutric, Chromic) in Damota Jalala Kebele occur on the middle and lower slopes of the sloping land and are developed on mixed parent material of granite and sandstone nature. This is judged from the exposed rocks in those areas. Furthermore, Cambisols are also observed on the upper slopes of the eastern part of Damota Jalala Kebele, which is covered by Limestone, in association with Leptosols. These Cambisols developed on limestone parent material are finer in texture as compared to those developed on the mixed granite and sandstone parent material. The Cambisols are important agricultural soils given the population pressure and chronic land shortage.

The Nitisols occur on a wide range of landforms that range from lower to upper slopes of sloping landforms and are developed dominantly on granite

parent material on the middle and upper slopes and mixture of granite and sandstone on the lower slopes. They occupy significant area in Ifa Oromia Kebele, while in other kebeles, they occur mainly as associations with Luvisols and Cambisols. The Nitisols are among the most important agricultural soils in all the kebeles.

The Calcic Luvisols (Hypereutric, Clayic, Chromic) in Finkile, Vertic Luvisols (Hypereutric, Clayic) in Damota Jalala and the Cutanic Luvisols (Skeletal, Chromic) in Kuro Jalala Kebeles occur on wide range of landforms that extend from upper parts of the lower slopes to lower parts of the upper slopes. Nevertheless, significant area of these soils is found on the middle slopes of the sloping landforms. They are developed from variety of parent materials that includes granite (Kuro Jalala), mixed granite and limestone (Finkile) and limestone (Damota Jalala). Those Luvisols developed on granite parent material are coarser in texture (more sand content), while those developed on limestone are finer in texture (more clay content). Those developed on the mixed parent material, on the other hand, are intermediate. These soils are also occurring in pocket areas in association with Nitisols and Vertisols. These soils are among the most important agricultural/cultivated soils in all the kebeles.

Vertisols are occurring in almost all the four kebeles over a wide range of landforms. The Calcic Mollic Gleyic Vertisols (Calcaric, Pellic, Chromic) in Finkile, Calcic Vertisols in Kuro Jalala and the Calcic Mollic Vertisols (Calcaric, Pellic, Chromic) in Ifa Oromia kebele occur on lower slopes of sloping landforms to level lands. Since most of them are developed on relatively low lying areas, their parent materials are colluvial materials derived from granite, sandstone, and limestone. They occupy significant area in all the four kebeles and occur in association with Nitisols, Luvisols and Fluvisols. They are also among the most important agricultural soils particularly during the off-season.

The Calcic Fluvisols (Calcaric, Clayic) in Finkile, Calcic Fluvisols (Calcaric) and Fluvisols in Kuro Jalala occur in the valleys of level lands (plains) near the periphery of water bodies such as edges of rivers and also lakes. Fluvial materials transported from the upper slopes are their parent materials. Therefore, sediments are derived from granite, sandstone, and limestones. The area occupied by these soils is most of the time temporarily flooded during the wet season and are therefore not highly productive during the wet season. They are, however, highly productive during the off-season by irrigation.

Table 7. Major soil mapping units and their area coverage in the four CASCAPE intervention kebeles in Haramaya Woreda

Kebele	Major landform (Landscape unit)	Soil type	Soil code	Area (ha)	%	Elevation (masl)
Finkile	Steep land	Lithic Leptosols	LP-li	51	8	2060-2100
	Sloping land	Cambisols	CM	28	4	2020
	Sloping land	Haplic Cambisols (Eutric, Clayic, Rhodic)	CM-ha-eu.ce.ro	23	4	2040-2080
	Sloping land	Luvisols (Rhodic)	LV-ro	44	7	2040-2060
	Sloping land	Calcic Luvisol (Hypereutric, Clayic, Chromic)	LV-cc-je.ce.cr	92	15	2040-2060
	Sloping land	Calcic Mollic Gleyic Vertisols (Calcaric, Eutric, Pellic, Chromic)	VR-gl.mo.cc-ca.eu.pe.cr	249	39	2020-2040
	Level land	Calcic Fluvisol (Calcaric, Eutric, Clayic)	FL-cc-ca-ca.eu.ce)	146	23	2020
Damota Jalala	Steep land	Lithic Leptosols	LP-li	431	25	2280-2380; 2180-2300
	Sloping land	Haplic Regosols (Eutric, Skeletic)	RG-ha-eu.sk	177	11	2060-2180
	Sloping land	Haplic Cambisols (Eutric, Chromic)	CM-ha-eu.cr	184	11	2100-2240
	Sloping land	Vertic Luvisols (Hypereutric, Clayic)	LV-vr.je.ce	764	45	2080-2280; 2080-2180
	Level land	Calcic Fluvisols (Calcaric, Eutric)	FL-cc-ca.eu	140	8	2040-2100
Kuro Jalala	Steep land	Leptosols	LP	148	9	2120-2220
	Sloping land	Cutanic Luvisols (Skeletic, Chromic)	LV-ct-sk.cr	648	38	2040-2160
	Level land	Calcic Vertisols	VR-cc	314	18	2080-2160
	Level to sloping	Vertisols	VR	363	21	2020-2100
	Level land (valley)	Fluvisols	FL	235	14	2020-2060
Ifa Oromia	Sloping land	Nitisols	NT	529	21	2040-2100
	Sloping land	Luvisols (Chromic)	LV-cr	446	18	2100-2240
	Level land	Calcic Mollic Vertisols (Calcaric, Eutric, Pellic, Chromic)	VR-mo.cc-ca.eu.pe.cr	1498	61	2040-2160

Figure 9 shows the sketch of the general soil-landscape representing the major soils types in the four CASCAPE intervention kebeles. Plate 2 shows some of the pedons opened on major agricultural soils of the four CASCAPE intervention kebeles in Haramaya Woreda. Figure 10 shows the geographic distribution of the different soil mapping units in the respective kebeles.

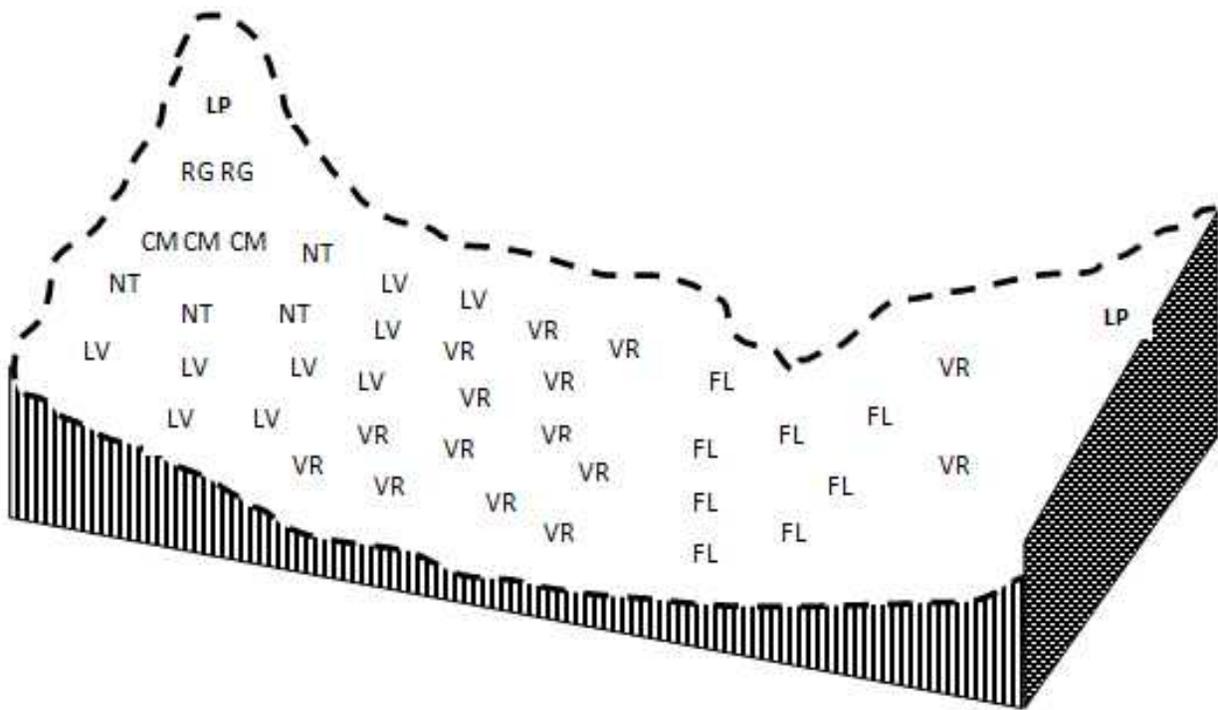


Figure 9. Sketch of the soil-landscape in CASCAPE intervention kebeles of Haramaya Woreda.

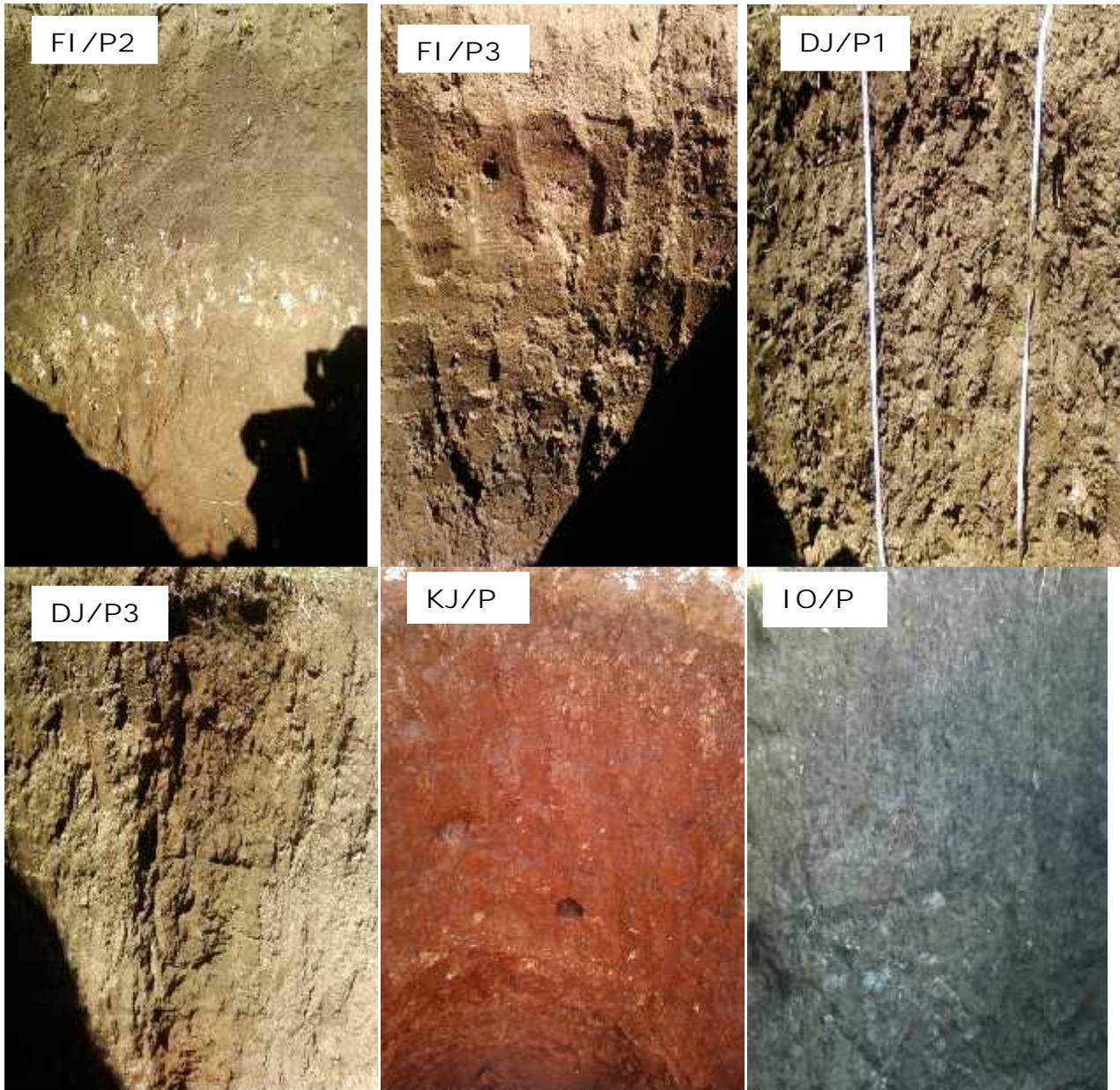


Plate 2. Some of the pedons opened to characterize major agricultural soils of the CASCAPE intervention kebeles in Haramaya Woreda.

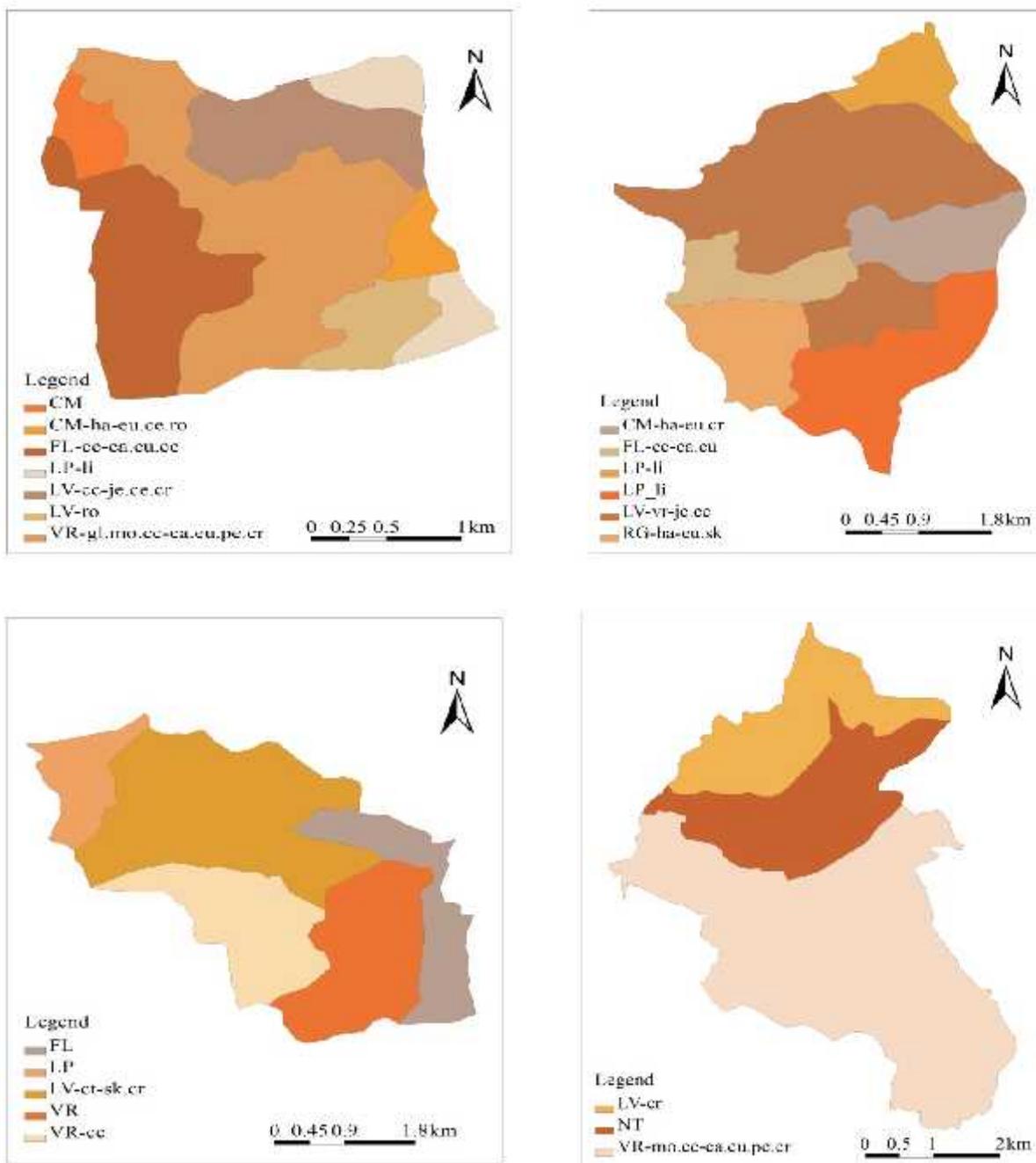


Figure 10. Soil maps of the four CASCAPE intervention kebeles in Haramaya Woreda.

Furthermore, comparison of the scientific classification with the traditional classification was made. Farmers classify their soils based on surface color and texture (qualitative) and they attach fertility terms to it in a very abstract way. Table 8 indicates the correlation between farmers' classification and the WRB system. As it can be seen from the correlation, different soil types can have the same name if they have the same color and/or texture. Furthermore, the farmers use color for fine textured soils and texture for coarse textured soils to classify them. Accordingly, any soil type (e.g., Vertisol, Luvisol, Cambisol, Regosol, etc) can be Biye Guracha if it has black color and fine texture.

Table 8. Correlation between local soil classification and the WRB system names

WRB (RSG level only)	Local name
Cambisol	Ashewa/Zabadu
Luvisol	Biye Guracha
Fluvisol	Ashewa/Chirecha
Vertisol	Biye Guracha
Luvisol	Biye Guracha
Cambisol	Biye Dimma/Zebadu
Fluvisol	Ashewa/Chirecha
Regosol	Ashewa
Luvisol	Ashewa
Vertisol	Biye Guracha

### 3.4.2. Soil Profile Descriptions and Analytical Data

#### 3.4.2.1. Soil Profiles

In Haramaya Woreda, a total of 10 pedons were opened on major agricultural soils in four CASCAPE intervention kebeles: Finkile (4), Damota Jalala (4), Kuro Jalala (1), and Ifa Oromia (1). Finkile and Damota are kebeles with high variability of soils within a short distance as a result of variations in topography and parent materials, among others. Kuro Jalala and Finkile are neighbouring kebeles as a result of which major soils identified in Finkile are also common in Kuro Jalala. That is why the number of the pedon was limited to 1. The case of Ifa Oromia is also the same. It shares boundaries with Kuro Jalala and there are similarities in major agricultural soil types. The distribution of the pedons on the different landforms is as follows: In Finkile, two were opened on middle slope position, one on lower slope and one on toe slope position. In Damota, one on upper slope, two on lower slope and one on toe slope position. In Kuro Jalala, the pedon was opened on middle slope position, while in Ifa Oromia, it was opened on bottom slope position of the landscape. Furthermore, 32 auger pits were also described on different soil-landscapes in these four kebeles of Haramaya Woreda. A total of 35 samples were collected from genetic horizons from the 10 pedons and analyzed for their selected physical and chemical properties at the Water Works and Design Supervision Enterprise Soil laboratory in Addis Ababa.

Presented below in Table 9 is the field description of the pedons' site and profile characteristics.

Table 9. Soil site and profile descriptions of pedons opened in four CASCAPE intervention kebeles of Haramaya Woreda (For analytical results, see Table 10)

Profile ID	HE/HMY/FI/P1	Land cover	Scattered trees, herbaceous
Date	19/11 (dd/mm)	Land use	Agriculture
Year	2013	Crop	Cereals, vegetables, Khat, fruits
Surveyor	Kibebew Kibret	Human influence	Vegetation disturbed, terracing, ploughing
Status	Reference profile description	Surface stone cover	None
Location country	Ethiopia	Erosion category	Water, gully
Location region	East Hararghe	Erosion area	5-10%
Location woreda	Haramaya	Erosion degree	Slight
Location kebele	Finkile	Sealing thickness	None
Longitude	42°02'24.6"	Crack width	None
Latitude	09°27'11.1"	Surface salt	None
Elevation	2063 m	Surface drainage	Well
Map ID		Soil drainage	Well
Map scale		Flooding frequency	None
Map unit ID		Depth to groundwater	Not observable
Topography	Strongly sloping, 10-15%	Depth to bedrock	Not observable
Major landform	Medium gradient hill	Rootable depth	170+ cm
Position on slope	Middle slope	Rooted depth	170 cm
Slope form	Straight	Depth of observation	170 cm
Slope gradient	12%	Local soil type	Ashewa/Zabadu
Geology	Igneous	Field WRB soil type	Nitisol
Parent material	Granitic basement	WRB soil type	Haplic Cambisol (Eutric, Clayic, Rhodic)

### Description of the soil horizons

Horizon	Depth (cm)	Description
Ap	0-20	Dark reddish brown (5YR 2.5/2, moist) and dark reddish brown (5YR 3/2, dry) colour; clay loam; weak coarse sub-angular blocky structure; very hard (dry), very friable (moist), slightly sticky and plastic when wet; many pores; no coarse fragments; no mottles; no coatings; common, fine roots; many biological pores; abrupt, smooth boundary; no reaction with HCl with pH value of 6.5.
A	20-36	Dark reddish brown (2.5YR 3/4, moist) and red (2.5YR 4/6, dry) colour; sandy clay; moderate coarse sub-angular blocky structure; very friable when moist, sticky and plastic when wet; many, very fine to coarse pores; few fine roots; no fragments; gradual, smooth boundary; no reaction with HCl with field measured pH value of 6.
Bt	36-45	Dark reddish brown (2.5YR 3/4, moist) and dark reddish brown (2.5YR 3/4, dry) sandy clay; moderate coarse sub-angular blocky structure; very friable when moist, sticky and plastic when wet; many very fine to fine pores; fine, few quartz coarse fragments; no mottles; common distinct clay coatings; very few, very fine roots; common burrows; clear, smooth boundary; no reaction with dilute HCl; field pH value of 6.
BC	45-170	Dark reddish brown (2.5YR 3/4, moist) and red (2.5YR 5/8, dry) colour; sandy clay loam; moderate coarse sub-angular blocky structure; hard (dry), very friable (moist), and sticky and plastic (wet) consistence; few very fine to fine pores; common to few quartz coarse fragments; common distinct clay coatings; few burrows; slight effervescence with dilute HCl; field pH value of 6.5.

Profile ID	HE/HYM/FI/P2	Land cover	Scattered trees, woody shrubs and herbaceous
Date	12/12 (dd/mm)	Land use	Crop agriculture and animal husbandry
Year	2013	Crop	Cereals (sorghum, maize), vegetables, khat
Surveyor	Kibebew Kibret	Human influence	Vegetation strongly disturbed, ploughing, terracing
Status	Reference profile description	Surface stone cover	None
Location country	Ethiopia	Erosion category	Water
Location region	East Hararghe	Erosion area	0-5%
Location woreda	Haramaya	Erosion degree	Slight
Location kebele	Finkile	Sealing thickness	None
Longitude	42°02'16"	Crack width	None
Latitude	09°27'43"	Surface salt	None
Elevation	2055 m	Surface drainage	Well
Map ID		Soil drainage	Well
Map scale		Flooding frequency	None
Map unit ID		Depth to groundwater	Not observable
Topography	Moderately steep, 15-30%	Depth to bedrock	Not observable
Major landform	Medium gradient hill	Rootable depth	200+ cm
Position on slope	Middle slope	Rooted depth	200 cm
Slope form	Straight	Depth of observation	200 cm
Slope gradient	21%	Local soil type	Biye Guracha
Geology	Igneous	Field WRB soil type	Calcic Luvisol
Parent material	Granitic basement	WRB soil type	Calcic Luvisol (Hypereutric, Clayic, Chromic)

### Description of the soil horizons (morphology)

Horizon	Depth (cm)	Description
Ap	0-30	Reddish brown (2.5YR 4/4, moist) and dark grayish brown (10YR 4/2, dry); clay loam; moderate medium granular to sub-angular blocky structure; hard (dry), very friable (moist), and very sticky and very plastic (wet) consistence; common, very fine to fine pores; common, fine coarse fragments of quartz nature; very few, very fine faint mottles; common, very fine to fine roots; very few burrows; clear, smooth boundary; slight effervescence with dilute HCl and field measured pH value of 7.
Bt1	30-60	Very dark gray (5YR 3/1, dry) and dark reddish gray (5YR 4/2, dry); clay; strong coarse sub-angular blocky structure; very hard (dry), very friable (moist), and very sticky and very plastic (wet) consistence; common, very fine to fine pores; few, fine coarse fragments of quartz nature; no mottles; few, very fine roots; few burrows and earthworm channels; clear, smooth boundary; no reaction with dilute HCl and field measured pH value of 6.5.
Btk1	60-105	Dark reddish brown (5YR 3/4, moist) and reddish brown (5YR 4/3, dry); clay loam; moderate medium sub-angular blocky to angular blocky structure; very hard (dry), very friable (moist), and very sticky and very plastic (wet) consistence; few, very fine pores; common, fine quartz and calcium carbonate fragments; few, very fine, faint mottles; very fine, very few roots; very few burrows and earthworm channels; few, very fine, faint mottles that are black in colour; gradual, wavy boundary; strong effervescence with dilute HCl and pH value of 8.
Bck2	105-200	Red (2.5YR 5/8, moist) and red (2.5YR 4/6); clay loam; moderate medium sub-angular blocky to angular blocky structure; slightly hard (dry), very friable (moist), and very sticky and very plastic (wet) consistence; few, very fine pores; very few, fine quartz fragments; common, medium, distinct mottles (red); very few, very fine roots; strong effervescence with dilute HCl and pH value of 8.5.

Profile ID	HE/HMY/FI/P3	Land cover	Scattered trees, shrubs, and herbaceous
Date	10/12 (dd/mm)	Land use	Crop agriculture and animal husbandry
Year	2013	Crop	Vegetables, cereals, khat
Surveyor	Kibebew Kibret	Human influence	Vegetation strongly disturbed, flood irrigation,
Status	Reference profile description	Surface stone cover	None
Location country	Ethiopia	Erosion category	None
Location region	East Hararghe	Sealing thickness	None
Location woreda	Haramaya	Crack width	None
Location kebele	Finkile	Surface salt	None
Longitude	42°01'44"	Surface drainage	Slow
Latitude	09°27'4"	Soil drainage	Well
Elevation	2021 m	Flooding frequency	Once or twice per year
Map ID		Flooding duration	Few hours
Map scale		Depth to groundwater	140 m
Map unit ID		Depth to bedrock	None
Topography	Nearly level, 0.5-1.0%	Rootable depth	120 cm
Major landform	Plain	Rooted depth	120 cm
Position on slope	Toe slope	Depth of observation	120 cm
Slope form	Straight	Local soil type	Ashewa (Chirecha)
Slope gradient	1%	Field WRB soil type	Fluvisol
Geology	Alluvial material of sedimentary origin	WRB soil type	Calcic Fluvisol (Eutric, Calcaric, Clayic)
Parent material	Unconsolidated alluvium/colluvium		

### Description of the soil horizons (morphology)

Horizon	Depth (cm)	Description
Ap	0-20	Reddish brown (2.5YR 4/3, moist) and pale brown (10YR 6/3, dry); sandy loam; single-grained structure; soft (dry), friable (moist), and slightly sticky and slightly plastic (wet) consistence; common, fine to medium pores; very few, faint clay coatings; common, fine, hard to soft calcium carbonate and quartz fragments; very few, very fine to fine, faint black mottles; very few, fine roots; very few burrows; clear, smooth boundary; moderate effervescence with dilute HCl; field measured pH value of 7.
A	20-40	Reddish black (2.5YR 2.5/1, moist) and pale brown (10YR 6/3, dry); loamy sand; loamy sand; single grained structure; slightly hard (dry), loose (moist), and slightly sticky and slightly plastic (wet) consistence; few fine pores; common, fine quartz and calcium carbonate fragments; very few, very fine faint black mottles; very fine, very few roots; very few burrows; clear, smooth boundary; moderate reaction with HCl; pH value of 7.
Bt1	40-68	Dark reddish brown (5YR 3/2, moist) and grayish brown (10YR 5/2, dry); sandy loam; weak, fine sub-angular blocky structure; hard (dry), loose (moist), and slightly sticky and slightly plastic (wet) consistence; few, fine pores, few, fine quartz and calcium carbonate fragments; very fine, few roots; very few burrows; diffuse, irregular boundary; moderate reaction with HCl and pH value of 7.5.
Btk	68-120	Black (5YR 2.5/1, moist) and dark grayish brown (10YR 4/2, dry); clay; moderate medium sub-angular blocky structure; very hard (dry), friable (moist), and sticky and plastic (wet) consistence; few, very fine pores; few, fine quartz and calcium carbonate fragments; very fine, very few roots; very fine, very few faint black mottles; strong reaction with dilute HCl; pH value of 8.

Profile ID	HE/HMY/FI/P4	Land cover	Grass and scattered trees of different species
Date	10/12 (dd/mm)	Land use	Crop agriculture and animal husbandry
Year	2013	Crop	Cereals, vegetables, khat
Surveyor	Kibebew Kibret	Human influence	Vegetation strongly disturbed, irrigation, ploughing, terracing
Status	Reference profile description	Surface stone cover	None
Location country	Ethiopia	Erosion category	None
Location region	East Hararghe	Sealing thickness	None
Location woreda	Haramaya	Crack width	Medium (1-2 cm)
Location kebele	Finkile	Crack depth	Deep (10-20 cm)
Longitude	42°01'48"	Crack distance	Closely spaced (0.2-0.5 m)
Latitude	09°26'47"	Surface salt	None
Elevation	2038 m	Surface drainage	Well
Map ID		Soil drainage	Moderate
Map scale		Flooding frequency	None
Map unit ID		Depth to groundwater	Not observable
Topography	Sloping, 5-10%	Depth to bedrock	Not observable
Major landform	Medium gradient hill	Rootable depth	200 cm
Position on slope	Lower slope	Rooted depth	200 cm
Slope form	Straight	Depth of observation	200 cm
Slope gradient	10%	Local soil type	Biye Guracha
Geology	Igneous	Field WRB soil type	Calcic Gleyic Vertisol
Parent material	Granitic basement	WRB soil type	Calcic Mollic Gleyic Vertisol (Calcaric, Eutric, Pellic, Chromic)

### Description of the soil horizons (morphology)

Horizon	Depth cm	Description
Ah	0-27	Reddish black (2.5YR 2.5/1, moist) and dark reddish gray (2.5YR 3/1, dry) colour; clay; strong coarse sub-angular blocky structure; very hard (dry), friable (moist), and very sticky and very plastic (wet) consistence; common very fine to fine pores; very few, fine feldspars and calcium carbonate fragments; coarse, few roots; very few burrows; clear, smooth boundary; moderate effervescence with dilute HCl and a field measured pH value of 7.
Ai1	27-64	Black (2.5Y 2.5/1, moist) and dark reddish gray (2.5YR 3/1, dry) colour; clay; strong coarse sub-angular blocky structure; very hard (dry), friable (moist), and very sticky and very plastic (wet) consistence; common, very fine to fine pores; very few, fine feldspar and calcium carbonate fragments; medium, few roots; very few burrows; clear, smooth boundary; slight reaction with HCl with field measured pH value of 6.5.
B1k1	64-90	Black (10YR 2/1, moist) and very dark gray (10YR 3/1) colour; clay; strong very coarse angular blocky structure; very hard (dry), friable (moist), and very sticky and very plastic (wet) consistence; common, very fine pores; very few, very fine faint red mottles; very few, fine feldspar and calcium carbonate fragments; very fine, very few roots; clear, smooth boundary; strong effervescence with dilute HCl; field measured pH value of 8; intersecting slickensides.
Bg1ik	90-140	Light reddish brown (5YR 6/4, moist) and weak red (5R 5/3) colour; clay; strong very coarse sub-angular blocky to angular blocky structure; very hard (dry), friable (moist), and very sticky and very plastic (wet) consistence; few, very fine to fine pores; few, fine to medium feldspar and calcium carbonate fragments; common, medium prominent black mottles; very few, very fine to coarse roots; diffuse, irregular boundary; strong effervescence with dilute HCl; field measured pH value of 8.5; intersecting slickensides.
Bg2ik	140-200	Light reddish brown (5YR 6/4, moist) and light olive brown (2.5Y 5/3, dry) colour; clay; strong very coarse sub-angular blocky to angular blocky structure; extremely hard (dry), friable (moist), and very sticky and very plastic consistence; few, very fine to fine pores; very few, medium feldspar and calcium carbonate fragments; common, medium prominent black mottles; strong reaction (effervescence) with HCl; field measured pH value of 8.5; intersecting slickensides.

Profile ID	HE/HMY/DJ/P1	Crop	Cereals, vegetables, khat, fruit trees
Date	16/12 (dd/mm)	Human influence	Vegetation strongly disturbed, terracing, ploughing
Year	2013	Surface stone cover	Many
Surveyor	Kibebew Kibret	Surface stone size	Large
Status	Reference profile description	Erosion category	Water, few gullies
Location country	Ethiopia	Erosion area	5-10%
Location region	East Hararghe	Erosion degree	Moderate
Location woreda	Haramaya	Sealing thickness	None
Location kebele	Damota Jalala	Crack width	Medium (1-2 cm)
Longitude	42°05'01"	Crack depth	Very deep (> 20 cm)
Latitude	09°25'45"	Crack distance	Closely spaced (0.2-0.5 m)
Elevation	2180 m	Surface salt	None
Map ID		Surface drainage	Rapid
Map scale		Soil drainage	Well
Map unit ID		Flooding frequency	None
Topography	Moderately steep, 15-30%	Depth to groundwater	Not observable
Major landform	Medium gradient hill	Depth to bedrock	80 cm
Position on slope	Upper slope	Rootable depth	80 cm
Slope form	Straight	Rooted depth	80 cm
Slope gradient	25%	Depth of observation	80 cm
Geology	Sedimentary rock	Local soil type	Biye Guracha
Parent material	Limestone basement	Field WRB soil type	Vertic Luvisol
Land cover	Scattered trees, woody shrubs, Herbaceous	WRB soil type	Vertic Luvisol (Hypereutirc, Clayic)
Land use	Cropping, animal husbandry		

#### Description of the soil horizons (morphology)

Horizon	Depth (cm)	Description
Ap	0-20	Dark brown (10YR 3/3, moist) and brown (7.5YR 4/2, dry) colour; silty clay; strong coarse angular blocky structure; hard (dry), friable (moist), and very sticky and very plastic (wet) consistence; common, very fine to fine pores; common, medium coarse fragment of unknown nature and calcium carbonate (mixed); very few, very fine faint black mottles; few, fine to coarse roots; gradual, smooth boundary; moderate reaction with HCl and field measured pH value of 6.5.
A	20-50	Very dark brown (7.5YR 2.5/2, moist) and dark grayish brown (10YR 4/2, dry) colour; heavy clay; strong coarse sub-angular blocky to angular blocky structure; hard (dry), friable (moist), and very sticky and very plastic (wet) consistence; common, very fine pores; common, faint clay coatings; few, medium calcium carbonate fragments; very few, very fine, faint black mottles; very fine to fine, very few roots; very few termite channels; clear, smooth boundary; moderate reaction with dilute HCl and field measured pH value of 7;
Bt	50-80	Dark yellowish brown (10YR 4/3, moist) and brown (10YR 4/3, dry) colour; heavy clay; moderate medium prismatic structure; extremely hard (dry), friable (moist), and very sticky and very plastic (wet) consistence; few, very fine to fine pores; common, faint clay coatings; few, fine faint mottles with mixed red and black colours; very few, medium calcium carbonate fragments; very fine, very few roots; moderate reaction with HCl and field measured pH value of 7.5.

Profile ID	HE/HMY/DJ/P2	Crop	Cereals, vegetables, khat, fruit trees
Date	17/12 (dd/mm)	Human influence	Vegetation intensively disturbed, irrigation, terracing
Year	2013	Surface stone cover	Very few
Surveyor	Kibebew Kibret	Surface stone size	Large
Status	Reference profile description	Erosion category	Water, gully
Location country	Ethiopia	Erosion area	0-5%
Location region	East Hararghe	Erosion degree	Slight
Location woreda	Haramaya	Sealing thickness	None
Location kebele	Damota Jalala	Crack width	Wide (2-5 cm)
Longitude	42°04'36"	Crack depth	Medium (2-10 cm)
Latitude	09°25'11.4"	Crack distance	Closely spaced (0.2-0.5 m)
Elevation	2119 m	Surface salt	None
Map ID		Surface drainage	Well
Map scale		Soil drainage	Well
Map unit ID		Flooding frequency	None
Topography	Sloping valley bottom, 5-10%	Depth to groundwater	Not observable
Major landform	Medium-gradient valley	Depth to bedrock	Not observable
Position on slope	Lower slope	Rootable depth	150 cm
Slope form	Concave straight	Rooted depth	150 cm
Slope gradient	10%	Depth of observation	150 cm
Geology	Igneous and sedimentary	Local soil type	Zebedu (Biye dimma)
Parent material	Granite and sandstone	Field WRB soil type	Cambisol
Land cover	Scattered trees, shrubs, and herbaceous plants	WRB soil type	Haplic Cambisol (Eutric, Chromic)
Land use	Crop cultivation and animal husbandry		

#### Description of the soil horizons (morphology)

Horizon	Depth (cm)	Description
Ap	0-25	Dark brown (7.5YR 3/4, moist) and reddish brown (2.5YR 4/3, dry) colours; clay; strong medium sub-angular blocky to blocky structure; hard (dr), very friable (moist), and very sticky and very plastic (wet) consistence; common very fine to fine pores; few, faint clay coatings; very few, fine quartz fragments; medium, few roots; few burrows; clear, smooth boundary; slight reaction with dilute HCl and field measured pH value of 6.5.
A1	25-50	Black (5YR 2.5/1, moist) and dark reddish brown (2.5YR 3/3, dry) colour; heavy clay; strong medium sub-angular blocky to angular blocky structure; very hard (dry), friable (moist), and very sticky and very plastic (wet) consistence; common, very fine to fine pores; very few, faint clay coatings; very few, fine quartz fragments; few, very fine roots; few burrows; clear, smooth boundary; no effervescence with dilute HCl; pH value of 6.5.
A2	50-90	Dark brown (7.5YR 3/3, moist) and red (2.5YR 4/6, dry) colour; heavy clay; strong medium sub-angular blocky to angular blocky structure; very hard (dry), friable (moist), and very sticky and very plastic (wet) consistence; common, very fine to fine pores; very few, faint clay coatings; very few, fine quartz fragments; very few, very fine faint black mottles; very fine, very few roots; very few burrows; clear, smooth boundary; no reaction with HCl; field measured pH value of 6.5.
AC	90-150	Dark red (2.5YR 3/6, moist) and red (2.5YR 5/8, dry) colour; heavy clay; strong, medium angular blocky structure; hard (dry), friable (moist), and very sticky and very plastic (wet) consistence; few, very fine to fine pores; very few, faint clay coatings; very few, fine quartz fragments; no reaction with dilute HCl; field measured pH value of 6.5.

Profile ID	HE/HMY/DJ/P3	Land use	Crop cultivation, animal husbandry
Date	16/12 (dd/mm)	Crop	Cereals, vegetables, selected fruit trees, khat
Year	2013	Human influence	Vegetation intensively disturbed, ploughing, flood/furrow irrigation
Surveyor	Kibebew Kibret	Surface stone cover	None
Status	Reference profile description	Erosion category	Water, gully
Location country	Ethiopia	Erosion area	0-5%
Location region	East Hararghe	Erosion degree	Slight
Location woreda	Haramaya	Sealing thickness	None
Location kebele	Damota Jalala	Crack width	Medium (1-2 cm)
Longitude	42°03'17"	Crack depth	Medium (2-10 cm)
Latitude	09°25'2.4"	Crack distance	Closely spaced (0.2-0.5 m)
Elevation	2055 m	Surface salt	None
Map ID		Surface drainage	Well
Map scale		Soil drainage	Well
Map unit ID		Flooding frequency	None
Topography	Nearly level, 0.5-1.0%	Depth to groundwater	Not observable
Major landform	Level land, plain	Depth to bedrock	Not observable
Position on slope	Toe slope	Rootable depth	120 cm
Slope form	Straight	Rooted depth	120 cm
Slope gradient	1%	Depth of observation	120 cm
Geology	Alluvium/colluviums of limestone origin	Local soil type	Ashewa/Chirecha
Parent material	Unconsolidated colluviums/alluvium	Field WRB soil type	Calcic Fluvisol
Land cover	Reverine vegetation, shrubs, herbaceous	WRB soil type	Calcic Fluvisol (Calcaric, Eutric)

#### Description of the soil horizons (morphology)

Horizon	Depth (cm)	Description
Apk1	0-20	Dark reddish brown (2.5YR 2.5/3, moist) and reddish brown (2.5YR 4/3, dry) colour; sandy clay loam; moderate fine granular and sub-angular blocky structure; slightly hard (dry), very friable (moist), and sticky and plastic (wet) consistence; common, fine pores; no coatings; very few, fine quartz fragments; no mottles; few fine roots; many burrows; clear, smooth boundary; strong reaction (effervescence) with dilute HCl; field measured pH value of 7.5.
Ak2	20-90	Dark reddish brown (5YR 3/4, moist) and reddish brown (2.5YR 4/4, dry) colour; clay loam; moderate medium sub-angular blocky structure; very hard (dry), very friable (moist), and very sticky and very plastic (wet) consistence; common, very fine to fine pores; very few, faint clay coatings; very few, very fine quartz and calcium carbonate fragments; few, fine dominant black mottles; very fine, few roots; many termite channels; strong reaction with dilute HCl; field measured pH value of 8.

Profile ID	HE/HMY/DJ/P4	Land use	Crop cultivation and animal husbandry
Date	16/12 (dd/mm)	Crop	Cereals, vegetables, khat, some fruit trees
Year	2013	Human influence	Vegetation intensively disturbed, ploughing, terracing, irrigation
Surveyor	Kibebew Kibret	Surface stone cover	None
Status	Reference profile description	Erosion category	Water erosion, gully
Location country	Ethiopia	Erosion area	0-5%
Location region	East Hararghe	Erosion degree	Slight
Location woreda	Haramaya	Sealing thickness	None
Location kebele	Damota Jalala	Crack width	Medium (1-2 cm)
Longitude	42°03'18.4"	Crack depth	Medium (2-10 cm)
Latitude	09°24'55.3"	Crack distance	Moderately widely spaced (0.5-2 m)
Elevation	2060 m	Surface salt	None
Map ID		Surface drainage	Rapid
Map scale		Soil drainage	Well
Map unit ID		Flooding frequency	None
Topography	Moderately steep, 15-30%	Depth to groundwater	Not observable
Major landform	Medium gradient hill	Depth to bedrock	Not observable
Position on slope	Middle slope	Rootable depth	50 cm
Slope form	Straight	Rooted depth	50 cm
Slope gradient	15%	Depth of observation	50 cm
Geology	Igneous/sedimentary basement	Local soil type	Ashewa
Parent material	Mixed granite and sand stone	Field WRB soil type	Regosol
Land cover	Scattered trees, woody shrubs, herbaceous	WRB soil type	Haplic Regosol (Eutric, Skeletic)

### Description of the soil horizons (morphology)

Horizon	Depth (cm)	Description
Ap	0-16	Reddish brown (2.5YR 4/4, moist) and brown (7.5YR 4/4, dry) colour; sandy clay loam; weak fine sub-angular blocky structure; hard (dry), friable (moist), and sticky and plastic (wet) consistence; common, fine pores; no observable coatings; common, fine quartz fragments; no mottles; fine, few roots; fine burrows; diffuse, irregular boundary; no reaction with dilute HCl; field measured pH value of 6.
At	16-30	Dark reddish brown (2.5YR 2.5/3, moist) and reddish brown (5YR 4/4, dry) colour; sandy clay; weak medium angular blocky structure; slightly hard (dry), friable (moist), and sticky and plastic (wet) consistence; common, very fine to fine pores; few, faint clay coatings; few, fine quartz fragments; very fine, few roots; very few burrows; diffuse, wavy boundary; no reaction with dilute HCl; field estimated pH value of 6.
C	30-50	Dark red (2.5YR 3/6, moist) and yellowish red (5YR 4/6, dry) colour; sandy clay loam; weak fine sub-angular blocky structure; hard (dry), friable (moist), and sticky and plastic (wet) consistence; common fine pores; very few, faint clay coatings; many, fine quartz fragments; no mottles; very fine, very few roots; very few burrows; no reaction with dilute HCl and field estimated pH value of 6.

Profile ID	HE/HMY/KJ/P1	Land cover	Scattered tree species, woody shrubs, herbaceous
Date	17/12 (dd/mm)	Land use	Crop cultivation, animal husbandry
Year	2013	Crop	Cereals, vegetables, khat, some fruit trees
Surveyor	Kibebew Kibret	Human influence	Vegetation intensively disturbed, ploughing, irrigation
Status	Reference profile description	Surface stone cover	None
Location country	Ethiopia	Erosion category	Water, gully
Location region	East Hararghe	Erosion area	0-5%
Location woreda	Haramaya	Erosion degree	Slight
Location kebele	Kuro Jalala	Crack width	Fine (< 1 cm)
Longitude	42°00'25''	Crack depth	Medium (2-10 cm)
Latitude	09°27'48''	Crack distance	Closely spaced (0.2-0.5m)
Elevation	2046 m	Surface drainage	Rapid
Map ID		Soil drainage	Well
Map scale		Flooding frequency	None
Map unit ID		Depth to groundwater	Not observable
Topography	Moderately steep, 15-30%	Depth to bedrock	Not observable
Position on slope	Middle slope	Rootable depth	160 cm
Slope form	Straight	Rooted depth	160 cm
Slope gradient	16%	Depth of observation	160 cm
Geology	Igneous	Local soil type	Ashewa Dimtu
Parent material	Granitic basement	Field WRB soil type	Regosol
		WRB soil type	Cutanic Luvisol (Skeletal, Chromic)

#### Description of the soil horizons (morphology)

Horizon	Depth (cm)	Description
Ah	0-25	Dark reddish brown (2.5YR 3/3, moist) and brown (7.5YR 4/2, dry) colour; sandy clay; strong coarse granular to moderate medium sub-angular blocky structure; hard (dry), friable (moist), and sticky and plastic (wet) consistence; common fine pores; very few, faint clay coatings; common, fine quartz fragments; no mottles; common, fine roots; very few burrows; clear, smooth boundary; no reaction with dilute HCl; field estimated pH value of 6.
A	25-80	Dark reddish brown (2.5YR 3/4, moist) and brown (7.5YR 5/4) colour; sandy clay loam; moderate medium angular blocky structure; very hard (dry), friable (moist), sticky and plastic (wet) consistence; few, fine pores; few, faint clay coatings; many, fine quartz fragments; very few, very fine distinct black mottles; very fine, very few roots; very few burrows; clear, smooth boundary; no reaction with dilute HCl and field pH value of 6.5.
Bt	80-160	Red (2.5YR 4/6, moist) and brown (7.5YR 5/3, dry) colour; clay loam; moderate coarse angular blocky structure; extremely hard (dry), friable (moist), and sticky and plastic (wet) consistence; very few, fine pores; very few, faint clay coatings; abundant, fine quartz fragments; very few, very fine distinct black mottles; very fine, very few roots; very fine burrows; no reaction with dilute HCl and pH value of 6.

Profile ID	HE/HMY/IO/P1	Land cover	Scattered trees, shrubs, herbaceous plants
Date	19/12 (dd/mm)	Land use	Crop cultivation and animal husbandry
Year	2013	Crop	Cereals, vegetables, khat, some fruit trees
Surveyor	Kibebew Kibret	Human influence	Ploughing, flood/furrow irrigation
Status	Reference profile description	Surface stone cover	None
Location country	Ethiopia	Erosion category	None
Location region	East Hararghe	Sealing thickness	None
Location woreda	Haramaya	Crack width	Very wide (5-10 cm)
Location kebele	Ifa Oromia	Crack depth	Deep (10-20 cm)
Longitude	41°56'47"	Crack distance	Very closely spaced (< 0.20 m)
Latitude	09°26'13"	Surface drainage	Slow
Elevation	2034 m	Soil drainage	Poor
Map ID		Flooding frequency	Twice a year
Map scale		Flooding duration	1-2 months
Map unit ID		Depth to groundwater	100 cm
Topography	Nearly level, 0.5-1.0%	Depth to bedrock	Not observable
Major landform	Level land, plain	Rootable depth	110 cm
Position on slope	Bottom	Rooted depth	110 cm
Slope form	Straight	Depth of observation	110 cm
Slope gradient	1%	Local soil type	Biye Guracha
Geology	Sedimentary	Field WRB soil type	Calcic Vertisol
Parent material	Limestone basement	WRB soil type	Calcic Mollic Vertisol (Calcaric, Eutric, Pellic, Chromic)

#### Description of the soil horizons (morphology)

Horizon	Depth (cm)	Description
Apk1	0-35	Black (5YR 2.5/1, moist) and black (2.5Y 2.5/1, dry) colour; clay; strong medium sub-angular blocky to angular blocky structure; very hard (dry), very friable (moist), and very sticky and very plastic (wet) consistence; common, very fine to fine pores; few, faint clay coatings; very few, fine calcium carbonate fragments; very few, very fine, faint black mottles; few, fine roots; very few burrows; clear, smooth boundary; extremely strong effervescence with dilute HCl; field measured pH value of 8.
Ai1k	35-65	Reddish black (2.5YR 2.5/1, moist) and very dark gray (5Y 3/1, dry) colour; clay; strong coarse sub-angular blocky to angular blocky structure; extremely hard (dry), friable (moist), and very sticky and very plastic (wet) consistence; common, very fine to fine pores; very few, faint clay coatings; very few, fine calcium carbonate fragments; very few, very fine, faint black mottles; very few, very fine to fine roots; very few burrows; clear, smooth boundary; extremely strong effervescence with dilute HCl and field estimated pH value of 8; intersecting slickensides and shiny ped faces.
Ai2K	65-110	Dark reddish gray (2.5YR 4/1, moist) and very dark gray (5Y 3/1, dry) colour; clay; strong, very coarse angular blocky structure; extremely hard (dry), friable (moist), and very sticky and very plastic (wet) consistence; common, very fine to fine pores; very few, faint clay and calcium carbonate coatings; very few, fine calcium carbonate fragments; few, very fine, distinct mottles; very few, very fine to fine roots; very few burrows; extremely strong effervescence with dilute HCl; field estimated pH value of 8; intersecting slickensides and shiny ped faces.

Table 10. Selected soil physical and chemical properties of pedons opened on major agricultural land in CASCAPE intervention kebeles in Haramaya Woreda

Parameters	HE/HMY/FI/P1				HE/HMY/FI/P2			
	0-20	20-36	36-45	45-170	0-30	30-60	60-105	105-200
Depth (cm)	0-20	20-36	36-45	45-170	0-30	30-60	60-105	105-200
Horizon	Ap	A	Bt	BC	Ap	Bt	Btk1	BCK2
Sand (%)	37.25	41.27	43.56	56.83	45.37	34.14	33.03	56.35
Silt (%)	20.92	16.78	12.54	16.45	17.86	19.12	10.46	13.51
Clay (%)	41.83	41.95	43.9	26.73	36.77	46.74	56.51	30.14
Textural class	C	C	C	SCL	SCL	C	C	SCL
pH-H <sub>2</sub> O	6.03	6.59	6.49	6.88	7.25	7.48	8.00	7.88
pH-KCl	5.12	5.65	5.56	6.04	6.39	6.56	7.12	7.00
EC (μS/cm)	0.09	0.08	0.08	0.14	0.09	0.15	0.16	0.14
OC (%)	1.38	1.11	0.73	0.46	1.31	1.09	0.45	0.37
TN (%)	0.16	0.1	0.07	0.04	0.13	0.1	0.04	0.03
Av. P (ppm)	37.1				46.3			
Av. S (%)	1.32				1.19			
Na (meq/100g)	0.78	0.89	0.79	0.74	0.86	1.03	1.62	1.00
K (meq/100 g)	0.52	0.61	0.49	0.42	0.78	0.60	0.52	0.46
Ca (meq/100 g)	22.13	17.57	16.69	14.38	18.86	28.80	34.24	27.40
Mg (meq/100g)	7.52	5.86	5.42	4.93	6.29	9.74	11.69	8.30
CEC (meq/100 g)	36.31	33.20	38.09	33.49	36.45	46.50	55.38	42.87
SB (meq/100 g)	30.96	24.93	23.39	20.46	26.79	40.18	48.08	37.17
ESP (%)	2.15	2.68	2.07	2.21	2.35	2.22	2.92	2.34
Zn (mg/kg)	1.45				2.76			
Mn (mg/kg)	68.04				18.82			
Cu (mg/kg)	5.55				2.98			
Fe (mg/kg)	26.15				21.37			

Parameters	HE/HMY/FI/P3				HE/HMY/FI/P4				
	0-20	20-40	40-68	68-120	0-27	27-64	64-90	90-140	140-200
Depth (cm)	0-20	20-40	40-68	68-120	0-27	27-64	64-90	90-140	140-200
Horizon	Ap	A	Bt1	Btk	Ah	Ai1	Bik1	Bg1ik	Bg2ik
Sand (%)	71.70	61.37	48.55	24.90	28.01	26.93	26.29	27.32	22.20
Silt (%)	7.07	15.25	15.44	25.03	21.17	15.04	10.84	16.27	17.29
Clay (%)	21.22	23.38	36.02	50.07	50.81	58.03	62.87	56.41	60.51
Textural class	SCL	SCL	SC	C	C	C	C	C	C
pH-H <sub>2</sub> O	7.86	7.98	7.74	7.96	7.63	7.87	7.90	8.11	8.16
pH-KCl	7.06	7.23	6.89	7.08	6.78	6.96	7.03	7.44	7.28
EC (μS/cm)	0.10	0.11	0.13	0.17	0.10	0.11	0.17	0.24	0.26
OC (%)	1.09	0.98	0.85	0.83	1.32	1.26	0.89	0.35	0.17
TN (%)	0.10	0.09	0.07	0.07	0.16	0.15	0.08	0.03	0.02
Av. P (ppm)	25.90				21.5				
Av. S (%)	0.80				0.59				
Na (meq/100g)	0.69	0.68	0.95	1.22	0.93	1.03	1.40	1.60	1.74
K (meq/100 g)	0.20	0.24	0.40	0.65	0.62	0.62	0.66	0.61	0.63
Ca (meq/100 g)	16.58	19.91	20.97	36.23	28.70	30.36	34.46	33.63	36.95
Mg (meq/100g)	5.66	6.50	6.99	12.08	9.28	10.26	11.20	11.64	12.89
CEC (meq/100 g)	29.89	33.13	34.86	55.22	48.16	47.41	50.57	50.62	56.50
SB (meq/100 g)	23.12	27.34	29.30	50.18	39.53	42.27	47.72	47.49	52.20
ESP (%)	2.29	2.05	2.72	2.21	1.92	2.18	2.76	3.17	3.07
Zn (mg/kg)	0.80				1.45				
Mn (mg/kg)	2.37				12.55				
Cu (mg/kg)	0.54				2.55				
Fe (mg/kg)	3.04				19.08				

HMY = Haramaya Woreda; FI = Finkile Kebele; P = Pedon; SCL = sandy clay loam; C = clay; Av. = available; SB = sum of bases; OC = organic carbon; TN = total nitrogen; EC = electrical conductivity

Parameters	HE/HMY/DJ/P1			HE/HMY/DJ/P2			
	0-20	20-50	50-80	0-25	25-50	50-90	90-150
Depth (cm)	Ap	A	Bt	Ap	A1	A2	AC
Sand (%)	23.58	25.33	23.51	42.08	47.68	49.33	53.54
Silt (%)	20.74	24.54	17.00	16.09	17.00	17.94	13.42
Clay (%)	55.67	50.14	59.49	41.83	35.58	32.72	33.04
Textural class	C	C	C	C	SC	SCL	SCL
pH-H <sub>2</sub> O	7.83	8.02	8.10	7.83	8.00	7.84	7.58
pH-KCl	6.96	7.13	7.14	7.01	7.14	6.91	6.68
EC (μS/cm)	0.13	0.15	0.15	0.14	0.11	0.09	0.12
OC (%)	1.04	0.89	0.59	1.16	0.97	0.80	0.05
TN (%)	0.11	0.07	0.04	0.13	0.10	0.07	0.04
Av P (ppm)	30.8			52.4			
Av. S (%)	1.58			1.44			
Na (meq/100g)	1.04	1.04	1.23	0.92	1.31	1.14	0.79
K (meq/100 g)	1.22	0.92	0.82	0.78	0.55	0.74	0.34
Ca (meq/100 g)	34.69	26.79	36.01	19.65	21.00	18.11	14.43
Mg (meq/100 g)	11.71	9.35	12.28	5.98	8.00	6.74	5.00
CEC (meq/100 g)	54.67	46.22	55.25	36.22	35.00	34.34	27.34
SB (meq/100 g)	48.65	38.10	50.34	27.33	30.00	26.73	20.52
ESP (%)	1.90	2.26	2.23	2.54	3.74	3.31	2.89
Zn (mg/kg)	3.29			2.94			
Mn (mg/kg)	6.45			8.98			
Cu (mg/kg)	3.14			1.49			
Fe (mg/kg)	9.1			3.09			

Parameters	HE/HMY/DJ/P3	
	0-20	20-90
Depth (cm)	Apk1	Ak2
Sand (%)	46.16	43.12
Silt (%)	26.92	18.61
Clay (%)	26.92	38.26
Textural class	SCL	CL
pH-H <sub>2</sub> O	7.83	8.10
pH-KCl	7.04	7.61
EC (μS/cm)	0.14	0.14
OC (%)	0.90	0.043
TN (%)	0.10	0.04
Av P (ppm)	28.00	
Av. S (%)	1.91	
Na (meq/100g)	1.06	1.13
K (meq/100 g)	1.00	0.43
Ca (meq/100 g)	21.09	18.59
Mg (meq/100 g)	7.00	6.20
CEC (meq/100 g)	37.31	35.03
SB (meq/100 g)	29.72	26.35
ESP (%)	2.84	3.23
Zn (mg/kg)	1.06	
Mn (mg/kg)	5.63	
Cu (mg/kg)	1.64	
Fe (mg/kg)	6.21	

HE/HMY/DJ/P4		
0-16	16-30	30-50
A	At	C
55.00	50.58	51.00
12.00	13.39	17.00
33.00	36.04	32.24
SCL	SC	SCL
7.00	6.60	6.85
5.80	6.23	6.00
0.06	0.06	0.00
1.34	1.03	0.76
0.14	0.10	0.07
29.80		
0.67		
0.95	0.91	0.96
0.44	0.40	0.30
11.50	14.41	12.87
4.11	5.35	4.57
26.79	32.21	29.79
17.00	21.07	18.70
3.53	2.83	3.21
1.31		
12.27		
1.59		
14.87		

HMY = Haramaya Woreda; DJ = Damota Jalala Kebele; P = Pedon; SCL = sandy clay loam; CL = clay loam; SC = sandy clay; C = clay; SB = sum of bases; OC = organic carbon; TN = total nitrogen; EC = electrical conductivity; Av. = Available

Parameters	HE/HMY/KJ/P			HE/HMY/IO/P		
	0-25	25-80	80-160	0-35	35-65	65-110
Depth (cm)	0-25	25-80	80-160	0-35	35-65	65-110
Horizon	Ah	A	Bt	Apk1	Ai1k	Ai2k
Sand (%)	53.61	55.38	45.00	14.39	12.46	21.66
Silt (%)	9.28	16.60	16.00	18.90	21.05	20.67
Clay (%)	37.11	28.02	39.49	66.71	66.49	57.67
Textural class	SC	SCL	CL	C	C	C
pH-H <sub>2</sub> O	7.00	6.89	6.87	8.15	8.26	7.93
pH-KCl	6.15	5.97	6	7.19	7.41	7.52
EC (μS/cm)	0.12	0.08	0.00	0.21	0.39	0.41
OC (%)	1.48	0.80	0.33	1.40	0.95	0.52
TN (%)	0.16	0.07	0.03	0.17	0.11	0.05
Av P (ppm)	45.40			26.10		
Av. S (%)	0.27			1.14		
Na (meq/100 g)	0.89	1.07	1.19	2.13	3.25	0.68
K (meq/100 g)	1.16	0.58	0.71	0.86	0.69	0.64
Ca (meq/100 g)	15.66	14.50	17.44	36.99	36.01	32.43
Mg (meq/100 g)	4.94	4.56	6.23	12.33	12.29	10.81
CEC (meq/100 g)	35.83	33.33	37.46	57.92	55.38	50.29
SB (meq/100 g)	22.66	20.71	25.57	52.31	52.25	44.56
ESP (%)	2.50	3.23	3.18	3.67	5.86	1.35
Zn (mg/kg)	2.12			3.87		
Mn (mg/kg)	12.67			4.60		
Cu (mg/kg)	1.46			6.33		
Fe (mg/kg)	16.43			9.03		

HMY = Haramaya Woreda; KJ = Kuro Jalala Kebele; IO = Ifa Oromia Kebele; P = Pedon; SCL = sandy clay loam; C = clay; CL = clay loam; Av. = available; SB = sum of bases; OC = organic carbon; TN = total nitrogen; EC = electrical conductivity

### 3.4.3. Synthesis

The detailed soil site and profile description of the 10 pedons is presented in Table 9, while the analytical results are also shown in Table 10 in Section 3.4.2.1. Therefore, reference should be made to these Tables for the following discussions on agronomic interpretation of morphological, physical, and chemical properties of the soils. Critical values of parameters as suggested in Booker Tropical Soil Manual (Landon, 1991), Hazelton and Murphy (2007), Jones (2003), FAO (2007) and Allison (1973) were used for assessing the status of the soil parameters.

#### 3.4.3.1. Agronomic Interpretation of Soil Morphological Properties

##### 1. Color

The surface color (moist) of the soils varied from reddish black (2.5YR 2.5/1) in Calcic Mollic Gleyic Vertisols of Finkile to dark brown (10YR 3/3) in Vertic Luvisols of Damota Jalala, while the color (dry) of the surface horizons differed between dark reddish gray (2.5YR 3/1) in same Calcic Mollic Gleyic Vertisols of Finkile and black (2.5Y 2.5/1) in Calcic Mollic Vertisols of Ifa Oromia. In most profiles, the surface color was dominantly brown or reddish brown indicating the effect of organic matter application by the farmers. On the other hand, the subsurface color (moist) varied from reddish black (2.5YR 2.5/1) in Calcic Fluvisols of Finkile to dark yellowish brown (10YR 4/3) in the Vertic Luvisols of Damota Jalala, which turned into dark reddish brown (2.5YR 3/3) in the Haplic Cambisols of Damota Jalala to very dark gray (5Y 3/1) in Calcic Mollic Vertisols of Ifa Oromia when dry. The difference in color under dry and moist conditions indicate light reflectance differences. The wet soils are darker due to absorption of most of the incoming radiation, while the dry ones are lighter due to higher albedo.

The difference in soil color among the pedons may indicate, partly, the difference in parent material or soil development stage (Sharma, 2002), geologic origin and degree of weathering of the soil material, leaching or accumulation of chemical compounds such as iron (Fisher and Binkley, 2000), redoximorphic features and physiographic position (Nuga et al., 2006), and organic matter content difference (surface soils) and carbonate accumulation (Dengiz et al., 2012).

## 2. Soil Structure and Consistence

Concomitant with the relatively high clay content of most soils in the studied kebeles, the soils were well structured. Accordingly, the field recorded structure (type) of the soils, at the surface and in the subsurface layers, varied from single grained in the Calcic Fluvisols through granular and sub-angular and angular blocky to prismatic structure. The only structure type that was not observed was the platy structure. The size of most structure types varied from fine to very coarse, while the grade ranged from weak to strong. Furthermore, the sizes, for the same structure type, were bigger in the subsurface layers as compared to those observed in the subsurface layers indicating the existence at the soil surface of more destructive forces that break bigger aggregates into smaller structural units. Majority of the structure types break into smaller structural units of the same type or other types indicating that these big structural units are not massive blocks. In soils with strong vertic properties, wedge-shaped structures were commonly observed. Stumbling blocks to the ready transmission of water and air could be these wedge-shaped structures which are also characterized by shiny faces called slickensides.

The differences in soil structure within a pedon could be attributed to differences in organic matter and clay content (Mohammed et al., 2005;

Ashenafi et al., 2010; Tobiasova et al., 2013), root distribution, biological activities, type and amount of cations, such as Ca, Mg, Na, Fe, etc, and carbonate and other cementing agents. On other hand differences in soil structure among adjacent soils could be attributed to, in addition to the above-mentioned factors, changes in micro-climate, soil management, and physicochemical nature of the soils (Cameron et al., 1981; Rose et al., 1996).

Owing to the relatively high clay content in most of the soils, the consistence of the soils was largely hard to very hard (dry), friable to very friable (moist), and slightly sticky and plastic to very sticky and very plastic (wet). This indicates that, for most of the soils in the studied kebeles of the Woreda, choosing appropriate time for tillage operation is required in order to maintain good tilth during seedbed preparation. For soils that are high in their clay content and well structured/aggregated, this 'appropriate time' often corresponds to the time when the soil moisture content is at or near field capacity. This is also the time when manipulations, for instance plowing by a tractor, are expected to cause limited damage to the structure of the soil (Ashenafi et al., 2010).

Within a profile, changes in consistence were also observed. These changes clearly reflect the changes in clay content down the soil profile and, to some extent organic matter content. The differences in consistence among the pedons could also be due to difference in clay content and type (Foth, 1990; Moradi, 2013).

### 3. Soil Depth

The Vertic Luvisols and Haplic Regosols have their depths limited by solid rock, while most others have a depth that extends from 110 to 200+ cm. Generally, soils on the steeper slopes are on average shallower than those on the middle and lower slopes suggesting the dominance of erosion over accumulation on the steeper slopes (Bono and Seiler, 1984; Belay, 2000; Engdawork, 2002). Soil depth is an important soil attribute that determines the volume of space available for storing water and nutrients, and providing good foothold for plants through root ramification. Accordingly, if all other soil attributes are at their optimum, the deeper soils can store adequate water and nutrients, and provide good physical support for successful plant growth/crop production (Miller and Donahue, 1995; Buol et al., 1997).

### 4. Porosity, Root Distribution and Other Related Features

As discussed above, majority of the soils studied have high clay content and are well aggregated/structured. Because of this combined effects of texture and structure, tests made in the field during profile description indicate that the soils generally have high total porosity. This high total porosity is the result of textural and structural porosity. Nevertheless, a general decrease in porosity with soil depth was observed in all the pedons, which might be the result of increasing compaction, decreasing of rooting effect and organic matter content (Pravin et al., 2013). Since plant roots and microbes live in the soil pores, for adequate microbial growth and, proliferation and penetration of roots, soils should contain a proportion of pores which are large macropores having diameter of 0.25 mm or larger (Saha, 2004).

The root distribution in a profile, to a greater extent, depended on the types of crops grown and soil characteristics, such as structure and the resulting porosity. As a result, roots were found from as shallow as 20 cm to 200+ cm depth. Nevertheless, abundance and size of roots decreased with soil depth.

As a result, most of the roots were found distributed in the upper quarter of the soil depth.

Other features recorded from the pedons and also auger pits include cracks, horizon boundaries, coarse fragments, mottles, coatings, biological activities, effervescence, and field measured pH. The details are presented in Table 9.

#### 3.4.3.2. Agronomic Interpretation of Particle Size Distribution

The dominant fractions in the opened pedons are clay and sand. In soils of the surface horizons, the sand content ranges from 14.4% in the Calcic Mollic Vertisols of Ifa Oromia to 71.7% in Calcic Fluvisols of Finkile. In subsurface soils also, the lowest (12.5%) and highest (61.4%) sand content are recorded in these same soils. On the other hand, the clay content varies between 21.2% in the Calcic Fluvisols of Finkile and 66.7% in the Calcic Mollic Vertisols of Ifa Oromia. These same soils also have the lowest (23.3%) and highest (66.5%) clay content in soils of the subsurface horizons. Only in the Calcic Fluvisols of Finkile is consistent increase in clay content with soil depth observed. The textural classes vary from sandy clay loam in the Calcic Fluvisols of Damota and Finkile to clay in the surface and subsurface layers of all the other soil types.

From rough estimation suggested by Moore et al. (1998), based on contents of clay and sand, and grade of soil structure, the available water holding capacity of the soils in the four CASCAPE intervention kebeles can be in the range of 130-190, 130-150, 110-120, and ~210 mm of water per meter depth of soil for the sandy clay loam, sandy clay, clay, and self mulching clay soils, respectively, that have medium to strong structure. Nevertheless, these are only indicative estimates and, thus, should not be used as a guide for site-specific water management plan development.

### 3.4.3.3. Agronomic Interpretation of Soil Chemical Properties

#### 1. Soil Reaction and Electrical Conductivity

The pH-H<sub>2</sub>O of the surface horizon soils ranged from 6.0 in the Cutanic Luvisols of Kuro Jalala to 8.2 in the Haplic Regosols of Damota Jalala. Following Karlton et al. (2013) rating, the pH of the Cutanic Luvisols falls in the range of moderately acidic, while that of the Haplic Regosols falls within the range of moderately alkaline. Furthermore, the lowest (5.1) and highest (7.2) pH-KCl was recorded in these same soils. In the subsurface soils, the pH-H<sub>2</sub>O varied from 6.5 in Haplic Cambisols of Finkile to 8.3 in the Calcic Mollic Vertisols of Ifa Oromia. In all the cases, pH-H<sub>2</sub>O was higher than pH-KCl indicating the existence of net negative charges on the exchange complexes of the soils and also presence of substantial quantity of exchangeable hydrogen ion (Mulugeta and Sheleme, 2011).

The differences observed could be reflections of differences in management, parent material and its state of weathering, and most importantly local landform that may cause differences in leaching intensities and level of erosion (Tamirat, 1992).

The pH-H<sub>2</sub>O recorded in the soils is within the range of soil pH that does not affect the availability of majority of essential plant nutrients, activity of beneficial microorganisms and, growth and development of most crops. However, potential problems can be expected in those soils with moderately acidic and moderately alkaline soils.

From the low electrical conductivity values recorded in almost all the pedons, it can be seen that the soils of the four kebeles are non-saline. Only those soils that are in the low lying areas, such as those around the periphery of Lakes Tinike and Adele, and in the valleys, that are likely to be affected by salinity.

## 2. Soil Organic Carbon, Total Nitrogen and C:N Ratio

Although the organic carbon content of all the pedons was within the range of very low as per Landon (1991) rating, it ranged from 0.9% in the surface horizons of the Vertic Luvisols of Damota Jalala to 1.5% in surface horizon soils of the Calcic Fluvisols of the same Kebele. In the subsurface horizon soils, it varied from 0.05% in the Haplic Cambisols of Damota Jalala to 1.26% in the Calcic Mollic Gleyic Vertisols of Finkile. In all the soil types, it decreased consistently with soil depth. The current results indicate that devising a better organic matter maintenance scenario is a necessity.

The total nitrogen content of the soils was also in the range of low following the rating suggested by Landon (1991) and it decreased consistently with soil depth. The results obtained in this study indicate that nitrogen deficiency is among the major nutrient-related problems for increased production and productivity in the studied kebeles. On the other hand, the fact that the total nitrogen is low implies that fertilizer additions have not replaced the total N lost due to harvest removal, leaching, and humus losses associated with cultivation (Malo et al., 2005).

The carbon to nitrogen ration (C:N) of the soils varied from 8:1 to 15:1, which indicates that organic matter decomposition is taking place in the soils at maximum possible rate under local environmental conditions (Allison, 1973). Furthermore, the recorded values are within the range for arable soils (Brady and Weill, 2008). On the other hand, Hadas et al. (2004) indicated that C: N values close or below 10 show soil organic matter degradation, which is the case in the surface horizon soils of almost all the pedons.

### 3. Available Phosphorus and Sulfur

These were nutrients analyzed on only surface horizons. The Olsen available phosphorus varied between 21.5 mg kg<sup>-1</sup> in the Calcic Mollic Gleyic Vertisols of Finkile and 52.4 mg kg<sup>-1</sup> in the Haplic Cambisols of Damota Jalala.

According to Olsen's P rating suggested by Landon (1991), the available P content of the major agricultural soils in the four kebeles falls in the range of high (>15 mgkg<sup>-1</sup>). The available P is even present in adequate amount for high P demanding crops, such as sugarbeet, potatoes and onions (Landon, 1991). This could be due to the carryover effect of the applied inorganic P fertilizer such as DAP, presence of limited P-fixation, the regular application of compost, and limited losses by erosion from agricultural fields (Awdenegest et al., 2013; Girma and Endalkachew, 2013).

The available sulfur ranged between 0.3% in Cutanic Luvisols of Kuro Jalala and 1.9% in Calcic Fluvisols of Damota Jalala kebele. As per rating suggested by Karlton et al. (2013), the available sulfur content of the surface horizons of the kebeles falls in the range of very high indicating that sulfur is not deficient in soils of the study kebeles.

### 4. Exchangeable Bases (Ca, Mg, K, and Na)

As per FAO (2006) rating of exchangeable bases, the exchangeable Ca of the soils in the four kebeles was within the range of high to very high. Similarly, the exchangeable Mg across all depths of the major soil types represented by the pedons was in the range of high (FAO, 2006). This indicates that major agricultural soils of the four kebeles do not have problems of Ca and Mg deficiency. The Ca:Mg ratio, which was 3:1, is also in the range that is favorable for most crops (Landon, 1991).

Exchangeable K ranged from 0.2 meq/100 g in Calcic Fluvisols of Finkile to 1.2 meq/100 g soil in Haplic Cambisols of Damota Jalala Kebele. As per

exchangeable bases ratings suggested by FAO (2006), the exchangeable K content of the soils falls in the range of low in the Calcic Fluvisols of Finkile, medium in Haplic Cambisols of Finkile and Haplic Regosols of Damota Jalala and high in the remaining soil types identified. In the soils with low and medium exchangeable K, immediate application of K-containing fertilizers is required.

The exchangeable Na in all the soils was not in the level that may cause problems to soils and plants. Nevertheless, as per FAO (2006) rating, it was very high in the surface soils of the Calcic Mollic Vertisols of Ifa Oromia and high in all the other soil types. Furthermore, the Calcic Fluvisols of Damota Jalala and Calcic Mollic Vertisols of Ifa Oromia can be regarded as potentially sodic (Landon, 1991).

#### 5. Cation Exchange Capacity and Base Saturation

As per CEC rating suggested by Landon (1991), the CEC of the major soils varied from high to very high. This means that the soils have high buffering capacity and ability to retain cations against leaching losses. This could be one reason for the high to very high level of exchangeable cations recorded in the soils. The CEC clay of the soils ranged from 79 to 142 meq/100 g clay, which supports the idea that the soils are dominated by 2:1 high activity clays, such as montmorillonite and smectite.

As per Metson (1961) suggested ratings of base saturation, the soils in all depths and pedons are high (60-80%) to very high (>80%) in their base saturation, while the surface horizons are all very high in their base saturation. Furthermore, the base saturation values indicate that the soils are very weakly to weakly leached (Metson, 1961).

## 6. Extractable Micronutrients (Zn, Mn, Cu, Fe)

Based on Zn ratings suggested by Karlton et al. (2013), the extractable Zn ranged from very low in Calcic Fluvisols of Finkile and low in Haplic Cambisols of Finkile to optimum in all the other soil. Therefore, the Calcic Fluvisols and Haplic Cambisols in Finkile require application of fertilizers that contain Zn.

Extractable Mn varied from  $2.37 \text{ mg kg}^{-1}$  in Calcic Fluvisols of Finkile to the Haplic Cambisols of Finkile. Based on extractable Mn ratings suggested by Jones (2003), the extractable Mn was medium in all the soil types except in the Haplic Cambisols of Finkile which was in the range of very high. This suggests that there is a need to apply Mn containing fertilizer to all major agricultural soils in the kebeles except the Haplic Cambisols of Finkile Kebele.

The extractable Cu content of the surface horizons of the soils ranged from  $0.54 \text{ mg kg}^{-1}$  in the Calcic Fluvisols of Finkile to  $6.33 \text{ mg kg}^{-1}$  in the Calcic Mollic Vertisols of Ifa Oromia Kebele. Following extractable Cu rating suggested by Karlton et al. (2013), it was low in the Calcic Fluvisols of Finkile and optimum in all the other soil types. Therefore, the Calcic Fluvisols of Finkile Kebele require application of Cu-containing fertilizers in order to boost yield.

Extractable Fe ranged from  $3.04 \text{ mg kg}^{-1}$  in Calcic Fluvisols of Finkile to a  $26.15 \text{ mg kg}^{-1}$  in Haplic Cambisols of Finkile. Based on ratings suggested by Jones (2003), the extractable Fe content of the soils can be rated as medium in the Calcic Fluvisols of Finkile and Haplic Cambisols of Damota Jalala to high in all the other soil types, which indicates that the Calcic Fluvisols of Finkile and Haplic Cambisols of Damota Jalala require application of Fe containing fertilizer for better crop yield.

The differences in the levels of the extractable micronutrients in major agricultural soils of the kebeles could be attributed to differences in parent material (Krauskorf, 1972), differences in soil pH (Barghouthi et al., 2012), organic matter and clay content.

#### 3.4.3.4. Agronomic Interpretation of Major Soil Types

The major agricultural soils in the four kebeles are those occurring on the middle to lower slope positions. These are the Cambisols, Nitisols, Luvisols, Vertisols, and to some extent Fluvisols. The Leptosols and Regosols are marginally used for agricultural production and significant area of land under these soil types is being put under rehabilitation. Yet, these soils, Leptosols and Regosols, are being used for production of crops, such as maize, sorghum, and non-food crop-khat.

The Leptosols and Regosols have depth limitations for successful production of crops, particularly the deep rooted ones. Furthermore, as observed from the pedons opened, the Vertic Luvisols and Haplic Regosols in Damota Jalala have their depths limited by solid rock. This may limit the rooting depth for deep rooted crops. As discussed in Section 3.4.3, almost all the soil types are well structured although the dominant structure types are the sub-angular and angular blocky ones. Furthermore, Calcic Mollic Gleyic Vertisols and Calcic Mollic Vertisols have the wedge-shaped structure containing slickensides. This may result in impeded drainage. Because of the high clay content recorded in all the soil types, the soils are characterized by extremely hard to hard (dry) and very sticky and very plastic (wet) consistence. It is therefore necessary to choose the right consistence (near friable range) for tillage operations in order to produce good soil tilth. The high clay content of the major soil types may also imply that these soils have good available water holding capacity and, thus, can support successful rainfed crop production.

All the soils do not have serious problem related to pH. The pH range recorded in all the soils is in the favourable range for availability of essential nutrient elements, activity of beneficial microorganisms and growth of most crops. Nevertheless, the moderately acidic pH of the Cutanic Luvisols and the moderately alkaline reactions in the Haplic Regosols and others may require careful inspection and protection from activities that aggravate soil acidity and alkalinity.

The major problem that all the major soil types have is related to low level of organic matter. In all the soil types, the organic carbon content was within the range of very low. As already indicated, the farmers are applying organic matter to their soil every cropping season. Nevertheless, the amount they apply is inadequate to raise and maintain the organic carbon level of the soils to optimum level. Furthermore, the crop residues are completely removed from farms and used for other purposes. Therefore, there is a need to devise a scenario for improving the organic carbon level of these soils for improving their health and crop yield. Following the organic carbon level, total nitrogen level was also in the range of low. Nevertheless, the soils have high level of available P and S.

Furthermore, all the soils have high level of exchangeable Ca and Mg. The exchangeable K was also high in most of the soil types except in the Calcic Fluvisols of Finkile (low) and, in the Haplic Cambisols of Finkile and Haplic Regosols of Damota Jalala which was medium. In these soils immediate application of K-containing fertilizers may be required in order to boost crop productivity. The level of exchangeable Na was also in the range that does pose problems to soil physical conditions and plant growth. All the soils have high CEC and base saturation.

The major agricultural soils have some problems related to micronutrients (Zn, Mn, Cu, and Fe). The Calcic Fluvisols and Haplic Cambisols in Finkile are

deficient in Zn and, thus, require application of fertilizers that contain Zn. Except in the Haplic Cambisols of Finkile, all the other soil types are deficient in Mn and require application of Mn containing fertilizers. Similarly, the Calcic Fluvisols of Finkile are deficient in Cu and, thus, require application of Cu-containing fertilizers. The Calcic Fluvisols of Finkile and Haplic Cambisols of Damota Jalala are deficient in their Fe content and, therefore, require immediate application of Fe containing fertilizers.

In conclusion, the soils require management interventions that improve their organic matter level and, application of organic and inorganic fertilizers containing the deficient nutrient elements in the respective soils. The country is now moving towards using blended fertilizer. Therefore, a fertilizer blends that contain N, K, Zn, Mn, Cu, and Fe should be one of the fertilizer types that should be made available to the farmers in the four CASCAPE intervention kebeles and other kebeles with similar soil types. Nevertheless, further study has to be conducted in order to determine the exact amount of each of the deficient nutrient elements to be applied.

### 3.5. Soils of CASCAPE Intervention Kebeles in Kombocha Woreda

#### 3.5.1. The Soil-Landscape in Kombolcha Woreda

##### 3.5.1. 1. Geology

Kombolcha Woreda borders Haramaya Woreda in the eastern direction. These two Woredas, therefore, have some similarities in their geology and landform. In most areas of this Woreda also, the geology is very much affected by processes that took place during the pre-historic Gondwana continent (Mohr, 1964; Tamir, 1974). The original rocks were the Pre-Cambrian granite and gneiss, which were later covered with limestones and sandstones during the Triassic, Jurassic and Cretaceous periods when the sea again covered the eastern part of the country.

In support of this, the recent geological map of the country, edited in 1996 at a scale of 1:2,000,000, also indicates that the geology of the Woreda is characterized by the Hamanlei formation that is dominantly Oxfordian limestones and sandstones, and the Adigrat formation that contains the Triassic and Middle-Jurassic sandstones. Nevertheless, as was also explained for Haramaya Woreda, the most recently formed rocks have been eroded and the original granite and gneiss are exposed once more in many areas of the four CASCAPE intervention kebeles. During the field work also, exposed and weathering boulders of granite nature were observed on steep slopes of Bilisuma and Were Mahamed kebeles (Plate 3A, B and C), while exposed and weathering large boulders of limestone (Plate 3D) and sandstones were seen in Kakali and Egu kebeles. Plate 3 shows some of the rocks identified in Bilisuma, Egu, Were Mahamed and Kakali kebeles.

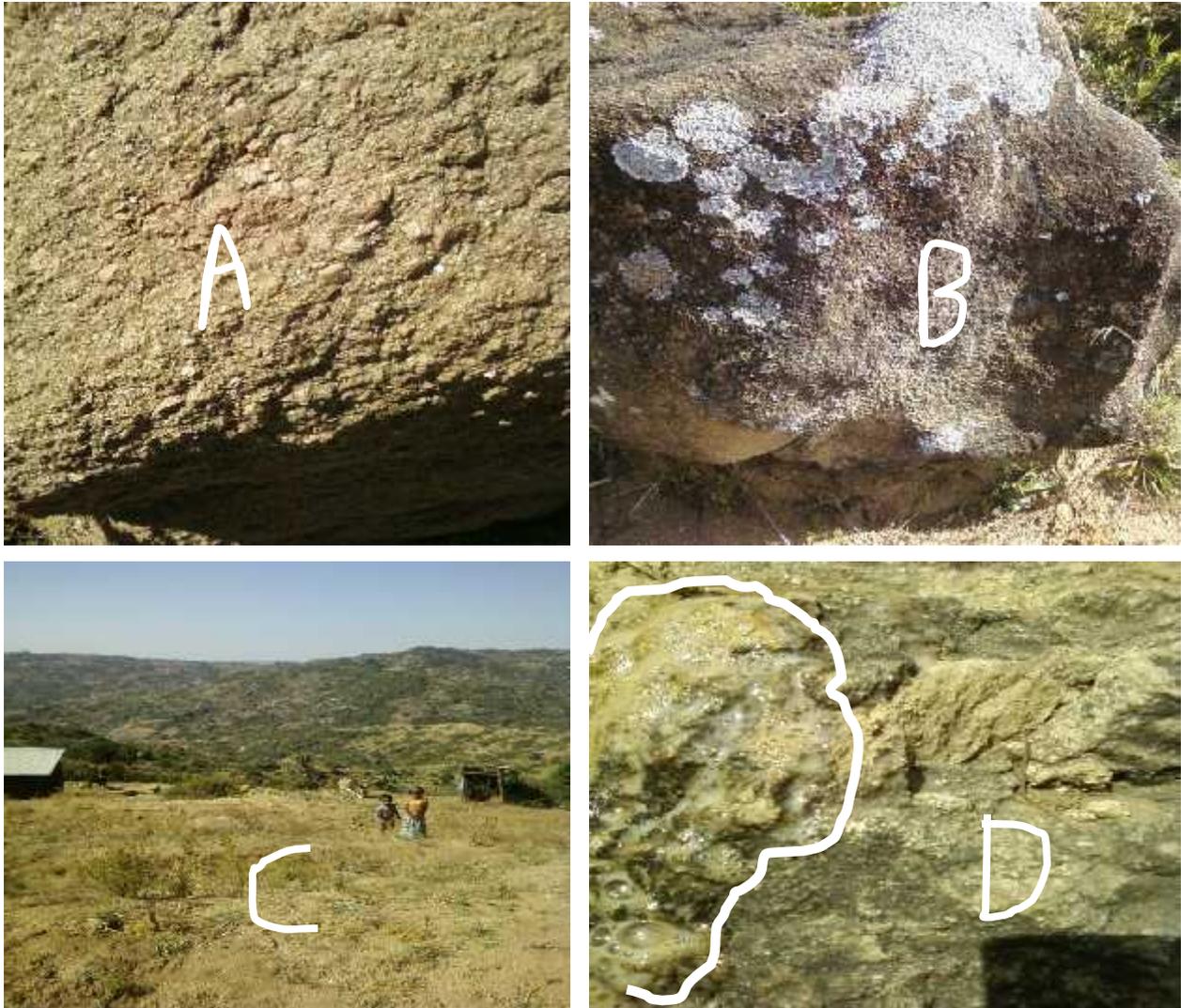


Plate 3. The different types of rocks observed in the four kebeles: (A) rotten granite, (B) weathering granite, (C) exposed boulders of granite on slopes, and (D) exposed and weathering limestone forming strong effervescence with 10% HCl.

### 3.5.1.2. The Landscape

The landscape of the Woreda, as inferred from observations made in the four CASCAPE intervention kebeles, is a very complex terrain that includes gently sloping dissected plains and plateaus to moderately steep and undulating medium to high gradient hills. In proportion of area occupied, the medium gradient to steep hills exceeds the plains and plateaus. Around river courses, limited valley floors are also present (Plate 4). Nevertheless, on a coarser

scale the whole Woreda forms a plateau. The commonly observed slope forms in the four kebeles vary from straight to concave straight. Figure 11 shows the contour and elevation maps, together with the locations of the auger observation points, of the four CASCAPE intervention kebeles in Kombolcha Woreda.

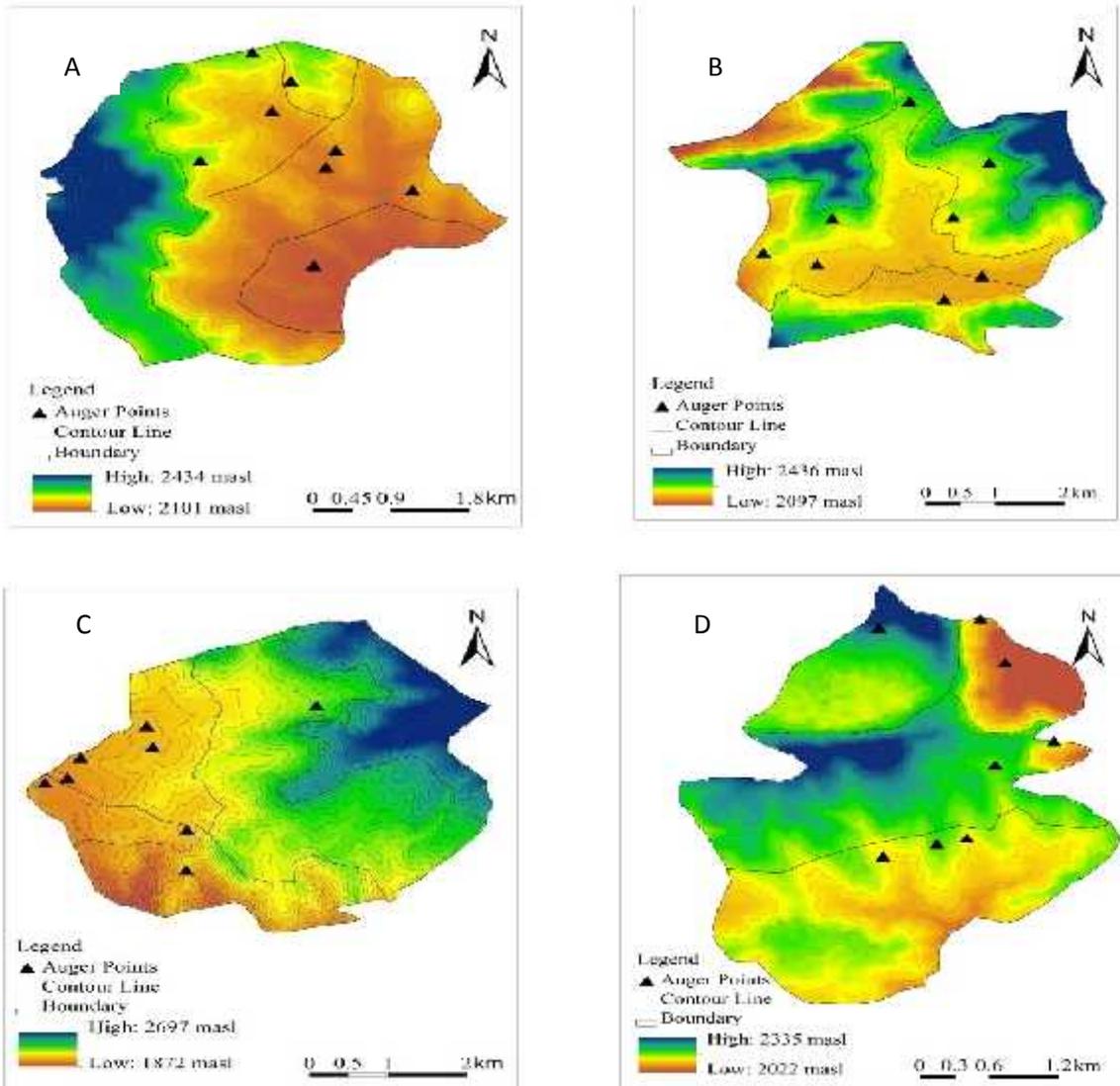


Figure 11. Contour and elevation maps of and locations of auger points in the four CASCAPE intervention kebeles in Kombolcha Woreda: (A) Bilisuma, (B) Egu, (C) Were Mahamed, and (D) Kakali.

### 3.5.1.3. Land Use

Owing to the generally high population pressure in the CASCAPE intervention kebeles and the consequent land scarcity, almost all slopes are put under cultivation/agricultural activities except the very steep hills. The steep hills are being put under rehabilitation following the natural resources management policy the country has adopted since recently. A combination of physical structures, such as stone/soil bunds and terraces, and biological measures, such as planting trees, are being practiced. As a result of these interventions and their protection from cultivation, the vegetation shows some signs of regeneration. At some places, however, the sides of the steep slopes themselves are covered by khat often intercropped with the likes of sorghum, maize, sweet potato and other crops. Also, the steep slopes are used as settlement areas.

The commonly observed vegetation cover is shrub and bushes composed of different species. Some of the steep slopes are covered by replanted and remnants of tree species, such as *Juniperus procera*, *Olea europaea*, *Podocarpus nubigenus* and *Acacia abyssinica*. Around homesteads, eucalyptus trees, such as *Eucalyptus globules* and *Eucalyptus camaldulensis* are found. Some agro-forestry tree species, such as *Acacia abyssinica*, and *Croton macrostachyus* are found on individual farmers' fields.

The middle slopes are mainly covered by field crops. The major field crops grown are sorghum and maize with wheat and fenugreek produced in some areas. These crops are grown under rainfed condition. Khat is also grown in most parts of the middle slopes under both rainfed and irrigated conditions. The lower slopes and valleys are also used for production of food crops during the rainy season, and vegetables, in addition to Khat, during the off-season by irrigation. Most parts of the CASCAPE intervention kebeles, particularly the valleys, have good surface and groundwater resources. As a

result, irrigation is practiced intensively around the valleys, while some irrigation is also practiced on the sloping lands by pumping water using motors. The main vegetable crops grown mainly as cash crops are potato, cabbage, carrot, onion, beet root, pepper, tomato, lettuce, shallot, and spinach.

Some of the flat lands, such as that in Egu Kebele, and the valleys are very much affected by waterlogging during the main rainy season and frost almost every year during the coldest months (October to January). Due to these factors, the yield obtained from these areas from the rainfed agriculture is often very low and is not enough to feed households. Particularly, those plains that are occupied by Vertisols may require some surface drainage.

The use of fertilizers is based on blanket recommendation of 100 kg ha<sup>-1</sup> each of urea and DAP regardless of soil and crop type. In addition to this, as a regular soil fertility maintenance program, every farmer is advised and monitored by development agents to apply organic matter to his soil either fresh or in the form of compost. However, due to limited inputs of organic materials for preparation of the compost, the impact of the applied compost on soil fertility and health is likely to be of insignificant nature. Similar to the practice in the entire Hararghe region, crop residues are used as animal feed, fuel, and construction material. Furthermore, the residues remaining in the field after harvesting the crops are burnt in fear of diseases and pests in the following cropping season. The combined effect of all these practices is low organic matter input into the soils. The farmers were also heard complaining about scarcity of improved seeds of the crops they are growing.

There is, therefore, a dire need for developing and implementing an integrated soil fertility management program in order to improve crop

production and productivity, and ensure food security of the farming community.

Plate 4 indicates the different land user types practiced on the different slope positions of the four kebeles.



Plate 4. The different types of land uses on different slope positions: (A) tops and sides of slopes covered mainly by khat, (B) lower slopes and valleys covered by khat and vegetables, and (C) and (D) middle slopes covered mainly by sorghum and maize, and also khat.

Although the farming system is mixed crop production and livestock husbandry, the livestock component is not that strong due to scarcity of animal feed in most of the Kebeles. Grazing land is very much scarce and is limited to small valley areas not used for agriculture, and on steep slopes. The farmers are using the cut and carry system. What they are cutting, most

of the time, is either tillers of sorghum and maize crops, crop residues, weeds or, under limited circumstances, grasses grown around border areas, and since very recently from protected areas.

#### 3.5.1.4. Soil-Landscape (Exploratory Survey Results)

The major soil mapping units identified through the exploratory survey and their area coverage in each kebele is indicated in Table 11 below. The mapping units are affected by landform and parent material (See Section 3.5.1.5 for details). Plate 5 shows the different soil types identified on different slope positions in the four CASCAPE intervention kebeles. The exploratory soil map of the four kebeles is illustrated in Figure 12.

Table 11. Major soil mapping units (exploratory) and their area coverage in the four CASCAPE intervention kebeles

Kebele	Soil type	Soil code	Area (ha)	%
Bilisuma	Lithic Leptosols	LP-li	480	27
	Regosols	RG	80	4
	Vertic Luvisols	LV-vr	291	16
	Calcic Vertisols	VR-cc	243	13
	Grumic Vertisols (Chromic)	VR-gm-cr	669	40
Egu	Lithic Leptosols	LP-li	675	32
	Haplic Regosols	RG-ha	388	18
	Vertic Luvisols (Chromic, Rhodic)	LV-vr-cr,ro	351	17
	Calcic Gleyic Vertisols (Chromic, Rhodic)	VR-cc-cr.ro	696	33
Were Mahamed	Lithic Leptosols	LP-li	816	37
	Calcic Vertic Luvisols	LV-vr.cc	923	41
	Gleyic Vertisols (Rhodic)	VR-gl.ro	364	16
	Calcic Fluvisols	FL-cc	135	6
Kakali	Regosols	RG	182	16
	Luvic Nitisols	NT-lv	444	39
	Vertic Luvisols (Rhodic)	LV-vr.ro	399	35
	Calcic Vertic Luvisols	LV-vr.cc	107	10



Plate 5. The different soil types occurring on different slope positions in the four CASCAPE intervention kebeles in Kombolcha Woreda: (A) Leptosols on granitic rock; (B) Fluvisols in the valley; (C) Cambisols on weathering sandstone; (D) Leptosols/Regosol on weathering granitic parent material; (E) Cambisols/Regosol on granitic parent material.

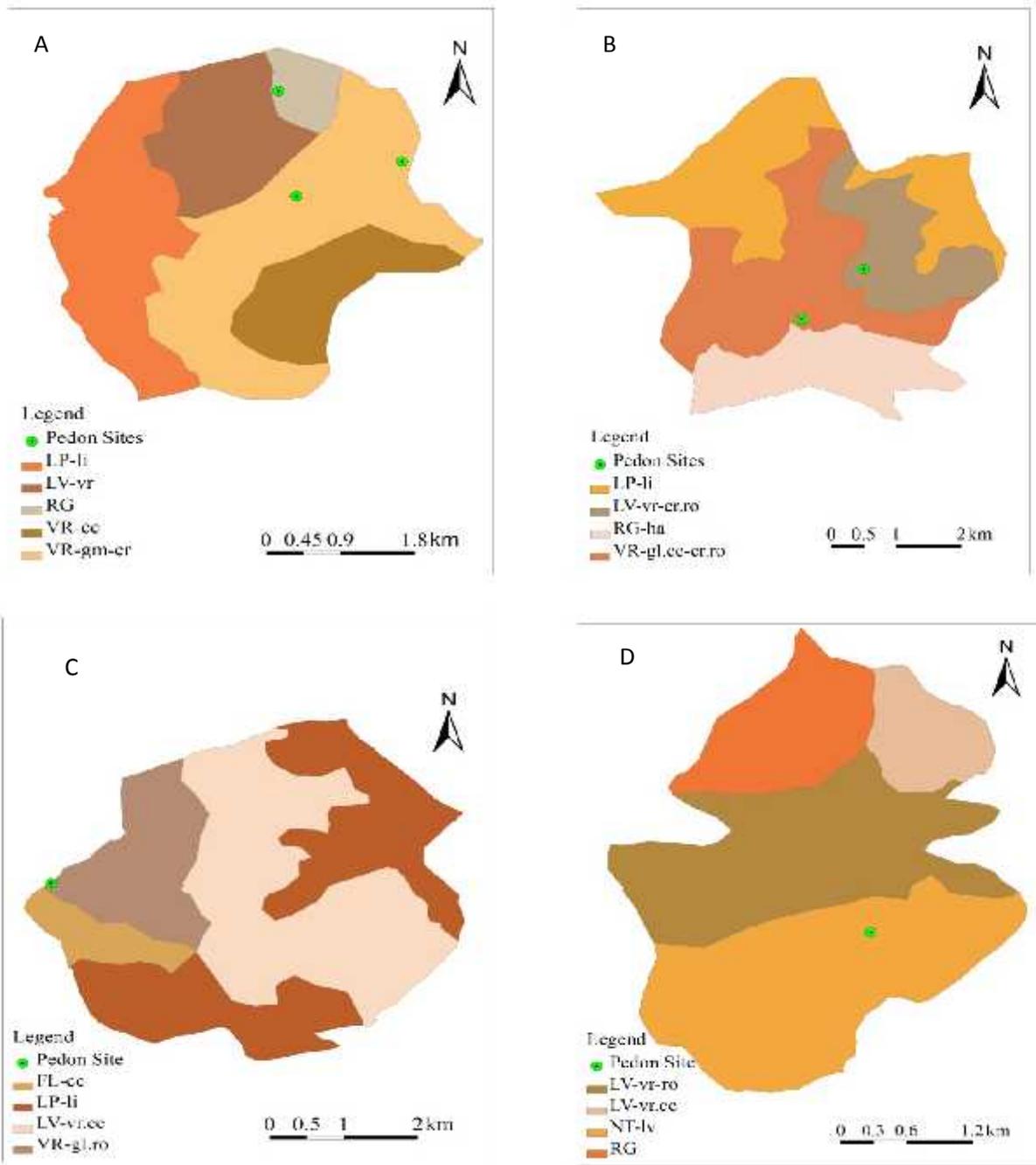


Figure 12. Exploratory soil maps of the four CASCAPE intervention kebeles in Kombolcha Woreda: (A) Bilisuma, (B) Egu, (C) Were Mahamed, and (D) Kakali.

#### 3.5.1.5. The Soil-Landscape (Final)

The major soil mapping units and the major landforms on which they are occurring, and their area coverage in the respective kebeles is indicated in Table 12. At RSG level, the major soil mapping units are Leptosols, Regosols, Cambisols, Nitisols, Luvisols, Vertisols, and Fluvisols.

The Leptosols occur on the steepest parts of the sloping landforms (hills) in each kebele and are formed from mainly granite and limestone parent materials. At some localized areas, they are also formed from sandstone parent material. Those formed on granite and sandstone are coarser in texture than those formed on limestone parent material. The Regosols also occur in association with the Leptosols on the upper slopes of the sloping landforms and are formed from granite and sandstone parent materials.

The Cambisols, on the other hand, occupy the upper parts of the middle slopes of sloping landform and are formed from sandstone parent material. The Nitisols occur over a wide range of landform which ranges from level landform to middle slope of sloping landform. They are formed on granite and sandstone parent material. The Nitisols also occur as associations with Luvisols and Vertisols.

The Haplic Luvisols in Bilisuma occur on the middle slope of the sloping landform and are formed from granite parent material, while those in Kakali occupy the lower slopes of the sloping landform and are formed on sandstone parent material. The Luvisols also occur as associations with Cambisols, Nitisols and Vertisols.

The Grumic Vertisols in Bilisuma dominate the toeslopes of the sloping landform and are formed mainly on granite parent material, whereas those in Egu occur on the extensive level landform and are formed from limestone parent material. The Calcic Vertisols, on the other hand, occupy the level landforms and are formed on mixed limestone and basaltic parent materials.

The Calcic Fluvisols occur in the valleys around waterways and are formed from alluvial material deposited during different time periods. The indicative sketch of the soil-landscape representing the four kebeles is indicated in Figure 13. Plate 6 shows the some of the pedons opened on representative major agricultural soils. The geographic distribution of the mapping units in each kebele is depicted in Figure 14.

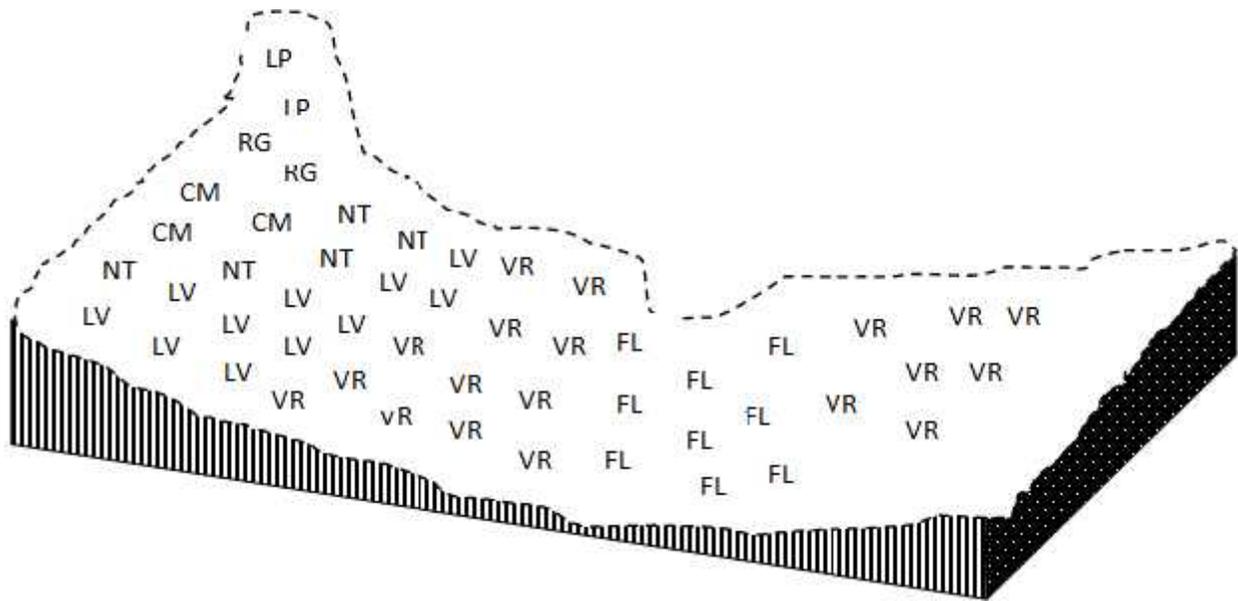


Figure 13. Indicative sketch of soil-landscape in the four kebeles.

Table 12. Major soil mapping units and their area coverage in the four CASCAPE intervention kebeles in Kombolcha Woreda

Kebele	Major landform	Soil type	Soil code	Area (ha)	%	Elevation (masl)
Bilisuma	Steep slope	Leptosols	LP	463	26	2240-2420
	Sloping land	Haplic Luvisol (Hypereutric, Skeletic)	LV-ha-je.sk	437	25	2160-2240
	Level land (valley)	Calcic Vertisols	VR-cc	189	11	2120
	Sloping land	Grumic Vertisol (Eutric, Rhodic)	VR-gm-eu.ro	210	12	2120-2200
	Level land (valley)	Grumic Vertisol (Eutric, Chromic)	VR-gm-eu.cr	462	26	2120-2240
Egu	Sloping land	Haplic Cambisols (Eutric, Chromic)	CM-ht-eu.cr	199	10	2200-2260
	Steep land	Lithic Leptosol	LP-li	627	30	2100-2420
	Sloping land	Vertic Luvisols	LV.vr	357	17	2200-2340
	Sloping land	Haplic Regosols	RG-ha	388	18	2180-2320
	Sloping land	Calcic Gleyic Vertisols	VR-gl.cc	258	12	2160-2260
	Level land	Grumic Vertisol (Eutric)	VR-gm.eu	280	13	2180-2200
Were Mahamed	Steep land	Leptosols	LP	963	43	2380-2680; 1880-2200
	Sloping land	Calcic Vertic Luvisols	LV-vr.cc	669	30	2140-2300
	Level land	Calcic Vertisols (Eutric, Chromic)	VR-cc-eu.cr	479	21	2140-2200
	Level land (valley)	Calcic Fluvisols		126	6	1980-2060
Kakali	Sloping land	Regosols	RG	183	16	2180-2320
	Sloping land	Luvic Nitisols	NT-iv	73	7	2160-2180
	Sloping land	Haplic Luvisols (Hypereutric, Skeletic, Clayic, Chromic)	LV-ha-je-sk.ce.cr	411	36	2120-2200
	Sloping land	Calcic Vertic Luvisols	LV-vr.cc	466	41	2040-2300

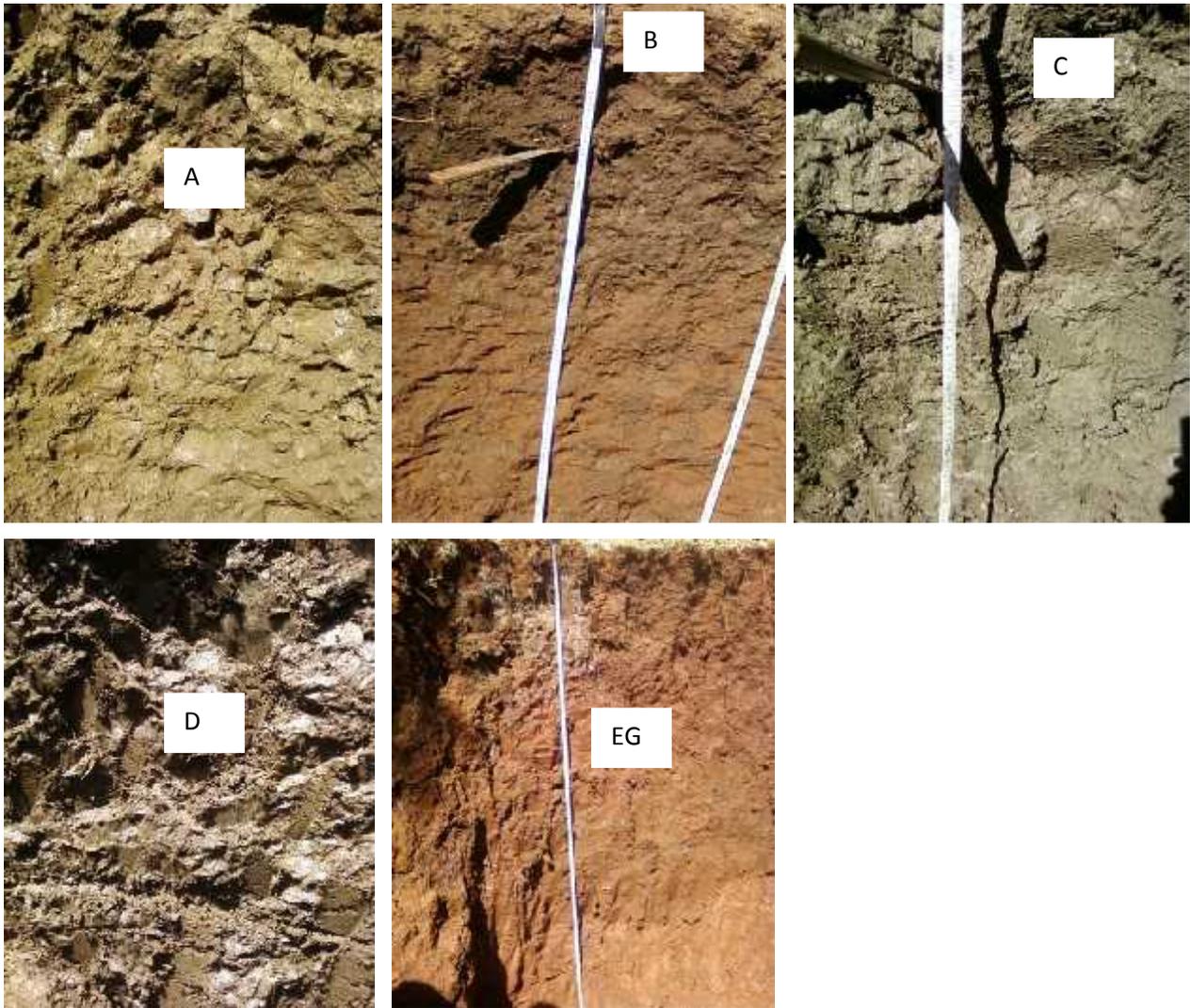


Plate 6. Overview of some of the pedons opened in the four CASCAPE intervention kebeles in Kombolcha Woreda. (A) Grumic Vertisol (Eutric, Rhodic), (B) Haplic Cambisols (Eutric, Chromic), (C) Grumic Vertisols (Eutric), (D) Calcic Vertisols (Eutric, Chromic), and (E) Haplic Luvisols (Hypereutric, Skeletic, Clayic, Chromic)

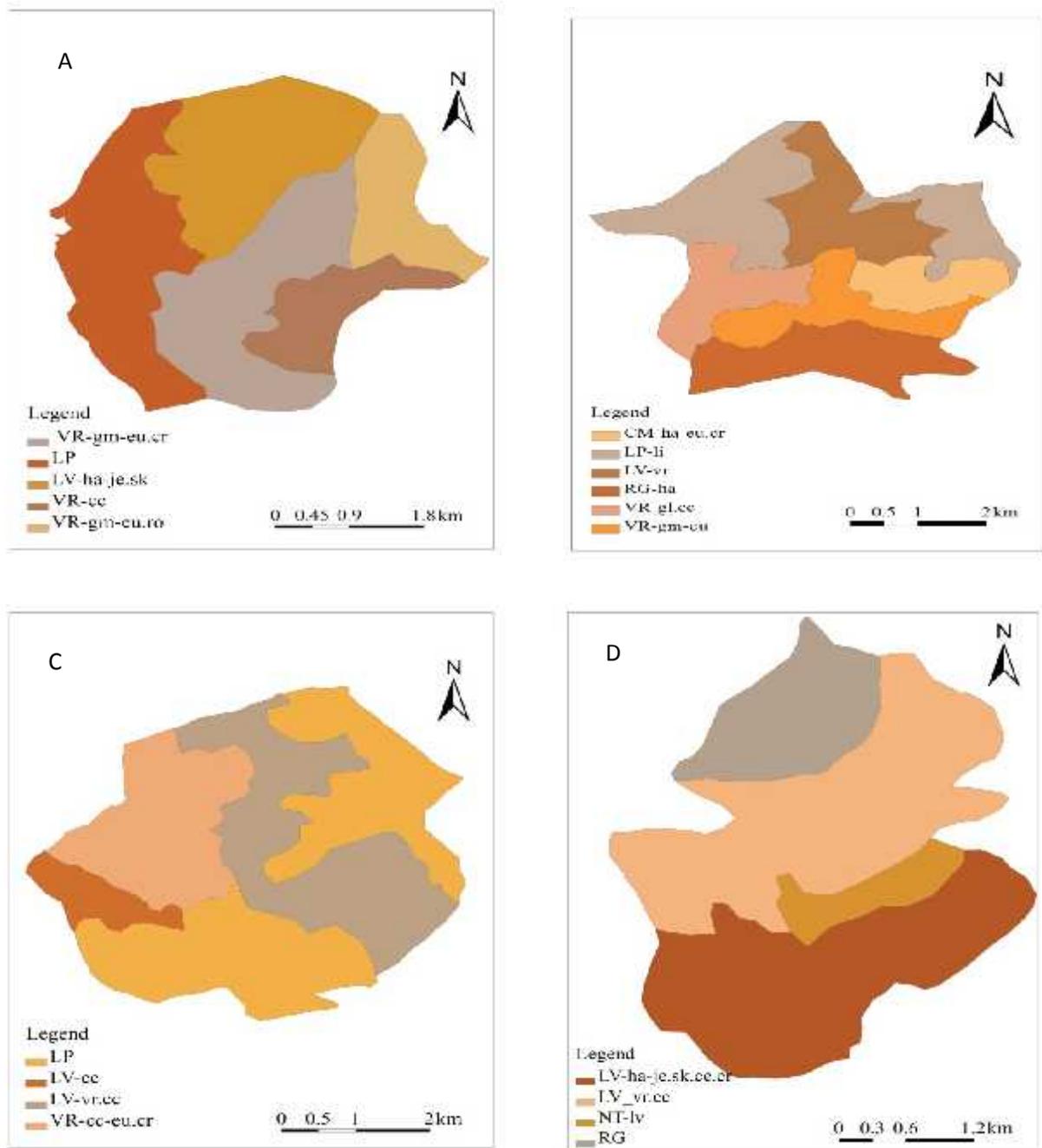


Figure 14. Soil maps of main soil types of the four CASCAPE intervention kebeles in Kombolcha Woreda: (A) Bilisuma, (B) Egu, (C) Were Mahamed, and (D) Kakali.

Names of soils based on local classifications were also correlated with the scientific names of the WRB classification system. The classification is done based on soil color and texture. The farmers actually have deep knowledge of their soils with regard to their productivity/fertility. However, this classification, as long as the soils have the same color and also productivity, puts different soils into one category. Also, the same soil type may have different names based on its color variation and also surface texture. Its correlation with the WRB could be important for communicating results among farmers easily. Nonetheless, it requires some refining and standardization in consultation with the farmers. The correlation between local and the WRB names is presented in Table 13.

Table 13. Correlation between local and WRB soil names in the four CASCAPE intervention kebeles in Gurawa Woreda

WRB name	Local name
Vertisol (Rhodic)	Qefera
Vertisol (Chromic)	BiyeGuracha
HaplicLuvisol	BiyeGuracha
Cambisol (Chromic)	QeferaDimma
HaplicLuvisol (Reddish)	BiyeDimma

### 3.5.2. Soil Profile Descriptions and Analytical Data

#### 3.5.2.1. Soil Profiles

A total of 7 pedons, representing major agricultural soils of four CASCAPE intervention kebeles in Kombolcha Woreda, were opened. The intervention kebeles are Bilisum (3), Egu (2), Were Mahamed (1), and Kakali (1). The distribution of the number of pedons opened was based on the variability of agricultural soils. In Bilisuma, two pedons were opened on the middle slope of sloping landform, while one was opened on level landform; In Egu, both were opened on level landform; In Were Mahamed, it was opened on level landform and in Kakali on lower slope of a sloping landform. Furthermore, 32 auger pits were also described in these four kebeles. A total of 29 samples were collected from genetic horizons of the 7 pedons and analyzed for their selected physical and chemical properties at the Water Works and Design Supervision Enterprise Soil laboratory in Addis Ababa.

The results of field descriptions of the pedons' site and profile characteristics are presented in Table 14.

Table 14. Soil site and profile descriptions of pedons opened in four CASCAPE intervention kebeles of Kombolcha Woreda (The analytical results are presented in Table 15)

Profile ID	HE/KOM/BL/P1	Land cover	Scattered trees of different species, shrubs and herbaceous plants
Date	21/12 (dd/mm)	Land use	Crop cultivation and animal husbandry
Year	2013	Crop	Cereals, vegetables, khat, few fruit trees
			Vegetation intensively disturbed, ploughing, terracing, flood/furrow
Surveyor	Kibebew Kibret	Human influence	irrigation
Status	Reference profile description	Surface stone cover	common
Location country	Ethiopia	Surface stone size	Large
Location region	East Hararghe	Erosion category	Water, gully
Location woreda	Kombolcha	Erosion area	0-5%
Location kebele	Bilisuma	Erosion degree	Slight
Longitude	42°06'13.3"	Sealing thickness	None
Latitude	9°28'06"	Crack width	None
Elevation	2196 m	Surface salt	None
Map ID		Surface drainage	Rapid
Map scale		Soil drainage	Well
Map unit ID		Flooding frequency	None
Topography	Moderately steep, 15-30%	Depth to groundwater	Not observable
Major landform	Medium gradient hill	Depth to bedrock	Not observable
Position on slope	Middle slope	Rootable depth	60 cm
Slope form	Straight	Rooted depth	60 cm
Slope gradient	28%	Depth of observation	60 cm
Geology	Igneous basement	Local soil type	Qefera Guracha
Parent material	Granite	Field WRB soil type	Luvisol
		WRB soil type	Haplic Luvisol (Hypereutric, Skeletic)

#### Description of the soil horizons (morphology)

Horizon	Depth (cm)	Description
Ah	0-15	Dusky red (10R 3/2, moist and dry) colour; clay; moderate medium granular to weak fine sub-angular blocky structure; slightly hard (dry), very friable (moist), and sticky and plastic (wet) consistence; no coatings; common, very fine to fine pores; few, fine quartz fragments; no mottles; few, medium to coarse roots; few burrows; clear, smooth boundary; slight reaction with dilute HCl; field measured pH value of 6.
Bt1	15-40	Dusky red (7.5YR 3/3, moist) and red (10R 4/6, dry) colour; clay; moderate coarse angular blocky structure; slightly hard (dry), very friable (moist), and very sticky and very plastic (wet) consistence; few, very fine pores; no observable coatings; very few, fine to medium quartz fragments; no observable mottles; few, very fine roots; very few, very fine burrows; clear, smooth boundary; no reaction with dilute HCl with field measured pH value of 6.
Bt2	40-60	Dusky red (7.5YR 3/4, moist) and red (10R 5/8, dry) colour; clay; Moderate coarse angular blocky structure; slightly hard (dry), very friable (moist), and very sticky and very plastic (wet) consistence; very few, fine pores; no observable coatings; very few, fine quartz fragments; no observable mottles; very few, very fine roots; very few burrows; no reaction with dilute HCl; field measured pH value of 6.

Profile ID	HE/KOM/BL/P2	Land cover	Scattered trees of different species, woody shrubs, herbaceous
Date	21/12 (dd/mm)	Land use	Crop cultivation, animal husbandry
Year	2013	Crop	Cereals, vegetables, khat, some fruit trees
Surveyor	KibebewKibret	Human influence	Vegetation intensively disturbed, ploughing, bunding, flood/furrow irrigation
Status	Reference profile description	Surface stone cover	None
Location country	Ethiopia	Erosion category	Water, gully
Location region	East Hararghe	Erosion area	0-5%
Location woreda	Kombolcha	Erosion degree	Slight
Location kebele	Billisuma	Sealing thickness	None
Longitude	42°07'02"	Crack width	Wide (2-5 cm)
Latitude	09°27'33"	Crack depth	Medium (2-10 cm)
Elevation	2144 m	Crack distance	Moderately widely spaced (0.5-2 m)
Map ID		Surface salt	None
Map scale		Surface drainage	Well
Map unit ID		Soil drainage	Well
Topography	Strongly sloping, 10-15%	Flooding frequency	None
Major landform	Medium gradient hill	Depth to groundwater	180 m
Position on slope	Toe slope	Depth to bedrock	Not observable
Slope form	Straight	Rootable depth	170 m
Slope gradient	13%	Rooted depth	170 m
Geology	Igneous	Depth of observation	180 m
Parent material	Granite basement	Local soil type	Oefera
		Field WRB soil type	Vertisol (Red)
		WRB soil type	Grumic Vertisol (Eutric, Rhodic)

#### Description of the soil horizons (morphology)

Horizon	Depth (cm)	Description
Ap	0-15	Dark reddish brown (2.5YR 2.5/3, moist) and reddish brown (2.5YR 4/3, dry) colour; clay; strong coarse granular structure; slightly hard (dry), very friable (moist), and sticky and plastic (wet) consistence; common, fine to medium pores; no observable coatings; very few, fine quartz fragments; no mottles; few, very fine to medium roots; very few burrows; clear, smooth boundary; slight reaction with dilute HCl; field measured pH value of 6.7.
Ai1	15-40	Very dusky red (5YR 2.5/2, moist) and reddish brown (2.5YR 4/4, dry) colour; clay; strong very coarse prismatic structure; very hard (dry), friable (moist), and very stick and very plastic (wet) consistence; common, very fine to coarse pores; very few, faint clay coatings; very few, fine quartz fragments; no observable mottles; very few, very fine roots; very few burrows; clear, smooth boundary; no reaction with HCl; field measured pH value of 6.5; slickensides.
BCi2	40-80	Dark reddish brown (2.5YR 3/4, moist) and dark reddish brown (2.5YR 3/3, moist) colour; heavy clay; strong coarse angular blocky structure; very hard (dry), very friable (moist), and very sticky and very plastic (wet) consistence; common, very fine to fine pores; very few, faint clay coatings; very few, fine quartz fragments; very few, very fine, faint black mottles; no roots; very few burrows; clear, smooth boundary; no reaction with dilute HCl; field measured pH value of 6.5; slickensides.
Ci3	80-140	Dusky red (2.5 YR 3/2, moist) and weak red (2.5YR 4/2, dry) colour; clay; strong coarse angular blocky structure; very hard (dry), very friable (moist), and very sticky and very plastic (wet) consistence; few, fine pores; very few, faint shiny faces; very few, very fine quartz fragments; very few, very fine, faint black mottles; no roots; very few burrows; clear, smooth boundary; no reaction with dilute HCl with field measured pH value of 6.5; slickensides.
Ci4i	140-180	Red (2.5YR 4/6, moist) and red (2.5YR 4/4, dry) colour; clay; strong coarse angular blocky structure; very hard (dry), very friable (moist), and very sticky and very plastic (wet) consistence; very few, very fine pores; very few, faint clay coatings; no coarse fragments; very few, very fine, faint black mottles; no roots; very few burrows; no reaction with dilute HCl; field measured pH value of 6.5; slickensides.

Profile ID	HE/KOM/BL/P3	Land use	Crop cultivation and animal husbandry
Date	21/12 (dd/mm)	Crop	Cereals, vegetables, khat, some fruit trees
Year	2013	Human influence	Ploughing, flood/furrow irrigation
Surveyor	Kibebew Kibret	Surface stone cover	None
Status	Reference profile description	Erosion category	Water
Location country	Ethiopia	Erosion area	0-5%
Location region	East Hararghe	Erosion degree	Slight
Location woreda	Kombolcha	Sealing thickness	None
Location kebele	Bilisuma	Crack width	Medium (1-2 cm)
Longitude	42°06'20"	Crack depth	Deep (10-20 cm)
Latitude	09°27'17.3"	Crack distance	Closely spaced (0.2-0.5 m)
Elevation	2139 m	Surface salt	None
Map ID		Surface drainage	Slow
Map scale		Soil drainage	Well
Map unit ID		Flooding frequency	None
Topography	Sloping, 5-10%	Depth to groundwater	Not observable
Major landform	Valley floor	Depth to bedrock	Not observable
Position on slope	Toe slope	Rootable depth	180 cm
Slope form	Straight	Rooted depth	180 cm
Slope gradient	6%	Depth of observation	180 cm
Geology	Igneous	Local soil type	Biye Guracha
Parent material	Granitic basement	Field WRB soil type	Vertisol
Land cover	Herbaceous	WRB soil type	Grumic Vertisol (Eutric, Chromic)

#### Description of the soil horizons (morphology)

Horizon	Depth (cm)	Description
Ah	0-20	Dark brown (7.5YR 3/4, moist) and brown (7.5YR 4/2, dry) colour; clay; strong coarse granular to strong fine sub-angular blocky structure; hard (dry), friable (moist), and very sticky and very plastic (wet) consistence; common, fine to medium pores; very few, faint silt coatings; common, fine quartz fragments; very few, very fine, faint black mottles; common, coarse roots; few burrows; clear, smooth boundary; slight reaction with dilute HCl; field pH of 6.5.
AC	20-65	Dark reddish brown (5YR 3/3, moist) and brown (7.5YR 5/2, dry) colour; clay; strong coarse sub-angular blocky structure; very hard (dry), friable (moist), and very sticky and very plastic (wet) consistence; common, very fine to fine pores; very few, faint clay coatings; few, fine quartz fragments; very few, very fine, faint black mottles; very few, fine roots; very few burrows; clear, smooth boundary; no reaction with dilute HCl; field measured pH value of 6.
C1	65-95	Black (5YR 2.5/1, moist) and dark reddish brown (5YR 2.5/2, dry) colour; sandy clay loam; strong very coarse prismatic structure; very hard (dry), friable (moist), and very sticky and very plastic (wet) consistence; few, very fine to fine pores; very few, faint clay coatings; fine, few quartz fragments; very few, very fine, faint black mottles; very few, very fine roots; very few burrows; gradual, smooth boundary; no reaction with HCl; field measured pH value of 6.5; slickensides.
2C	95-180	Very dark brown (10YR 2/2, moist) and brown (10YR 4/3, dry) colour; clay; strong very coarse prismatic structure; very hard (dry), friable (moist), and very sticky and very plastic (wet) consistence; few, very fine pores; very few, faint clay coatings; common, fine quartz fragments; very few, very fine, faint mottles; no reaction with HCl; field estimated pH value of 6.5; slickensides.

Profile ID	HE/KOM/EG/P1	Land cover	Scattered different tree species, woody shrubs, herbaceous plants
Date	25/12 (dd/mm)	Land use	Crop cultivation and animal husbandry
Year	2013	Crop	Cereals, vegetables, khat
Surveyor	KibebewKibret	Human influence	Vegetation intensively disturbed, ploughing, bunding
Status	Reference profile description	Surface stone cover	None
Location country	Ethiopia	Erosion category	Water, small gully
Location region	East Hararghe	Erosion area	0-5%
Location woreda	Kombolcha	Erosion degree	Slight
Location kebele	Egu	Sealing thickness	None
Longitude	42°06'41"	Crack width	None
Latitude	09°29'30.2"	Surface salt	None
Elevation	2218 m	Surface drainage	Well
Map ID		Soil drainage	Well
Map scale		Flooding frequency	None
Map unit ID		Depth to groundwater	Not observable
Topography	Strongly sloping, 10-15%	Depth to bedrock	Not observable
Major landform	Medium gradient hill	Rootable depth	110 cm
Position on slope	Middle slope	Rooted depth	110 cm
Slope form	Concave straight	Depth of observation	110 cm
Slope gradient	13%	Local soil type	QeferaDimma
Geology	Sedimentary	Field WRB soil type	Cambisol
Parent material	Sandstone basement	WRB soil type	Haplic Cambisol (Eutric, Chromic)

#### Description of the soil horizons (morphology)

Horizon	Depth (cm)	Description
Ap	0-25	Dark brown (7.5YR 3/2, moist) and dark yellowish brown (10YR 4/4, dry) colour; clay; strong coarse sub-angular blocky to angular blocky structure; very hard (dry), friable (moist), and very sticky and very plastic (wet) consistence; many, very fine to medium pores; very few, faint clay coatings; no coarse fragments and mottles; fine, few roots; fine burrows; clear, smooth boundary; no reaction with dilute HCl; field measured pH value of 6.5.
Ah	25-45	Very dusky red (2.5YR 2.5/2, moist) and reddish brown (5YR 4/4, dry) colour; clay; strong very coarse prismatic structure; very hard (dry), friable (moist), and very sticky and very plastic (wet) consistence; many, very fine to fine pores; very few, faint clay coatings; very few, fine quartz and feldspar fragments; no mottles; very few, very fine roots; very few burrows; diffuse, smooth boundary; no reaction with dilute HCl and field estimated pH value of 6.5.
Bw1	45-60	Dark reddish brown (2.5YR 3/4, moist) and yellowish red (5YR 5/6, dry) colour; sandy clay loam; strong very coarse prismatic structure; extremely hard (dry), friable (moist), and very sticky and very plastic (wet) consistence; few, very fine to fine pores; very few, faint clay coatings; few, fine quartz/feldspar fragments; very few, very fine, faint black mottles; very few, very fine roots; very few burrows; gradual, smooth boundary; no reaction with HCl; field estimated pH value of 7.
Bw2	60-90	Yellowish red (5YR 4/6, moist) and reddish yellow (5YR 6/8, dry) colour; clay; strong very coarse sub-angular blocky to angular blocky structure; extremely hard (dry), very friable (moist), and very sticky and very plastic (wet) consistence; few, very fine to fine pores; common, distinct silt coatings; very few, very fine quartz/feldspar fragments; few, very fine, faint black mottles; very few, very fine roots; very few burrows; gradual, smooth boundary; no reaction with dilute HCl and pH value of 7.
Bw3	90-110	Yellowish brown (10YR 5/8, moist) and reddish yellow (5YR 7/6, dry) colour; silty clay; strong coarse sub-angular blocky to angular blocky structure; very hard (dry), very friable (moist), and very sticky and very plastic (wet) consistence; very few, very fine pores; common, distinct silt coatings; very few, very fine quartz/feldspar fragments; few, fine, distinct black and red mottles; no roots and biological activities; no reaction with dilute HCl and pH value of 7.

Profile ID	HE/KOM/EG/P2	Land cover	Scattered tree species, woody shrubs and herbaceous plants
Date	25/12 (dd/mm)	Land use	Crop cultivation and animal husbandry
Year	2013	Crop	Cereals, vegetables, khat, some fruit trees
Surveyor	KibebewKibret	Human influence	Vegetation intensively disturbed, ploughing, flood/furrow irrigation
Status	Reference profile description	Surface stone cover	None
Location country	Ethiopia	Erosion category	None
Location region	East Hararghe	Erosion degree	Slight, gully
Location woreda	Kombolcha	Sealing thickness	0-5%
Location kebele	Egu	Sealing consistence	None
Longitude	42°6'9.6"	Crack width	Very wide (5-10 cm)
Latitude	09°29'2.7"	Crack depth	Deep (10-20 cm)
Elevation	2181 m	Crack distance	Closely spaced (0.2-0.5 m)
Map ID		Surface salt	None
Map scale		Surface drainage	Slow
Map unit ID		Soil drainage	Poor
Topography	Very gently sloping, 1-2%	Flooding frequency	None
Major landform	Level land, plain	Depth to groundwater	Not observable
Position on slope	Toe slope	Depth to bedrock	Not observable
Slope form	Straight	Rootable depth	180 cm
Slope gradient	1.5%	Rooted depth	180 cm
Geology	Sedimentary	Depth of observation	180 cm
Parent material	Limestone basement	Local soil type	BiyeGuracha
		Field WRB soil type	Vertisol
		WRB soil type	Grumic Vertisol (Eutric)

#### Description of the soil horizons (morphology)

Horizon	Depth (cm)	Description
Ap	0-20	Very dark brown (10YR 2/2, moist) and dark grayish brown (10YR 4/2, dry) colour; clay; strong coarse granular and strong very coarse angular blocky structure; very hard (dry), very friable (moist), and very sticky and very plastic (wet) consistence; many, fine to medium pores; very few, faint clay coatings; no coarse fragments and mottles; few, very fine to fine roots; very few burrows; clear, irregular boundary; no reaction with dilute HCl; field measured pH value of 7.
AC	20-80	Black (10YR 2/1, moist) and very dark gray (10YR 3/1, dry) colour; clay; strong coarse angular blocky structure; extremely hard (dry), very friable (moist), and very sticky and very plastic (wet) consistence; common, very fine to fine pores; common, distinct clay coatings; very few, fine calcium carbonate fragments; no mottles; very few, fine roots; very few burrows; clear, irregular boundary; slight reaction with dilute HCl; field measured pH value of 7. Slickensides.
C	80-180	Dark grayish brown (10YR 4/2, moist) and grayish brown (10YR 5/2, dry) colour; clay; strong coarse sub-angular blocky to angular blocky structure; extremely hard (dry), very friable (moist), and very sticky and very plastic (wet) consistence; few, very fine pore; few, faint clay coatings; very few, fine calcium carbonate fragments; no mottles; very few, very fine roots; very few burrows; clear, irregular boundary; slight reaction with dilute HCl; field measured pH value of 7; slickenside.

Profile ID	HE/KOM/WM/P1	Land cover	Scattered trees, shrubs, herbaceous
Date	27/12 (dd/mm)	Land use	Crop cultivation and animal husbandry
Year	2013	Crop	Cereals, vegetables, khat, some fruit trees
Surveyor	KibebewKibret	Human influence	Vegetation intensively disturbed, ploughing, terracing, irrigation
Status	Reference profile description	Surface stone cover	Very few
Location country	Ethiopia	Surface stone size	Stones
Location region	East Hararghe	Erosion category	Water, gully
Location woreda	Kombolcha	Erosion area	0-5%
Location kebele	Were Mahammed	Erosion degree	Slight
Longitude	42°10'4.6"	Sealing thickness	None
Latitude	09°27'56.8"	Crack width	Wide (2-5 cm)
Elevation	2004 m	Crack depth	Very deep (>20 cm)
Map ID		Crack distance	Closely spaced (0.2-0.5 m)
Map scale		Surface salt	None
Map unit ID		Surface drainage	Slow
Topography	Gently sloping, 2-5%	Soil drainage	Poor
Major landform	Level land, plateau	Flooding frequency	None
Position on slope	Toe slope	Depth to groundwater	Not observable
Slope form	Concave straight	Depth to bedrock	Not observable
Slope gradient	5%	Rootable depth	180 cm
Geology	Sedimentary and Igneous	Rooted depth	180 cm
Parent material	Mixed basalt and limestone	Depth of observation	180 cm
		Local soil type	BiyeGuracha
		Field WRB soil type	Calcic Vertisol
		WRB soil type	Calcic Vertisol (Eutric, Chromic)

#### Description of the soil horizons (morphology)

Horizon	Depth (cm)	Description
Apk1	0-20	Brown (7.5YR 4/2, moist) and grayish brown (2.5Y 5/2, dry) colour; clay; strong coarse angular blocky structure; slightly hard (dry), very friable (moist), and very sticky and very plastic (wet) consistence; common, very fine to fine pores; fine, faint sand coatings; common, fine calcium carbonate fragments; no mottles; few, fine roots; few burrows; clear, smooth boundary; strong effervescence with dilute HCl and field measured pH value of 8.
2A	20-50	Very dark brown (10YR 2/2, moist) and dark grayish brown (2.5Y 4/2, dry) colour; heavy clay; strong very coarse prismatic structure; very hard (dry), very friable (moist), and very sticky and very plastic (wet) consistence; few, very fine to fine pores; very few, faint clay coatings; few, fine calcium carbonate fragments; very few, very fine, faint black mottles; very few, very fine roots; very few burrows; clear, smooth boundary; moderate reaction with dilute HCl; field measured pH value of 7.5.
Bti1	50-130	Black (2.5YR 2.5/1, moist) and dark gray (2.5Y 4/1, dry) colour; clay; strong coarse angular blocky structure; extremely hard (dry), very friable (moist), and very sticky and very plastic (wet) consistence; few, very fine pores; very few, faint shiny faces; very few, fine carbonate fragments; no mottles; very few, very fine roots; very few burrows; clear, irregular boundary; moderate reaction with dilute HCl; field measured pH value of 7.5; slickensides.
Btik2	130-180	Dark grayish brown (10YR 4/2, moist) and grayish brown (2.5Y 5/2, dry) colour; clay; strong medium angular blocky structure; extremely hard (dry), very friable (moist), and very sticky and very plastic (wet) consistence; few, very fine to fine pores; very few, faint clay coatings; few, fine carbonate fragments; few, fine, distinct black mottles; very few, very fine roots; no biological activity; extremely strong reaction with dilute HCl; field measured pH value of 8.5; slickensides.

Profile ID	HE/KOM/KK/P1	Land cover	Scattered trees, woody shrubs, herbaceous
Date	29/12 (dd/mm)	Land use	Crop cultivation, animal husbandry
Year	2013	Crop	Cereals, vegetables, khat, some fruit trees
Surveyor	KibebewKibret	Human influence	Vegetation intensively disturbed, ploughing, irrigation
Status	Reference profile description	Surface stone cover	Very few
Location country	Ethiopia	Surface stone size	Large boulders
Location region	East Hararghe	Erosion category	Water, gully
Location woreda	Kombolcha	Erosion area	5-10%
Location kebele	Kakali	Erosion degree	Moderate
Longitude	42°8'13.4"	Sealing thickness	None
Latitude	09°27'51.9"	Crack width	None
Elevation	2162 m	Surface drainage	Well
Map ID		Soil drainage	Well
Map scale		Flooding frequency	None
Map unit ID		Depth to groundwater	Not observable
Topography	Moderately steep, 15-30%	Depth to bedrock	Not observable
Major landform	Medium gradient hill	Rootable depth	200 cm
Position on slope	Lower slope	Rooted depth	200 cm
Slope form	Straight	Depth of observation	200 cm
Slope gradient	17%	Local soil type	Biye Dimma
Geology	Sandstone	Field WRB soil type	Luvisol
Parent material	Sedimentary	WRB soil type	Haplic Luvisol (Hypereutric, Skeletic, Clayic, Chromic)

#### Description of the soil horizons (morphology)

Horizon	Depth (cm)	Description
Ah	0-15	Dark red (10R 3/6, moist) and red (10R 4/6, dry) colour; clay; strong coarse granular and angular blocky structure; hard (dry), very friable (moist), and very sticky and very plastic (wet) consistence; many, fine to medium pores; no visible coatings; very few, very fine quartz/feldspar fragments; no mottles; few, coarse roots; common termite channels; diffuse, smooth boundary; no reaction with dilute HCl and pH value of 6.
Bt	15-58	Dusky red (10R 3/4, moist) and red (10R 4/6, dry) colour; clay; strong coarse sub-angular blocky to angular blocky structure; hard (dry), very friable (moist), and very sticky and very plastic (wet) consistence; common, very fine to fine pores; few, faint clay coatings; very few, fine quartz/feldspar fragments; no mottles; few, medium roots; very few termite channels; diffuse, smooth boundary; no reaction with HCl and pH value of 6.
B2	58-88	Weak red (10R 4/4, moist) and red (10R 4/8, dry) colour; clay; strong coarse angular blocky structure; hard (dry), very friable (moist), and very sticky and very plastic (wet) consistence; few, very fine to fine pores; few, faint clay coatings; very few, fine quartz/feldspar fragments; no mottles; very few, very fine roots; very few termite channels; diffuse, smooth boundary; no reaction with dilute HCl; pH value of 6.
BC	88-140	Dark reddish brown (2.5YR 2.5/4, moist) and red (10R 4/8, dry) colour; clay; strong very coarse sub-angular blocky to angular blocky structure; hard (dry), friable (moist), and very sticky and very plastic (wet) consistence; very few, very fine to fine pores; few, faint clay coatings; very few, very fine quartz/feldspar fragments; no mottles; very few, very fine roots; very few termite channels; diffuse, smooth boundary; no reaction with dilute HCl; pH value of 6.
C	140-200	Dark red (2.5YR 3/6, moist) and light red (2.5YR 6/8, dry) colour; clay; moderate medium sub-angular blocky to angular blocky structure; very hard (dry), friable (moist), and very sticky and very plastic (wet) consistence; few, very fine to fine pores; very few, faint clay coatings; abundant, fine quartz/feldspar fragments; no mottles; very few, very fine roots; very few burrows; no reaction with dilute HCl with pH value of 6.

Table 15. Selected soil physical and chemical properties of representative pedons opened on major agricultural soils in CASCAPE intervention kebeles in KombolchaWoreda

Parameters	HE/KOM/BL/P1			HE/KOM/BL/P2				
	0-15	15-40	40-60	0-15	15-40	40-80	80-140	140-180
Depth (cm)	Ah	Bt1	Bt2	Ap	Ai1	Bt1i	Bt2i	Bt3i
Sand (%)	20.79	26.03	29.01	25.28	26.25	25.99	19.45	25.76
Silt (%)	33.35	14.79	12.53	20.00	18.97	12.69	16.96	14.85
Clay (%)	45.86	59.17	58.47	54.72	54.79	61.32	63.59	59.39
Textural class	C	C	C	C	C	C	C	C
pH-H <sub>2</sub> O	6.53	5.78	6.11	6.15	6.51	6.97	7.17	7.25
pH-KCl	5.63	5.03	5.38	5.18	5.68	6.18	6.25	6.37
EC (μS/cm)	0.07	0.06	0.05	0.06	0.05	0.07	0.13	0.13
OC (%)	1.32	1.13	0.9	1.06	0.81	0.63	0.48	0.45
TN (%)	0.12	0.1	0.07	0.10	0.07	0.06	0.04	0.03
Av.P (mg kg-l)	24.6			18.10				
Av. S (%)	0.46			1.22				
Na (meq/100 g)	0.78	1.10	0.94	0.95	0.93	0.85	0.87	0.89
K (meq/100 g)	0.49	0.57	0.57	0.64	0.56	0.57	0.66	0.64
Ca (meq/100 g)	24.15	30.36	25.01	25.62	28.17	28.56	36.89	34.77
Mg (meq/100 g)	8.33	10.12	8.34	8.40	9.67	9.24	11.87	11.45
CEC (meq/100 g)	40.28	49.49	42.13	45.20	45.70	45.20	56.69	50.23
SB (meq/100 g)	33.75	42.15	34.85	35.61	39.33	39.22	50.28	47.75
ESP (%)	1.93	2.22	2.24	2.10	2.04	1.88	1.53	1.78
Zn (mg/kg)	1.08			0.70				
Mn (mg/kg)	23.14			19.27				
Cu (mg/kg)	2.98			2.80				
Fe (mg/kg)	27.03			30.33				

Parameters	HE/KOM/BL/P3			
	0-20	20-65	65-95	95-180
Depth (cm)	Ah	Bt1	2Ai1	2Bti2
Sand (%)	36.64	35.76	40.88	27.93
Silt (%)	16.9	11.58	21.20	19.08
Clay (%)	46.46	52.65	37.92	52.99
Textural class	C	C	CL	C
pH-H <sub>2</sub> O	6.49	6.61	6.42	6.93
pH-KCl	5.57	5.80	5.51	6.16
EC (μS/cm)	0.03	0.04	0.05	0.07
OC (%)	1.55	1.32	1.27	0.99
TN (%)	0.15	0.12	0.10	0.09
Av.P (mg/ kg)	25.3			
Av. S (%)	0.96			
Na (meq/100 g)	0.90	0.94	1.07	1.19
K (meq/100 g)	0.75	0.58	0.57	0.65
Ca (meq/100 g)	29.40	30.24	28.29	30.10
Mg (meq/100 g)	10.08	10.50	9.15	10.18
CEC (meq/100 g)	43.37	49.30	46.12	48.85
SB (meq/100 g)	41.14	42.26	39.07	42.12
ESP (%)	2.08	1.91	2.31	2.43
Zn (mg/kg)	0.76			
Mn (mg/kg)	13.94			
Cu (mg/kg)	2.24			
Fe (mg/kg)	18.59			

OM = KombolchaWoreda; BL = BilisumaKebele; P = Pedon; C = clay; CL = clay loam; OC = organic carbon; TN = total nitrogen; EC = electrical conductivity; Av. = Available; SB = sum of bases

Parameters	HE/KOM/EG/P1					KOM/EG/P2		
	0-25	25-45	45-60	60-90	90-110	0-20	20-80	80-180
Depth (cm)	0-25	25-45	45-60	60-90	90-110	0-20	20-80	80-180
Horizon	Ap	A1	A2	AC	C	Ap	Bti1	Bti2
Sand (%)	36.41	39.56	47.65	51.55	47.02	32.96	19.93	21.76
Silt (%)	23.32	20.15	14.66	19.58	18.70	19.46	24.89	15.21
Clay (%)	40.27	40.30	37.69	28.86	34.28	47.58	55.18	63.03
Textural class	C	C	SCL	SCL	SCL	C	C	C
pH-H <sub>2</sub> O	6.62	6.85	7.00	6.88	7.17	6.85	6.76	7.96
pH-KCl	5.65	6.09	6.04	5.94	6.24	5.96	5.83	7.34
EC (μS/cm)	0.06	0.06	0.06	0.06	0.06	0.07	0.07	0.21
OC (%)	1.00	0.65	0.40	0.34	0.24	1.88	0.86	0.28
TN (%)	0.10	0.05	0.04	0.03	0.02	0.23	0.11	0.03
Av.P (mg kg-l)	20.40					40.00		
Av. S (%)	0.65					1.26		
Na (meq/100 g)	0.95	0.87	0.91	0.87	0.80	0.93	1.05	1.17
K (meq/100 g)	0.71	0.49	0.38	0.29	0.36	0.90	0.53	0.58
Ca (meq/100 g)	29.57	27.06	22.99	20.60	20.74	32.25	38.74	37.58
Mg (meq/100 g)	10.14	9.30	7.94	7.00	6.64	11.18	13.34	12.96
CEC (meq/100 g)	44.99	45.04	34.98	37.17	35.62	50.01	59.41	54.47
SB (meq/100 g)	41.37	37.73	32.22	28.76	28.54	45.26	53.66	52.29
ESP (%)	2.10	1.94	2.60	2.34	2.25	1.87	1.76	2.16
Zn (mg/kg)	2.83					3.20		
Mn (mg/kg)	25.33					7.79		
Cu (mg/kg)	3.97					3.01		
Fe (mg/kg)	83.20					20.57		

Parameters	HE/KOM/WM/P				KOM/KK/P				
	0-20	20-50	50-130	130-180	0-15	15-58	58-88	88-140	140-200
Depth (cm)	0-20	20-50	50-130	130-180	0-15	15-58	58-88	88-140	140-200
Horizon	Apk1	2A	Bti1	Btik2	Ah	Bt	B2	BC	C
Sand (%)	33.54	38.64	18.70	14.85	22.39	28.64	29.09	31.43	50.97
Silt (%)	9.49	16.93	15.38	17.47	25.17	12.59	25.03	28.48	10.21
Clay (%)	56.97	44.44	65.92	67.68	52.44	58.76	45.88	40.09	38.81
Textural class	C	C	C	C	C	C	C	C	SC
pH-H <sub>2</sub> O	7.92	8.12	8.14	8.36	6.65	6.49	6.80	6.23	5.91
pH-KCl	7.25	7.20	7.38	7.49	5.80	5.73	5.84	5.38	5.36
EC (μS/cm)	0.08	0.12	0.15	0.28	0.05	0.08	0.05	0.04	0.04
OC (%)	0.92	0.70	0.57	0.31	1.08	0.87	0.64	0.51	0.10
TN (%)	0.10	0.07	0.06	0.03	0.10	0.07	0.06	0.04	0.01
Av.P (mg/kg)	26.00				33.40				
Av. S (%)	0.79				1.14				
Na (meq/100 g)	0.85	0.82	1.13	1.72	1.09	1.04	0.97	0.77	1.47
K (meq/100 g)	0.42	0.31	0.49	0.74	0.97	1.04	0.58	0.35	0.20
Ca (meq/100 g)	31.56	34.00	38.00	40.00	23.87	21.78	22.07	17.25	17.97
Mg (meq/100 g)	10.52	10.97	13.08	13.88	7.96	7.54	7.50	5.47	5.72
CEC (meq/100 g)	52.14	50.00	56.87	61.27	40.51	42.79	41.64	31.10	30.63
SB (meq/100 g)	43.00	46.00	53.00	57.00	33.89	31.39	31.11	23.84	25.36
ESP (%)	1.63	1.63	1.98	2.80	2.70	2.43	2.33	2.47	4.81
Zn (mg/kg)	2.00				1.78				
Mn (mg/kg)	12.86				11.89				
Cu (mg/kg)	1.82				1.54				
Fe (mg/kg)	10.23				15.16				

OM = KombolchaWoreda; WM = Were Mahamedkebele; KK = Kakalikebele; P = Pedon; C = clay; SC = sandy clay; SCL = sandy clay loam; OC = organic carbon; TN = total nitrogen; EC = electrical conductivity; Av. = Available; SB = sum of bases

### 3.5.3. Synthesis

Morphological, physical, and chemical properties of the pedons are presented in Tables 14 and 15 in Section 3.5.2. For the discussions presented below, reference should be made to those Tables. The results are interpreted using critical values of parameters as suggested in Booker Tropical Soil Manual (Landon, 1991), Hazelton and Murphy (2007), Jones (2003), FAO (2006), Karlton et al. (2013) and Allison (1973).

#### 3.5.3.1. Agronomic Interpretation of Soil Morphological Properties

##### 1. Color

The surface color (moist) varied between dusky red (10R 3/2) at the surface horizon of the Haplic Luvisols of Bilisuma Kebele to very dark brown (10YR 2/2) at the surface horizon of Pedon 2 in the Grumic Vertisols (Eutric) of Egu Kebele. Similarly, the color (dry) of the surface layers ranged from dusky red (10R 3/2) in the Haplic Luvisols of Bilisuma to grayish brown (2.5Y 5/2) in the Calcic Vertisols of Were Mahamed Kebele. The brown to dark brown colors recorded in the majority of the surface horizons might be due to the organic matter which farmers apply regularly.

The subsurface color (moist) varied from dusky red (10R 3/4) in the Haplic Luvisols of Kakali to yellowish brown (10YR 5/8) in the Haplic Cambisols of Egu Kebele. The subsurface color (dry) of the soils ranged from red (10R 4/8) in the Haplic Luvisols of Kakali to grayish brown (2.5Y 5/2) in the Calcic Vertisols of Were Mahamed Kebele.

##### 2. Soil Structure and Consistence

The structure of the surface horizons ranged from moderate, medium to strong, coarse granular structure to weak, fine sub-angular blocky and strong very coarse angular blocky structure. Moderate to strong, medium to very coarse sub-angular blocky and angular blocky structures characterize

the subsurface layers as well. In soils with strong swelling and shrinking properties (the Grumic Vertisols in Bilisuma and Egu, and the Calcic Vertisols in Were Mahamed kebele), wedge-shaped structural units were also observed. The surfaces of these wedge-shaped structures are shiny with limited porosity.

In almost all the major soil types, the consistence was slightly to very hard when dry, friable to very friable when moist, and slightly to very sticky and very plastic when wet and varied with clay content down the soil profile.

### 3. Soil Depth

The soil depth, as recorded from road cuts, gulleys, auger pits and pedons, was largely deeper than 25-50 cm. More than 90% of the auger observation points have depth that is greater than 120 cm. Similarly, the pedons have more than 60 cm depth. As per soil depth ratings suggested by Broderson (2000), majority of soils of the kebeles are moderately to very deep. Nevertheless, the steep slopes are characterized by extremely shallow soils.

### 4. Porosity, Root Distribution and Other Related Features

The total porosity of the soils was high with variable pore sizes and abundances from the surface horizons down to the subsurface horizons. The abundance ranged from very few to common, while the size of the pores ranged from very fine to medium. The size and abundance of pore spaces declined with soil depth due to the obvious increase in soil compaction due to overburden pressure, decrease in organic matter content and root distribution with soil depth (Pravinet al., 2013).

In the cropped fields, the root depth was mainly dependent on the types of crops grown. Most of the roots were found in the upper 50-60 cm depth of the pedons. Very few roots were found below these depth limits.

Other important features recorded include coarse fragments, mottles, coatings, effervescence, and field measured pH. The details of these attributes are indicated in Table 14.

#### 3.5.3.2. Agronomic Interpretation of Soil Particle Size Distribution

At the surface horizons, the sand content ranges from 20.8% in the Haplic Luvisols of Bilisuma to 36.6% in the Grumic Vertisols (Eutric, Chromic) of the same Kebele, whilst the clay content varies from 40.3% in the Haplic Cambisols of Egu to 57.0% in the Calcic Vertisols of Were Mahamed Kebele. Similarly, in the subsurface horizons, the sand content ranges from 14.9% in the Calcic Vertisols of Were Mahamed to 56.1% in the Grumic Vertisols (Eutric) of Egu Kebele, whereas the clay content varies from 28.9% in the Haplic Cambisols of Egu to 67.7% in the Calcic Vertisols of Were Mahamed Kebele. In terms of proportion, the clay separate, followed by sand, was dominant as a result of which the textural class ranged from sandy clay loam to clay.

From rough estimation, as suggested by Moore et al. (1998), the available water holding capacity of the soils can be in the range of 130-190, 130-150, 110-120, and ~210 mm of water per meter depth of soil for the sandy clay loam, sandy clay, clay, and self mulching clay soils, respectively. Nonetheless, these values are only indicative and, thus, care should be taken in applying these values in the development of specific water management plans.

### 3.5.3.3. Agronomic Interpretation of Soil Chemical Properties

#### 1. Soil Reaction and Electrical Conductivity

At the surface horizons, the pH-H<sub>2</sub>O ranged from 6.2 in the Grumic Vertisols (Rhodic) of Bilisuma to 7.9 in the Calcic Vertisols of Were Mahamed Kebele, while in the subsurface horizons it was in the range between 5.8 in the Haplic Luvisols of Bilisuma and 8.4 in the Calcic Luvisols of Were Mahamed Kebele. Except in the Grumic Vertisols (Rhodic) of Bilisuma and the Calcic Vertisols of Were Mehamed Kebeles where the pH-H<sub>2</sub>O increased with soil depth, it did not show any regular variability with soil depth.

Following pH rating of Karlton et al. (2013), the pH of the surface soils was moderately acidic in Haplic Luvisols and Grumic Vertisols of Bilisuma, neutral in the Haplic Cambisols and Grumic Vertisols of Egu, and the Haplic Luvisols of Kakali, and moderately alkaline in the Calcic Vertisols of Were Mahamed Kebele. Furthermore, as per Landon (1991) rating, the pH of the surface soils was medium in all the soil types except in the Calcic Vertisols of Were Mahamed Kebele, which was high. Except the pH in the Calcic Vertisols of Were Mahamed, the pH of the other soils is in the range that favourable for most crops, availability of essential nutrients and activity of beneficial microorganisms. In the subsurface soils, the pH was moderately acidic to neutral in all the soil types except in the Calcic Vertisols of Were Mahamed Kebele which was moderately alkaline.

The pH-KCl of the soils was lower than the pH-H<sub>2</sub>O in all the pedons and their respective depths and, hence, resulting in positive  $\Delta$ pH values. This indicates that major agricultural soils of the four kebeles have net negative charges on the surfaces of their colloidal particles/exchange sites and, presumably, high exchangeable hydrogen on the exchange complex as well.

The electrical conductivity values, across pedons and depths, were less than 1, which implies that the major agricultural soils of the four kebeles do not

contain quantity of soluble salts that can interfere with the growth of sensitive plants. Therefore, the soils are non-saline soils (Landon, 1991).

## 2. Organic Carbon, Total Nitrogen Contents and C:N Ratio

The organic carbon content of the surface soils, which ranged from 0.9% in the Calcic Vertisols of Were Mahamed to 1.9% in the Grumic Vertisols of Egu Kebele, was in the range of very low as per rating of Landon (1991). Similarly, the organic carbon content of the subsurface soils which varied from 0.1% in the Haplic Luvisols of Kakali to 1.3% in the Grumic Vertisols (Chromic) of Bilisuma Kebele, was in the range of very low. The organic carbon content showed a consistently decreasing trend with soil depth in all the pedons.

Total nitrogen content decreased consistently with soil depth in all the pedons. Across the kebeles, it varied from 0.1 to 0.2% in the surface horizons and 0.01 to 0.1% in the subsurface horizons.

Based on ratings suggested in Landon (1991), the total nitrogen content was low in all the soil types except the Grumic Vertisols (Chromic) of Bilisuma and Grumic Vertisols of Egu Kebeles, which was in the range of medium in the surface horizons, and very low (<0.1%) to low in the subsurface horizons. The results of this study indicate that major agricultural soils of the kebeles might be deficient in nitrogen and, hence, response to application of nitrogen fertilizers is expected.

The carbon to nitrogen ratio (C:N) of the surface horizons ranged from 8:1 to 11:1, while in the subsurface horizons, it was 8:1 to 15:1. As suggested by Allison (1973), the C:N ratio of surface and subsurface horizons of the studied soils indicates the presence of maximum rate of decomposition of organic materials added to the soils.

### 3. Available Phosphorus and Sulfur

Available phosphorus varied from 18.10 mg kg<sup>-1</sup> in the Grumic Vertisols (Rhodic) of Bilisuma Kebele to 40.0 mg kg<sup>-1</sup> in the Grumic Vertisols of Egu Kebele. Based on rating suggested in Landon (1991), the available P content of all the soil types as in the range of high (> 15 mg kg<sup>-1</sup>). Nonetheless, the available P content in the Grumic Vertisols (Rhodic) of Bilisuma Kebele is in the range of 'questionable' for crops with high P demand (Landon, 1991). Such crops include sugarbeet, potatoes and onions, which are among the major vegetable crops grown in the kebeles. These soils, therefore, may require application of P containing fertilizer when growing these crops. Available sulfur, which varied from 0.5% in the Haplic Luvisols of Bilisuma to 1.3% in the Grumic Vertisols of Egu, was in the range of excess based on Landon (1991) rating.

### 4. Exchangeable Bases

Exchangeable Ca in the surface soils varied from 23.9 meq/100 g soil in the Haplic Luvisols of Kakali to 32.3 meq/100 g soil in the Grumic Vertisols of Egu Kebele, while in the subsurface soils, it ranged from 17.3 meq/100 g soil in the Haplic Luvisols of Kakali to 40.0 meq/100 g soil in the Calcic Vertisols of Were Mahamed Kebele. The exchangeable Mg of the surface soils ranged from 8 meq/100 g soil in the Haplic Luvisols of Kakali to 11.2 meq/100 g soil in the Grumic Vertisols of Egu Kebele whereas in the subsurface soils it was 5.5 meq/100 g soil in the Haplic Luvisols of Kakali to 13.9 meq/100 g soil in the Calcic Vertisols of Were Mahamed Kebele.

Based on ratings suggested in Landon (1991), both Ca and Mg were high in major agricultural soils of the kebeles. Based on FAO (2006) rating also, the two exchangeable bases were high to very high. The Ca:Mg ratio in the surface horizons ranged from 2.9 to 3.1:1. In soils where the ratio is less than 3:1, P uptake may be inhibited (Yates, 1964). Furthermore, Eckert

(1987) suggested that a ratio of 1:1 to 4:1 indicates low Ca relative to the Mg present.

The exchangeable K of the surface soils ranged from 0.4 meq/100 g soil in the Calcic Vertisols of Were Mahamed to 1.0 meq/100 g soil in the Haplic Luvisols of Kakali kebeles. In the subsurface soils, it ranged from 0.2 to 1.0 meq/100 g soil in the Haplic Luvisols of Kakali. Similarly, the exchangeable Na varied from 0.78 to 1.09 in the surface horizons of Haplic Luvisols in Bilisuma and Kakali, respectively, and 0.77 to 1.72 meq/100 g in the subsurface soils of Haplic Luvisols in Kakali and Calcic Vertisols of Were Mahamed Kebele, respectively.

The exchangeable K was in the range of medium (0.3-0.6 meq/100 g soil) in the surface soils of Calcic Vertisols in Were Mahamed and high (0.6-1.2 meq/100 g soil) in all the other soil types, whereas it was low (< 0.2 meq/100 g soil) to high in the subsurface horizons (FAO, 2006). Exchangeable Na was also high (0.7-2.0 meq/100 g soil) in the soils. However, the exchangeable sodium percentage was not in the range that affects plants and physical conditions of soils. Nevertheless, Landon (1991) suggested that soils with exchangeable Na > 1 meq/100 g soil should be regarded as potentially sodic. Based on this suggestion, most soils require careful inspection with respect to the dynamics of exchangeable Na.

##### 5. Cation Exchange Capacity and Sum of Bases

Across all the pedons opened, it ranged from a minimum of 40.28 meq/100 g soil in Haplic Luvisols of Bilisuma to 52.14 meq/100 g soil in the Calcic Vertisols of Were Mahamed Kebele at the surface layer and 30.6 to 61.3 meq/100 g soil in the subsurface layers of Haplic Luvisols in Kakali and Calcic Vertisols in Were Mahamed, respectively. Based on rating of CEC results for top soils suggested by Landon (1991), the CEC of the surface horizons was very high (> 40 meq/100 g soil).

Based on rating suggested by Metson (1961), the base saturation of the major agricultural soils in the four kebeles was high (60-80%) to very high (> 80%), which indicates that the soils are very weakly leached.

#### 6. Extractable Micronutrients (Zn, Mn, Cu, Fe)

The extractable Cu of the studied major agricultural soils, based on ratings suggested by Karlton et al. (2013), was in the range of optimum (> 0.9 ppm) in all the soil types, whereas Zn was very low ( $\leq 1.0$  ppm) in the Grumic Vertisols of Bilisuma and to optimum (> 1.5 ppm) in the other soil types. Similarly, the extractable Fe content of all the major soil types was above the range that is quoted as causing deficiency levels in soils (2.5-4.5 ppm) (Landon, 1991). The extractable Mn was medium (1.0-20.0 mg kg<sup>-1</sup>) in all the soil types except in the Haplic Luvisols of Bilisuma and Haplic Cambisols of Egu where it was high (21-50 mg kg<sup>-1</sup>) (Jones, 2003).

From the forgoing discussions, it can be concluded that the major agricultural soils in the CASCAPE intervention kebeles have problems related to organic matter level (all the major soils), total nitrogen (Luvisols at Bilisuma and Kakali, Calcic Vertisols at Were Mahamed, Grumic Vertisols (Rhodic) at Bilisuma, and Cambisols of Egu), and Zinc (Grumic Vertisols (Rhodic and Chromic) of Bilisuma). Therefore, these soils require management interventions that can alleviate these limitations. Building organic matter content of the soils should be top priority given its positive impact on physical, chemical, and biological properties of soils, all of which are important for maintaining soil health. The fertilizer blend that should be provided to farmers of the four kebeles and other kebeles with similar soil types should contain nitrogen and Zn. Nevertheless, the amount of each of these nutrient elements to be applied for each soil and crop types has to be determined experimentally.

#### 3.5.3.4. Agronomic Interpretation of Major Soil Types

The major agricultural soils identified from opening pedons are Haplic Cambisols, Haplic Luvisols, Grumic Vertisols and Calcic Vertisols.

The Cambisols are deep enough to support cultivation of most food crops and are well structured with moderately acidic pH at the surface layer and neutral in the subsurface layers. This pH range is considered as preferred pH range for most crops. Nevertheless, these soils are with very low organic carbon and total nitrogen contents. The soils are fertile with medium to high levels of exchangeable bases, high available phosphorus, and medium to high levels of Zn, Cu, Mn, and Fe.

The Haplic Luvisols are 60-200+ cm deep and, hence, are suitable for production of annual and perennial crops. They are well structured with high clay content and pH that is between moderately acidic to neutral. The soils were, nevertheless, very low in their organic carbon and low in their total nitrogen content. The soils are fertile except their very low level of Zn.

The Vertisols are >180 cm deep, well structured and with high clay content. Nevertheless, the wedge-shaped structure covered by the slickensides may create an internal drainage problem once the cracks are closed. The soils are also with a high clay content. They have a favorable pH range that varies between moderately acidic to moderately alkaline pH range. Similar to the other soil types, they were very low in their organic carbon level and low in their total nitrogen content. On the other hand, the soils are rich in basic cations, available phosphorus, sulphur, Mn, Fe, and Cu. The Grumic Vertisols of Bilisuma were, however, very low in their Zn content.

### 3.6. Soils of CASCAPE Intervention Kebeles in Meta Woreda

#### 3.6.1. The Soil-Landscape in Meta Woreda

##### 3.6.1. 1. Geology

Meta Woreda is among the Woredas found in east Hararghe Highlands. Therefore, its geology is very much similar to the geology of Haramaya and Kombolcha Woredas although there are notable differences in some parts of the Woreda. The geology of this Woreda was also shaped by processes that took place during the pre-historic Gondwana Continent and later by the Triassic, Jurassic, and Cretaceous periods (Mohr, 1964; Tamir, 1974). In some parts of the Woreda, the original rocks were dominantly the Pre-Cambrian granite and gneiss, which were later re-deposited as limestones and sandstones during the Triassic, Jurassic and Cretaceous periods when the sea again covered the eastern part of the country.

Furthermore, the recently published geological map of the country, edited in 1996 at a scale of 1:2,000,000, also indicates that the geology of the Woreda is dominated by the Hamanlei, Adigrat, Urandab, and Alage formations. The Hamanlei and Adigrat formations consist of limestones and sandstones, respectively. The subalkaline basalts and the minor rhyolites and trachytes solidified during Oligocene and Miocene periods, while the shaly limestones and marl were formed during the late Jurassic period.

During the field survey work, these geological features were observed. Chelenko Lola, Hawi Bilisuma, and Durisitu Bilisuma, which are located along the main highway to Harar and Addis Ababa, are dominantly covered by limestone, while Bekelcha Oromia Kebele, which is located to the South of Kulubi, is covered mainly by basaltic rocks. In pocket areas, granitic rocks and sandstones were also observed. The common rock types present in the four kebeles are illustrated in Plate 7.

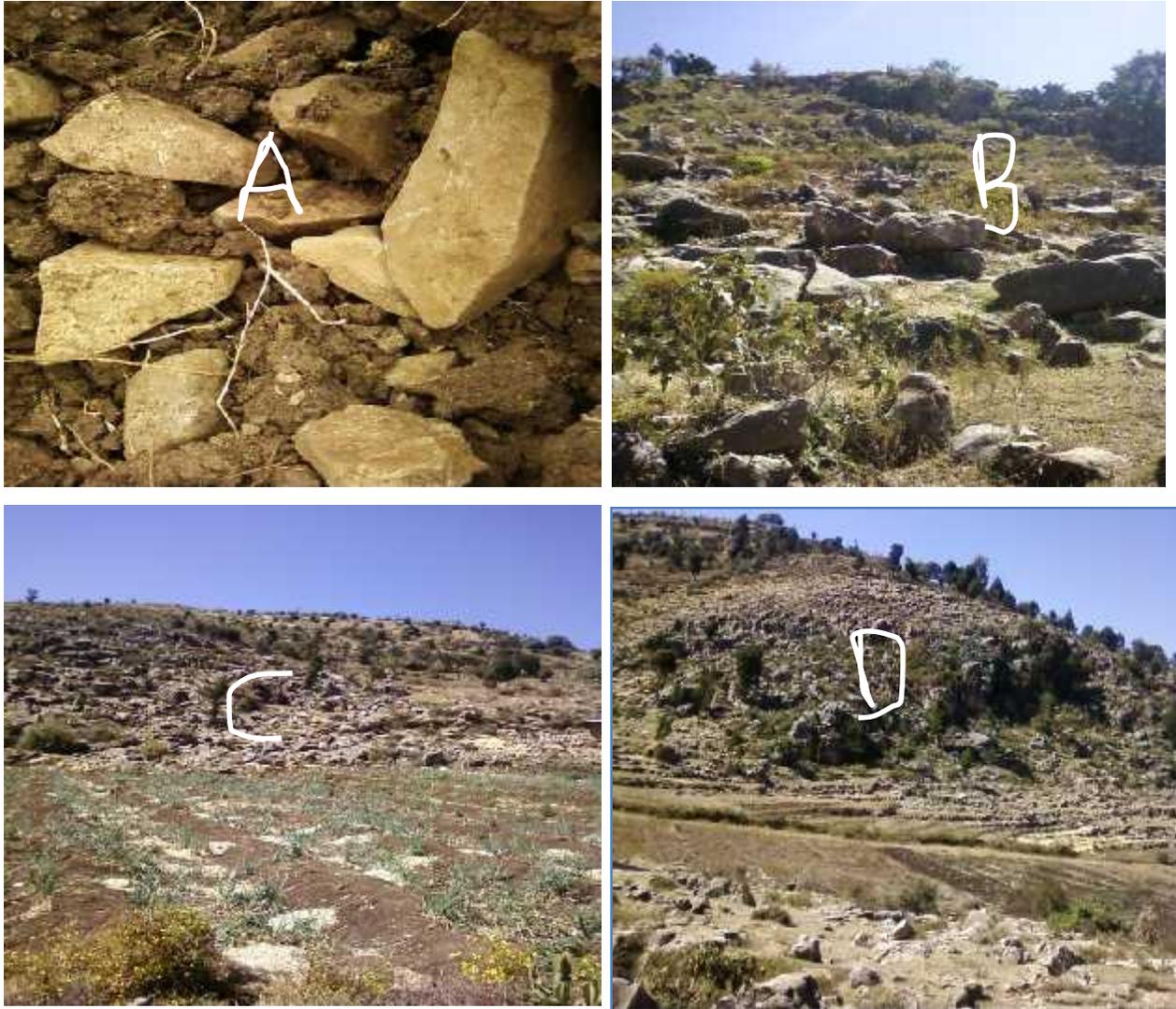


Plate 7. The dominant types of rocks identified in CASCAPE intervention kebeles of Meta Woreda: (A) discolored basalt cobbles mixed with soil in Bekelecha Oromia kebele; (B)-(D) limestone outcrops occupying almost all the hilly areas in Chelenko Lola, Hawi Bilisuma, and Dursitu Bilisuma Kebeles.

3.6.1.2. The Landscape

Although the Woreda as a whole forms part of the eastern plateau, locally dominant landforms differ from place to place. Accordingly, the topography of the four CASCAPE intervention kebeles is nearly level land to strongly steep land with the later occupying larger proportion of the total area in the kebeles. The major landforms vary from valley floors around river courses,

plain and plateaus to extremely undulating and dissected medium gradient hills and mountains. In most parts of the kebeles, a saucer-shaped landscape, with the hills and slopes surrounding the low lying areas, is very common. The slope forms are very complex, but generally vary between straight, concave straight, and convex concave. Plate 8 shows the typical landforms in the intervention kebeles, while Figure 15 shows the contour and elevation maps of the kebeles, together with the locations of the auger observation sites.



Plate 8. Some of the typical landforms in CASCAPE intervention kebeles of Meta Woreda.

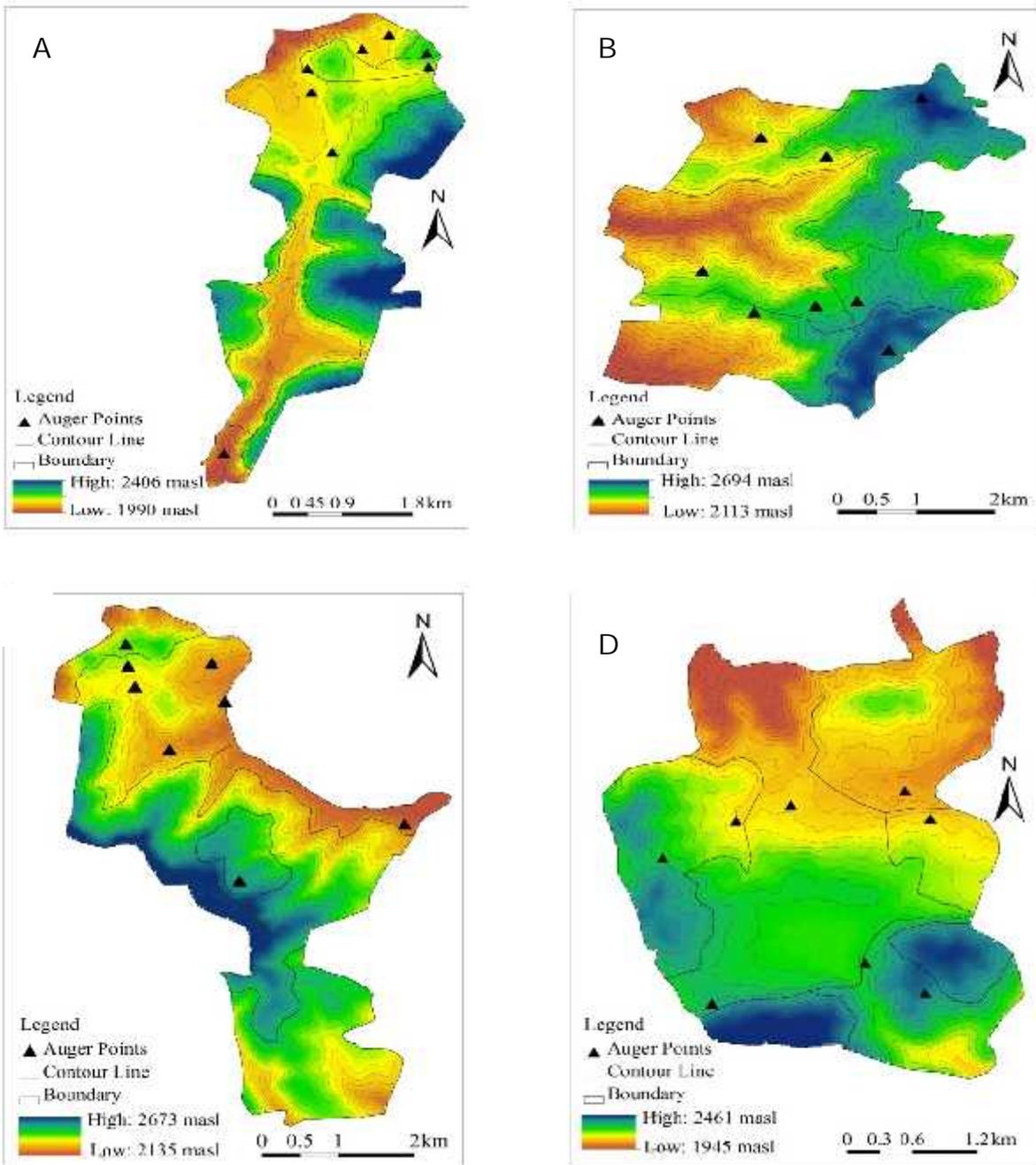


Figure 15. Contour and elevation maps of and location of the auger points in the four CASCAPE intervention kebeles in Meta Woreda: (A) Chelenko Lola, (B) Bekelcha Oromia, (C) Hawi Bilisuma, and (D) Dursitu Bilisuma.

### 3.6.1.3. Land Use

Similar to most other places in Hararghe region, Meta Woreda is also highly populated. On the contrary, land that is suitable for agriculture with low level of management the subsistence farmers use is disproportionately small. This has forced the farming community of the four CASCAPE kebeles in the Woreda to expand agriculture to the steep slopes. During the field survey work, cropped fields on steep slopes and tops of the hills were observed. On these steep slopes, food crops such as sorghum and maize, often intercropped with Khat, are grown on these steep slopes. The farmers are actually using some soil and water conservation practices, such as stone bunds and terraces, when using these steep slopes. Some of the steep slopes, particularly those covered with rock outcrops and degraded vegetation, are now put under rehabilitation following the watershed management program that is being implemented throughout the country. Because of this intervention, some of the degraded hills are now rehabilitating.

The major agricultural lands are concentrated on the middle, lower, and toe slopes. On these slopes, almost every piece of land is put under cultivation. Although the agricultural activity is mainly rainfed, small-scale irrigation is also widely practiced where there is water. The dominant field crops grown in the Woreda, as observed in the four kebeles, are sorghum, maize, teff, wheat, barley, horse bean, haricot bean, and some oil crops. Commonly grown horticultural crops include potato, onion, tomato, garlic, pepper, cabbage, and others. The vegetable crops are grown using both rainfed agriculture and irrigation during the off-season. As a result, they are grown as cash crops. Khat is almost everywhere and is grown both under rainfed and irrigated conditions as the main cash crop.

The agronomic practices used are not different from those in other Woredas. Fertilizer application is based on blanket recommendation of about 100 kg ha<sup>-1</sup>

<sup>1</sup> urea and DAP. Application of organic matter in the form of compost or fresh is also common in the Woreda.

Scattered surface and groundwater resources are available in the four kebeles although serious shortage of water was observed in some parts of Bekelcha Oromia Kebele. Plate 9 shows areas where the agricultural activities are most concentrated.

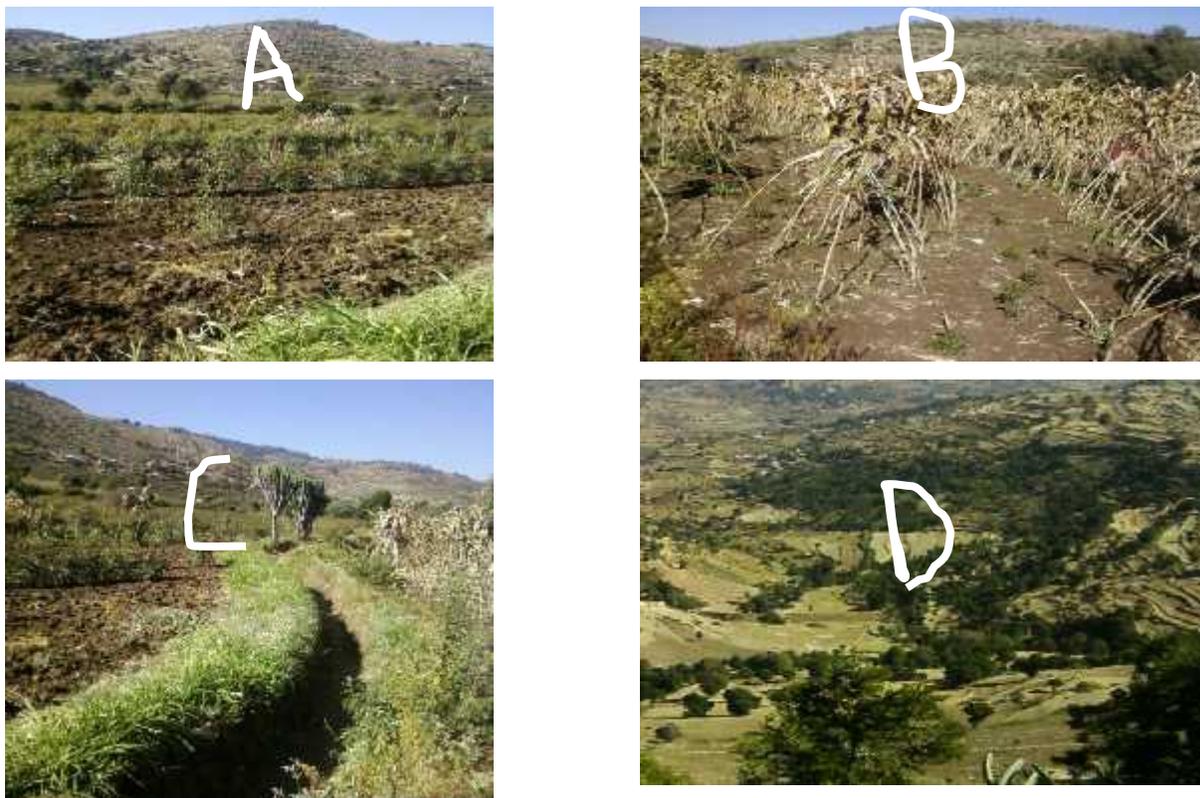


Plate 9. The toe slopes are areas where agricultural activities are most concentrated: Some of the major crops grown on these slopes: (A) Kahat and (B) sorghum, (C) irrigation is key activity on these slopes during the off-season and, (D) the soil and water conservation practices the farmers apply when cultivating the steep slopes.

#### 3.6.1.4. Soil-Landscape (Exploratory Survey Results)

Parent material and topography effects condition the formation of soils in these kebeles more than other soil forming factors do (See Section 3.6.1.5. for the details). Table 16 presents the major soil mapping units identified through the exploratory survey and their area coverage in the respective kebeles. Plate 10 shows the different soil types identified on different parent materials and landforms.

Table 16. Major soil mapping units identified through exploratory soil survey and their area coverage in the four CASCAPE intervention kebeles

Kebele	Soil type	Soil code	Area (ha)	%
Chelenko Lolala	Lithic Leptosols	LP-li	125	10
	Leptosols (Eutric)	LP-eu	350	28
	Regosols	RG	10	1
	Luvic Nitisols (Rhodic)	NT-lv	63	5
	Haplic Luvisols (Chromic)	LV-ha-cr	62	5
	Calcic Vertisols	VR-cc	582	47
	Calcic Fluvisols	FL-cc	41	3
Bekelcha Oromia	Leptosols	LP	382	20
	Regosols	RG	125	7
	Cambisols	CM	482	26
	Luvisols	LV	354	19
	Calcic Gleyic Vertisols	VR-gl-cc	521	28
Hawi Bilisuma	Lithic Leptosols	LP-li	97	6
	Leptosols (Eutric)	LP-eu	659	41
	Luvisols	LV	335	21
	Vertic Luvisols	LV-vr	328	20
	Vertisols	VR	95	6
	Calcic Vertisols	VR-cc	106	7
Dursitu Bilisuma	Lithic Leptosols	LP-li	120	9
	Vertic Cambisols (Skeletal)	CM-vr-sk	202	16
	Luvic Nitisols	NT-lv	77	6
	Nitic Vertic Luvisols (Rhodic)	LV-vr-ni-ro	150	12
	Calcic Vertic Luvisols (Rhodic)	LV-vr.cc-ro	241	19
	Calcic Vertisols (Chromic)	VR-cc-cr	483	38

The results indicate the occurrence of different soil units in the respective kebeles. Figure 16 shows the distribution of these soils within each kebele.



Plate 10. The different soil types formed on different parent materials and landscape positions in the four CASCAPE intervention kebeles in Meta Woreda.

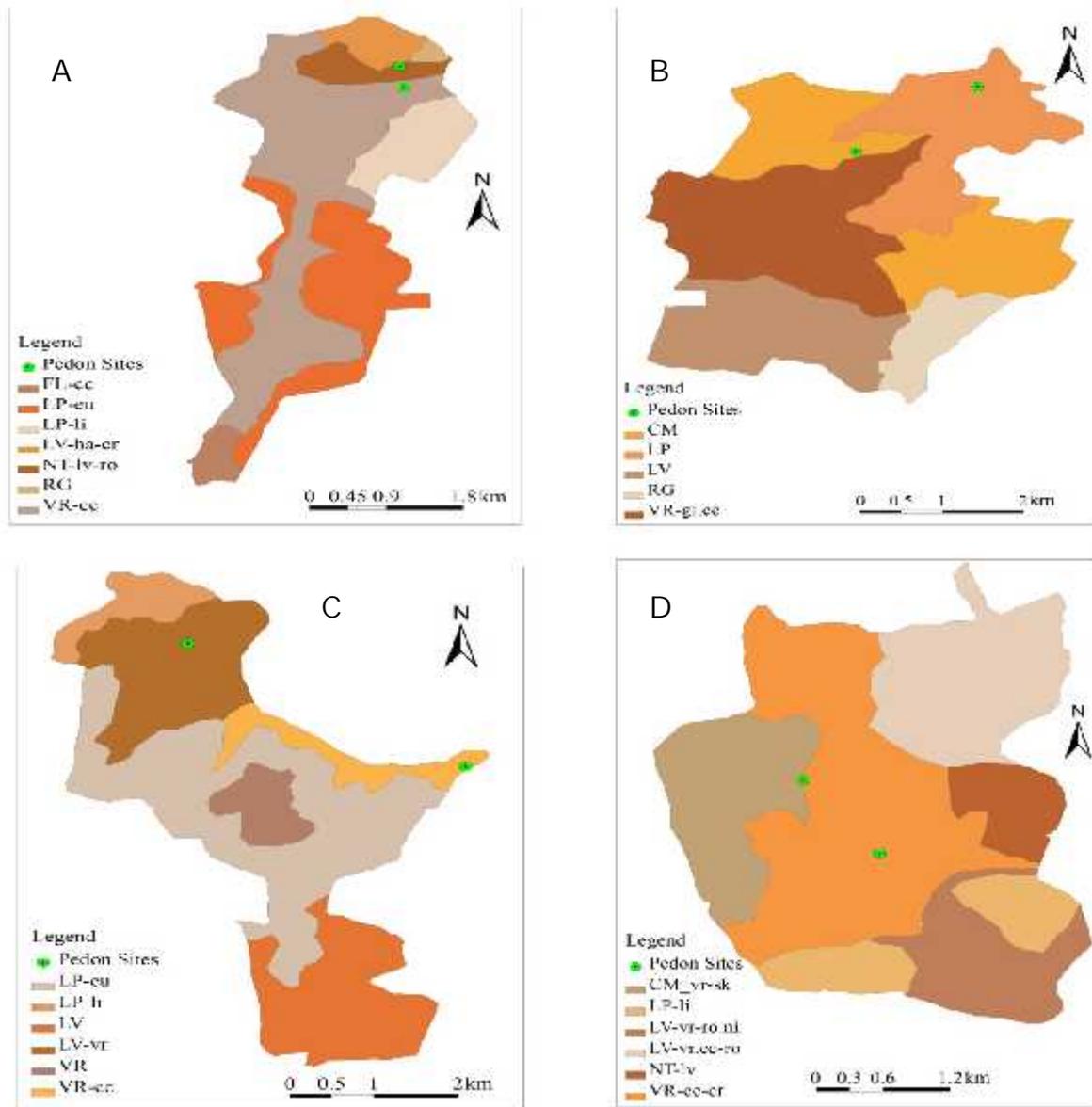


Figure 16. Exploratory soil map of the four CASCAPE intervention kebeles in Meta Woreda and location of pedon sites: (A) Chelenko Lola, (B) Bekelcha Oromia, (C) Hawi Bilisuma, and (D) Dursitu Bilisuma.

#### 3.6.1.5. The Soil-Landscape (Final)

The different soil mapping units identified, the soil-landscape and their area coverage in the respective kebeles is indicated in Table 17.

Leptosols occur on the steepest parts of hills and mountains and are developed on different parent materials that are occurring in each kebele. Those in Chelenko Lola, Hawi Bilisuma, and Dursitu Bilisuma are developed mainly on granitic and limestone parent materials, while those in Bekelecha Oromia are formed from basaltic parent materials. Furthermore, those formed from granitic parent materials are found to be coarser in their texture, while those developed on limestone and basaltic parent materials are generally finer in their texture. The Regosols identified in Chelenko Lola also occur on steep slopes of the sloping landforms and are developed from granitic parent material.

The Cambisols, on the other hand, occur on different landforms ranging from level land (toe slope) in Dursitu Bilisuma to lower slope of sloping landform in Bekelcha Oromia Kebele. They are developed mainly on basaltic parent materials and also sandstone. In localized pocket areas, they are also formed from limestone parent material in the other kebeles. They also occur as associations with Luvisols and Vertisols.

The Haplic Nitisols occur on the middle slope of a sloping landform in Chelenko Lola and lower slope of a sloping landform in Hawi Bilisuma Kebele. These soils are developed on sandstone and granite parent materials in Chelenko Lola, while in Hawi Bilisuma, they are formed on sandstone parent material. Because of the nature of their parent materials, they are relatively coarser in texture as compared to those soils developed on limestone and basaltic parent materials. In small pocket areas, they also occur in association with Luvisols and Vertisols.

The Luvisols occur on a wide range of landforms and are developed from different parent materials in the kebeles. The Vertic Gleyic Luvisols (Hypereutric, Clayic, Chromic) occur on upper slope of sloping land in Bekelcha Oromia and are developed on basaltic parent material. The Haplic Luvisols (Chromic) in Chelenko Lola occur on the lower slopes of sloping landform and are formed from sandstone parent material. The Calcic Luvisols (Hypereutric, Clayic) in Hawi Bilisuma Kebele occur in the valley and are developed on basaltic parent material. The Vertic Luvisols (Hypereutric, Clayic, Chromic) in Dursitu Bilisuma also occur on level land and are formed on basalt parent material. On the other hand, Nitic Vertic Luvisols (Rhodic) occur on level to sloping land and developed on mixed limestone and sandstone parent materials. The common associations with the Luvisols are Nitisols and Vertisols.

The Vertisols occur mainly on the lower slopes of sloping land and level lands and are developed mainly from basalt and limestone parent materials. The Calcic Gleyic Vertisols (Calcaric, Rhodic) in Chelenko Lola occur in the valley floor and are developed from limestone parent material. The Calcic Gleyic Vertisols (Eutric, Pellic, Chromic) occupy the level land in Dursitu Kebele and are developed from mixed parent material of basalt, sandstone, and limestone. They also occur as association in Luvisol and some Cambisol areas.

The Fluvisols do not occupy significant areas. They occur within the valleys in the periphery of permanent and intermittent water bodies. They are developed from alluvial materials of different origin.

Figure 17 shows a rough sketch of a representative soil-landscape in the four kebeles. Some of the pedons opened on major agricultural lands in the four kebeles are illustrated in Plate 11. The geographic distribution of the soils in each kebele is depicted in Figure 18.

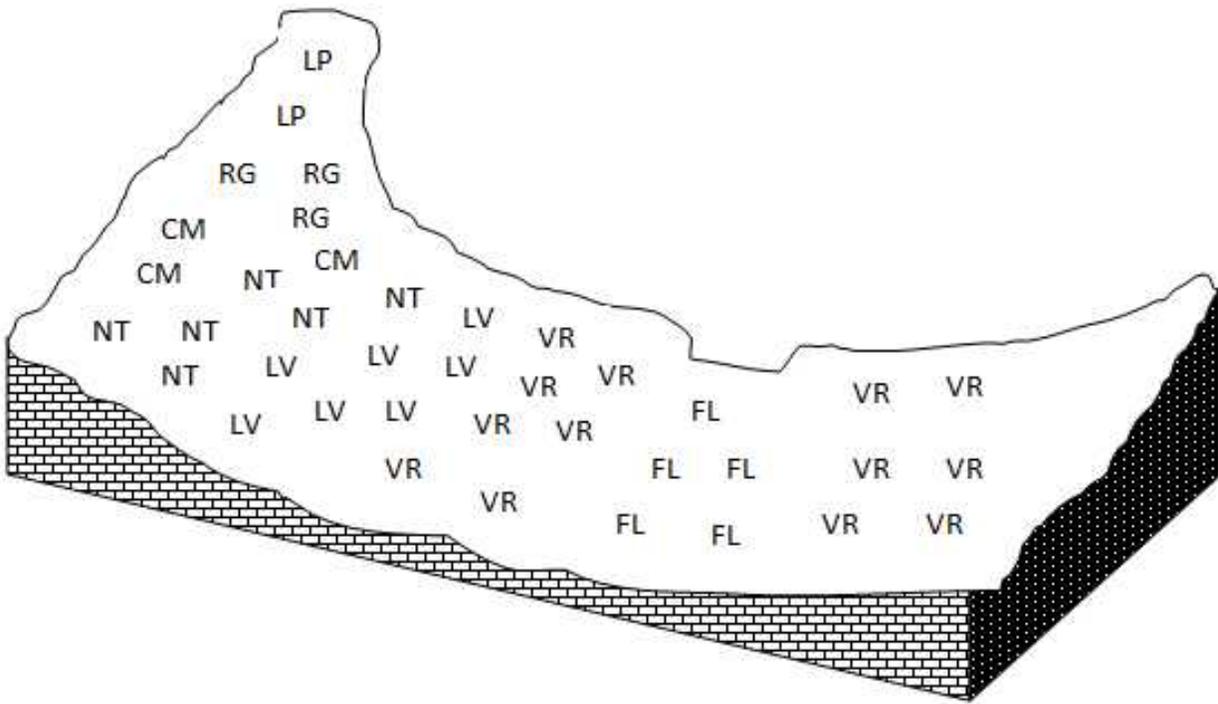


Figure 17. An indicative sketch of representative soil-landscape in the four CASCAPE intervention kebeles in Meta Woreda.

Table 17. The major mapping units and their area coverage in the four CASCAPE intervention kebeles in Meta Woreda

Kebele	Major landform (Landscape unit)	Soil type	Soil code	Area (ha)	%	Elevation (masl)*
Chelenko Lola	Steep land	Leptosols (Eutric)	LP-eu	350	28	2160-2400; 2160-2300
	Steep land	Lithic Leptosol	LP-li	125	10	2200-2400
	Sloping land	Regosols	RG	10	1	2180-2200
	Sloping land	Haplic Nitisol (Eutric, Rhodic)	NT-ha-eu.ro	63	5	2140-2200
	Sloping land	Haplic Luvisols (Chromic)	LV-ha-cr	62	5	2040-2180
	Level land (valley)	Calcic Gleyic Vertisols (Calcaric, Rhodic)	VR-gl-cc-ca.eu	582	47	2000-2180
	Level land (valley)	Calcic Fluvisols	FL-cc	41	3	2020-2160
Bekelcha Oromia	Steep land	Lithic Leptosols	LP-li	40	2	2500-2660
	Steep land	Leptosols (Eutric)	LP-eu	169	9	2500-2640
	Sloping land	Haplic Cambisols (Eutric)	CM-ha-eu	460	25	2160-2460
	Sloping land	Luvisols	LV	304	16	2120-2480
	Sloping land	Vertic Gleyic Luvisols (Hypereutric, Clayic, Chromic)	LV-gl-vr-je.ce.cr	193	10	2420-2680
	Sloping land	Calcic Gleyic Vertisols	VR-gl-cc	698	37	2160-2580
Hawi Bilisuma	Steep land	Leptosols (Eutric)	LP-eu	565	35	2360-2660
	Steep land	Lithic Leptosols	LP-li	96	6	2180-2400
	Sloping land	Haplic Nitisols (Eutric, Chromic)	NT.ha.eu.cr	96	6	2220-2360
	Level land	Haplic Luvisols	LV-ha	335	21	2240-2440
	Level to sloping land	Vertic Luvisols	LV-vr	252	16	2200-2340
	Level land (valley)	Calcic Luvisols (Hypereutric, Clayic)	LV-cc-je.ce	276	17	2140-2360
Dursitu Bilisuma	Steep land	Lithic Leptosols	LP-li	120	9	2300-2460; 2280-2380
	Sloping land	Vertic Cambisol	CM-vr	138	11	2200-2340
	Level land	Vertic Luvisols (Hypereutric, Clayic, Chromic)	LV-vr-je.ce.cr	600	47	1960-2200
	Sloping land	Nitic Vertic Luvisols (Rhodic)	LV-vr-ni.ro	150	12	2140-2340
	Level land	Calcic Gleyic Vertisols (Eutric, Pellic, Chromic)	VR-gl-cc-eu.pe.cr	266	21	2200-2280

masl = meters above sea level

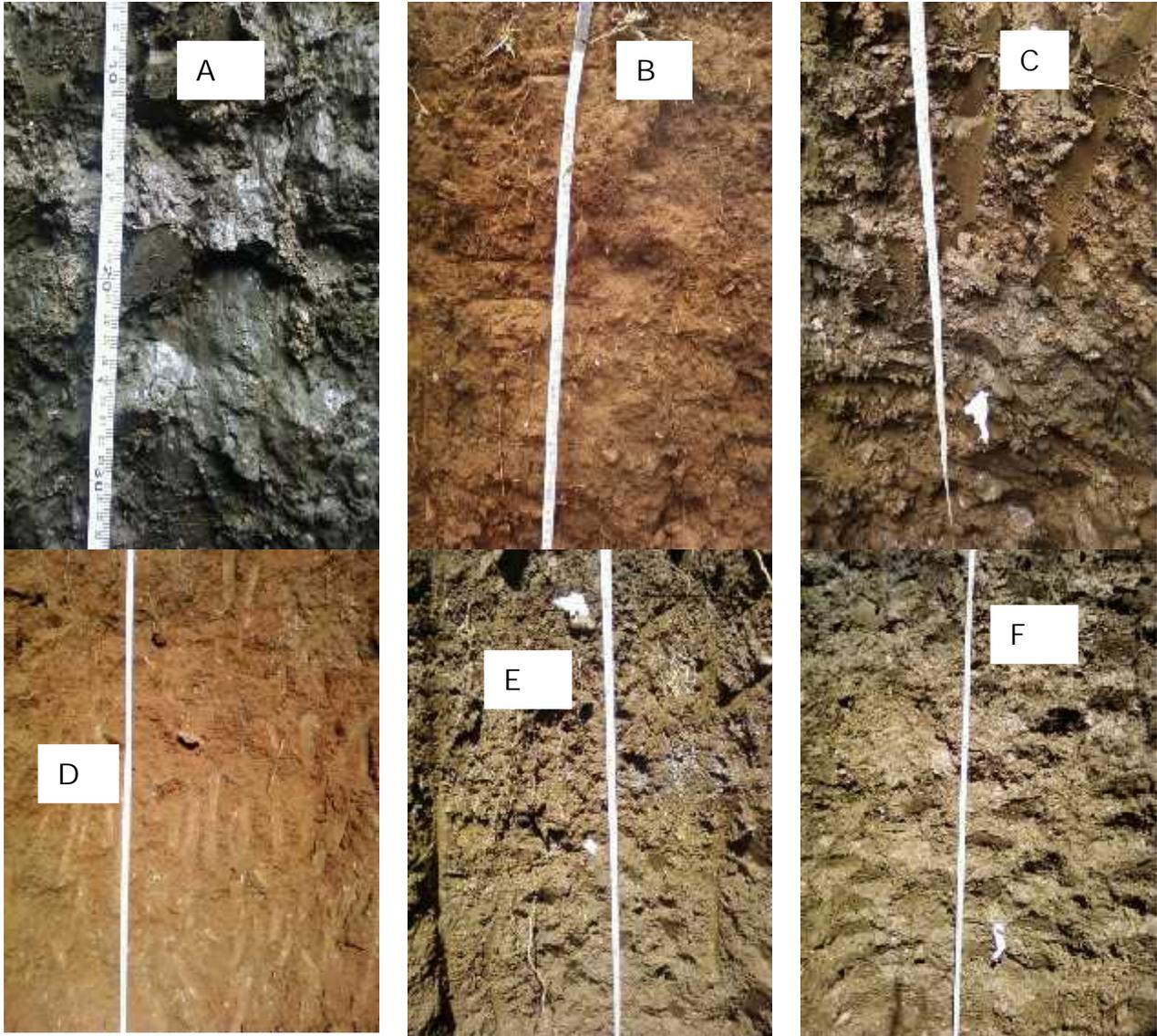


Plate 11. Some of the pedons representing the major agricultural soils in the four CASCAPE intervention kebeles in Meta Woreda: (A) Vertisol (Chelenko Lola), (B) Cambisol (Bekelcha), (C) Vertisol (Bekelcha), (D) Nitisol (Hawi Bilisuma), (E) Luvisol (Dursitu Bilisuma), and (F) Vertisol (Dursitu Bilisuma).

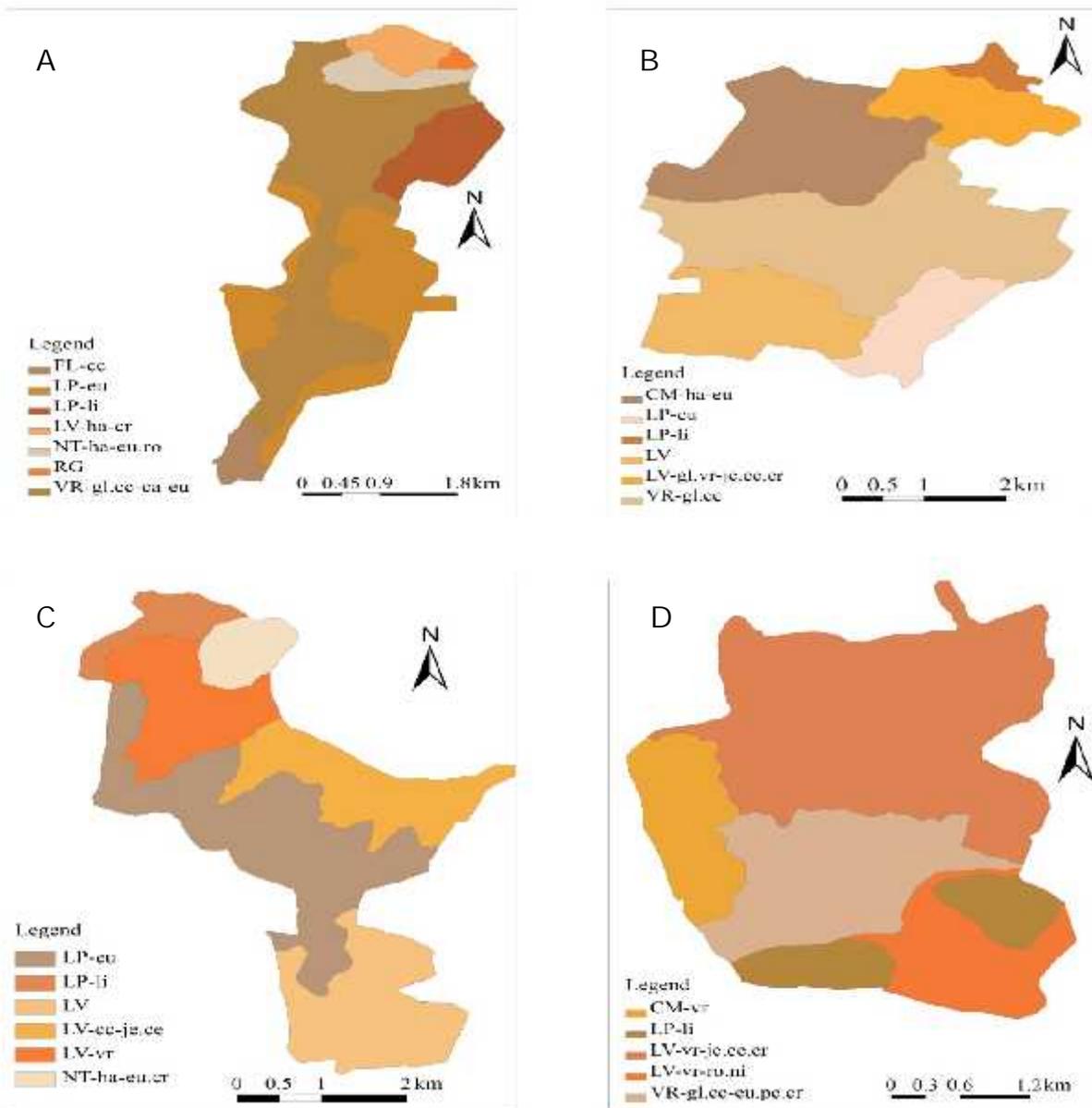


Figure 18. Soil maps of the four CASCAPE intervention kebeles in Meta Woreda: (A) Chelenko Lola, (B) Bekelcha Oromia, (C) Hawi Bilisuma, and (D) Dursitu Bilisuma.

An attempt was also made to correlate the local soil names with the WRB one. Farmers classify their soils based primarily on soil color and also texture. The texture-based naming is used for the coarse textured soils, while color is used indiscriminately for both fine and coarse textured soils. In addition to color and texture, farmers are also using terms that indicate the level of soil fertility. These terms are used to distinguish between soils of the same color or texture. Although the farmers seem to know their soils very well, the limitation of this classification is that soils with very different properties can have the same name if they have the same color and texture. Furthermore, names for the same soil can differ from kebele to kebele or even from village to village. Nevertheless, it can be standardized and used for easy communication among the farmers. The correlations are indicated in Table 18.

Table 18. Correlations among local and WRB soil names in the four CASCAPE intervention kebeles in Meta Woreda

RSG	Local name
Nitisol	Biye Dimma
Vertisol	Biye Guracha
Cambisols (Coarse textured)	Ashewa
Luvisols (dark color)	Biye Guracha
Luvisols	Suphee
Regosol, Leptosols	Ashewa

### 3.6.2. Soil Profile Descriptions and Analytical Data

#### 3.6.2.1. Soil Profiles

A total of 8 pedons (2 per kebele), representing major agricultural soils of the four CASCAPE intervention kebeles in Meta Woreda, were opened. The intervention kebeles are Chelenko Lola, Bekelcha Oromia, Hawi Bilisuma, and Dursitu Bilisuma. In Chelenko Lola, one pedon was opened on middle slope of sloping landform, while the other one was opened on level land (valley floor). In Bekelcha Oromia, one on middle slope and one on upper slope were opened. In Hawi Bilisuma too, one on lower slope of sloping landform and one on level land (valley) were opened. On the other hand, the two pedons in Durisitu Bilisuma Kebele were opened on level land.

Furthermore, 32 auger pits were also described on different landforms in these four kebeles. A total of 34 soil samples were collected from genetic horizons of the 8 pedons and analyzed for their selected physical and chemical properties at the Water Works and Design Supervision Enterprise Soil laboratory in Addis Ababa. The results of field descriptions of the pedons' site and profile characteristics are presented in Table 19.

Table 19. Soil site and profile descriptions of pedons opened in four CASCAPE intervention kebeles in Meta Woreda

Profile ID	HE/MTA/CL/P1	Land cover	Scattered tree species, shrubs and herbaceous plants
Date	31/12 (dd/mm)	Land use	Crop cultivation and animal husbandry
Year	2013	Crop	Cereals, vegetables, khat
Surveyor	Kibebew Kibret	Human influence	Vegetation intensively disturbed, ploughing, terracing
Status	Reference profile description	Surface stone cover	Many
Location country	Ethiopia	Surface stone size	Fine gravel to stones
Location region	East Hararghe	Erosion category	Water, gully
Location woreda	Meta	Erosion area	5-10%
Location kebele	Chelenko Lola	Erosion degree	Moderate
Longitude	41°37'32.5"	Crack width	None
Latitude	09°25'23.6"	Surface drainage	Well
Elevation	2145 m	Soil drainage	Well
Map ID		Flooding frequency	None
Map scale		Depth to groundwater	Not observable
Map unit ID		Depth to bedrock	Not observable
Topography	Moderately steep, 15-30%	Rootable depth	200 cm
Major landform	Medium gradient mountain	Rooted depth	200 cm
Position on slope	Middle slope	Depth of observation	200 cm
Slope form	Concave straight	Local soil type	Biye Dimma
Slope gradient	21%	Field WRB soil type	Nitisol
Geology	Sedimentary	WRB soil type	Haplic Nitisol (Eutric, Rhodic)
Parent material	Sandstone basement		

Horizon	Depth (cm)	Description
Ah	0-20	Red (10R 4/6, moist) and red (10R 4/8, dry) colour; sandy clay; strong very coarse sub-angular blocky structure; extremely hard when dry, very friable when moist, and very sticky and very plastic when wet; common, very fine to fine pores; very few, faint sand and silt coatings; very few, fine coarse fragments of mixed nature; no mottles; very few, fine roots; few burrows; diffuse, smooth boundary; no reaction with dilute HCl and pH value of 6.5.
A1	20-60	Dusky red (10R 3/4, moist) and red (10R 4/6, dry) colour; sandy clay; strong very coarse angular blocky structure; extremely hard (dry), friable (moist), and very sticky and very plastic (wet) consistence; few, very fine to fine pores; no coatings; very few, medium mixed coarse fragments; no mottles; very few, very fine roots; few burrows; gradual, smooth boundary; no reaction with dilute HCl; field measured pH value of 6.5.
A2	60-110	Dusky red (10R 3/4, moist) and red (10R 5/8, dry) colours; sandy clay; strong medium sun-angular blocky to angular blocky structure; very hard (dry), friable (moist), and very sticky and very plastic (wet) consistence; common, very fine to fine pores; no coatings; very few, fine mixed coarse fragments; no mottles; very fine, very few roots; very few burrows; gradual, smooth boundary; no reaction with HCl; field measured pH value of 6.5.
B1	110-150	Dark red (10R 3/6, moist) and red (10R 5/8, dry) colour; clay; strong coarse sub-angular blocky to angular blocky structure; extremely hard (dry), firm (moist), and very sticky and very plastic (wet) consistence; common, very fine pores; no coatings; very few, medium coarse fragments of mixed nature; no mottles; very few, very fine roots; gradual, smooth boundary; no reaction with dilute HCl and pH value of 6.5.
B2	150-200	Red (10R 4/8, moist) and light red (10R 6/8, dry) colour; sandy clay; strong medium sub-angular blocky to angular blocky structure; extremely hard when dry, firm when moist, and very sticky and very plastic when wet; common, very fine pores; no coatings; very few, coarse, coarse fragments of mixed nature; no mottles; very few, very fine roots; no reaction with HCl and field measured pH value of 6.5.

Profile ID	HE/MTA/CL/P2	Land cover	Scattered trees, bushes, herbaceous plants
Date	01/01 (dd/mm)	Land use	Crop cultivation and animal husbandry
Year	2014	Crop	Cereals, vegetables, khat, some fruit trees
Surveyor	Kibebew Kibret	Human influence	Vegetation intensively disturbed, ploughing
Status	Reference profile description	Surface stone cover	Few
Location country	Ethiopia	Surface stone size	Fine
Location region	East Hararghe	Erosion category	Water
Location woreda	Meta	Erosion area	0-5%
Location kebele	Chelenko Lola	Erosion degree	Slight
Longitude	41°37'33.9"	Crack width	Medium (1-2 cm)
Latitude	09°25'12.5"	Crack depth	Deep (10-20 cm)
Elevation	2156 m	Crack distance	Closely spaced (0.2-0.5 m)
Map ID		Surface drainage	Well
Map scale		Soil drainage	Slow
Map unit ID		Flooding frequency	None
Topography	Sloping, 5-10%	Depth to groundwater	Not observable
Major landform	Valley floor	Depth to bedrock	Not observable
Position on slope	Lower slope	Rootable depth	185 cm
Slope form	Convex straight	Rooted depth	185 cm
Slope gradient	8%	Depth of observation	185 cm
Geology	Sedimentary	Local soil type	Biye Guracha
Parent material	Limestone basement	Field WRB soil type	Calcaric Vertisol
		WRB soil type	Calcic Gleyic Vertisol (Calcaric, Eutric)

#### Description of the soil horizons (morphology)

Horizon	Depth (cm)	Description
Apk1	0-20	Very dark brown (10YR 2/2, moist) and very dark gray (7.5YR 3/1, dry) colour; clay; strong medium sub-angular blocky to angular blocky structure; extremely hard when dry, very friable when moist, and very sticky and very plastic when wet; common, very fine to medium pores; few, distinct clay coatings; very few, fine calcium carbonate fragments; no observable mottles; very few, fine roots; very few burrows; clear, smooth boundary; strong effervescence with dilute HCl; field measured pH value of 7.5.
A1K	20-50	Very dark grayish brown (10YR 3/2, moist) and very dark gray (10YR 3/1, dry) colour; clay; strong coarse angular blocky structure; extremely hard (dry), very friable (moist), and very sticky and very plastic (wet) consistence; common, very fine to fine pores; very few, faint clay coatings; very few, fine calcium carbonate fragments; no mottles; very few, very fine roots; very few burrows; clear, smooth boundary; extremely strong effervescence with dilute HCl with pH value of 8.
Ci1k	50-80	Dark grayish brown (10YR 4/2, moist) and dark gray (10YR 4/1, dry) colour; clay; strong coarse angular blocky structure; very hard (dry), very friable (moist), and very sticky and very plastic (wet) consistence; common, very fine to fine pores; very few, faint clay coatings; very few, fine calcium carbonate fragments; very few, very fine faint mottles that are black in colour; very few, very fine roots; no burrows; gradual, smooth boundary; extremely strong reaction with dilute HCl; field measured pH value of 8.5; slickenside.
Cg1ik	80-130	Very dark gray (10YR 3/1, moist) and gray (10YR 5/1, dry) colour; clay; strong very coarse angular blocky structure; extremely hard (dry), very friable (moist), and very sticky and very plastic (wet) consistence; common, very fine pores; very few, faint clay coatings; few, fine calcium carbonate fragments; many, fine, prominent mottles (black); very few, very fine roots; gradual, smooth boundary; extremely strong reaction with dilute HCl; pH value of 8.5; slickensides
Cg2ik	130-185	Dark gray (10YR 4/1, moist) and gray (10YR 5/1, dry) colour; clay; strong very coarse angular blocky structure; extremely hard when dry, very friable when moist, and very sticky and very plastic when wet; common, very fine pores; very few, faint clay coatings; few, fine calcium carbonate fragments; many, fine, prominent black mottles; no roots; extremely strong reaction with dilute HCl; field measured pH value of 8.5; slickensides.

Profile ID	HE/MTA/BO/P1	Land cover	Protected forest, bushes, herbaceous plants
Date	02/01 (dd, mm)	Land use	Crop cultivation and animal husbandry
Year	2014	Crop	Cereals, vegetables, khat, fruit trees
Surveyor	Kibebew Kibret	Human influence	Vegetation disturbed, ploughing, terracing
Status	Reference profile description	Surface stone cover	Few
Location country	Ethiopia	Surface stone size	Medium gravel to large boulders
Location region	East Hararghe	Erosion category	Water, gully
Location woreda	Meta	Erosion area	5-10%
Location kebele	Bekelcha Oromia	Erosion degree	Moderate
Longitude	41°38'44"	Crack width	None
Latitude	09°24'36.9"	Surface drainage	Rapid
Elevation	2372 m	Soil drainage	Well
Map ID		Flooding frequency	None
Map scale		Depth to groundwater	Not observable
Map unit ID		Depth to bedrock	Not observable
Topography	Moderately steep, 15-30%	Rootable depth	70 cm
Major landform	Medium gradient mountain	Rooted depth	70 cm
Position on slope	Middle slope	Depth of observation	70 cm
Slope form	Straight	Local soil type	Ashewa
Slope gradient	25%	Field WRB soil type	Cambisol
Geology	Sedimentary	WRB soil type	Haplic Cambisol (Eutric)
Parent material	Sandstone basement		

#### Description of the soil horizons (morphology)

Horizon	Depth (cm)	Description
Ah	0-10	Reddish brown (2.5YR 4/4, moist) and red (2.5YR 4/8, dry) colour; silt loam; strong moderate sub-angular blocky structure; hard when dry, very friable when moist, and sticky and plastic when wet; many, medium to fine pores; no coatings; very few, very fine mixed quartz and feldspar fragments; no mottles; very few, fine roots; very few burrows; diffuse, smooth boundary; no reaction with dilute HCl and pH value of 6.5.
A	10-30	Red (2.5YR 4/6, moist) and reddish brown (2.5YR 5/4, dry) colour; clay rich silt loam; moderate coarse sub-angular blocky to angular blocky structure; very hard (dry); very friable (moist), and sticky and plastic (wet) consistence; common fine to medium pores; very few, faint sesquioxide coatings; few, fine to medium mixed quartz and feldspar fragments; no observable mottles; very few, very fine to fine roots; very few burrows; diffuse, smooth boundary; no reaction with dilute HCl and field measured pH value of 6.5.
AC	30-50	Red (2.5YR 4/6, moist) and red (2.5YR 5/6, dry) colour; sandy clay loam; moderate medium sub-angular blocky to angular blocky structure; very hard when dry, friable when moist, and sticky and plastic when wet; few, very fine to fine pores; very few, faint clay coatings; common, fine feldspar and quartz fragments; no mottles; very few, very fine to fine roots; very few burrows; gradual, smooth boundary; no reaction with dilute HCl; field measured pH value of 6.5.
C	50-70	Reddish brown (2.5YR 4/4, moist) and light red (2.5YR 6/6, dry) colour; sandy clay loam; moderate coarse sub-angular blocky structure; very hard (dry), friable (moist), and sticky and plastic (wet) consistence; very few, fine pores; very few, faint clay coatings; common, medium feldspar and not known coarse fragments; no mottles; very few, very fine roots; very few burrows; no reaction with dilute HCl; pH value of 6.5.

Profile ID	HE/MTA/BO/P2	Land cover	Different scattered tree species, some patchy bushes, herbaceous
Date	02/01 (dd/mm)	Land use	Crop cultivation and animal husbandry
Year	2014	Crop	Cereals, khat, vegetables
Surveyor	Kibebew Kibret	Human influence	Vegetation intensively disturbed, terracing, ploughing
Status	Reference profile description	Surface stone cover	Many
Location country	Ethiopia	Surface stone size	Medium gravel to boulders
Location region	East Hararghe	Erosion category	Water, rill
Location woreda	Meta	Erosion area	0-5%
Location kebele	Bekelcha Oromia	Erosion degree	Slight
Longitude	41°39'33.3"	Crack width	Extremely wide (> 10 cm)
Latitude	09°25'9.6"	Crack depth	Deep (10-20 cm)
Elevation	2660 m	Crack distance	Closely spaced (0.2-0.5 m)
Map ID		Surface drainage	Well
Map scale		Soil drainage	Slow
Map unit ID		Flooding frequency	None
Topography	Moderately steep, 15-30	Depth to groundwater	Not observable
Major landform	Medium gradient mountain	Depth to bedrock	Not observable
Position on slope	Upper slope	Rootable depth	185 cm
Slope form	Concave	Rooted depth	60 cm
Slope gradient	26%	Depth of observation	180 cm
Geology	Igneous	Local soil type	Biye Guracha (Suphe)
Parent material	Basalt basement	Field WRB soil type	Vertisol
		WRB soil type	Vertic Gleyic Luvisol (Hypereutric, Clayic, Chromic)

#### Description of the soil horizons (morphology)

Horizon	Depth (cm)	Description
Ap	0-15	Dark brown (7.5YR 3/3, moist) and brown (7.5YR 4/2, dry) colour; clay; strong very coarse sub-angular blocky structure; extremely hard when dry, very friable when moist, and very sticky and very plastic when wet; many very fine to medium pores; few, faint clay coatings; few, fine to medium unspecified coarse fragments; no mottles; few, fine roots; common burrows; clear, smooth boundary; no reaction with HCl and field measured pH value of 6.5.
Ai1	15-60	Black (7.5YR 2.5/1, moist) and dark brown (7.5YR 3/2, dry) colour; clay; strong coarse angular blocky structure; extremely hard when dry, very friable when moist, and very sticky and very plastic when wet; common, very fine to fine pores; few, faint coatings; very few, fine unknown coarse fragments; no mottles; very few, fine roots; few burrows; gradual, irregular boundary; no reaction with HCl and field measured pH value of 6.5; slickensides
Ai2	60-95	Dark reddish brown (5YR 3/2, moist) and brown (7.5YR 4/3, dry) colour; clay; strong very coarse angular blocky structure; extremely hard (dry), friable (moist), and very sticky and very plastic (wet) consistence; common, very fine pores; very few, faint clay coatings; very few, fine unspecified coarse fragments; very few, very fine, faint red mottles; no roots, but very few burrows; diffuse, irregular boundary; no reaction with dilute HCl and field measured pH value of 6.5; slickensides.
Bt1i	95-135	Very dark brown (10YR 2/2, moist) and dark gray (7.5YR 4/1, dry) colour; clay; strong coarse sub-angular blocky to angular blocky structure; extremely hard (dry), friable (moist), and very sticky and very plastic (wet) consistence; few, very fine to fine pores; very few, faint clay coatings; very few, fine unspecified coarse fragments; very few, very fine, faint black mottles; no roots and other biological activities; gradual, irregular boundary; no reaction with dilute HCl and pH value of 6.5; slickensides.
Bt2i	135-180	Dark olive brown (2.5Y 3/3, moist) and brown (7.5YR 5/1, dry) colour; clay; strong medium angular blocky structure; extremely hard when dry, friable when moist, and very sticky and very plastic when wet; few, very fine pores; very few, faint clay coatings; very few, fine unspecified coarse fragments; very few, very fine black mottles; no roots and indicators of other biological activity; no reaction with dilute HCl; field measured pH value of 6.5; slickensides.

Profile ID	HE/MTA/HB/P1	Land cover	Scattered tree species, patchy bushes and herbaceous plants
Date	04/01 (dd/ mm)	Land use	Crop cultivation and animal husbandry
Year	2014	Crop	Cereals, vegetables, khat
Surveyor	Kibebew Kibret	Human influence	Vegetation intensively disturbed, ploughing, terracing
Status	Reference profile description	Surface stone cover	Common
Location country	Ethiopia	Surface stone size	Medium gravel to large boulders
Location region	East Hararghe	Erosion category	Water, mostly gully
Location woreda	Meta	Erosion area	5-10%
Location kebele	Hawi Bilisuma	Erosion degree	Severe
Longitude	41°42'56.8"	Crack width	None
Latitude	09°26'23.8"	Surface drainage	Well
Elevation	2272 m	Soil drainage	Well
Map ID		Flooding frequency	None
Map scale		Depth to groundwater	Not observable
Map unit ID		Depth to bedrock	Not observable
Topography	Moderately steep, 15-30	Rootable depth	200 cm
Major landform	Medium gradient hill	Rooted depth	200 cm
Position on slope	Lower slope	Depth of observation	200 cm
Slope form	Straight	Local soil type	Biye Dimma
Slope gradient	22%	Field WRB soil type	Nitisol
Geology	Sedimentary	WRB soil type	Haplic Nitisol (Eutric, Chromic)
Parent material	Sandstone basement		

#### Description of the soil horizons (morphology)

Horizon	Depth (cm)	Description
Ah	0-30	Dark reddish brown (2.5YR 3/4, moist) and red (2.5YR 4/6, dry) colour; clay; strong coarse sub-angular blocky to angular blocky structure; very hard when dry, very friable when moist, and very sticky and very plastic when wet; common, very fine to medium pores; very few, faint clay coatings; very few, fine quartz fragments; no mottles; few, fine roots; common termite channels; diffuse, smooth boundary; no reaction with HCl; pH value of 6.
B1	30-100	Red (2.5YR 2/8, moist) and red (2.5YR 4/6, dry) colour; clay; strong coarse angular blocky; very hard when dry, very friable when moist, and very sticky and very plastic when wet; common, very fine to fine pores; very few, faint clay coatings; very few, fine quartz fragments; no mottles; very few, fine roots; common termite channels; diffuse, smooth boundary; no reaction with HCl and field measured pH value of 6.5.
B2	100-120	Red (2.5YR 4/8, moist) and red (2.5YR 4/8, dry) colour; clay; strong very coarse prismatic structure; very hard (dry), very friable (moist), and very sticky and very plastic (wet) consistence; few, very fine to fine pores; very few, faint clay coatings; very few, fine quartz fragments; no mottles; very few, very fine roots; few termite channels; diffuse, smooth boundary; no reaction with HCl and field measured pH value of 6.5.
B3	120-200	Dark red (2.5YR 3/6, moist) and red (2.5YR 5/6, dry) colour; clay; strong coarse prismatic structure; very hard when dry, very friable when moist, and very sticky and very plastic when wet; few, very fine pores; very few, faint clay coatings; very few, fine quartz fragments; no mottles; very few, very fine roots; few termite channels; no reaction with dilute HCl; field measured pH value of 6.5.

Profile ID	HE/MTA/HB/P2	Land cover	Patchy bush and herbaceous plants
Date	04/01 (dd/mm)	Land use	Crop cultivation and animal husbandry
Year	2014	Crop	Cereals, vegetables, khat, some fruit trees
Surveyor	Kibebew Kibret	Human influence	Vegetation intensively disturbed, ploughing, irrigation
Status	Reference profile description	Surface stone cover	Few
Location country	Ethiopia	Surface stone size	Medium gravel to large boulders
Location region	East Hararghe	Erosion category	Water, big gully
Location woreda	Meta	Erosion area	5-10%
Location kebele	Hawi Bilisuma	Erosion degree	Moderate
Longitude	41°44'42"	Crack width	Medium (1-2 cm)
Latitude	09°25'31"	Crack depth	Medium (2-10 cm)
Elevation	2137 m	Crack distance	Closely spaced (0.2-0.5 m)
Map ID		Surface drainage	Well
Map scale		Soil drainage	Well
Map unit ID		Flooding frequency	None
Topography	Very gently sloping, 1-2%	Depth to groundwater	Not observable
Major landform	Valley floor	Depth to bedrock	Not observable
Position on slope	Toe slope	Rootable depth	200 cm
Slope form	Straight concave	Rooted depth	200 cm
Slope gradient	2%	Depth of observation	200 cm
Geology	Igneous	Local soil type	Biye Guracha
Parent material	Basalt basement	Field WRB soil type	Calcic Vertisol
		WRB soil type	Calcic Luvisol (Hypereutric, Clayic)

#### Description of the soil horizons (morphology)

Horizon	Depth (cm)	Description
Ah	0-30	Dark brown (7.5YR 3/2, moist) and black (2.5Y 2.5/1, dry) colour; clay; strong medium sub-angular blocky and granular structure; extremely hard when dry, very friable when moist, and very sticky and very plastic when wet; common, very fine to medium pores; very few, faint clay coatings; very few, fine calcium carbonate fragments; no mottles; few, fine roots; very few burrows; clear, smooth boundary; slight reaction with dilute HCl; field measured pH value of 6.5.
Ak1	30-130	Dark brown (7.5YR 3/3, moist) and dusky red (2.5YR 3/2, dry) colour; clay; strong coarse prismatic structure; extremely hard when dry, very friable when moist, and very sticky and very plastic when wet; common, very fine to fine pores; very few, faint clay coatings; very few, fine calcium carbonate fragments; no observable mottles; very few, very fine roots; no other indicators of biological activity; gradual, smooth boundary; strong reaction with dilute HCl; field measured pH value of 7.5.
Bt1k	130-200	Very dark brown (7.5YR 2.5/2, moist) and black (7.5YR 2.5/1, dry) colour; clay; strong very coarse prismatic structure; extremely hard (dry), friable (moist), and very sticky and very plastic (wet) consistence; common, very fine pores; very few, faint clay coatings; few, fine calcium carbonate fragments; very few, very fine roots; no other indicators of biological activity; strong effervescence with dilute HCl; field measured pH value of 8.

Profile ID	HE/MTA/DB/P1	Land cover	Riverine vegetation, bushes, and herbaceous
Date	06/01 (dd/mm)	Land use	Crop cultivation and animal husbandry
Year	2014	Crop	Cereals, legumes, khat, vegetables, some fruit trees
Surveyor	Kibebew Kibret	Human influence	Vegetation intensively disturbed, terracing, irrigation
Status	Reference profile description	Surface stone cover	Few
Location country	Ethiopia	Surface stone size	Medium gravel to boulders
Location region	East Ethiopia	Erosion category	Water, mainly gully
Location woreda	Meta	Erosion area	5-10%
Location kebele	Dursitu Bilisuma	Erosion degree	Moderate
Longitude	41°35'23.7"	Crack width	Extremely wide (> 10 cm)
Latitude	09°24'56.4"	Crack depth	Deep (10-20 cm)
Elevation	2146 m	Crack distance	Closely spaced (0.2-0.5 m)
Map ID		Surface drainage	Well
Map scale		Soil drainage	Well
Map unit ID		Depth to groundwater	Not observable
Topography	Sloping, 5-10%	Depth to bedrock	Not observable
Major landform	Level land, plateau	Rootable depth	165 cm
Position on slope	Medium-gradient escarpment zone	Rooted depth	165 cm
Slope form	Convex concave	Depth of observation	160 cm
Slope gradient	10%	Local soil type	Suphee
Geology	Igneous	Field WRB soil type	Vertic Luvisol
Parent material	Basalt basement	WRB soil type	Vertic Luvisol (Hypereutric, Clayic, Chromic)

#### Description of the soil horizons (morphology)

Horizon	Depth (cm)	Description
Ap	0-30	Very dark gray (10YR 3/1, moist) and very dark grayish brown (10YR 3/2, dry) colour; clay; moderate fine granular to sub-angular blocky; very hard when dry, very friable when moist, and very sticky and very plastic when wet; common, fine to medium pores; few, distinct clay coatings; very few, fine coarse fragments of unknown nature; no observable mottles; few, fine roots; very few burrows; clear, smooth boundary; no reaction with dilute HCl and field measured pH value of 6.5.
A	30-60	Black (7.5YR 2.5/1, moist) and dark grayish brown (10YR 4/2, dry) colour; clay; moderate fine sub-angular blocky structure; very hard (dry), very friable (moist), and very sticky and very plastic (wet) consistence; common, fine pores; fine, faint clay coatings; very few, fine coarse fragments of unknown nature; very few, very fine, faint mottles that are red in colour; very few, very fine to fine roots; very few termite channels; clear, smooth boundary; moderate reaction with dilute HCl; field measured pH value of 7.
Bt1	60-90	Reddish brown (2.5Y 4/3, moist) and grayish brown (10YR 5/2, dry) colour; clay; weak very fine sub-angular blocky structure; hard when dry, friable when moist, and very sticky and very plastic when wet; common, very fine to fine pores; very few, faint clay coatings; few, fine to medium coarse fragments of unknown nature; very few, very fine, faint mottles (black); very few, very fine to fine roots; no other indicators of biological activity; clear, smooth boundary; moderate reaction with dilute HCl; field measured pH value of 7.
Bt2	90-165	Dark brown (7.5YR 3/2, moist) and grayish brown (10YR 5/2, dry) colour; clay; strong moderate sub-angular blocky to angular blocky structure; extremely hard (dry), friable (moist), and very sticky and very plastic (wet) consistence; common, very fine pores; very fine, faint clay coatings; very few, fine coarse fragments of unknown nature; very few, very fine, faint black mottles; very few, very fine roots with no other indicators of biological activity; slight reaction with dilute HCl; field measured pH value of 7.

Profile ID	HE/MTA/DB/P2	Land cover	Patchy bushes and herbaceous
Date	06/01 (dd/mm)	Land use	Crop cultivation and animal husbandry
Year	2014	Crop	Cereals, vegetables, khat
Surveyor	Kibebew Kibret	Human influence	Ploughing, flood/furrow irrigation
Status	Reference profile description	Surface stone cover	Very few
Location country	Ethiopia	Surface stone size	Stones
Location region	East Ethiopia	Erosion category	Water
Location woreda	Meta	Erosion area	0-5%
Location kebele	Dursitu Bilisuma	Erosion degree	Slight
Longitude	41°35'45.7"	Crack width	Extremely wide (> 10 cm)
Latitude	09°24'30.6"	Crack depth	Deep (10-20 cm)
Elevation	2238 m	Crack distance	Closely spaced (0.2-0.5 m)
Map ID		Surface drainage	Well
Map scale		Soil drainage	Well
Map unit ID		Flooding frequency	None
Topography	Nearly level, 0.5-1.0%	Depth to groundwater	Not observable
Major landform	Level land, plain	Depth to bedrock	Not observable
Position on slope	Toe slope	Rootable depth	200 cm
Slope form	Straight concave	Rooted depth	200 cm
Slope gradient	1%	Depth of observation	200 cm
Geology	Igneous and sedimentary	Local soil type	Biye Guracha
Parent material	Basalt mixed with sandstone and limestone	Field WRB soil type	Calcic Vertisol
		WRB soil type	Calcic Gleyic Vertisol (Eutric, Pellic, Chromic)

#### Description of the soil horizons (morphology)

Horizon	Depth (cm)	Description
Ap	0-17	Black (10YR 2/1, moist) and very dark gray (10YR 3/1, dry) colour; clay; strong fine sub-angular blocky structure; extremely hard (dry), very friable (moist), and very sticky and very plastic (wet) consistence; common, fine to medium pores; very few, faint clay coatings; no coarse fragments and mottles; few, fine roots; very few burrows; clear, smooth boundary; no reaction with dilute HCl; field pH value of 6.
Ai1	17-60	Very dark brown (10YR 2/2, moist) and very dark grayish brown (10YR 3/2, dry) colour; clay; strong medium angular blocky structure; extremely hard when dry, very friable when moist, and very sticky and very plastic when wet; common, very fine to fine pores; very few, faint clay coatings; very few, fine quartz fragments; few, very fine mottles; very few, very fine roots; no other indicators of biological activity; clear, irregular boundary; no reaction with dilute HCl; pH value of 6; slickensides.
Cg1i	60-130	Dar grayish brown (10YR 4/2, moist and dry) colour; clay; strong fine angular blocky structure; extremely hard (dry), very friable (moist), and very sticky and very plastic (wet) consistence; common, very fine to fine pores; very few, faint clay coatings; very few, fine coarse fragments of unspecified nature; many, fine, prominent mottles; very few, very fine roots; no other indicators of biological activity; clear, smooth boundary; extremely strong effervescence with dilute HCl; field measured pH value of 8; slickensides.
Cg2i	130-190	Dark grayish brown (2.5YR 4/2, moist) and grayish brown (10YR 5/2, dry) colour; clay; strong coarse angular blocky structure; extremely hard when dry. Very friable when moist, and very sticky and very plastic when wet; common, very fine pores; very fine, faint clay coatings; few, fine coarse fragments of unspecified nature; many, medium, prominent mottles; very few, very fine roots; no other indicators of biological activity; extremely strong effervescence with HCl and field measured pH value of 8; slickensides.

Table 20. Selected soil physical and chemical properties of representative pedons opened on major agricultural soils in CASCAPE intervention kebeles in Meta Woreda

Parameters	HE/MTA/CL/P1				
	0-20	20-60	60-110	110-150	150-200
Depth (cm)	Ah	A1	A2	B1	B2
Sand (%)	50.55	48.52	52.56	36.82	33.22
Silt (%)	10.30	12.36	8.25	23.17	23.70
Clay (%)	39.15	39.12	39.19	40.01	43.09
Textural class	SC	SC	SC	C	C
pH-H <sub>2</sub> O	6.00	5.87	6.07	6.83	6.79
pH-KCl	5.12	4.95	5.22	5.87	5.76
EC (μS/cm)	0.04	0.03	0.03	0.07	0.05
OC (%)	0.45	0.39	0.27	0.25	0.23
TN (%)	0.04	0.04	0.03	0.02	0.02
Av.P (mg/kg)	26.40				
Av. S (%)	1.12				
Na (meq/100 g)	0.73	1.46	0.66	0.81	0.95
K (meq/100 g)	0.17	0.16	0.15	0.16	0.19
Ca (meq/100 g)	11.76	14.42	11.76	18.48	17.98
Mg (meq/100 g)	5.77	4.24	3.78	6.72	6.42
CEC (meq/100 g)	32.41	34.48	31.35	38.35	34.89
SB (meq/100 g)	18.43	24.96	19.57	33.04	25.84
ESP (%)	2.48	4.68	2.51	2.21	3.17
Zn (mg/kg)	1.40				
Mn (mg/kg)	20.00				
Cu (mg/kg)	2.00				
Fe (mg/kg)	23.50				

Parameters	HE/MTA/CL/P2				
	0-20	20-50	50-80	80-130	130-185
Depth (cm)	Apk1	At1k	2Ai1k	2Atg1ik	2Ag2ik
Sand (%)	34.41	19.18	27.50	18.96	30.59
Silt (%)	10.75	13.11	17.58	13.14	8.68
Clay (%)	54.84	67.72	54.93	67.89	60.74
Textural class	C	C	C	C	C
pH-H <sub>2</sub> O	7.21	8.13	8.22	7.91	8.00
pH-KCl	6.33	7.21	7.40	7.00	7.10
EC (μS/cm)	0.09	0.18	0.21	0.21	0.18
OC (%)	1.03	0.69	0.51	0.37	0.26
TN (%)	0.10	0.08	0.06	0.05	0.03
Av.P (mg/ kg)	21.90				
Av. S (%)	1.09				
Na (meq/100 g)	0.80	0.93	0.95	0.79	0.85
K (meq/100 g)	0.54	0.72	0.74	0.68	0.53
Ca (meq/100 g)	21.83	33.70	34.88	35.75	30.24
Mg (meq/100 g)	7.28	11.66	11.77	12.21	9.94
CEC (meq/100 g)	40.47	53.53	54.03	52.60	45.55
SB (meq/100 g)	30.45	47.01	48.34	49.42	41.56
ESP (%)	1.98	1.74	1.75	1.50	1.88
Zn (mg/kg)	0.78				
Mn (mg/kg)	6.48				
Cu (mg/kg)	1.75				
Fe (mg/kg)	11.29				

MTA = Meta Woreda; CL = Chelenko Lola Kebele; P = Pdeon; SC = sandy clay; C = clay; EC = electrical conductivity; OC = organic carbon; TN = total nitrogen; SB = sum of bases; Av. = Available

Parameters	HE/MTA/BO/P1			
	0-10	10-30	30-50	50-70
Depth (cm)	0-10	10-30	30-50	50-70
Horizon	Ah	A	AC	C
Sand (%)	39.26	50.40	50.30	51.97
Silt (%)	20.25	13.16	12.17	16.35
Clay (%)	40.49	36.44	37.53	31.68
Textural class	C	SC	SC	SCL
pH-H <sub>2</sub> O	6.46	6.47	6.50	6.77
pH-KCl	5.88	5.75	5.65	5.90
EC (μS/cm)	0.08	0.06	0.07	0.09
OC (%)	1.22	1.15	1.11	0.69
TN (%)	0.16	0.14	0.13	0.07
Av.P (mg/kg)	23.00			
Av. S (%)	1.28			
Na (meq/100 g)	0.61	0.58	0.86	0.86
K (meq/100 g)	0.40	0.25	0.17	0.18
Ca (meq/100 g)	16.16	20.20	19.39	23.66
Mg (meq/100 g)	5.25	6.46	6.06	7.75
CEC (meq/100 g)	32.50	34.69	35.13	37.70
SB (meq/100 g)	22.43	27.49	26.48	32.46
ESP (%)	1.89	1.67	2.45	2.28
Zn (mg/kg)	2.67			
Mn (mg/kg)	35.91			
Cu (mg/kg)	1.26			
Fe (mg/kg)	38.76			

Parameters	HE/MTA/BO/P2				
	0-15	15-60	60-95	95-135	135-185
Depth (cm)	0-15	15-60	60-95	95-135	135-185
Horizon	Ap	Ai1	Ai2	Bt1i	Bt2i
Sand (%)	26.70	22.49	32.53	23.88	15.45
Silt (%)	30.81	35.04	26.99	18.49	22.76
Clay (%)	42.49	42.47	40.49	57.63	61.79
Textural class	C	C	C	C	C
pH-H <sub>2</sub> O	6.32	6.08	6.07	6.61	6.50
pH-KCl	5.41	5.13	5.10	5.77	5.69
EC (μS/cm)	0.07	0.06	0.07	0.14	0.10
OC (%)	1.75	1.61	1.04	0.50	0.32
TN (%)	0.21	0.18	0.12	0.06	0.03
Av.P (mg/kg)	28.33				
Av. S (%)	0.57				
Na (meq/100 g)	0.88	1.05	1.05	1.18	1.14
K (meq/100 g)	0.42	0.40	0.51	0.93	0.85
Ca (meq/100 g)	30.53	31.38	26.46	31.97	34.99
Mg (meq/100 g)	9.75	10.60	8.40	10.80	11.66
CEC (meq/100 g)	46.09	45.63	39.72	50.24	59.17
SB (meq/100 g)	41.59	43.42	36.42	44.88	48.64
ESP (%)	1.92	2.30	2.64	2.36	1.92
Zn (mg/kg)	3.53				
Mn (mg/kg)	50.03				
Cu (mg/kg)	1.18				
Fe (mg/kg)	53.15				

MTA = Meta Woreda; BO = Bekelcha Oromia Kebele; P = Pedon; C = clay; SC = sandy clay; SCL = sandy clay loam; EC = electrical conductivity; OC = organic carbon; TN = total nitrogen; Av. = Available

Parameters	HE/MTA/HB/P1				HE/MTA/HB/P2		
	0-30	30-100	100-120	120-180	0-30	30-130	130-200
Depth (cm)	Ah	B1	B2	B3	Ap	Ak1	Bt1k
Sand (%)	24.30	53.17	53.36	46.21	35.49	33.89	27.42
Silt (%)	38.87	7.13	8.11	15.22	15.61	19.94	12.81
Clay (%)	36.83	39.71	38.53	38.57	48.90	46.17	59.78
Textural class	CL	SC	SC	SC	C	C	C
pH-H <sub>2</sub> O	6.68	7.12	6.98	6.53	7.23	7.11	8.00
pH-KCl	5.82	6.16	6.00	5.64	6.38	6.19	7.15
EC (μS/cm)	0.10	0.10	0.10	0.10	0.10	0.10	0.20
OC (%)	0.56	0.36	0.19	0.17	1.30	0.72	0.63
TN (%)	0.06	0.04	0.02	0.01	0.13	0.07	0.06
Av.P (mg/kg)	49.30				56.00		
Av. S (%)	0.86				1.46		
Na (meq/100 g)	0.75	0.73	0.70	0.71	0.81	1.02	0.97
K (meq/100 g)	0.12	0.10	0.10	0.18	1.29	0.51	0.55
Ca (meq/100 g)	15.80	16.48	17.64	19.39	31.20	29.40	33.92
Mg (meq/100 g)	5.82	4.12	5.88	6.87	10.40	10.08	11.45
CEC (meq/100 g)	32.56	32.24	31.96	33.37	47.93	45.20	50.23
SB (meq/100 g)	22.49	21.43	24.32	27.15	43.70	41.01	46.89
ESP (%)	2.27	2.05	1.95	2.13	1.70	2.26	1.93
Zn (mg/kg)	0.40				2.39		
Mn (mg/kg)	12.15				29.83		
Cu (mg/kg)	1.25				3.82		
Fe (mg/kg)	12.30				33.86		

MTA = Meta Woreda; HB = Hawi Bilisuma Kebele; P = Pedon; C = clay; SC = sandy clay; EC = electrical conductivity; OC = organic carbon; TN = total nitrogen; Av. = Available; SB = sum of bases

Parameters	HE/MTA/DB/P1				HE/MAT/DB/P2			
	0-30	30-60	60-90	90-165	0-17	17-60	60-130	130-190
Depth (cm)	Ap	A	Bt1	Bt2	Ap	Ati1	Atg1i	Ag2i
Sand (%)	24.45	34.45	29.29	20.09	46.11	33.92	18.03	21.11
Silt (%)	15.11	24.72	15.00	17.28	6.47	9.75	12.02	10.96
Clay (%)	60.44	40.83	55.71	62.63	47.43	56.33	69.95	67.93
Textural class	C	C	C	C	SC	C	C	C
pH-H <sub>2</sub> O	7.15	7.65	7.83	7.78	6.42	6.73	7.88	7.93
pH-KCl	6.27	6.63	6.89	6.84	5.50	5.81	6.85	6.96
EC (μS/cm)	0.09	0.14	0.15	0.12	0.13	0.14	0.37	0.36
OC (%)	1.25	0.99	0.89	0.71	1.76	0.90	0.34	0.29
TN (%)	0.13	0.10	0.09	0.07	0.16	0.11	0.05	0.03
Av.P (mg/kg)	31.10				25.30			
Av. S (%)	1.20				1.25			
Na (meq/100 g)	0.84	0.88	0.76	0.98	0.74	0.87	1.33	0.78
K (meq/100 g)	0.34	0.46	0.29	0.34	0.58	0.53	0.59	0.71
Ca (meq/100 g)	38.52	36.38	37.66	37.66	38.52	39.74	36.62	39.24
Mg (meq/100 g)	12.84	11.98	12.41	12.84	12.84	12.96	12.64	13.08
CEC (meq/100 g)	59.55	52.57	53.50	61.87	58.15	55.88	54.03	54.97
SB (meq/100 g)	52.54	49.71	51.12	51.82	52.68	54.11	51.18	53.81
ESP (%)	1.41	1.68	1.43	1.58	1.28	1.56	2.46	1.41
Zn (mg/kg)	0.96				3.10			
Mn (mg/kg)	8.77				29.55			
Cu (mg/kg)	1.78				5.12			
Fe (mg/kg)	11.29				26.44			

MTA = Meta Woreda; DB = Dursitu Bilisuma Kebele; P = Pedon; C = clay; EC = electrical conductivity; OC = organic carbon; TN = total nitrogen; Av. = Available; SB = sum of bases

### 3.6.3. Synthesis

The morphological, physical and chemical properties of the pedons are presented in Tables 18 and 19 in Section 3.6.2. Therefore, for discussions presented hereunder, reference should be made to those tables. The results are interpreted using critical values of parameters as suggested in Booker Tropical Soil Manual (Landon, 1991), Hazelton and Murphy (2007), Jones (2003), FAO (2006), Karlton et al. (2013) and Allison (1973).

#### 3.6.3.1. Agronomic Interpretation of Soil Morphological Properties

##### 1. Soil Color

The surface color (moist) varied from dark reddish brown (2.5YR 3/4) in Haplic Nitisols of Hawi Bilisuma to very dark gray (10YR 3/1) in Vertic Luvisols of Dursitu Bilisuma Kebele, whilst the surface color (dry) varied from red (10R 4/8) in Haplic Nitisols of Chelenko Lola to black (2.5Y 5/1) in Calcic Luvisols of Hawi Bilisuma Kebele. In majority of the cases, the color of the surface horizon soils was brown, very dark brown, or reddish brown. This could be due to the effect of organic matter added to the soil each year albeit in small quantity and its reaction with iron.

The subsurface color (moist) also showed difference within a pedon and among pedons in which it varied from dusky red (10R 3/4) in Haplic Nitisols of Chelenko Lola to dark olive brown (2.5Y 3/3) in the Vertic Gleyic Luvisols of Bekelcha Oromia Kebele. Similarly, the subsurface color (dry) varied from red (10R 4/6) in Haplic Nitisols of Chelenko Lola to grayish brown (10YR 5/2) in Calcic Gleyic Vertisol of Dursitu Bilisuma Kebele. The general correlation observed is that soils developed on limestone and basalt tend to be darker in color, whereas those developed on sandstones and granites were dominantly reddish in color.

## 2. Soil Structure and Consistence

The structure of the surface horizons were moderate to strong, fine to very coarse sub-angular to angular blocky with the granular structure limited to the Calcic Luvisols of Hawi Bilisuma and Vertic Luvisols of Dursitu Bilisuma Kebele. In the different subsurface horizons, the structure attributes varied widely in terms of grade, size, and type. In accordance with this, weak very fine to strong coarse sub-angular blocky, strong fine to very coarse angular blocky, and strong coarse to very coarse prismatic structure types were identified. In addition to these, wedge-shaped structures were also recognized in the Vertisols. Differences in soil structure among pedons might reflect differences in soil texture, clay mineralogy, organic matter content, nature of adsorbed cations, biological processes, and management practices followed.

Across the surface horizons of all the soil types, the consistence was hard to extremely hard when dry, very friable when moist, and sticky and plastic to very sticky and very plastic when wet. In the subsurface horizons as well, hard to extremely hard (dry), firm to very friable (moist), and sticky and plastic to very sticky and very plastic (wet) consistence was recorded. The consistence values recorded in the soils indicate the strength of cohesive and adhesive forces in the soils. Furthermore, the differences in consistence might reflect differences in clay content and clay mineralogy, and also organic matter content among the different major agricultural soils in the studied kebeles.

## 3. Soil Depth

Observations made on road cuts, deep gullies, auger points, and pedons indicate that most of the major agricultural soils in the four kebeles, except those on steep slopes, are deep enough (more than 60 cm deep) to support the growth of most cultivated crops.

#### 4. Porosity, Root Distribution and Other Related Features

The total porosity of the soils, both surface and subsurface, was relatively high based on rough approximations made in the field. The sizes of the pores were also different in different horizons of the pedons. Collectively, the abundance of the pores, from the surface down to the deeper layers, was in the range of few to common with sizes that included very fine to medium pores. The large size pores were mostly concentrated in the upper horizons.

The root distribution depends largely on the types of plants grown and the pore size distribution. In this study, roots were found to depths that extend from 60 to 200+ cm. Nevertheless, the distribution and the sizes of the roots decreased with soil depth. This is commensurate with the general decrease in size of pore spaces. As was observed from pore size distribution, the size of pores becomes finer, thus, resulting in very few and very fine roots penetrating into the deeper layers of the pedons.

Features like coarse fragments, mottles, coatings, horizon boundaries, and other indicators of biological activities were recorded for each pedon. The details of these characteristics are depicted in Table 18.

##### 3.6.3.2. Agronomic Interpretation of Soil Particle Size Distribution

Clay and sand are the dominant fractions in most of the soil types. The lowest (24.3%) and highest (50.6%) sand content (surface) are recorded in Haplic Nitisols of Hawi Bilisuma and Chelenko Lola respectively, both of which are developed from sandstone parent material. In the subsurface soil, it ranges from 15.5% in the Vertic Gleyic Luvisols of Bekelcha Oromia to 53.4% in the Haplic Nitisols of Hawi Bilisuma Kebele. Likewise, the clay content varies from 36.8% in the Haplic Nitisols of Hawi Bilisuma to 60.4% in the Vertic Luvisols of Dursitu Bilisuma and 31.7% in the Vertic Gleyic Luvisols of Bekelcha Oromia to 70.0% in the Calcic Gleyic Vertisols of

Dursitu Bilisuma Kebele at the surface and subsurface horizons, respectively. The textural classes are between clay loam to clay at the surface horizons and sandy clay loam to clay at the subsurface horizons. Only in the Calcic Luvisols of Hawi Bilisuma and the Haplic Nitisols of Chelenko Lola is sand content decreased and clay increased with soil depth, respectively.

In general, soils with the highest sand content are those developed on sandstone parent materials, while those with the highest clay content are developed on limestones and basalt.

Moore et al. (1998) made estimates of available water-holding capacity based on texture and structure. Based on his rough guide, the available water-holding capacity of the soils can range between 130-150 mm/m soil depth for the sandy clay soils (Haplic Nitisols of Chelenko Lola, Haplic Cambisols of Bekelcha Oromia, and Haplic Nitisols of Hawi Bilisuma) to ~210 mm/m for clays with self-mulching properties. Nevertheless, for development of site-specific soil-water management scenarios, it is imperative to use data obtained from measured water retention and release characteristics of these different textured soils.

### 3.6.3.3. Agronomic Interpretation of Soil Chemical Properties

#### 1. Soil Reaction and Electrical Conductivity

In the surface soils, the pH-H<sub>2</sub>O values ranged from 6.0 in Haplic Nitisols of Chelenko Lola to 7.2 in Calcic Luvisols of Hawi Bilisuma Kebele. Similarly, in the subsurface soils, it varied from 5.9 in the Haplic Nitisols to 8.2 in the Calcic Gleyic Vertisols of Chelenko Lola Kebele. The pH-H<sub>2</sub>O increased consistently down the soil profile in only Pedon 1 of Bekelcha Oromia and Pedon 2 of Durisitu Bilisuma Kebele. The differences observed could be attributed to differences in management, parent material, drainage, and

organic matter content. The relatively high pH-H<sub>2</sub>O values were recorded in the pedons that have calcic horizon.

According to pH-H<sub>2</sub>O (1:2.5 soil:water suspension) interpretation suggestions made by Landon (1991), the pH of the surface and subsurface soils was in the range of medium (5.5-7.0) to high (7.0-8.5). On the other hand, based on pH-H<sub>2</sub>O ratings suggested by Karlitun et al. (2013), the pH-H<sub>2</sub>O of the surface and subsurface horizons was within the range of moderately acidic (5.6-6.5) to neutral (6.6-7.3), and moderately acidic to moderately alkaline (7.4-8.4), respectively. As pointed out by Landon (1991), the most suitable pH range for most cultivated crops is the neutral range. On the basis of this, the pH (surface) of the major agricultural soils of the four kebeles is within this suitable range availability of essential nutrients, activity of beneficial microorganisms and plant growth. However, the high pH values recorded in some subsurface horizons of the calcareous soils (e.g., Calcic Gleyic Vertisols of Chelenko Lola) and the moderately acidic reactions in Haplic Nitisols of Chelenko Lola need special attention and protection from activities that intensify the problem.

The  $\Delta$ pH across depths and pedons was positive implying the dominance of clay minerals with permanent charges and presence of appreciable reserve acidity. The values of electrical conductivity for both the surface and subsurface horizons were all less than 1, which means that the soils are salt free.

## 2. Soil Organic Carbon, Total Nitrogen, and C:N Ratio

In the surface soil, it ranged from 0.5% in Haplic Nitisols of Chelenko Lola Kebele to 1.8% in the Vertic Gleyic Luvisols of Bekelecha Oromia and in the Calcic Gleyic Vertisols of Dursitu Bilisuma Kebele. In the subsurface soils, it varied from 0.2% in Haplic Nitisols of Hawi Bilisuma to 1.6% in the Vertic Gleyic Luvisols of Bekelcha Oromia. It showed a consistently decreasing

trend with soil depth in all the pedons. As per ratings suggested by Landon (1991), the organic carbon content of all the soils, surface and subsurface, was within the range of very low (< 2%).

The total nitrogen content was determined following the micro Kjeldhal method (Hesse, 1971). Similar to the organic carbon content, in almost all the pedons, it decreased down the soil profile. Total nitrogen content of the surface soils ranged from 0.04% in Haplic Nitisols of Chelenko Lola to 0.2% in Vertic Gleyic Luvisols of Bekelcha Oromia, while in the subsurface soils, it varied from 0.01% in the Haplic Nitisols of Hawi Bilisuma to 0.2% in the Vertic Gleyic Luvisols of Bekelcha Oromia Kebele. It also decreased consistently with soil depth in all the soil types.

Following rating of total nitrogen suggested by Landon (1991), the total nitrogen content of the surface soils was very low in the Haplic Nitisols of Chelenko Lola, low in the Haplic Nitisols of Hawi Bilisuma, Calcic Gleyic Vertisols of Chelenko Lola, Calcic Luvisols of Hawi Bilisuma, and Vertic Luvisols of Dursitu Bilisuma, and medium in all the other soil types. The results indicate that all the soil types are deficient in nitrogen and, hence, require application of appropriate nitrogen fertilizers based on site-and crop-specific recommendations.

The carbon to nitrogen ratio (C:N) for the surface soils was between 8:1 in Haplic Cambisols and Vertic Gleyic Luvisols of Bekelcha Oromia to 11:1 in Haplic Nitisols of Chelenko Lola and Calcic Gleyic Vertisols of Dursitu Bilisuma Kebele. For the subsurface soils, it was between 7:1 to 17:1, which indicates that organic matter decomposition proceeds at a faster rate (Allison, 1973). Furthermore, the surface soils' C:N ratio is within the range that is considered normal for arable soils (Allison, 1973).

### 3. Available Phosphorus and Sulfur

Available phosphorus was determined using the Olsen method (Olsen et al., 1954). Available P ranged from 21.9 mg kg<sup>-1</sup> in the Calcic Gleyic Vertisols of Chelenko Lola to 56 mg kg<sup>-1</sup> in the Calcic Luvisols of Hawi Bilisuma kebele. Differences in native P sources, organic matter content, rates of fertilizer application, clay content and type, soil pH and other related factors might be attributed to the observed differences.

Based on available Olsen P interpretation guidelines suggested in Landon (1991), all the major agricultural soils of the kebeles were high (> 15 mg kg<sup>-1</sup>) in their available P content, which means that response to application of P fertilizer is unlikely. Furthermore, the available P content of the soils studied was within the range of adequate P for high P demanding crops, such as sugarbeet, potatoes, and onions.

The available sulfur, which ranged from 0.6% in the Vertic Gleyic Luvisols of Bekelcha Oromia to 1.5% in Calcic Luvisols of Hawi Bilisuma, was excess based on available S ratings suggested in Landon (1991) after Chapman (1966). Differences in native S sources, organic matter content, and pH, among others, might be responsible for the differences observed.

### 4. Exchangeable Bases (Ca, Mg, K, Na)

However, none of the exchangeable bases followed regular trend with soil depth in all the pedons.

Exchangeable Ca of the surface soils ranged from 16.2 meq/100 g soil in Haplic Cambisols of Bekelcha Oromia to 38.52 meq/100 g of soil in the Vertic Luvisols and Calcic Gleyic Vertisols of Dursitu Bilisuma Kebele. The subsurface soils exchangeable Ca, on the other hand, varied from 14.0 meq/100 g soil in the Haplic Nitisols of Chelenko Lola to 39.7 in the Calcic

Gleyic Vertisols of Dursitu Bilisuma Kebele. As per FAO (2006) ratings of exchangeable bases, the agricultural soils of the four kebeles are high to very high in their exchangeable Ca and Mg.

The exchangeable K of the surface soils ranged from 0.2 meq/100 g soil in the Haplic Nitisols of Hawi Bilisuma to 1.3 meq/100 g soil in the Calcic Gleyic Vertisols of Dursitu Bilisuma Kebele. In the surface soils, it ranged from 0.2 to 0.9 meq/100 g soil. Following the FAO (2006) rating, the exchangeable K of the surface soils was low in the Haplic Nitisols of Chelenko Lola and Hawi Bilisuma Kebeles, medium in the Calcic Gleyic Vertisols of Chelenko Lola, Haplic Cambisols and Vertic Gleyic Luvisols of Bekelcha Oromia, and Vertic Luvisols of Dursitu Bilisuma, high in the Calcic Gleyic Vertisols of Dursitu Bilisuma, and very high in the Calcic Luvisols of Hawi Bilisuma Kebele. Furthermore, exchangeable K occupies less than 2% of the exchange site (CEC) in all the surface horizons, which also implies that K deficiency is likely to occur. Those soils with low and medium exchangeable K require application of K containing fertilizers.

Although the exchangeable Na was high in all the soil types, except in the Haplic Cambisols of Bekelcha Oromia which was medium, it is not high enough to cause problems on plants and soil physical conditions. Nonetheless, Landon (1991) pointed out that soils with exchangeable Na greater than 1 meq/100 g soil should be regarded as potentially sodic. Based on this indicative critical value, the subsurface soils of the Vertic Gleyic Luvisols of Bekelecha Oroimia and Calcic Luvisols of Hawi Bilisuma Kebeles may be regarded as potentially sodic and, thus, necessary precautions should be taken not to aggravate the potential.

## 5. Cation Exchange Capacity and Sum of Bases

Cation exchange capacity of the surface soils varied from 32.5 meq/100 g soil in Haplic Cambisols of Bekelcha Oromia to 59.6 meq/100 g soil in the

Vertic Luvisols of Dursitu Bilisuma. It also ranged from 31.4 to 61.9 meq/100 g soil in the subsurface horizons. The likely reasons for the observed differences in CEC among the pedons could be due to differences in clay content and clay mineralogy, and to a limited extent organic matter content and its state of decomposition.

Based on rating suggested by Landon (1991), the CEC of the surface soils of the four kebeles was within the range of high to very high. The CEC of the clay fraction ranged from 74 to 123 meq/100 g clay.

The base saturation of the surface layers was 69 to 91%, which is high to very high (Metson, 1961) and indicates that the soils are very weakly to weakly leached (Metson, 1961). Similarly, in the subsurface layers, it varied from 62-98%, which is also high to very high and indicates that the soils are very weakly to weakly leached (Metson, 1961).

## 6. Extractable Micronutrients

The extractable micronutrients (Zn, Mn, Cu, and Fe) were determined on the surface soils only. The extractable Zn varied from 0.4 mg kg<sup>-1</sup> in the the Haplic Nitisols of Hawi Bilisuma to 3.5 mg kg<sup>-1</sup> in the Vertic Gleyic Luvisols of Bekelcha Oromia. As per Zn ratings suggested by Karlton et al. (2013), it was very low in Calcic Gleyic Vertisols in Chelenko Lola and Haplic Nitisols of Hawi Bilisuma, low in the Haplic Nitisols of Chelenko Lola and Vertic Luvisols of Dursitu Bilisuma and optimum in all the other soil types. Soils with very low to low Zn content need application of Zn containing fertilizer.

Manganese also varied from 6.5 mg kg<sup>-1</sup> in the Calcic Gleyic Vertisols of Chelenko Lola to 50.0 mg kg<sup>-1</sup> Vertic Gleyic Luvisols of Bekelcha Oromia kebele. The Calcic Gleyic Vertisols of Chelenko Lola, the Haplic Nitisols of Hawi Bilisuma and the Vertic Luvisols of Dursitu Bilisuma were medium in their Mn content, while the remaining soil types were high (Jones, 2003).

The extractable Cu content of the soil was  $1.2 \text{ mg kg}^{-1}$  soil in Vertic Gleyic Luvisols of Bekelcha Oromia to  $5.1 \text{ mg kg}^{-1}$  soil in the Calcic Gleyic Vertisols Dursitu Bilisuma. Following the rating suggested by Karlton et al. (2013), the extractable Cu of the soils was optimum, which means that there is no need to apply Cu containing fertilizer to major agricultural soils of the four kebeles.

The extractable Fe content of the soils also ranged from  $11.29 \text{ mg kg}^{-1}$  in Calcic Gleyic Vertisols of Chelenko Lola to  $53.2 \text{ mg kg}^{-1}$  in Vertic Gleyic Luvisols of Bekelcha Oromia kebele. The extractable Fe content of the major agricultural soils was in the range of high (Jones, 2003), which indicates that major agricultural soils of the four kebeles do not require application of Fe containing fertilizer.

One of the fertilizer blends that should be provided to farmers of the four CACAPE intervention kebeles and other kebeles with similar soil types should contain N, K, Zn, and Mn. Further study has to be conducted to determine the dose of each of these nutrients to be applied for each soil type and crop, and decide their respective proportion in the blend.

#### 3.6.3.4. Agronomic Interpretation of Major Soil Types

The major agricultural soils in the four kebeles are the Cambisols, Nitisols, Luvisols, and Vertisols. Leptosols and Regosols are marginally used for agricultural purpose and are being abandoned for rehabilitation.

Where they are used for crop production, the Leptosols and Regosols may present limitations related mainly to rootable depth. They may not store adequate water, in addition to other nutrient related problems, for successful crop production under rainfed crop production.

Except in the Haplic Cambisols in Bekelcha Oromia, all the major agricultural soil types identified in the kebeles have depth that is greater than 100 cm. This depth is deep enough for growing both shallow and deep rooted crops provided that other soil conditions are not limiting. The soils do not have serious structure-related problems except the fact that the spheroidal type of soil structure was not commonly observed in the surface layers of the soils. Furthermore, the wedge-shaped structures covered by the impermeable shiny surfaces of slickensides in the Calcic Gleyic Vertisols may pose some internal soil drainage problems. The relatively high clay content in all the soil types has resulted in extremely hard to hard consistence when dry and very sticky and very plastic consistence when wet. These may present some problems related to workability when these soils are dry and wet. Therefore, these soils should be worked when the moisture content is near field capacity in order to produce good soil tilth and minimize destruction of the soil structure.

The surface soil pH recorded in all the soil types is within the range that is favourable for availability of most essential nutrient elements, activity of most essential microorganisms and growth of most cultivated crops. Nevertheless, the moderately acidic soil reaction recorded in the surface soils of Haplic Nitisols of Chelenko Lola, Haplic Cambisols and Vertic Gleyic Luvisols of Bekelecha Oromia may require some attention not to intensify the acidity by, for instance application of acidic chemical fertilizers. On the other hand, the moderately alkaline soil reaction recorded in the subsurface soils of some of the major soil types should receive attention.

In all the soil types, the organic carbon content was in the range of very low. Although farmers are advised to regularly apply organic matter to their field every cropping season, the amount applied is inadequate to significantly raise the low level of organic carbon to optimum level. Furthermore, crop residues are completely harvested from farms and used for other purposes.

Added to these is the continuous tillage almost throughout the year, which enhances rapid oxidation of the small amount of organic matter present in the soil. It is, therefore, necessary to introduce better practices that may assist in building the organic carbon level of the soils.

Following the low organic carbon content in the soils, the total nitrogen content of was very low in the Haplic Nitisols of Chelenko Lola, low in the Haplic Nitisols of Hawi Bilisuma, Calcic Gleyic Vertisols of Chelenko Lola, Calcic Luvisols of Hawi Bilisuma, and Vertic Luvisols of Dursitu Bilisuma, and only medium in all the other soil types. This indicates almost all the soil types are nearly deficient in nitrogen and, thus, require application of nitrogen containing fertilizers based on site- and crop-specific recommendations for improving yield from its current level.

On the other hand, all the major agricultural soils contain adequate Ca and Mg, and high cation exchange capacity. Nevertheless, some of the soil types are deficient in K. Accordingly, the Haplic Nitisols of Chelenko Lola and Hawi Bilisuma Kebeles are deficient in K and the Calcic Gleyic Vertisols of Chelenko Lola, Haplic Cambisols and Vertic Gleyic Luvisols of Bekelcha Oromia, and Vertic Luvisols of Dursitu Bilisuma also contain only medium level of exchangeable K. These soils may require immediate application of K containing fertilizers.

Calcic Gleyic Vertisols in Chelenko Lola, Haplic Nitisols of Hawi Bilisuma, Haplic Nitisols of Chelenko Lola and Vertic Luvisols of Dursitu Bilisuma are all deficient in Zn and thus require Zn fertilizers. Furthermore, the Calcic Gleyic Vertisols of Chelenko Lola, the Haplic Nitisols of Hawi Bilisuma and the Vertic Luvisols of Dursitu Bilisuma contain only medium level of extractable Mn and may require some supplementary addition of Mn containing fertilizer.

From the foregoing discussion, it can be concluded that the soils in the study kebele are good except the indicated problems, most of which are related to

chemical soil fertility. Therefore, to solve the problems fertilizers that contain the deficient nutrients in the specific soils should be provided to the farmers in the form of blends. Other alternatives should also be sought for in order to promote integrated soil fertility management approach.

### 3.7. Soils of CASCAPE Intervention Kebeles in Gurawa Woreda

#### 3.7.1. The Soil-Landscape in Gurawa Woreda

##### 3.7.1.1. Geology

The geology of Gurawa Woreda, like the other CASCAPE intervention woredas in the Eastern zone, is complex. As per the recent geological map prepared by Geological Survey of Ethiopia (1:2,000,000 scale), the geology of the Woreda was shaped by processes that took place during Jurassic, Oligocene-Miocene, and early Proterozoic periods. During these periods, different rock types were formed. The Urandab formation is formed during the Late Jurassic period and consists of Oxfordian-Kimmeridgian marl and shale-limestones. During the Jurassic period the Adigrat (sandstones) and Hamanlei (Oxfordian limestone and shale) formations were formed.

The Alage formation from the Oligocene-Miocene period is composed of transitional and sub-alkaline basalts with minor rhyolites and trachyte eruptives. The Early Proterozoic period gave rise to the formation of the Momora Group that contains biotite schist, gneiss, marble and graphitic schist.

The observations made during the field work in the four CASCAPE intervention kebeles very much consolidate the information that is contained in the map. From the top of the high altitude areas, such as Mount Gara Muleta, down to the deep gorges, an intriguing sequence of rocks was observed whereby the steep slopes were built up dominantly by basalts or basaltic rocks, whereas the gorges and areas near stream banks are covered by limestones, and at some localized places by sandstones. Plate 12 below shows the different types of rocks identified in the four kebeles.

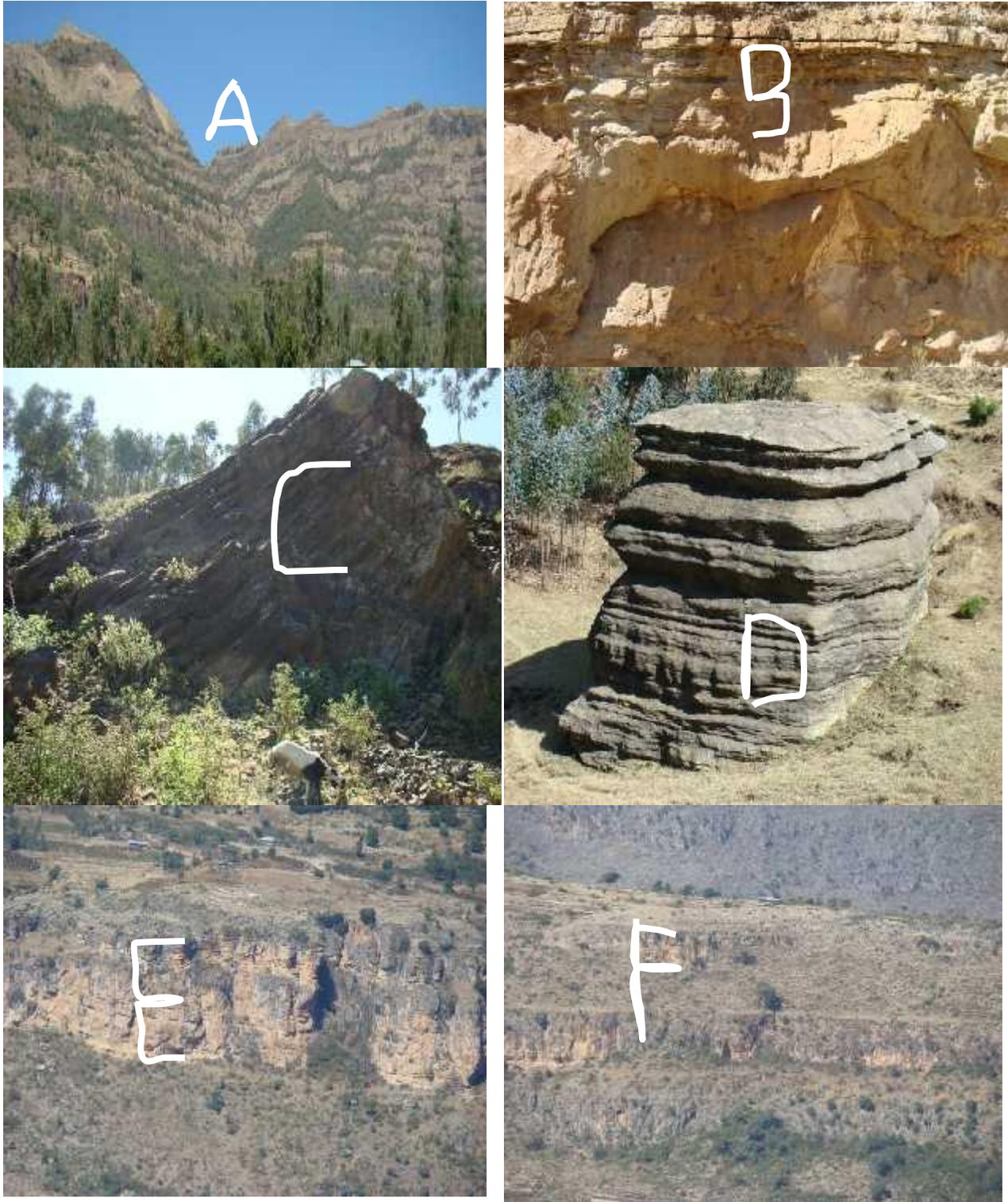


Plate 12. Partial overview of the geologic features identified in CASCAPE intervention kebeles: (A) Dissected basaltic mountain (Mount Gara Muleta), (B) weathering sandstone on middle slopes, (C) & (D) basalt outcrops with spectacular features, (E) and (F) limestone outcrops in the low lying areas.

### 3.7.1.2. The Landscape

Gurawa Woreda is characterized by a complex terrain that includes valleys, plains, plateaus, hills and high peak mountains. On a coarse scale, nevertheless, the general landform of the Woreda, particularly the CASCAPE intervention kebeles area, can be viewed as piedmont plateau. The local topography, on the other hand, varies greatly. In the four kebeles, the topography varies from sloping land to very steep land that includes Mount Gara Muleta. The major landforms include valley floors, dissected plains and plateaus, undulating medium to high gradient hills, and high gradient mountains. The study kebeles, except Lafto Ila Tatesa, are found at the foot of Mount Gara Muleta and its chains that form part of the Arsi-Bale massif. Within the kebeles, there are many mini-watersheds with different kinds of local topography, including terraced landscapes. Though there are many slope forms, the dominant ones are the straight, concave straight, and concave convex ones. Plate 13 shows the typical landforms in the kebeles. The contour and elevation maps of the kebeles, together with the location of the auger points, are depicted in Figure 19.

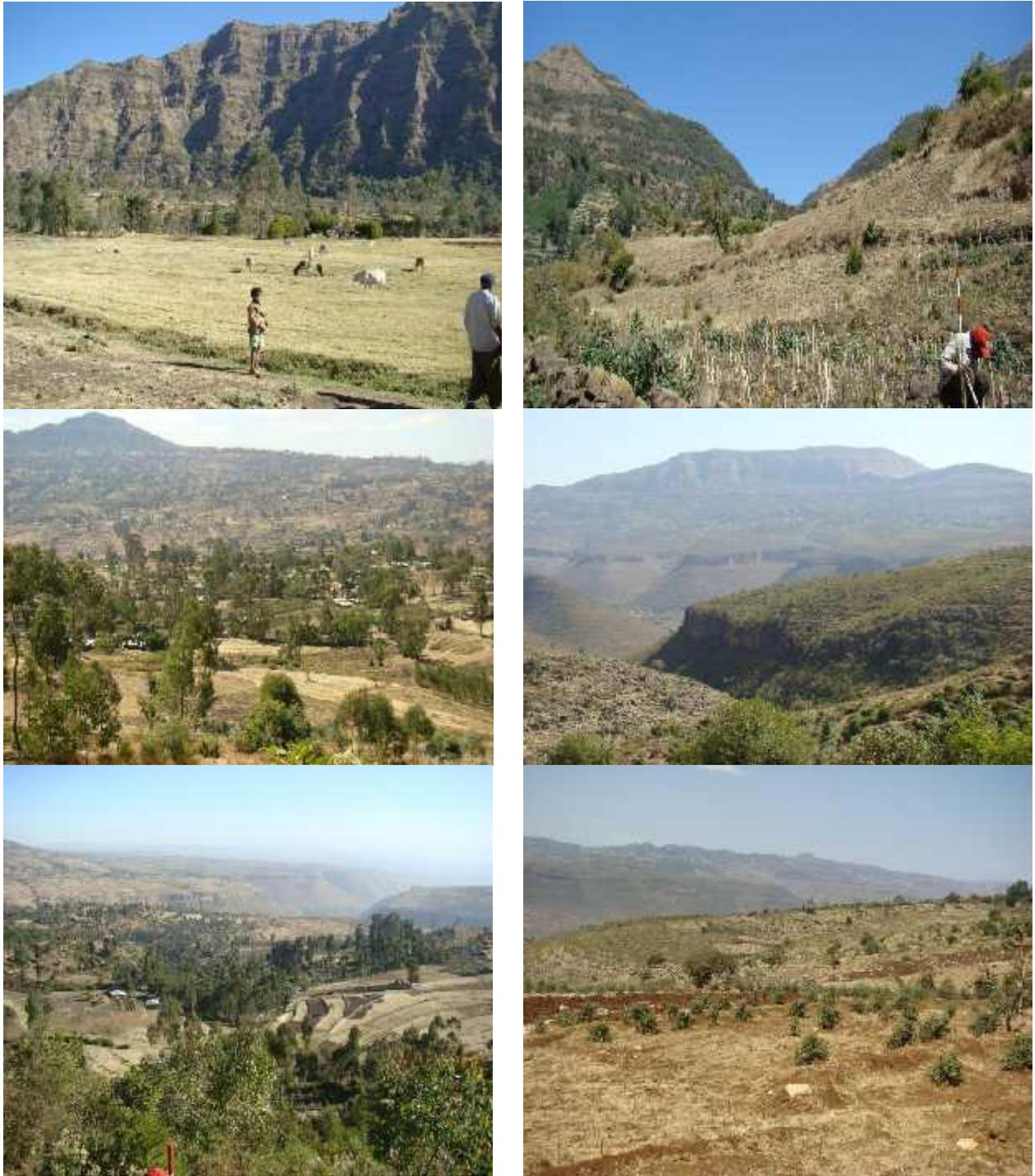


Plate 13. Some of the typical landscape features in the four CASCAPE intervention kebeles in Gurawa Woreda.

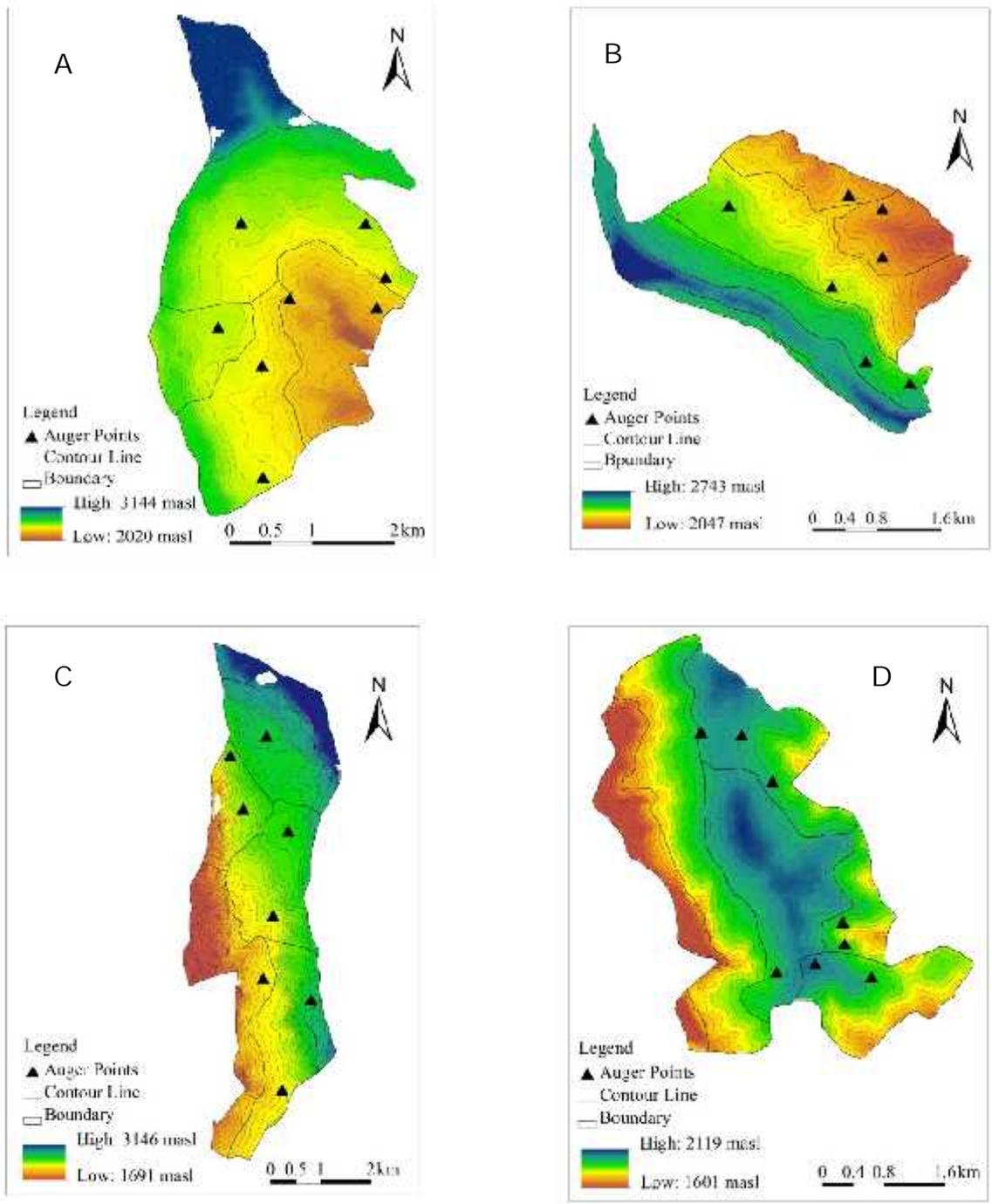


Figure 19. Contour and elevation maps of and location of auger points in the four CASCAPE intervention kebeles in Gurawa Woreda: (A) Rasa Janata, (B) Ula Janata, (C) Lencha, and (D) Lafto Ila Tatesa.

### 3.7.1.3. Land Use

Due to population growth at an alarming rate, every piece of land that has not been cultivated before is being brought under cultivation/agricultural production. This has made the steep slopes, which are luxuriously considered 'unsuitable' for agriculture, victims of this misfortune. Nevertheless, the farmers are trying their best to minimize soil losses from their farms by using different protective measures, such as terracing, bunding, and using some biological measures. Moreover, extensive watershed management works, through mass mobilization, that involve integrated use of physical and biological measures are being implemented on the steep slopes. Some of the cultivated fields on steep slopes are also being abandoned in order to rehabilitate them. The foots of Mount Gara Muleta and its chains that extend all the way to the town of Gurawa are all covered by forest of different species. A well established nursery is also available there to support this effort. On the cultivated steep slopes, sorghum and maize often intercropped with Khat are the major crops.

The major agricultural lands are concentrated mainly on the middle, lower, and toe slopes, and valley floors. The commonly grown rainfed field crops are sorghum, maize, wheat, haricot bean, horse bean, and teff. Horticultural crops include potato, onion, sweat potato, pepper, and shallot. Khat and coffee are the major cash crops grown in most of the kebeles. Where there is water, small-scale irrigation is practiced. Except Lafto Ila Tatesa Kebele, the other three Kebeles have scattered water resources in the form of springs and groundwater that can be developed. Using these water resources, farmers are producing two to three times per year. This is very important for ensuring food security and improving income. Nonetheless, the method of irrigation being used is still traditional one, which causes loss of large quantity of the scarce water resource and the rate of extraction seems to exceed the rate of recharge in some areas.

Fertilizer use in most instances is based on blanket recommendation of around 100 kg ha<sup>-1</sup> nitrogen (urea) and phosphorus (DAP). Furthermore, farmers also apply compost to their field every year before planting albeit in small amount. The supply of improved seeds is still the farmers' main concern although efforts are being made to improve the supply (e.g., CASCAPE's effort).

Although mixed crop-livestock production is the major farming system, the livestock component is still weak due mainly to scarcity of feed. There are not much grazing lands. As a result, farmers are using the cut and carry system, which will not allow them to keep many livestock. What they are usually cutting and carrying is the crop residues, particularly sorghum and maize. It is only Rasa Janata and Lencha Kebeles that have some pocket areas of grazing land.

The vegetation cover in the study kebeles consists of protected forests, such as that on Mount Gara Muleta, composed of different species. Eucalyptus is almost everywhere in these kebeles. Different agro-forestry trees are also observed in the farms.

#### 3.7.1.4. Soil-landscape (Exploratory Survey Results)

The major soil types (RSG level) identified in the four kebeles are Leptosols, Cambisols, Nitisols, Luvisols, Calcisols (in Lencha), and Vertisols. The different soil mapping units identified in each kebele and the area that each mapping unit is occupying is presented in Table 21. Furthermore, Plate 14 illustrates these soil types developed from different parent materials and on different slope positions (see Section 3.7.1.5 for detailed elaboration).

Table 21. Major soil mapping units (exploratory) identified and their area coverage in the four kebeles

Kebele	Soil name	Soil code	Area (ha)	% total area
Lafto Ila Tatesa	Rendzic Leptosols	LP-rz	167	12
	Vertic Cambisols	CM-vr	229	16
	Cambisols (Rhodic)	CM-ro	330	24
	Luvic Nitisols	NT-lv	193	14
	Vertic Luvisols	LV-vr	466	34
Lencha	Leptosols (Eutric)	LP-eu	162	8
	Rendzic Leptosols	LP-rz	203	11
	Vertic Calcisols	CL-vr	417	22
	Luvic Nitisols	NT-lv	382	20
	Luvisols	LV	42	2
	Gleyic Luvisols	LV-gl	357	18
Rasa Janata	Vertisols	VR	371	19
	Leptosols (Eutric)	LP-eu	152	12
	Luvic Nitisols (Eutric)	NT-lv-eu	120	10
	Vertic Luvisols	LV-vr	457	37
	Calcic Vertisols	VR-cc	242	20
Ula Janata	Gleyic Vertisols	VR-gl	252	21
	Leptosols	LP	156	17
	Regosols	RG	112	12
	Luvisols (Rhodic)	LV-ro	99	10
	Vertic Luvisols	LV-vr	258	27
	Vertisols	VR	323	34

The distribution of these mapping units in the respective kebeles is also indicated in Figure 20. The exploratory survey results clearly indicate the existence of high diversity of soils within a kebele, mainly due to differences in parent material and slope positions.



Plate 14. Some of the soil types formed from different parent materials occurring on the different slope positions in the four kebeles.

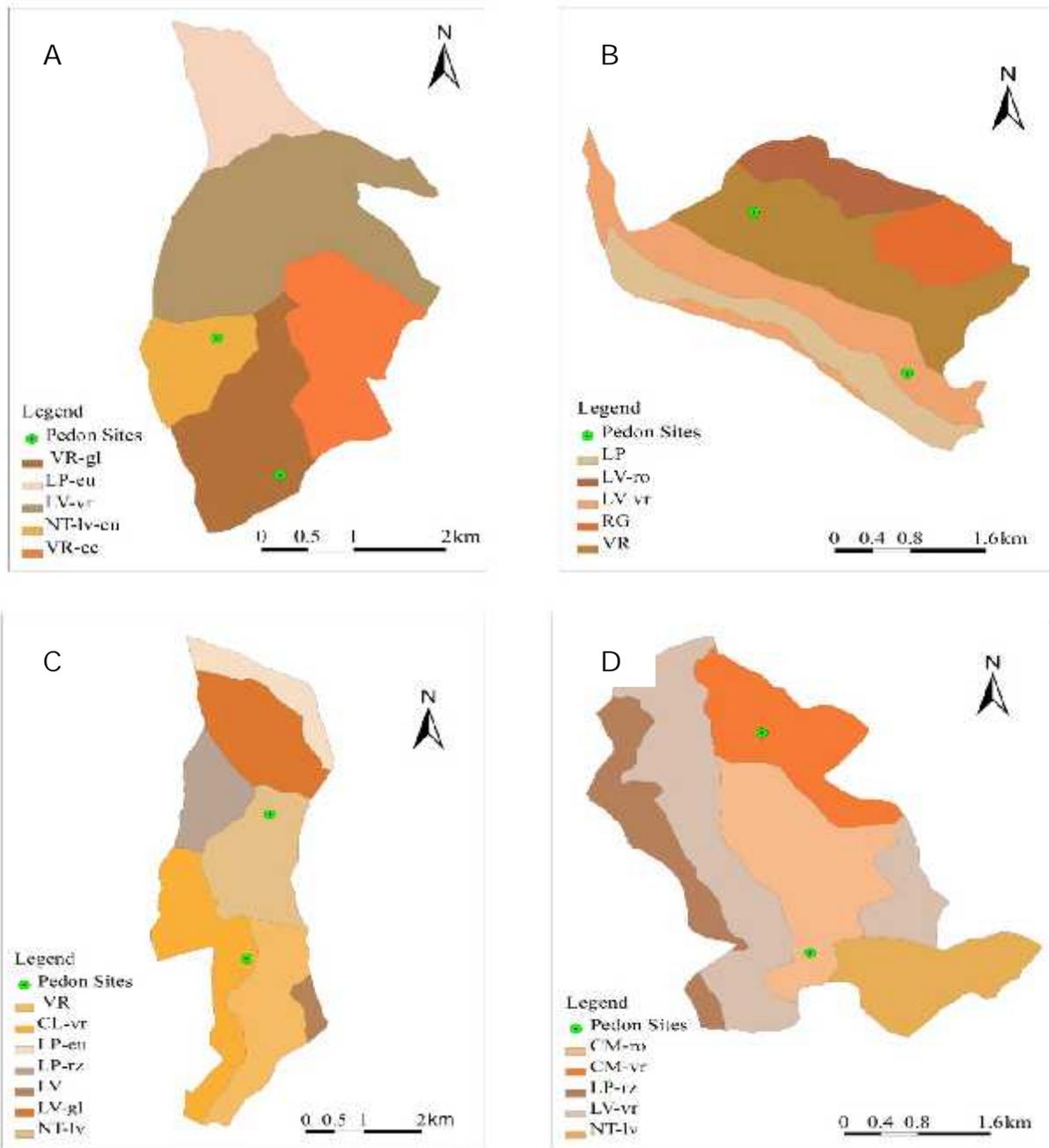


Figure 20. Exploratory soil maps and location of pedon sites of the four CASCAPE intervention kebeles in Gurawa Woreda: (A) Rasa Janata, (B) Ula Janata, (C) Lencha, and (D) Lafto Ila Tatesa.

#### 3.7.1.5. The soil-landscape (final)

The major soil types occurring in the four kebeles are Leptosols, Cambisols, Nitisols, Luvisols, and Vertisols. In Lencha Kebele, a Calcisol is also identified. The different mapping units identified and the major landform on which they occur, and the proportion of area each mapping unit occupies is indicated in Table 21. The geographic distribution of the soils in each kebele is depicted in Figure 22. Plate 15 illustrates some of the pedons opened on representative agricultural soils in the four kebeles.

Though there is minor difference in the sequence of soils along a toposequence in the four kebeles, a general sequence of soils from the steepest part to the lowest point can be perceived as indicated in Figure 21. The Leptosols occur mostly on the steepest parts of the kebeles in Rasa Janata, Ula Janata and Lencha Kebeles, whereas in Lafto Ila Tatesa, the Leptosols occur in the lowest parts of the Kebele that are covered by limestone outcrops.

Cambisols occur on the steep parts of the terraced landscapes, such as those in Ula Janata, and developed mainly from basaltic and limestone parent materials. The Nitisols, identified in all but Ula Janata Kebele, occur on the middle to lower slopes of the sloping landforms and are developed on either basalt or limestone parent material. They also occur on level lands in some pocket areas (e.g., in Lafto Ila Tatesa). The Luvisols occupy the middle to lower slopes of the sloping landforms in the four kebeles and are formed from basalt and limestone parent materials. The Vertisols, on the other hand, occur on the lowest points, mostly the toe slopes, of the sloping landforms. They are dominantly developed from basalt parent material. However, in some pocket areas (e.g., Rasa Janata) they are also developed on limestone parent material. In general, the Calcic Vertisols are developed from a mixture of basalt and limestone materials.

The Vertic Hypercalcaric Calcisol, which is identified in Lencha Kebele only, occurs on the west-facing side slopes and is formed from limestone parent material.

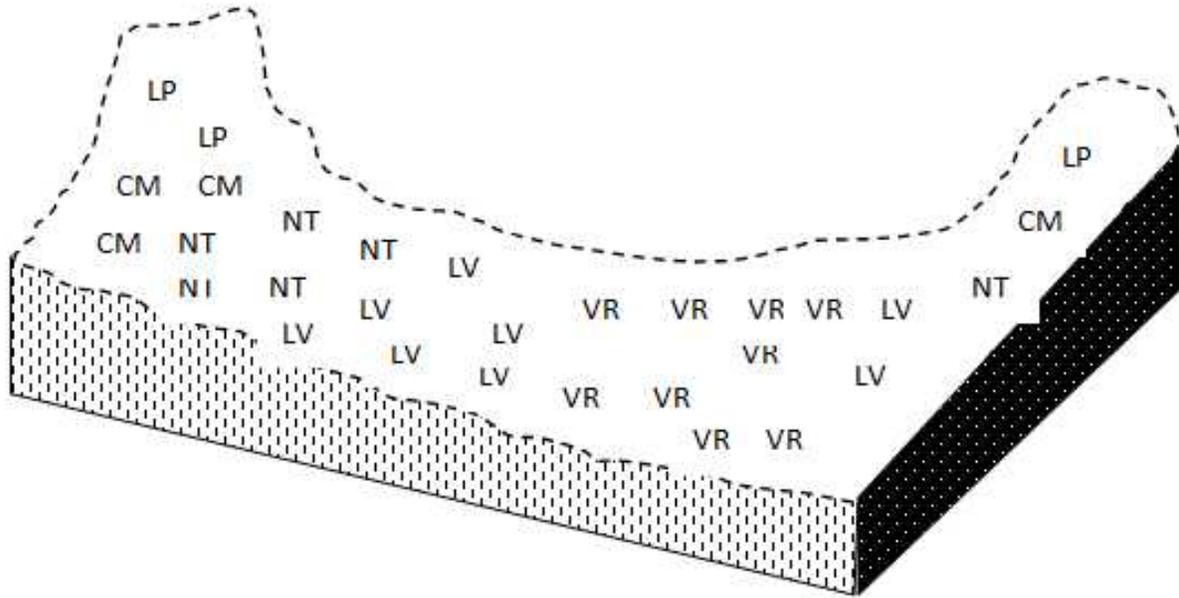


Figure 21. A general sketch of soil-landscape for the CASCAPE intervention kebeles in Gurawa Woreda.

Table 22. The different mapping units and their area coverage in the four CASCAPE intervention kebeles in Gurawa Woreda

Kebele	Major landform (landscape unit)	Soil type	Soil code	Area (ha)	%	Elevation (masl)
Rasa Janata	Steep land	Leptosol (Eutric)	LP-eu	152	12	2540-3140
	Level land	Luvic Nitisols (Eutric)	NT-lv-eu	120	10	2340-2440
	Sloping land	Vertic Luvisols	VR-vr	457	37	2320-2540
	Sloping land	Calcic Vertisols	VR-cc	242	20	2040-2340
	Level land	Mollic Gleyic Vertisols (Eutric, Pellic)	VR-gl.mo-eu.pe	252	21	2280-2480
Ula Janata	Steep land	Leptosols	LP	156	19	2480-2740
	Sloping land	Vertic Cambisols (Eutric, Skeletic)	CM-vr-eu.sk	38	5	2300-2380
	Sloping land	Luvisols (Rhodic)	Lv-ro	99	12	2160-2260
	Sloping land	Nitic Vertic Luvisol (Hypereutric, Clayic, Chromic)	LV-vr-ni-je.ce.cro	258		
	Sloping land	Vertic Luvisols	LV-vr	258	31	2380-2480
Lencha	Sloping land	Vertisols	VR	286	34	2080-2380
	Steep land	Leptosols (Eutric)	LP-eu	162	8	2560-3140
	Sloping land	Luvic Nitisols (Eutric)	NT-lv-eu	529	27	2200-2460
	Level land	Gleyic Luvisol	LV-gl	358	18	2360-2560
	Sloping land	Luvisols	LV	42	2	2400-2620
	Sloping land	Vertic Hypercalcic Calcisols (Clayic)	CL-je-vr.ce	474	24	1700-2200
LaftollaT atesa	Sloping land	Vertisols	VR	371	19	2200-2460
	Valley	Calcic Leptosols	LP-cc	361	23	1620-1900
	Sloping land	Vertic Cambisols (Eutric, Clayic, Rhodic)	CM-vr-eu.ce.ro	229	15	1920-2100
	Sloping land	Haplic Cambisols (Eutric, Clayic, Chromic))	CM-ha-eu.ce.cr	330	21	2020-2100
	Level to sloping land	Luvic Nitisols	NT-lv	193	12	1900-2060
Sloping land	Vertic Luvisols	LV-vr	466	30	1860-2000	

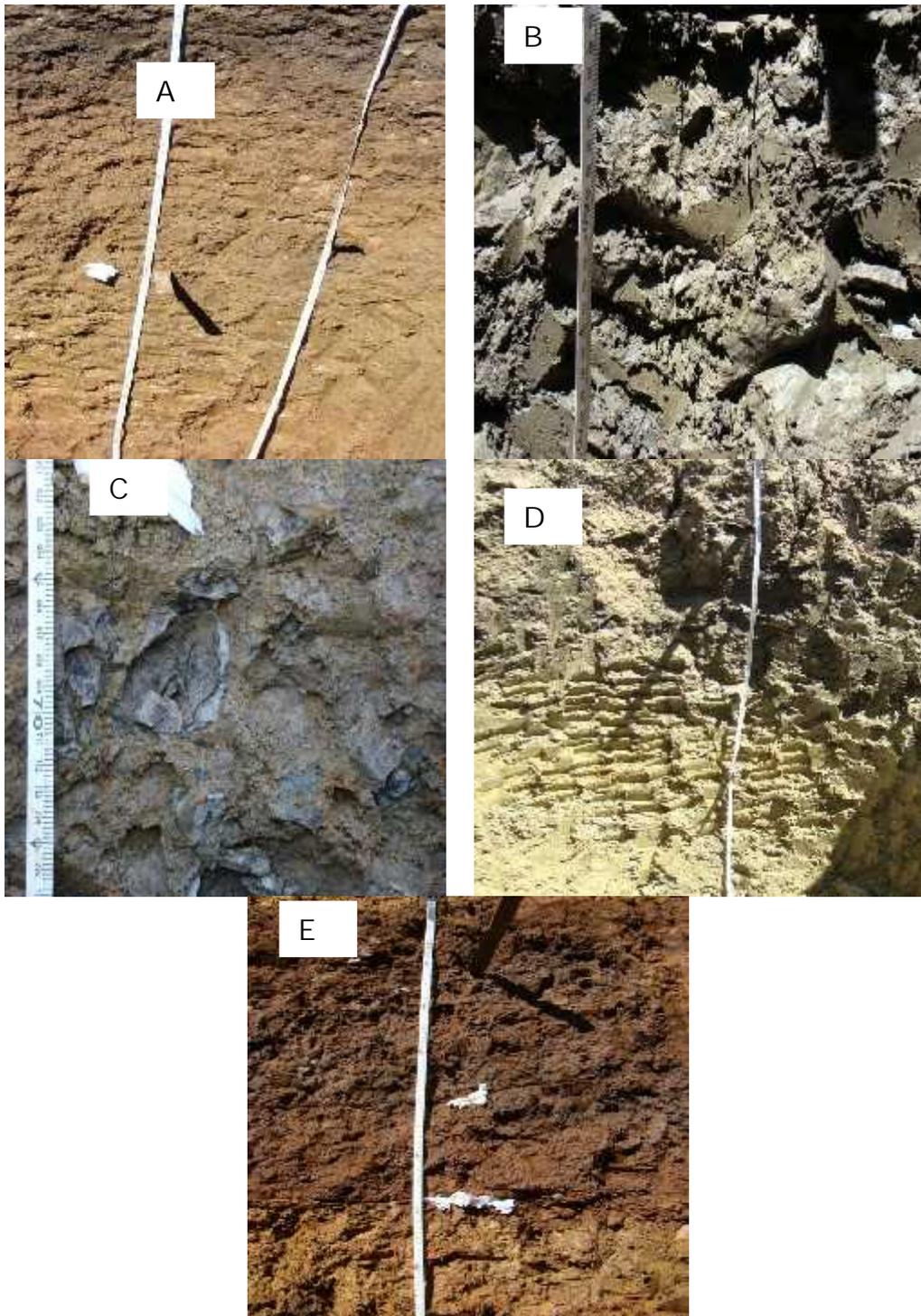


Plate 15. Some of the pedons representing major agricultural soils of the four CASCAPE intervention kebeles in Gurawa Woreda: (A) Luvic Nitisol (Rasa Janata), (B) Mollic Gleyic Vertisol (Rasa Janata), (C) Vertic Cambisol (Ula Janata), (D) Vertic Hypercalcic Calcisol (Lencha), (E) Haplic Cambisol (Lafto Ila Tatesa).

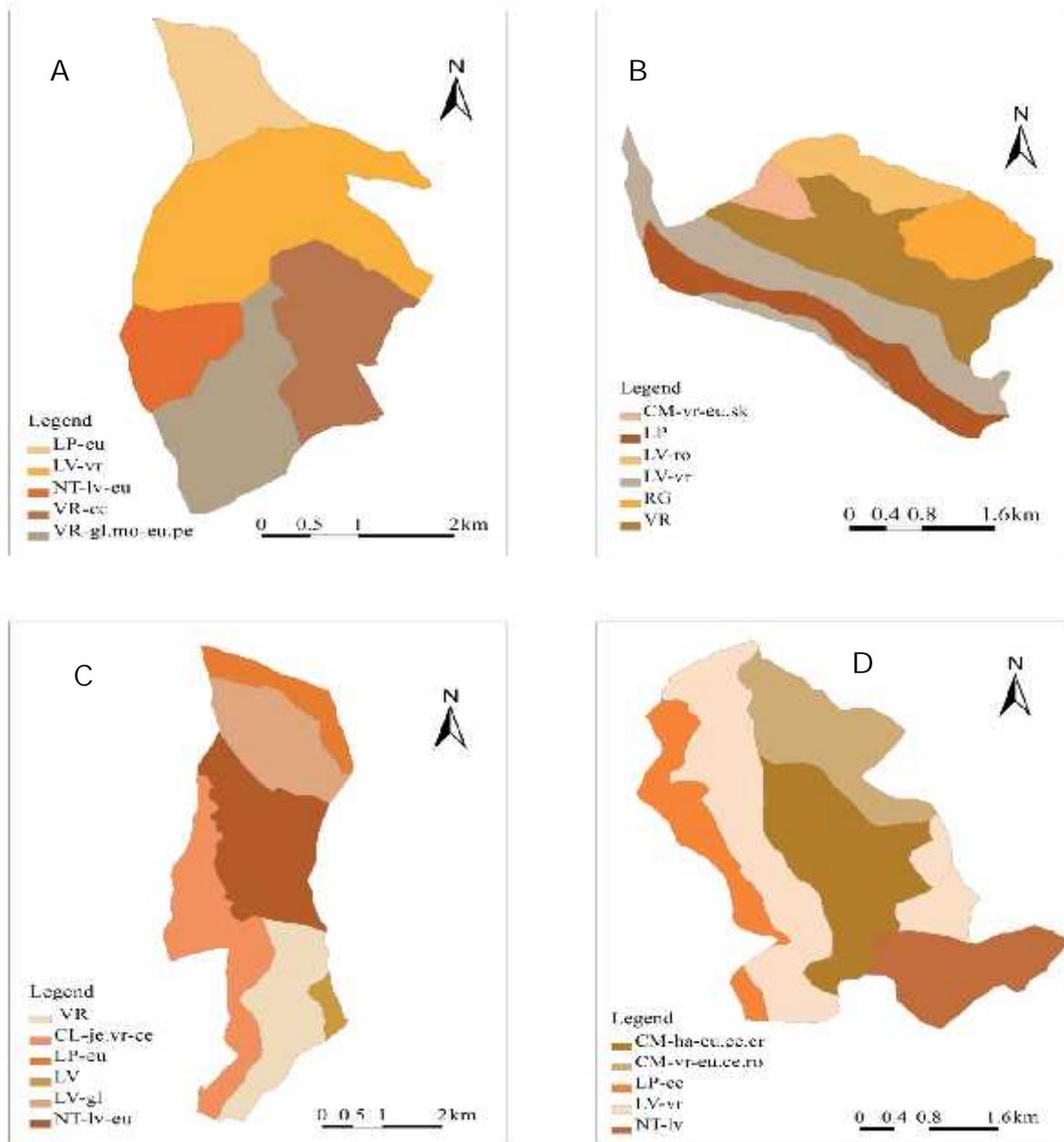


Figure 22. Soil maps of the four CASCAPE intervention kebeles in Gurawa Woreda: (A) Rasa Janata, (B) Ula Janata, (C) Lencha, and (D) Lafto Ila Tatesa.

Names of soils based on local classifications were also recorded to correlate them with the WRB names. Similar to the experience in other CASCAPE intervention woredas, the classification is done based on soil colour and also texture. Terms that indicate the productivity and/or fertility of a soil are also used to distinguish between soils of similar colour. The farmers actually have deep knowledge of their soil with regard to their productivity. However, this classification, as long as the soils have the same colour and also productivity, puts different soils into one category although they could be very different soils from scientific perspective. Also, the same soil type may have different names based on its colour variation and also surface texture. Its correlation with the WRB could be important for communicating results among farmers. Nonetheless, it requires some refining and standardization in consultation with the farmers. The correlation between local and the WRB names is presented in Table 23.

Table 23. Correlation between local and WRB soil names in the four CASCAPE intervention kebeles in GurawaWoreda

WRB name	Local name
Nitisols	QeferaDimma
Vertisol (Black)	BiyeGuracha
Luvisol (Chromic)	SupeeDhimma
VerticCambisol (Black)	SupeeGuracha
Calcisol	Supee
LuvicNitisol	SupeeDimma
HaplicCambisol	Qefera
VerticCambisol (Rhodic)	QeferaDimma

### 3.7.2. Soil Profile Descriptions and Analytical Data

#### 3.7.2.1. Soil Profiles

A total of 8 (2 per kebele) pedons, representing major agricultural soils of four CASCAPE intervention kebeles in Gurawa Woreda, were opened. The intervention kebeles are Rasa Janata (2), Ula Janata (2), Lencha (2), and Lafto Ila Tatesa (2). Furthermore, 32 auger pits were also described in these four kebeles. A total of 35 soil samples were collected from genetic horizons of the 8 pedons and analyzed for their selected physical and chemical properties at the Water Works and Design Supervision Enterprise Soil laboratory in Addis Ababa.

Presented below in Tables 24 and 25, respectively, are the results of field descriptions of the pedons' site and profile characteristics, and the analytical results.

The results are interpreted using critical values of parameters as suggested in Booker Tropical Soil Manual (Landon, 1991), Hazelton and Murphy (2007), Jones (2003), FAO (2007), Karlton et al. (2013), and Allison (1973).

Table 24. Soil site and profile descriptions of pedons opened in four CASCAPE intervention kebeles of Gurawa Woreda (see Table 25 for the analytical data)

Profile ID	HE/GRW/RJ/P1	Land cover	Protected forest, patchy shrubs, herbaceous
Date	25/01 (dd/mm)	Land use	Crop cultivation and animal husbandry
Year	2014	Crop	Cereals, vegetables, khat, some fruit trees, sugarcane
Surveyor	Kibebew Kibret	Human influence	Vegetation intensively disturbed, irrigation
Status	Reference profile description	Surface stone cover	Very few
Location country	Ethiopia	Surface stone size	Medium gravel to stones
Location region	East Hararghe	Erosion category	None
Location woreda	Gurawa	Crack width	Wide (2-5 cm)
Location kebele	Rasa Janata	Crack depth	Deep (10-20 cm)
Longitude	41°47'31.6"	Crack distance	Closely spaced (0.2-0.5 m)
Latitude	09°11'9.2"	Surface salt	None
Elevation	2376 m	Surface drainage	Well
Topography	sloping, 5-10%	Soil drainage	Well
Major landform	Level land, plateau	Flooding frequency	None
Position on slope	Middle slope	Depth to groundwater	Not observable
Slope form	Concave convex	Depth to bedrock	Not observable
Slope gradient	9%	Rootable depth	180+ cm
Geology	Basalt	Rooted depth	35 cm
Parent material	Igneous origin	Depth of observation	180 cm
		Local soil type	Qefera Dimma (Red soil)
		Field WRB soil type	Nitisol
		WRB soil type	Luvic Nitisol (Eutric)

#### Description of the soil horizons (morphology)

Horizon	Depth (cm)	Description
Ap	0-35	Black (5YR 2.5/1, moist) and brown (7.5YR 4/3, dry) colour; clay; strong coarse sub-angular blocky to angular blocky structure; hard when dry; very friable when moist, and very sticky and very plastic when wet; many, medium to fine pores; few, faint clay coatings; no visible coarse fragments of any nature; no observable mottles; very few, very fine roots; very few burrows; diffuse, smooth boundary; no reaction with dilute HCl and field measured pH value of 6.5.
B1	35-90	Reddish brown (5YR 4/4, moist) and reddish yellow (7.5YR 6/6, dry) colour; clay; strong coarse angular blocky structure; very hard (dry), very friable (moist), and very sticky and very plastic (wet) consistence; common, fine to very fine pores; very fine, faint clay coatings; no visible coarse fragments; no mottles; no visible roots; diffuse, smooth boundary; no reaction with dilute HCl; field measured pH value of 6.5.
B2	90-180	Red (2.5YR 4/6, moist) and strong brown (2.5YR 5/6, dry) colour; clay; strong coarse angular blocky structure; very hard (dry), very friable (moist), and very sticky and very plastic (wet) consistence; common, very fine roots; very few, faint clay coatings; no coarse fragments; no mottles; no roots; no reaction with dilute HCl; field measured pH value of 6.

Profile ID	HE/GRW/RJ/P2	Land cover	Protected forest, patchy shrubs, herbaceous
Date	25/01 (dd/mm)	Land use	Crop cultivation and crop husbandry, and forestry
Year	2014	Crop	Cereals, pulses, vegetables, khat, some fruit trees
Surveyor	KibebewKibret	Human influence	Vegetation moderately disturbed, ploughing, irrigation
Status	Reference profile description	Surface stone cover	Very few
Location country	Ethiopia	Surface stone size	Stones
Location region	East Hararghe	Erosion category	None
Location woreda	Gurawa	Crack width	Medium (1-2 cm)
Location kebele	Rasa Janata	Crack depth	Very deep (> 20 cm)
Longitude	41°47'53.6"	Crack distance	Closely spaced (0.2-0.5 m)
Latitude	09°10'12.8"	Surface salt	None
Elevation	2339 m	Surface drainage	Well
		Soil drainage	Poor
		Flooding frequency	None
Map unit ID		Depth to groundwater	Not observable
Topography	Sloping, 5-10%	Depth to bedrock	Not observable
Major landform	Level land, plateau	Rootable depth	200+ cm
Position on slope	Middle slope	Rooted depth	200 cm
Slope form	Concave straight	Depth of observation	200 cm
Slope gradient	9%	Local soil type	Biye Guracha (Black soil)
Geology	Igneous	Field WRB soil type	Vertisol
Parent material	Basalt	WRB soil type	Mollic Gleyic Vertisol (Eutric, Pellic)

#### Description of the soil horizons (morphology)

Horizon	Depth (cm)	Description
Ap	0-35	Black (10YR 2/1, moist) and very dark gray (10YR 3/1, dry) colour; clay; strong medium sub-angular blocky structure; extremely hard (dry), friable (moist), and very sticky and very plastic (wet) consistence; many, medium to very fine pores; common, distinct clay coatings; very few, fine coarse fragments of unspecified nature; no mottles; few, fine to medium roots; few burrows; diffuse, smooth boundary; no reaction with dilute HCl; field pH of 7.
C1	35-60	Very dark gray (2.5Y 3/1, moist) and very dark gray (10YR 3/1, dry) colour; clay; strong medium prismatic structure; extremely hard when dry, friable when moist, and very sticky and very plastic when wet; common; very fine to fine pores; few, distinct clay coatings; very few, fine coarse fragments of unspecified nature; no observable mottles; very few, medium roots; no other indicators of biological activity; diffuse, smooth boundary; no reaction with dilute HCl; field pH of 7.
Ci1	60-110	Black (2.5Y 2.5/1, moist) and dark gray (10YR 4/1, dry) colour; clay; strong very coarse prismatic structure; extremely hard when dry, friable when moist, and very sticky and very plastic when wet; common, very fine roots; very few, faint clay coatings; very few, fine coarse fragments of unspecified nature; no mottles; very few, coarse roots; very few burrows; clear, smooth boundary; no reaction with dilute HCl and field measured pH of 7; slickensides.
Cg1i	110-150	Very dark grayish brown (2.5Y 3/2, moist) and very dark gray (2.5Y 3/1, dry) colour; clay; strong very coarse angular blocky structure; few, very fine pores; very few, faint clay coatings; no coarse fragments; many, medium, distinct red mottles; very few, coarse roots; no other indicators of biological activity; clear, smooth boundary; no reaction with dilute HCl; field measured pH value of 7; slickensides.
Cg2i	150-200	Grayish brown (2.5Y 5/2, moist) and dark gray (2.5Y 4/1, dry) colour; clay; strong coarse angular blocky structure; extremely hard (dry), friable (moist), and very sticky and very plastic (wet) consistence; few, very fine roots; very few, faint clay coatings; no coarse fragments; many, medium, prominent red mottles; very few, coarse roots; no other indicators of biological activity; no reaction with dilute HCl and field measured pH value of 6; slickensides.

Profile ID	HE/GRW/UJ/P1	Land cover	Protected forest, shrubs, herbaceous
Date	25/01 (dd/mm)	Land use	Crop cultivation and animal husbandry, and forestry
Year	2014	Crop	Cereals, vegetables, khat, pulses,
Surveyor	Kibebew Klbret	Human influence	Vegetation moderately disturbed, ploughing, terracing
Status	Reference profile description	Surface stone cover	Few
Location country	Ethiopia	Surface stone size	Medium gravel to large boulders
Location region	East Hararghe	Erosion category	Water
Location woreda	Gurawa	Erosion area	0-5%
Location kebele	Ula Janata	Erosion degree	Slight
Longitude	41°49'4.3"	Crack width	Medium (1-2 cm)
Latitude	09°8'49.7"	Crack depth	Deep (10-20 cm)
Elevation	2444 m	Crack distance	Closely spaced (0.2-0.5 m)
Map ID		Surface drainage	Rapid
Map scale		Soil drainage	Well
Map unit ID		Depth to groundwater	Not observable (too deep)
Topography	Moderately steep, 15-30%	Depth to bedrock	Not observable
Major landform	Medium-gradient escarpment	Rootable depth	170 cm
Position on slope	Upper slope	Rooted depth	170 cm
Slope form	Concave straight	Depth of observation	170 cm
Slope gradient	24%	Local soil type	Supe Dimma
Geology	Igneous	Field WRB soil type	Vertic Luvisol
Parent material	Basalt	WRB soil type	Nitic Vertic Luvisol (Hypereutric, Clayic, Chromic)

#### Description of the soil horizons (morphology)

Horizon	Depth (cm)	Description
Ap	0-20	Reddish black (2.5YR 2.5/1, moist) and brown (7.5YR 4/2, dry) colour; clay; strong coarse granular and moderate medium sub-angular blocky structures; hard when dry, very friable when moist, and very sticky and very plastic when wet; many, fine to medium pores; few, distinct clay coatings; very few, fine to coarse fragments of unspecified nature; no observable mottles; few, very fine roots; very few burrows; clear, smooth boundary; no reaction with dilute HCl and field measured pH value of 6.
A	20-50	Dusky red (2.5YR 3/2, moist) and brown (7.5YR 4/3, dry) colour; clay; strong fine sub-angular blocky structure; very hard (dry), friable (moist), and very sticky and very plastic (wet) consistence; common, very fine to fine pores; very few, faint clay coatings; very few, fine to coarse fragments of unspecified nature; very few, very fine, faint mottles (red); very few, very fine roots; no other indicators of biological activity; diffuse, wavy boundary; no effervescence with dilute HCl; field measured pH value of 6.
Bt1	50-70	Very dark grey (5YR 3/1, moist) and very dark brown (7.5YR 2.5/2, dry) colour; clay; strong medium angular blocky structure; very hard (dry), friable (moist), and very sticky and very plastic (wet) consistence; common, very fine pores; very few, faint clay coatings; very few, fine coarse fragments of unknown nature; very few, very fine, faint mottles (red); very few, very fine roots; no other indicators of biological activity; diffuse, wavy boundary; no reaction with dilute HCl; field pH value of 6.
B	70-110	Dark reddish brown (5YR 3/3, moist) and brown (7.5YR 4/4, dry) colour; clay; strong medium sub-angular blocky to angular blocky structure; extremely hard (dry), friable (moist), and very sticky and very plastic (wet) consistence; few, very fine pores; no observable coatings; few, fine to coarse gravel fragments; very few, very fine, faint mottles (red); no roots and other indicators of biological activity; very few, very fine roots with no other indicators of biological activity; no effervescence with dilute HCl and field estimated pH value of 6.
Bt2	110-170	Reddish brown (5YR 4/3, moist) and yellowish brown (10YR 5/4, dry) colour; clay; strong medium angular blocky structure; extremely hard when dry. Friable when moist, and very sticky and very plastic when wet; few, very fine roots; no observable coatings; few, fine to coarse gravel fragments; very few, very fine, faint red mottles; no roots and other indicators of biological activity; no reaction with HCl; field pH of 6.

Profile ID	HE/GRW/UJ/P2	Land cover	Protected forest, patchy bushes, herbaceous
Date	25/01 (dd/mm)	Land use	Crop cultivation, animal husbandry, forestry
Year	2014	Crop	Cereals, pulses, khat, some fruits, sugarcane, oil crops, vegetables
Surveyor	KibebewKibret	Human influence	Vegetation intensively disturbed, ploughing, terracing, irrigation
Status	Reference profile description	Surface stone cover	Very few
Location country	Ethiopia	Surface stone size	Medium gravel to stones
Location region	East Hararghe	Erosion category	None
Location woreda	Gurawa	Crack width	Wide (2-5 cm)
Location kebele	Ula Janata	Crack depth	Very deep (> 20 cm)
Longitude	41°48'11.7"	Crack distance	Closely spaced (0.2-0.5 m)
Latitude	09°9'56.7"	Surface drainage	Well
Elevation	2369 m	Soil drainage	Rapid
		Flooding frequency	None
Map unit ID		Depth to groundwater	Too deep to observe
Topography	Sloping, 5-10%	Depth to bedrock	80 cm
Major landform	Dissected plateau	Rootable depth	80 cm
Position on slope	Lower slope	Rooted depth	60 cm
Slope form	Concave straight	Depth of observation	80 cm
Slope gradient	10%	Local soil type	Supe Guracha
Geology	Igneous	Field WRB soil type	Vertic Cambisol
Parent material	Basalt	WRB soil type	Vertic Cambisol (Eutric, Skeletic)

#### Description of the soil horizons (morphology)

Horizon	Depth (cm)	Description
Ap	0-15	Black (10YR 2/1, moist) and dark gray (10YR 4/1, dry) colour; clay; strong moderate sun-angular blocky structure; extremely hard (dry), very friable (moist), and very sticky and very plastic (wet) consistence; many, very fine to medium pores; few, distinct clay coatings; common, fine to coarse gravel fragments; very few, very fine, faint mottles (red); very few, fine roots; very few burrows; clear, smooth boundary; no reaction with HCl and field measured pH of 6.5.
A	15-35	Grayish brown (10YR 5/2, moist) and dark gray (10YR 4/1, dry) colour; clay; strong medium sub-angular blocky structure; extremely hard when dry, very friable when moist, and very sticky and very plastic when wet; many, very fine to medium roots; few, distinct clay coatings; common, fine to coarse gravel fragments; few, fine, faint mottles (red); very few, very fine roots; very few burrows; clear, smooth boundary; no reaction with HCl; field pH value of 6.5.
B	35-60	Olive brown (2.5Y 4/3, moist) and light olive brown (2.5Y 5/3, dry) colour; clay; weak very fine sub-angular blocky structure; extremely hard (dry), friable (moist), and very sticky and very plastic (wet) consistence; few, fine pores; few, distinct iron coatings; common, fine to coarse gravel fragments; common, fine, distinct red mottles; no observable roots and other indicators of biological activity; diffuse, irregular boundary; no reaction with HCl and field pH of 6.
BC	60-80	Olive brown (2.5Y 4/4, moist) and olive brown (2.5Y 4/3, dry) colour; clay; weak very fine sub-angular blocky structure; extremely hard (dry), friable (moist), and very sticky and very plastic (wet) consistence; few, distinct clay coatings; many, fine to coarse gravel fragments; common, fine, distinct red mottles; no roots and other indicators of biological activity; no reaction with HCl and field pH value of 6.

Profile ID	HE/GRW/LH/P1	Land cover	Scattered trees, patchy shrubs, herbaceous
Date	27/01 (dd/mm)	Land use	Crop cultivation and animal husbandry
Year	2014	Crop	Cereals, khat, vegetables, pulses
Surveyor	Kibebew Kibret	Human influence	Vegetation intensively disturbed, ploughing, terracing, irrigation
Status	Reference profile description	Surface stone cover	Very few
Location country	Ethiopia	Surface stone size	Large exposed boulders
Location region	East Hararghe	Erosion category	Water, gully
Location woreda	Gurawa	Erosion area	5-10%
Location kebele	Lencha	Erosion degree	Moderate
Longitude	41°46'39.5"	Crack width	Very wide (5-10 cm)
Latitude	09°10'10.2"	Crack depth	Very deep (> 20 cm) (65)
Elevation	2202 m	Crack distance	Closely spaced (0.2-0.5 m)
Map ID		Surface drainage	Rapid
Map scale		Soil drainage	Poor
Map unit ID		Depth to groundwater	Not observable
Topography	Moderately steep, 15-30%	Depth to bedrock	Not observable
Major landform	Medium-gradient hill	Rootable depth	70 cm
Position on slope	Middle slope	Rooted depth	70 cm
Slope form	Straight	Depth of observation	145 cm
Slope gradient	29%	Local soil type	Supe
Geology	Sedimentary	Field WRB soil type	Vertic Calcisol
Parent material	Limestone	WRB soil type	Vertic Hypercalcic Calcisol (Clayic)

#### Description of the soil horizons (morphology)

Horizon	Depth (cm)	Description
Apk1	0-20	Dark gray (2.5Y 4/1, moist) and light brownish gray (2.5Y 6/2, dry) colour; clay; weak very coarse sub-angular blocky and massive; extremely hard when dry, very friable when moist, and very sticky and very plastic when wet; few, very fine to fine pores; very few, fine clay coatings; moderately cemented with calcium carbonate; very few, fine calcium carbonate fragments; few, very fine, faint black mottles; very few, very fine roots; no other indicators of biological activity; clear, smooth boundary; strong reaction with dilute HCl; field pH value of 7.5.
Bk2	20-45	Dark grayish brown (2.5Y 4/2, moist) and grayish brown (2.5Y 5/2, dry) colour; clay; moderate very coarse angular blocky structure; extremely hard (dry), very friable (moist), and very sticky and very plastic (wet) consistence; very few, very fine pores; very few, faint clay coatings; very few, fine calcium carbonate fragments; indurated with calcium carbonate; very few, very fine, faint black mottles; very few, very fine to coarse roots; no other indicators of biological activity; clear, smooth boundary; strong effervescence with HCl and field measured pH value of 7.5.
Bck3	45-70	Olive gray (5Y 4/2, moist) and dark grayish brown (2.5Y 4/2, dry) colour; clay; moderate very coarse angular blocky structure; extremely hard when dry, very friable when moist, and very sticky and very plastic when wet; few, very fine pores; very few, faint clay coatings; few, fine calcium carbonate fragments; indurated by calcium carbonate; few, very fine, faint black mottles; very few, fine roots; no other indicators of biological activity; clear, smooth boundary; extremely strong effervescence with dilute HCl; field measured pH value of 8.5.
Ck4	70-110	Pale olive (5Y 6/4, moist) and light yellowish brown (2.5Y 6/4, dry) colour; clay; weak very coarse massive; extremely hard (dry), very friable (moist), and very sticky and very plastic (wet) consistence; very few, very fine pores; very few, faint clay coatings; very few, fine calcium carbonate fragments; indurated with calcium carbonate; very few, very fine, faint black mottles; no roots and other indicators of biological activity; diffuse, smooth boundary; extremely strong effervescence with dilute HCl; field pH value of 8.5.
Ck5	110-145	Yellow (5Y 7/6, moist) and pale brown (2.5Y 7/4, dry) colour; clay; weak, coarse massive; extremely hard (dry), friable (moist), and very sticky and very plastic (wet) consistence; very few, very fine pores; very few, faint clay coatings; common, fine to medium calcium carbonate fragments; indurated by calcium carbonate; very few, very fine, faint black mottles; no roots and indicators of other biological activity; extremely strong reaction with dilute HCl; field pH value of 8.5.

Profile ID	HE/GRW/LH/P2	Land cover	Protected forest, scattered agro-forestry trees, bushes, herbaceous
Date	27/01 (dd/mm)	Land use	Crop cultivation, animal husbandry, forestry
Year	2014	Crop	Cereals, pulses, vegetables, some fruits, khat
Surveyor	KibebewKibret	Human influence	Vegetation moderately disturbed, ploughing, furrow/flood irrigation
Status	Reference profile description	Surface stone cover	Very few
Location country	Ethiopia	Surface stone size	Stones
Location region	East Hararghe	Erosion category	None
Location woreda	Gurawa	Crack width	Wide (2-5 cm)
Location kebele	Lencha	Crack depth	Very deep (> 20 cm)
Longitude	41°46'53.5"	Crack distance	Very closely spaced (< 0.20 m)
Latitude	09°11'49.7"	Surface drainage	Well
Elevation	2380 m	Soil drainage	Well
Map ID		Flooding frequency	None
Map scale		Depth to groundwater	Not observable
Map unit ID		Depth to bedrock	Not observable
Topography	Strongly sloping, 10-15%	Rootable depth	200 cm
Major landform	Medium gradient hill	Rooted depth	120 cm
Position on slope	Middle slope	Depth of observation	200 cm
Slope form	Concave straight	Local soil type	Supe Dimma (Red soil)
Slope gradient	14%	Field WRB soil type	Nitisol
Geology	Igneous	WRB soil type	Luvic Nitisol (Eutric)
Parent material	Basalt		

#### Description of the soil horizons (morphology)

Horizon	Depth (cm)	Description
Ap	0-20	Black (10YR 2/1, moist) and dark grayish brown (10YR 4/2, dry) colour; clay; strong very coarse angular blocky structure; hard (dry), very friable (moist), and very sticky and very plastic (wet) consistence; many, very fine to fine pores; very few, faint clay coatings; very few, fine coarse fragments of unspecified nature; no mottles; few, fine roots; very few burrows; gradual, smooth boundary; slight effervescence with dilute HCl; field pH of 6.5.
B1	20-45	Olive (5Y 4/3, moist) and dark yellowish brown (10YR 4/4, dry) colour; clay; strong coarse angular blocky structure; very hard when dry, very friable when moist, and very sticky and very plastic when wet; common, very fine to fine pores; very few, faint clay coatings; no coarse fragments; no mottles; very few, fine roots; very few burrows; diffuse, smooth boundary; no reaction with HCl and field pH of 6.
B2	45-90	Black (5YR 2.5/1, moist) and yellowish brown (10YR 5/4, dry) colour; clay; strong coarse angular blocky structure; very hard (dry), friable (moist), and very sticky and very plastic (wet) consistence; few, very fine to fine pores; very few, faint clay coatings; no coarse fragments; no mottles; very few, very fine roots; no other indicators of biological activity; diffuse, smooth boundary; no reaction with HCl; field pH of 6.5.
B3	90-120	Very dark gray (5YR 3/1, moist) and dark grayish brown (10YR 4/2, dry) colour; clay; strong medium prismatic structure; very hard when dry, friable when moist, and very sticky and very plastic when wet; few, very fine pores; no coatings; no coarse fragments; very few, very fine, faint black mottles; very few, very fine to fine roots; no other indicators of biological activity; diffuse, irregular boundary; no reaction with HCl; pH value of 6.5.
BC	120-200	Light olive brown (2.5Y 5/4, moist) and brown (10YR 5/3, dry) colour; clay; strong coarse angular blocky structure; extremely hard (dry), friable (moist), and very sticky and very plastic (wet) consistence; few, very fine pores; no coatings; no coarse fragments; no mottles; no roots and other indicators of biological activity; no reaction with HCl; field pH value of 6.5.

Profile ID	HE/GRW/LT/P1	Land cover	Scattered trees, bushes, herbaceous
Date	29/01 (dd/mm)	Land use	Crop cultivation and animal husbandry
Year	2014	Crop	Cereals, other crops (coffee), khat
Surveyor	KibebewKibret	Human influence	Vegetation intensively disturbed, ploughing, terracing, bunding
Status	Reference profile description	Surface stone cover	Very few
Location country	Ethiopia	Surface stone size	Stones
Location region	East Hararghe	Erosion category	Water
Location woreda	Gurawa	Erosion area	0-5%
Location kebele	LaftollaTatesa	Erosion degree	Slight
Longitude	41°46'11.1"	Crack width	None
Latitude	09°01'45.4"	Surface drainage	Rapid
Elevation	2030 m	Soil drainage	Well
Map ID		Flooding frequency	None
Map scale		Depth to groundwater	Not observable
Map unit ID		Depth to bedrock	200 cm
Topography	Moderately steep, 15-30%	Rootable depth	160 cm
Major landform	Medium-gradient hills	Rooted depth	160 cm
Position on slope	Middle slope	Depth of observation	160 cm
Slope form	Straight	Local soil type	Qefera
Slope gradient	20%	Field WRB soil type	Cambisol
Geology	Igneous and sedimentary	WRB soil type	Haplic Cambisol (Eutric, Clayic, Chromic)
Parent material	Basalt and limestone		

#### Description of the soil horizons (morphology)

Horizon	Depth (cm)	Description
Ap	0-20	Dark reddish brown (2.5YR 2.5/3, moist) and red (2.5YR 4/6, dry) colour; sandy clay loam; strong medium sub-angular blocky to angular blocky structure; very hard when dry, very friable when moist, and very sticky and very plastic when wet; many, very fine to medium pores; few, distinct clay coatings; very few, fine coarse fragments of unspecified nature; no mottles; common, fine roots; few burrows; clear, smooth boundary; slight reaction with HCl; field pH of 6.5.
A	20-50	Reddish brown (2.5YR 4/4, moist) and dark reddish brown (2.5YR 3/4, dry) colour; sandy clay loam; strong medium angular blocky structure; hard (dry), very friable (moist), and very sticky and very plastic (wet) consistence; common, very fine to fine pores; very few, faint clay coatings; very few, fine coarse fragments of unknown nature; no mottles; few, very fine roots; very few burrows; diffuse, smooth boundary; no reaction with HCl; field measured pH value of 6.
B1	50-67	Dark reddish brown (2.5YR 3/4, moist) and red (2.5YR 4/8, dry) colour; clay loam; strong medium angular blocky structure; very hard when dry, very friable when moist, and very sticky and very plastic when wet; common, very fine pores; very few, faint clay coatings; no coarse fragments; very few, very fine, faint red mottles; very few, very fine roots; very few burrows; diffuse, smooth boundary; no reaction with HCl; pH value of 6.
B2	67-160	Pale olive (5Y 6/4, moist) and reddish yellow (7.5YR 6/6, dry) colour; clay; strong medium angular blocky structure; very hard (dry), friable (moist), and very sticky and very plastic (wet) consistence; common, very fine pores; very few, distinct clay coatings; no coarse fragments; common, fine, distinct mottles; very few, very fine roots and no other indicators of biological activity; no reaction with HCl; field measured pH value of 6.

Profile ID	HE/GRW/LT/P2	Land cover	Scattered trees, bushes, herbaceous
Date	29/01 (dd/mm)	Land use	Crop cultivation and animal husbandry
Year	2014	Crop	Cereals, coffee, khat, vegetables
Surveyor	KibebewKibret	Human influence	Vegetation intensively disturbed, ploughing, flood/furrow irrigation
Status	Reference profile description	Surface stone cover	Few
Location country	Ethiopia	Surface stone size	Coarse gravel
Location region	East Hararghe	Erosion category	None
Location woreda	Gurawa	Crack width	Medium (1-2 cm)
Location kebele	LaftollaTatesa	Crack depth	Deep (10-20 cm)
Longitude	41°45'54.5"	Crack distance	Closely spaced (0.2-0.5 m)
Latitude	09°03'24.8"	Surface salt	None
Elevation	2047 m	Surface drainage	Well
Map ID		Soil drainage	Well
Map scale		Flooding frequency	None
Map unit ID		Depth to groundwater	Not observable
Topography	Sloping, 5-10%	Depth to bedrock	60 cm
Major landform	Medium-gradient hill	Rootable depth	60 cm
Position on slope	Upper slope	Rooted depth	60 cm
Slope form	Straight	Depth of observation	120 cm
Slope gradient	10%	Local soil type	Qefera Dimma
Geology	Sedimentary	Field WRB soil type	Vertic Cambisol
Parent material	Limestone basement	WRB soil type	Vertic Cambisol (Eutric, Clayic, Rhodic)

#### Description of the soil horizons (morphology)

Horizon	Depth (cm)	Description
Ap	0-30	Dark reddish brown (2.5YR 3/3, moist) and reddish brown (5YR 4/4, dry) colour; strong coarse granular to strong moderate sub-angular blocky structure; hard when dry, very friable when moist, and very sticky and very plastic when wet; many, fine to medium pores; few, faint clay coatings; very few, fine coarse fragments of unknown nature; very few, very fine, faint black mottles; common, fine roots and few burrows; gradual, smooth boundary; slight reaction with HCl; field pH of 6.
A	30-60	Dark reddish brown (2.5YR 2.5/4, moist) and dark grayish brown (2.5YR 3/4, dry) colour; strong coarse sub-angular blocky to angular blocky structure; very hard (dry), very friable (moist), and sticky and plastic (wet) consistence; common, fine pores; very few, faint clay coatings; very few, fine coarse fragments of unspecified nature; no mottles; few, very fine to fine roots; very few burrows; gradual, smooth boundary; no reaction with HCl; field measured pH value of 6.
Bt1	60-85	Dark reddish brown (2.5YR 3/4, moist) and red (2.5YR 4/6, dry) colour; strong medium angular blocky structure; hard when dry, very friable when moist, and sticky and plastic when wet; common, very fine to fine pores; very few, faint clay coatings; very few, fine coarse fragments of unknown nature; no mottles; very few, very fine to fine roots; very few burrows; gradual, smooth boundary; no reaction with HCl; pH value of 5.5.
BC	85-120	Dark reddish brown (2.5YR 2.5/3, moist) and dark reddish brown (2.5YR 2.5/4, dry) colour; strong medium angular blocky structure; hard (dry), very friable (moist), and sticky and plastic (wet) consistence; common, very fine pores; very few, faint clay coatings; very few, fine coarse fragments of unknown nature; no mottles; very few, fine roots; very few burrows; no reaction with HCl; field measured pH value of 5.5.

Table 25. Selected soil physical and chemical properties of representative pedons opened on major agricultural soils in CASCAPE intervention kebeles in GurawaWoreda

Parameters	HE/GRW/RJ/P1			HE/GRW/RJ/P2				
	0-35	35-90	90-180	0-35	35-60	60-110	110-150	150-200
Depth (cm)	0-35	35-90	90-180	0-35	35-60	60-110	110-150	150-200
Horizon	Ap	B1	B2	Ap	A1	Ai1	Ag1i	Ag2i
Sand (%)	32.9	34.5	13.5	24.2	24.2	17.3	11.8	16.6
Silt (%)	18.9	14.8	33.8	11.9	9.7	17.4	26.5	14.1
Clay (%)	48.2	50.8	52.7	63.9	66.0	65.3	61.8	69.3
Textural class	C	C	C	C	C	C	C	C
pH-H <sub>2</sub> O	5.96	5.70	5.89	6.33	6.51	6.94	6.92	6.98
pH-KCl	5.04	4.67	5.02	5.48	5.59	6.13	5.04	6.07
EC (μS/cm)	0.06	0.04	0.06	0.09	0.09	0.10	0.09	0.20
OC (%)	1.11	0.82	0.24	1.47	1.04	0.67	0.50	0.28
TN (%)	0.10	0.07	0.02	0.15	0.11	0.07	0.05	0.03
Av.P (mg/kg)	31.60			39.30				
Av. S (%)	1.19			1.28				
Na (meq/100 g)	0.80	0.88	1.04	0.83	0.91	0.97	1.21	0.98
K (meq/100 g)	0.51	0.39	0.43	0.45	0.47	0.38	0.49	0.50
Ca (meq/100 g)	22.68	23.52	21.84	36.29	37.15	36.72	35.75	43.20
Mg (meq/100 g)	7.56	7.56	6.72	12.10	12.53	12.10	12.21	14.69
CEC (meq/100 g)	44.28	42.91	41.54	51.65	55.88	56.35	54.97	62.92
SB (meq/100 g)	31.55	32.34	30.03	49.66	51.06	50.17	49.67	59.36
ESP (%)	1.81	2.04	2.51	1.60	1.63	1.72	2.21	1.55
Zn (mg/kg)	4.68			1.37				
Mn (mg/kg)	88.46			17.71				
Cu (mg/kg)	6.11			3.33				
Fe (mg/kg)	61.20			37.43				

GRW = GrawaWoreda; RJ = Rasa Janata Kebele; P = Pedon; EC = electrical conductivity; OC = Organic matter; TN = total nitrogen; Av. = Available; SB = sum of bases; C = clay

Parameters	HE/GRW/UJ/P1					HE/GRW/UJ/P2			
	0-20	20-50	50-70	70-110	110-170	0-15	15-35	35-60	60-80
Depth (cm)	0-20	20-50	50-70	70-110	110-170	0-15	15-35	35-60	60-80
Horizon	Ap	A	Bt1	B	Bt2	Ap	A	Bt	BC
Sand (%)	32.8	32.8	30.2	34.9	25.3	15.1	31.5	25.2	34.1
Silt (%)	18.9	21.0	12.7	16.0	20.6	18.3	14.1	15.4	15.4
Clay (%)	48.3	46.2	57.1	49.1	54.1	66.6	54.4	59.4	50.5
Textural class	C	C	C	C	C	C	C	C	C
pH-H <sub>2</sub> O	6.06	5.89	6.10	6.01	6.00	6.44	6.59	6.41	6.68
pH-KCl	5.13	5.84	5.18	5.04	5.03	5.50	5.57	5.51	5.73
EC (μS/cm)	0.06	0.06	0.09	0.08	0.09	0.14	0.13	0.06	0.19
OC (%)	2.22	1.42	1.39	1.04	0.31	1.54	0.34	0.28	0.26
TN (%)	0.21	0.16	0.13	0.10	0.03	0.16	0.05	0.04	0.03
Av.P (mg/kg)	37.00					36.80			
Av. S (%)	1.13					1.34			
Na (meq/100 g)	0.79	0.75	0.89	1.25	1.22	0.95	1.24	1.38	1.33
K (meq/100 g)	1.34	1.26	0.64	0.50	0.39	0.67	0.24	0.29	0.47
Ca (meq/100 g)	26.88	22.26	23.94	23.74	23.33	36.81	35.86	39.24	37.46
Mg (meq/100 g)	9.24	7.14	7.98	7.63	7.78	12.84	12.10	13.08	12.20
CEC (meq/100 g)	43.37	34.70	41.09	41.94	42.73	54.90	51.65	55.92	53.50
SB (meq/100 g)	38.24	31.41	33.45	33.13	32.71	51.27	49.43	53.99	51.46
ESP (%)	1.81	2.16	2.16	2.99	2.86	1.73	2.40	2.47	2.48
Zn (mg/kg)	5.32					2.30			
Mn (mg/kg)	57.40					21.31			
Cu (mg/kg)	0.90					2.75			
Fe (mg/kg)	62.73					25.66			

UJ = Ula Janata Kebele

Parameters	HE/GRW/LH/P1					HE/GRW/LH/P2				
	0-20	20-45	45-70	70-110	110-145	0-20	20-45	45-90	90-120	120-200
Horizon	Apk1	Bt1k	Bck2	Ck3	Ck4	Ap	Bt1	Bt2	Bt3	BC
Sand (%)	39.59	30.02	25.73	21.48	23.88	51.79	44.09	39.90	33.46	35.49
Silt (%)	7.29	6.36	23.34	29.71	21.15	7.50	10.75	9.66	10.73	20.43
Clay (%)	53.12	63.62	50.93	48.81	54.98	40.71	45.16	50.44	55.81	44.08
Textural class	C	C	C	C	C	SC	C	C	C	C
pH-H <sub>2</sub> O	7.79	7.93	7.90	7.85	7.84	5.27	4.93	5.14	5.29	5.68
pH-KCl	6.93	7.00	7.03	7.00	6.94	4.30	4.01	4.20	4.33	4.72
EC (μS/cm)	0.20	0.34	0.39	0.38	0.35	0.06	0.04	0.04	0.04	0.07
OC (%)	1.35	0.57	0.49	0.23	0.13	2.87	1.81	1.03	0.92	0.25
TN (%)	0.15	0.06	0.04	0.03	0.01	0.28	0.22	0.10	0.07	0.03
Av. P (mg/kg)	51.50					24.90				
Av. S (%)	1.06					0.93				
Na (meq/100 g)	0.82	1.01	0.95	0.98	0.98	0.78	0.78	0.98	1.02	0.93
K (meq/100 g)	0.85	0.99	0.92	0.90	0.89	0.57	0.41	0.37	0.39	0.22
Ca (meq/100 g)	33.28	29.60	30.05	28.78	28.67	17.93	18.83	23.92	21.36	25.68
Mg (meq/100 g)	11.65	10.15	10.16	9.73	9.28	5.98	6.85	8.54	7.69	7.63
CEC (meq/100 g)	51.55	44.12	44.16	42.32	45.83	34.79	41.87	44.58	45.51	38.61
SB (meq/100 g)	46.60	41.74	42.07	40.39	39.81	25.25	26.87	33.82	30.47	34.46
ESP (%)	1.60	2.29	2.15	2.33	2.14	2.24	1.87	2.21	2.24	2.41
Zn (mg/kg)	7.26					3.04				
Mn (mg/kg)	2.64					40.31				
Cu (mg/kg)	2.70					4.29				
Fe (mg/kg)	13.32					87.61				

GRW = GrawaWoreda; LH = LenchaKebele

Parameters	HE/GRW/LT/P1				HE/GRW/LT/P2			
	0-20	20-50	50-67	67-160	0-30	30-60	60-85	85-120
Horizon	Ap	A	Bt1	Bt2	Ap	A	Bt1	BC
Sand (%)	54.25	49.75	38.67	29.90	9.77	18.50	17.15	17.77
Silt (%)	9.36	14.20	17.52	21.57	26.73	14.72	20.43	22.53
Clay (%)	36.40	36.05	43.81	48.53	63.50	66.78	62.42	59.70
Textural class	SCL	SC	C	C	C	C	C	C
pH-H <sub>2</sub> O	6.09	6.14	6.04	6.02	6.00	5.52	5.56	5.69
pH-KCl	5.20	5.20	5.08	5.26	5.03	4.54	4.59	4.80
EC (μS/cm)	0.06	0.06	0.05	0.07	0.06	0.04	0.04	0.05
OC (%)	1.21	1.16	1.11	0.15	2.02	1.57	1.28	1.03
TN (%)	0.15	0.12	0.10	0.01	0.25	0.18	0.13	0.10
Av. P (mg/kg)	32.10				35.47			
Av. S (%)	0.76				1.10			
Na (meq/100 g)	0.75	0.81	0.80	0.82	0.87	0.79	0.78	0.87
K (meq/100 g)	0.25	0.26	0.27	0.41	0.42	0.39	0.34	0.35
Ca (meq/100 g)	18.27	15.81	18.88	13.25	25.22	18.55	23.03	23.97
Mg (meq/100 g)	6.64	5.41	6.29	4.14	8.41	6.75	7.68	8.56
CEC (meq/100 g)	36.56	33.01	37.86	29.70	50.27	38.04	46.81	48.38
SB (meq/100 g)	25.91	22.29	26.25	18.62	34.92	26.47	31.82	33.75
ESP (%)	2.05	2.47	2.12	2.76	1.73	2.07	1.66	1.81
Zn (mg/kg)	1.45				2.39			
Mn (mg/kg)	24.97				24.39			
Cu (mg/kg)	1.83				3.24			
Fe (mg/kg)	31.08				28.61			

GRW = GrawaWoreda; LT = LaftollaTatesaKebele; P = Pedon; EC = electrical conductivity; OC = Organic matter; TN = total nitrogen; Av. = Available; SB = sum of bases; C = clay; SCL = sandy clay loam; CL = clay loam

### 3.7.3. Synthesis

The morphological, physical and chemical properties of the pedons are presented in Tables 24 and 25 in Section 3.7.2. For the discussions presented below, reference should be made to those tables.

#### 3.7.3.1. Agronomic Interpretation of Soil Morphological Properties

##### 1. Colour

Soil colour matrix exhibited different degrees of variability within a pedon and among pedons where wide ranges of hue, value, and chroma were recorded. Accordingly, the surface colours (moist) varied from reddish black (2.5YR 2.5/1) in Luvic Nitisols (Eutric) in Ula Janata to dark gray (2.5Y 4/1) in Vertic Hypercalcic Calcisols (Clayic) in Lencha Kebele with most of the soils types exhibiting black colour while a few with dark reddish brown colour. Similarly, the surface colour (dry) varied between extremes of red (2.5YR 4/6) in Haplic Cambisols (Eutric, Clayic, Chromic) of Lafto Ila Tatesa and light brownish gray (2.5Y 6/2) in Vertic Hypercalcic Calcisols (Clayic) of Lencha with brown and gray to very dark gray being the intermediate colours. On the other hand, the subsurface colour (moist) exhibited high variability and ranged from dark reddish brown (2.5YR 2.5/3) in Vertic Cambisols (Eutric, Clayic, Rhodic) of Lafto Ila Tatesa to yellow (5Y 7/6) in the Vertic Hypercalcic Calcisols (Clayic) of Lencha Kebele. The subsurface colour (dry) also ranged from dark reddish brown (2.5YR 2.5/4) in the Vertic Cambisols of Lafto Ila Tatesa Kebele to pale brown (2.5Y 7/4) in the Vertic Hypercalcic Calcisols (Clayic) of Lencha Kebele with different intermediate colours.

The differences in colour when moist and dry indicate the difference in light reflection properties of soils when they are moist and dry. When moist, the soils absorb most of the light and become darker. When dry, however, most of the light is reflected and the soils become lighter in colour. The surface

and subsurface colour differences within a pedon may indicate differences in organic matter content, clay content, and reduction and oxidation processes, whereas those differences among pedons could explain differences in parent material in addition to organic matter and clay content differences, and reduction and oxidation processes.

## 2. Soil Structure and Consistence

At the surface horizons, strong coarse granular, weak very coarse to strong coarse sub-angular blocky, strong very coarse angular blocky and massive (in the Vertic Hypercalcic Calcisols) structure types were identified. In the subsurface layers, on the other hand, massive (also in the Vertic Hypercalcic Calcisols only), weak very fine to strong coarse sub-angular blocky, strong coarse to strong very coarse angular blocky, and strong medium to strong very coarse prismatic structure types were identified. Furthermore, in the Mollic Gleyic Vertisols (Eutric, Pellic) of Rasa Janata Kebele, wedge-shaped structures with intersecting slickensides were observed.

The high clay content with swelling and shrinking properties, climate and biological processes might have favoured the formation of prismatic and blocklike structure types. Quality of soils with these structure types is commonly limited due to limited rootability and impeded drainage. The differences in soil structure among the pedons and within a pedon could be related to differences in soil texture, clay mineralogy, types of adsorbed cations, organic matter content, and management practices followed, such as tillage.

Owing to the moderate to high clay content, the consistence within and among the pedons was hard to extremely hard, friable to very friable, and sticky and plastic to very sticky and very plastic in almost all the soil types identified. The differences recorded may reflect differences in clay content

and clay mineralogy, and to a limited extent organic matter content in the surface layers.

### 3. Soil Depth

The soil depth, as observed from road cuts, gulleys, auger points, and pedons, is more than 50 cm in most places except the steep slopes. This means that most soils on the middle, lower, and toe slopes do not have limitations related to soil depth for growing most plants. However, limitations to root penetration may come from conditions related to the soil structure within a profile.

### 4. Porosity, Root Distribution, and Other Features

The porosity, based on field estimation, of the surface horizons was very few to many in abundance with sizes of very fine to medium in all the soil types. In the subsurface horizons, it varied from very few, very fine to many, medium pores. In general, pore abundance and size decreased with soil depth.

Root distribution closely followed the pore size distribution and the types of plants grown. Almost all the fields were cultivated fields on which annual crops of different types were grown. As a result, most of the roots were found in the upper 20-30 cm with very few, fine to very fine roots penetrating into the deeper layers.

Other important features like coarse fragments, mottles, coatings, other biological activities, horizon boundaries, effervescence tests, and pH were also recorded. The details of these features for each pedon are indicated in Table 24.

### 3.7.3.2. Agronomic interpretation of Soil Particle Size Distribution

Results of laboratory analysis indicate that the clay fraction, followed by sand, is the dominant fraction in the major agricultural soils of the four kebeles. Nevertheless, variations in the proportion of these separates within a pedon and among pedons were observed. The sand content of the surface layers ranges between 15% in Vertic Cambisols (Eutric, Skeletic) of Ula Janata Kebele to 54% in the Haplic Cambisols (Eutric, Clayic, Chromic) of Lafto Ila Tatesa Kebele, while in the subsurface layers, it varies from 12% in Luvic Nitisols of Rasa Janata to 67% in Haplic Cambisols of Lafto Ila Tatesa Kebele with no regular variation with soil depth observed in all the soil types represented by the pedons. Similarly, the clay content varies from a low of 36% in Haplic Cambisols of Lafto Ila Tatesa to a high of 67% in the Vertic Cambisols of Ula Janata in the surface horizons. In the subsurface horizons, it ranges from 28% in the Haplic Cambisols of Lafto Ila Tatesa to 69% in the Mollic Gleyic Vertisols of Rasa Janata Kebele. Only in Luvic Nitisols of Rasa Janata was a consistent, but very small, increase in clay content with soil depth observed. In all the other soil types represented by the pedons, the clay content showed irregular variations with soil depth.

Based on rough estimation suggested by Moore et al. (1998) the available water holding capacity of the soils can be in the range of 130-190, 120-210, 130-150, 110-120, and ~210 mm of water per meter depth of soil for the sandy clay loam, clay loam, sandy clay, clay, and self mulching clay soils, respectively. Absolute amounts for rootable soil depths of only 20-30 cm is thus shallow to store adequate plant available water for rainfed agriculture. These values are only indicative and, hence, may not be good enough for developing sound water management plans for the study kebeles. Furthermore, available water holding capacity depends not only on clay content, but also on clay mineralogy, organic matter content and bulk density. Therefore, characterization of the different soils in terms of their

water retention and release characteristics, and permeability, is a requisite for developing efficient soil-water management plan.

### 3.7.3.3. Agronomic interpretation of Soil Chemical Properties

#### 1. Soil Reaction and Electrical Conductivity

Soil reaction, measured from 1:2.5 soil:water suspension and KCl solution, exhibited different degrees of variability with soil depth (inconsistently) and among pedons. In the surface layers, the pH-H<sub>2</sub>O ranged from 5.3 in the Luvic Nitisols of Lencha to 7.8 in Vertic Hypercalcic Calisols of the same Kebele. In the subsurface soils, it varied from 4.9 in the Luvic Nitisols to 7.9 in the Vertic Hypercalcic Calisols of the same kebele. These pH values are within the ranges of strongly acidic ( $\leq 5.5$ ) and moderately alkaline (7.4-8.4) (Karlton et al., 2013).

Following ratings suggested by Landon (1991), pH-H<sub>2</sub>O of major agricultural soils of the kebeles was in the range of medium to high in the surface soils and low to high in the subsurface layers. The medium pH range is considered suitable for most cultivated/commercial crops. Within the indicated pH range of the surface soils, availability of most essential plant nutrients, except Mn and P, is expected to be optimum. Therefore, in the Vertic Hypercalcic Calisols of Lencha, availability of Mn could be curtailed, whereas in the Luvic Nitisols of the same Kebele, availability of P could be affected due to the low pH value.

The values of electrical conductivity, surface and subsurface horizons, indicate that the soils are non-saline. Therefore, salinity is not expected to be a problem in major agricultural soils of the kebeles in the many years to come.

## 2. Soil Organic Carbon, Total Nitrogen, and C:N Ratio

Similar to the other soil properties, differences in organic carbon and total nitrogen contents were observed within a pedon and among pedons. In all the pedons, the organic carbon content decreased consistently with soil depth. Except in Nitic Vertic Luvisols of Ula Janata, Luvic Nitisols of Lencha, and Vertic Cambisols of Lafto Ila Tatesa Kebeles which was low, the organic carbon content of the surface layer soils was in the range of very low (Landon, 1991). In subsurface soils of all the soil types, it was in the range of very low as per Landon (1991) rating. This suggests that organic matter content improvement and maintenance in agricultural soils of the kebeles requires a different approach than that being practiced hitherto and needs to be considered more seriously.

The total nitrogen content of the surface layer soils, on the other hand, was in the range of low in Luvic Nitisols of Rasa Janata Kebele and medium in all the other soil types (Landon, 1991). This indicates that major agricultural soils of the kebeles have nitrogen deficiency and, therefore, require application of site-specific recommended rate of appropriate N fertilizers (organic and inorganic) to improve crop yield.

The carbon to nitrogen ratio (C:N) of the surface soils varied from 8:1 in Haplic and Vertic Cambisols of Lafto Ila Tatesa to 11:1 in Luvic Nitisols of Rasa Janata and Nitic Vertic Luvisols of Ula Janata, while the ratio in the subsurface soils ranged from 7:1 to 15:1 both of which indicate that organic matter decomposition proceeds at an optimum rate under the local environmental conditions (Allison, 1973).

## 3. Available Phosphorus and Sulfur

These nutrient elements were determined for soils of the surface horizons only. Like the other soil properties, these two essential plant nutrients also

differed from one pedon to another. Accordingly, the Olsen available P ranged from a minimum of 24.90 mg kg<sup>-1</sup> in Luvic Nitisols of Lencha to 51.50 mg kg<sup>-1</sup> in Vertic Hypercalcic Calcisols of the same Kebele. The highest and lowest values were recorded in soils with the highest and lowest pH-H<sub>2</sub>O values respectively, which clearly shows the impact soil reaction has on availability of P.

Nevertheless, the available P content was within the range of high (> 15 mg kg<sup>-1</sup>) in all the pedons indicating that a response to application of P fertilizer is unlikely (Landon, 1991). Furthermore, based on available P interpretation depending on crop demands, the available P of the soils was adequate even for those crops with high P demand, such as sugarbeet, potatoes, and onion (Landon, 1991).

The available sulphur also differed among the pedons in which it ranged from 0.76% in Haplic Cambisols of Lafto Ila Tatesa to 1.34% in Vertic Cambisols of Ula Janata Kebele. Based on ratings indicated in Landon (1991), the available sulphur was within the range of excess in all the major soil types.

#### 4. Exchangeable Bases (Ca, Mg, K, Na)

In the surface soils, exchangeable Ca ranged from 17.9 mg kg<sup>-1</sup> of Luvic Nitisols of Lencha to 36.8 mg kg<sup>-1</sup> in Vertic Cambisols. In the subsurface soils, it varied from 13.3 mg kg<sup>-1</sup> in the Haplic Cambisols of Lafto Ila Tatesa to 43.2 mg kg<sup>-1</sup> in the Mollic Gleyic Vertisols of Rasa Janata Kebele. Based on FAO (2006) ratings, the exchangeable Ca was within the range of high in the Luvic Nitisols of Lencha and Haplic Cambisols of Lafto Ila Tatesa Kebeles. In all the other soil types, it was within the range of very high. Landon (1991) also suggested that exchangeable Ca of about 10 meq/100 g soil can be taken as high value, which applies to the studied soils also.

In soils of the subsurface horizons, exchangeable Mg also ranged from 6.0 mg kg<sup>-1</sup> in the Luvic Nitisols of Lencha to 12.8 mg kg<sup>-1</sup> in the Vertic Cambisols of Ula Janata Kebele. In the subsurface soils, on the other hand, it varied from 4.1 mg kg<sup>-1</sup> in the Haplic Cambisols of Lafto Ila Tatesa to 14.7 mg kg<sup>-1</sup> the Mollic Gleyic Vertisols of Rasa Janata Kebele. Based on ratings outlined in Landon (1991), the exchangeable Mg of the major agricultural soils in the four kebeles was within the range of high indicating that Mg present in the soil is usually sufficient.

Exchangeable K ranged from 0.3 mg kg<sup>-1</sup> in Haplic Cambisols of Lafto Ila Tatesa to 1.3 mg kg<sup>-1</sup> in the Mollic Gleyic Vertisols of Rasa Janata in the surface horizon soils. In the subsurface soils, it ranged from 0.24 mg kg<sup>-1</sup> in the Vertic Cambisols to 1.3 mg kg<sup>-1</sup> in the Nitic Vertic Luvisols of Ula Janata Kebele. Following the FAO (2006) ratings, the exchangeable K content was medium in the Luvic Nitisols and Mollic Gleyic Vertisols of Rasa Janata and, Haplic and Vertic Cambisols of Lafto Ila Tatesa. Nevertheless, it was high in the other major soil types identified.

The exchangeable Na occupies a very small proportion of the exchange complex although it was in the range of high in the surface and subsurface soils of all the major soil types (FAO, 2006).

## 5. Cation Exchange Capacity and Sum of Bases

In soils of the surface horizons, the CEC ranged from 34.8 to 54.9 meq/100 g soil in Luvic Nitisols of Lencha and Vertic Cambisols of Ula Janata, respectively, which was in the range of high to very high (Landon, 1991). Similarly, in the subsurface layer soil it varied from to 29.7 meq/100 g soil in Haplic Cambisols of Lafto Ila Tatesa to 62.9 meq/100 g soil in Vertic Cambisols of Ula Janata, which also fall in the range of high to very high.

The base saturation of the surface soils, which ranged from 69% in Vertic Cambisols of Lafto Ila Tatesa to 96% in Mollic Gleyic Vertisols of Rasa Janata, indicates that the soil are weakly to very weakly leached, respectively (Metson, 1961). The values recorded in the subsurface soils of the major soil types also indicate that the soils are weakly to very weakly leached.

## 6. Extractable Micronutrients

The extractable Zn content of the soils ranged from 1.4 mg kg<sup>-1</sup> in Mollic Gleyic Vertisols of Rasa Janata to 7.3 mg kg<sup>-1</sup> in Vertic Hypercalcic Calcisols of Lencha Kebele, which according to Karlton et al. (2013) rating was in the range of optimum.

The extractable Mn ranged from 2.6 mg kg<sup>-1</sup> in Vertic Hypercalcic Calcisol of Lencha to 88.5 mg kg<sup>-1</sup> in Luvic Nitisols of Rasa Janata. According to Jones (2003), the extractable Mn content of the soils was high to very high.

The extractable Cu ranged from 0.9 mg kg<sup>-1</sup> in Luvic Nitisols of Ula Janata to 6.1 mg kg<sup>-1</sup> in Mollic Gleyic Vertisols of Rasa Janata. Except in the Nitic Vertic Luvisols of Ula Janata Kebele which was low, the extractable Cu content of the soils was within the range of optimum (Karlton et al., 2013). Therefore, the Nitic Vertic Luvisols of Ula Janata require application of Cu containing fertilizer.

The extractable Fe content of the soils also ranged from 13.3 mg kg<sup>-1</sup> in Vertic Hypercalcic Calcisols of Lencha to 87.6 mg kg<sup>-1</sup> in Luvic Nitisols of the same Kebele. The highest and lowest values of extractable Fe were recorded in soils with the lowest and highest pH Values, respectively, indicating the high influence pH has on extractable Fe content. Based on ratings of Jones (2003), the extractable Fe content of the major agricultural soils in the four kebeles was high.

#### 3.7.3.4. Agronomic Interpretation of Major Soil Types

The major agricultural soils of the four CASCAPE intervention kebeles are Haplic and Vertic Cambisols, Luvic Nitisols, Nitic Vertic Luvisols, and Mollic Gleyic Vertisols with Vertic Hypercalcic Calcisols occurring in Lencha Kebele. Furthermore, the Leptosols and Regosols, which occur on the steep slopes of the respective kebeles, are marginally used for agricultural production.

The Leptosols and Regosols are mostly shallow to support successful crop production, particularly the deep rooted crops. Most of the Leptosols and Regosol areas, particularly these days, are left for vegetation/forest cover, which has to continue in the future as well.

All the other major agricultural soils of the four kebeles do not have problem related to soil depth. Nevertheless, the Mollic Gleyic Vertisols and Vertic Hypercalcic Calcisols may have limitations related to impeded drainage. This may limit the effective root depth. The high clay content of all the soil types may affect their workability under wet and dry conditions unless and otherwise the right moisture content (near friable consistence) is chosen for tillage operations. Extensive and deep cracks in Vertic Cambisols, Mollic Gleyic Vertisols, Nitic Vertic Luvisols and Vertic Hypercalcic Calcisols may create additional evaporation sites in the deeper parts of these soils and result in soil desiccation. This may, in turn, aggravate the soil moisture deficit stress during sensitive stages of crops unless managed.

The strongly acidic reaction in the Luvic Nitisols of Lencha Kebele and the moderately alkaline reaction in the Vertic Hypercalcic Calcisols may affect availability of some micro and macro nutrients, activity of beneficial microorganisms and, growth and development of sensitive crops. Therefore, managing the soil reaction in these soils is required.

Although farmers in all the kebeles are applying organic matter before the next cropping season, the level of organic carbon in all the identified major

agricultural soils remains at very low to low levels. To improve the health of the soils, improving and maintaining the organic carbon level is essential. Nevertheless, low level of total nitrogen was recorded in the Luvic Nitisols of Rasa Janata Kebele only, with all the other soil types characterized by medium level of total nitrogen. The implication is that these agricultural soils require continuous application of appropriate rate and type of nitrogen containing fertilizers. Surprisingly enough, however, all the soil types had high available P content.

Except the medium exchangeable potassium level in the Luvic Nitisols and Mollic Gleyic Vertisols of Rasa Janata and, Haplic and Vertic Cambisols of Lafto Ila Tatesa Kebeles, all the other soil types identified had adequate levels of Ca, Mg and K. Therefore, the Luvic Nitisols, Mollic Gleyic Vertisols and, Haplic and Vertic Cambisols in the indicated kebeles may require application of K-containing fertilizers for further improvement of crop yield.

All the major agricultural soils represented by the pedons do not have deficiency problems of most micronutrients except the Nitic Vertic Luvisols of Ula Janata Kebele which were low in their extractable copper.

### 3.8. Soils of CASCAPE Intervention Kebeles in Habro Woreda

#### 3.8.1. The Soil-Landscape in Habro Woreda

##### 3.8.1. 1. Geology

As per the geological map obtained from Geological Survey of Ethiopia (1:2000,000), the geology of Habro Woreda consists of Alage Formation which contains transitional and subalkaline basalts with minor rhyolite and trachyte eruptives; Mormora Group that contains biotite schist, gneiss, marble and graphitic schist; Alghe Group dominated by biotite and hornblende gneisses, granulite and migmatite with minor metasedimentary gneisses; Hamanlei Formation that contains Oxfordian limestone and shale; Adigrat Formation characterized by Triassic-Middle Jurassic sandstone and; Urandab Formation which consists of Oxfordian-Kimmeridgian marl and shale-limestone.

##### 3.8.1.2. The Landscape

The topography of the Woreda as a whole may be considered as piedmont plateau, most of it dissected, and plains and valleys in some areas. These Woreda has many peaks that form part of the Arsi-Bale massif or mountain chain. In the CASCAPE intervention kebeles, a saucer-shaped landscape in which the plains and plateaus are surrounded by hills and mountains of different ranges is the major landform. The topography varies from nearly flat land to very steep land with a corresponding landform of plains and plateaus to high gradient mountains. Depressions that contain lakes (e.g. the re-emerged Lake Chercher) are also found in the study kebeles. The dominant slope form is straight slope. Plate 16 presents the different landforms as observed in the CASCAPE intervention kebeles. Figure 23 indicates the contour and elevation maps of the four kebeles, together with the location of the auger observation points.



Plate 16. Overview of some of the soil-landscapes in the four CASCAPE intervention kebeles in Habro Woreda.

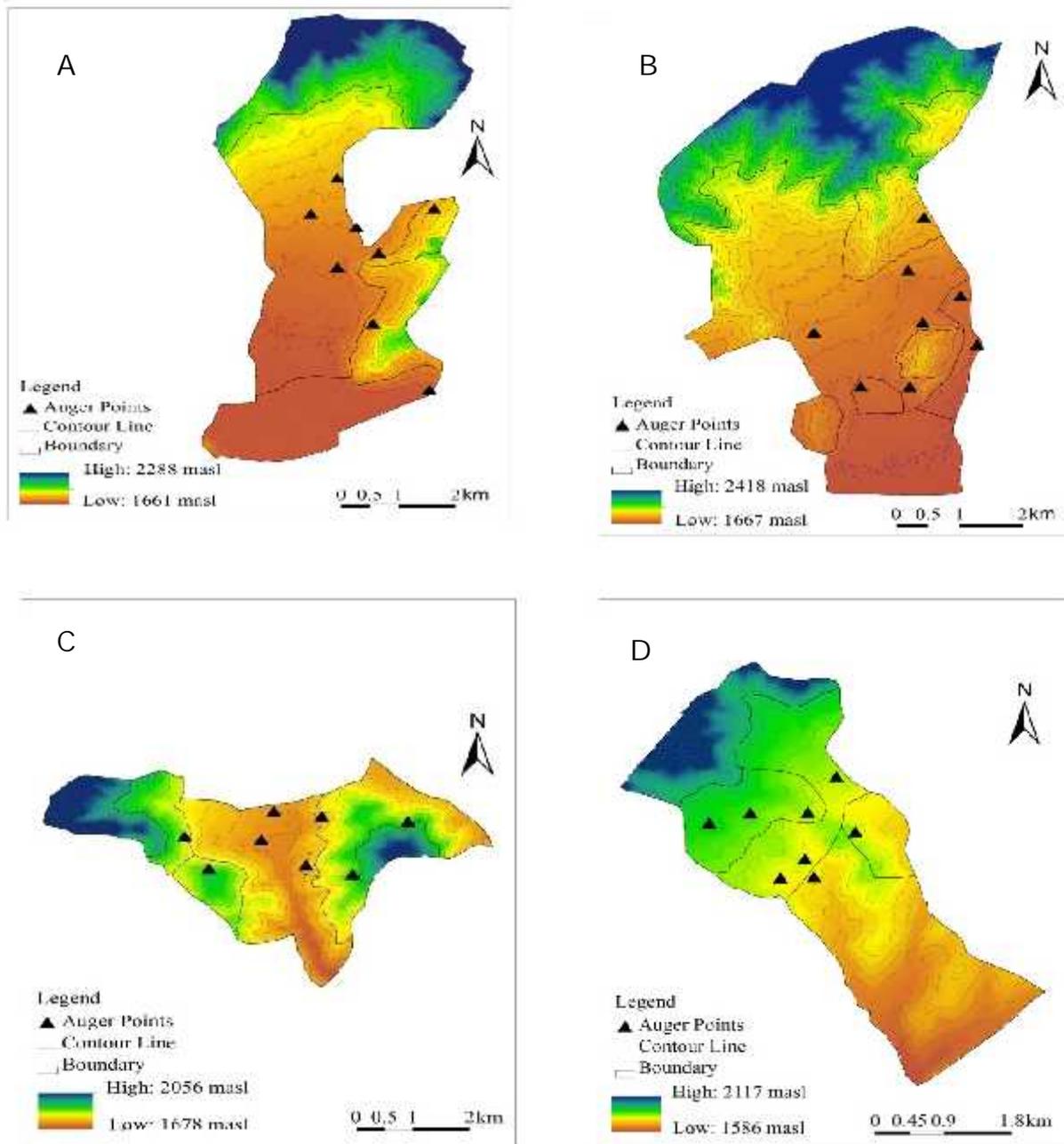


Figure 23. Contour and elevation maps of and location of auger points in the four CASCAPE intervention kebeles in Habro Woreda: (A) Haro Chercher, (B) Bareda, (C) Garbi Gobe, and (D) Ifa Jiru.

### 3.8.1.3. Land Use

In Habro Woreda, the landholding per capita is relatively better as compared to the other CASCAPE intervention woredas. However, some of the hilly areas are still under cultivation, which indicates the existence of increasing pressure on the more susceptible land resources on the steep slopes. The encouraging thing, nevertheless, is that the mountainous areas are already being rehabilitated and protected through the country-wide watershed management program which started some years back. The regenerating vegetation cover was observed during the field work as well.

Due to the saucer-shaped nature of the landscape around most of the plains and plateaus, which are also major agricultural lands, waterlogging seems a common problem. This, coupled with the fine-textured nature of the soils, may affect yield of sensitive crops considerably.

Mixed crop-livestock agriculture is the major farming system throughout the Woreda. The main crops grown in the area are cereals such as teff (*Eragrostis tef*), maize (*Zea mays*), wheat (*Triticum aestivum*), barley (*Hordeum vulgare*), haricot bean (*Phaseolus vulgaris*) and sorghum (*Sorghum bicolor*), and cash crops such as coffee (*Coffea arabica*), khat (*Catha edulis*), pepper (*Capsicum species*) and onion (*Allium cepa* L.). Agricultural land is very much limited and as a result, intercropping is a common practice in these areas. Common bean and maize are often intercropped to increase yields and maximize land use. Growing maize and sorghum in khat alleys, particularly on steep slopes, is also another common practice.

Since most of the land is put under cultivation, the available grazing lands are the steep slope areas. As a result, the livestock component of the farming system is not strong enough. The cut and carry system is, therefore,

a common practice. Nevertheless, the situation is better than the other CASCAPE intervention Woredas.

In areas where there are water sources, small-scale irrigation is commonly practiced during the off-season. Commonly grown crops using irrigation are the likes of onion, potato, pepper, cabbage, tomato, and khat. These crops are mainly used as sources of income rather than for consumption. The irrigation activities around Lake Chercher are typical examples (Plate 17).

Fertilizer application is dominantly based on blanket recommendation. Furthermore, the farmers are applying organic residues of different types during the off-season with the intention of improving and maintaining soil organic matter level and probably enhancing soil fertility status and soil health. Plate 17 shows the different types of organic materials added to the soil during off-season, irrigation practices around Lake Chercher, and some of the emerging salinity problems in irrigated areas of Garbi Gobe Kebele.

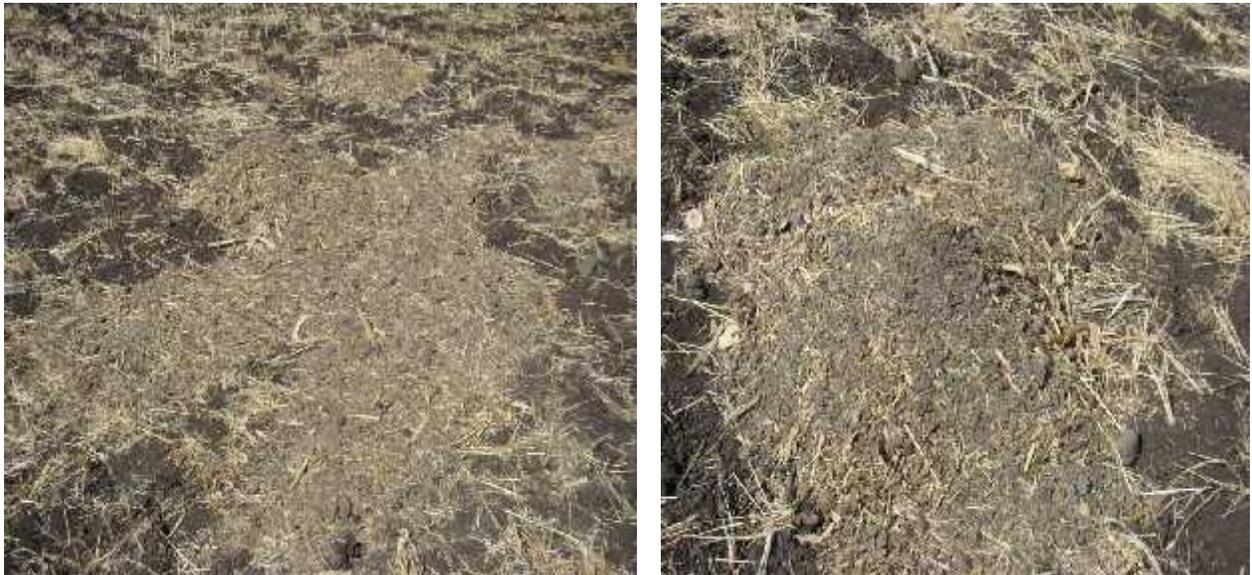




Plate 17. Some of the organic materials added to soil in Bareda Kebele, irrigation activity (flood irrigation) around Lake Chercher in Haro Chercher Kebele and some surface salinity problems observed in Garbi Gobe Kebele in Habro Woreda.

#### 3.8.1.4. The Soil-Landscape (Exploratory Survey Results)

The soil mapping units identified through the exploratory survey and their area coverage in each kebele is presented in Table 26. The results show that different soil types occur along a typical topo-sequence. The details of soil-landscape and parent material effects are presented in Section 3.8.1.5. Plate 18 presents photos of some of the soil types occurring in the four kebeles. The maps of these mapping units are presented in Figure 24.

Table 26. The major soil mapping units identified through exploratory survey and their area coverage in each kebele

Kebele	Soil type	Soil code	Area (ha)	%
Haro Chercher	Leptosols (Eutric)	LP-eu	719	25
	Vertic Luvisols	LV-vr	106	4
	Luvisols (Rhodic)	LV-ro	295	10
	Vertisols	VR	1283	44
	Calcic Vertisols	VR-cc	496	17
Bareda	Leptosols (Eutric)	LP-eu	986	32
	Leptosols	LP	155	5
	Cambisols	CM	210	7
	Vertic Luvisols	LV-vr	1585	51
	Calcic Vertisols	VR-cc	96	3
	Fluvisols (Clayic)	FL-ce	47	2
Garbi Gobe	Leptosols	LP	303	19
	Regosols	RG	130	8
	Nitisols	NT	596	36
	Calcic Vertisols (Eutric)	VR-cc.eu	609	37
Ifa Jiru	Leptosols	LP	310	23
	Nitisols	NT	178	13
	Luvisols	LV	563	42
	Vertisols	VR	289	22



Plate 18. The different soil types identified during the exploratory survey work in the four CASCAPE intervention kebeles in Habro Woreda. From the photos, it can be seen that the dominant soil types are those with prominent cracking properties.

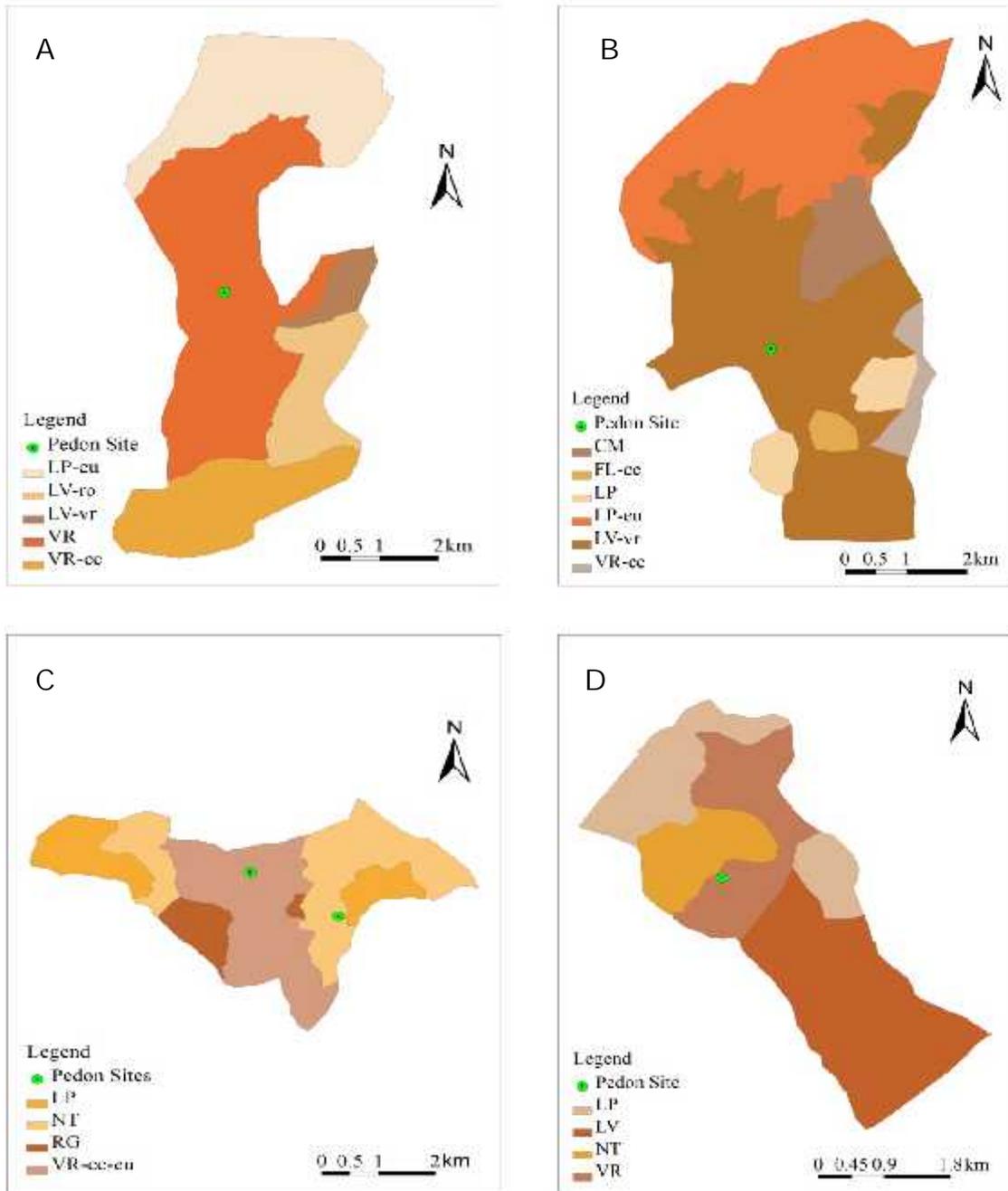


Figure 24. Exploratory soil maps of and location of pedon sites in the four CASCAPE intervention kebeles in Habro Woreda: (A) Haro Chercher, (B) Bareda, (C) Garbi Gobe, and (D) Ifa Jiru.

#### 3.8.1.5. The Soil-Landscape (Final)

At RSG level, the major soil types identified in the four kebeles are Leptosols, Regosols, Cambisols, Nitisols, Luvisols, Vertisols, and Fluvisols. The major soil mapping units indentified and the landform on which they occur, and their area coverage in each kebele is presented in Table 27.

The Leptosols occur on the steepest slopes of the hills and mountains and are developed on basaltic parent material. The Regosols also occur on the upper slopes of sloping landform in Garbi Gobe kebele and are formed on sandstone parent material.

The Cambisols occur on the lower slopes of the mountain chains and are developed on basaltic parent material. They also occur in association with Nitisols, Luvisols and Vertisols. The Haplic Nitisols in Garbi Gibe kebele occur on level land to middle slope of sloping landform and are developed on mixed granite/sandstone parent material, while the Nitisols in Ifa Jiru occur on level land and are formed from basaltic parent material. They are often associated with the Luvisols and Cambisols.

Except in Garbi Gobe Kebele, Luvisols are the major soil types in the study area. They occur on the level land (plateau) and are developed on basaltic parent material. They are strongly associated with Vertisols and also Nitisols in areas where they occur. The Vertisols also occur on the level land (mainly the plains) and are developed from basaltic parent material. They also occupy significant area in the four kebeles. Associated with the Vertisols are the Fluvisols which occur around the big water ways from the slopping landforms down to the valleys. Figure 25 shows a sketch of the soil-landscape representing the four kebeles. Plate 19 shows some of the pedons opened on major agricultural soils. Figure 26 shows the geographic distribution of the major soil mapping units in the respective kebeles.

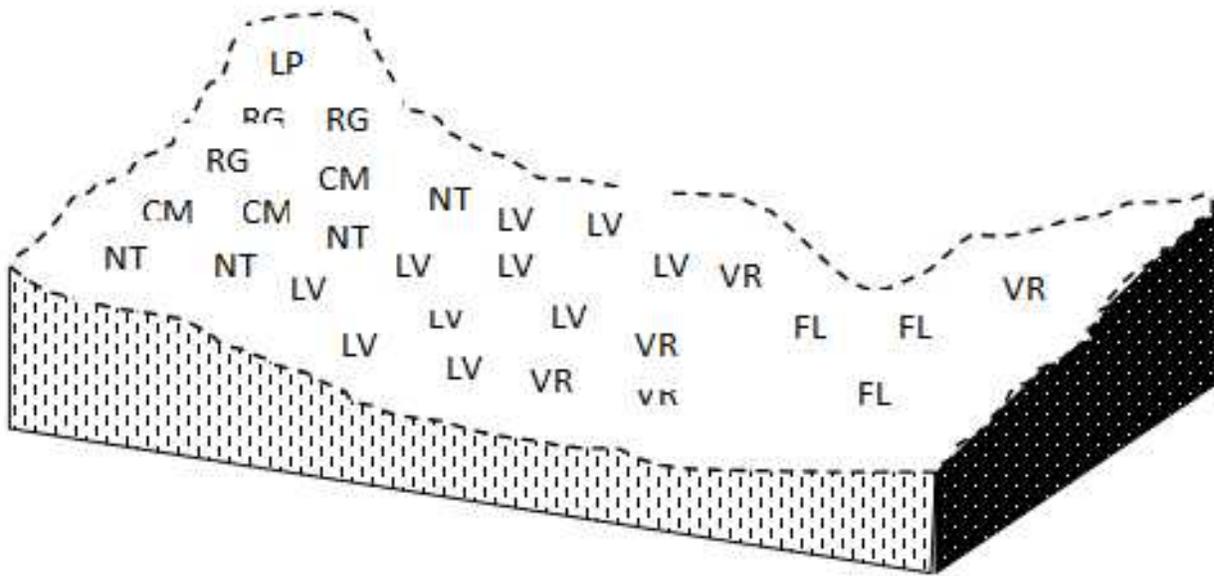


Figure 25. Sketch of general soil-landscape representing the four CASCAPE intervention kebeles in Habro Woreda.

Table 27. The soil mapping units and their area coverage in the four CASCAPE intervention kebeles in Habro Woreda

Kebele	Major landform (Landscape unit)	Soil type	Soil code	Area (ha)	%	Elevation (masl)
Haro Chercher	Steep land	Leptosols (Eutric)	LP-eu	719	25	1840-2280
	Level land	Calcic Vertic Luvisols (Hypereutric, Clayic, Chromic)	LV-vr-cc-je.ce.cr	1683	58	1680-1840
	Level land	Calcic Vertisols	VR-cc	496	17	1680-1720
Bareda	Steep land	Leptosols	LP	155	5	1720-1820
	Steep land	Leptosols (Eutric)	LP-eu	986	32	1960-2400
	Sloping land	Cambisols	CM	210	7	1780-1960
	Level land	Calcic Vertic Luvisol (Hypereutric, Clayic, Chromic)	LV-vr-cc-je.ce.cr	1681	55	1680-1960
	Level land (valley)	Fluvisol (Clayic)	FL-ce	47	1	1700-1720
Garbi Gobe	Steep slope	Leptosols (Eutric)	LP	304	19	1860-2040; 1840-1940
	Sloping land	Regosols	RG	118	7	1780-1820
	Sloping land	Haplic Nitisols (Eutric)	NT-ha-eu	596	36	1780-1860; 1740-1840
	Level land	Calcic Vertisols (Eutric)	VR-cc-eu	620	38	1680-1780
Ifa Jiru	Steep land	Leptosols	LP	26	2	1820-2100
	Level land	Nitisols	NT	178	16	1740-1820
	Level land	Calcic Vertic Luvisol (Hypereutric, Clayic, Chromic)	LV-vr-cc-je.ce.cr	615	54	1660-1820
	Level land	Vertisols	VR	321	28	1600-1680

masl = meters above sea level

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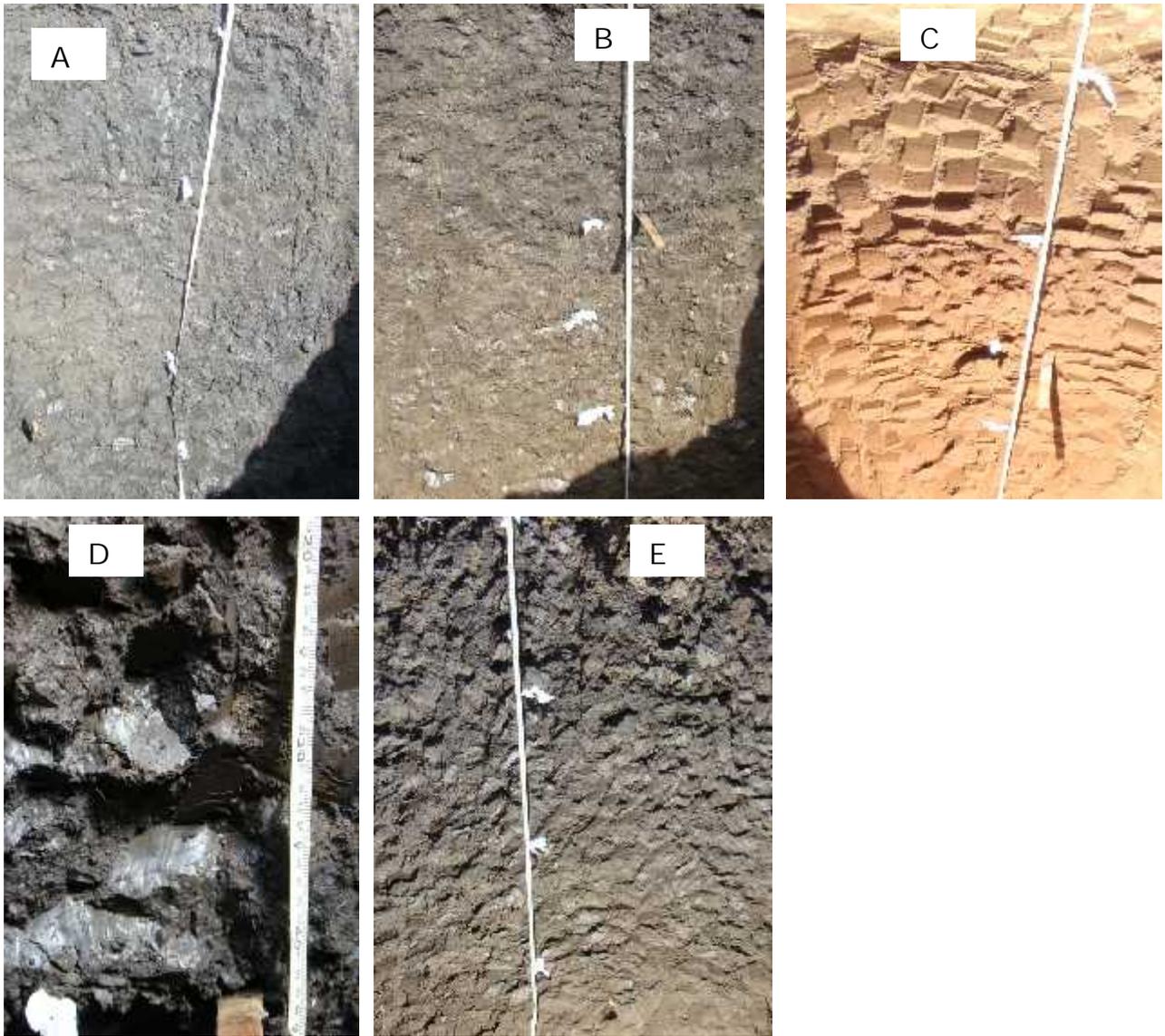


Plate 19. The pedons opened on major agricultural soils of the four CASCAPE intervention kebeles in Habro Woreda: (A) Calcic Vertic Luvisol (Haro Chercher), (B) Calcic Vertic Luvisol (Bereda), (C) Haplic Nitisol (Garbi Gobe), (D) Calcic Vertisol (Garbi Gobe), and (E) Calcic Vertic Luvisol (Ifa Jiru).

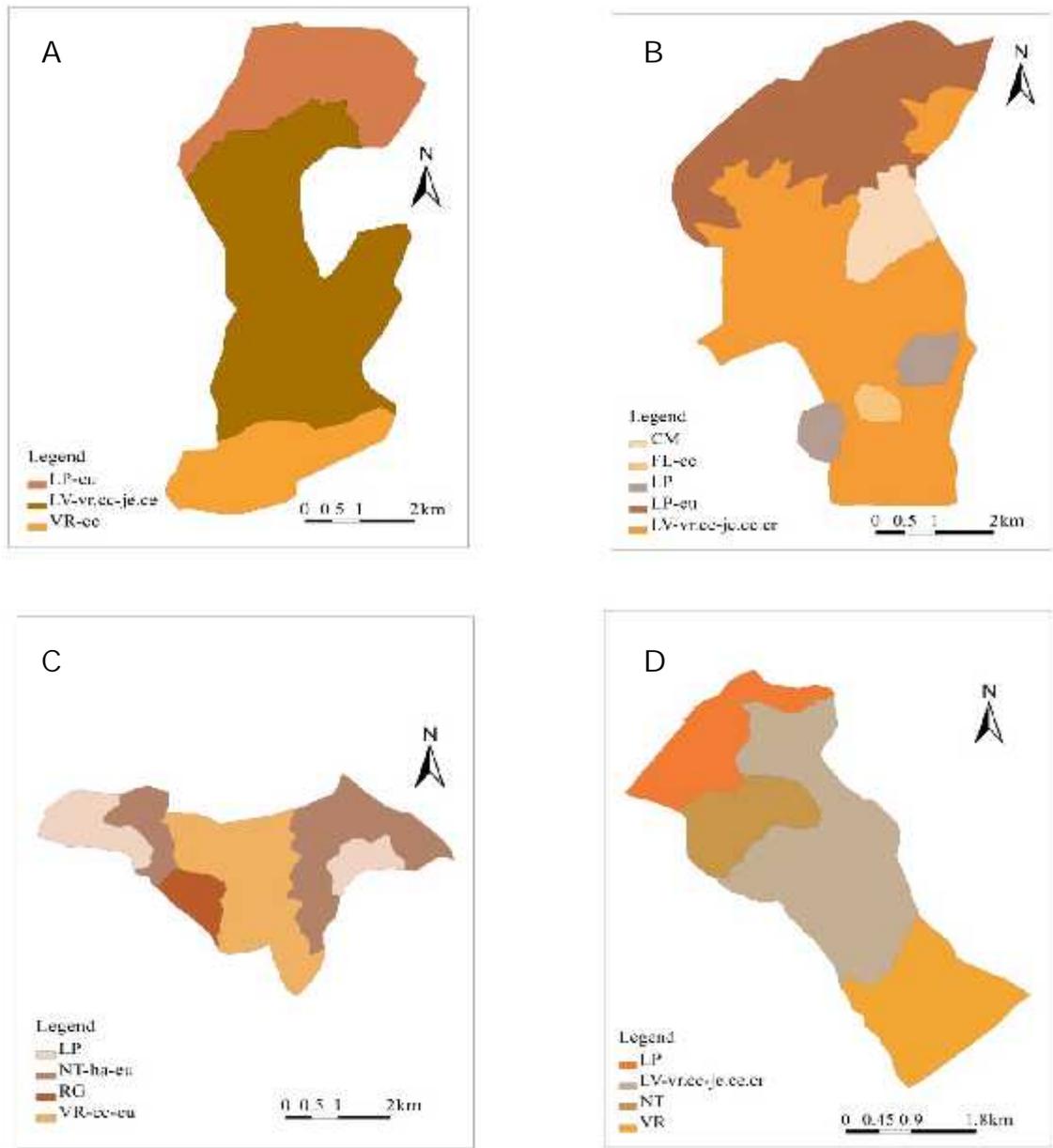


Figure 26. Soil maps of the four CASCAPE intervention kebeles in Habro Woreda: (A) Haro Chercher, (B) Bareda, (C) Garbi Gobe, and (D) Ifa Jiru

Names of soils based on local classifications were also recorded to correlate them with the WRB names. Similar to the experience in other CASCAPE intervention woredas, the classification is done based on soil colour and also texture. Terms that indicate the productivity and/or fertility of a soil are also

used to distinguish between soils of similar colour. The farmers actually have deep knowledge of their soil with regard to their productivity. However, this classification, as long as the soils have the same colour and also productivity, puts different soils into one category although they could be very different soils from scientific perspective. Also, the same soil type may have different names based on its colour variation and also surface texture. Its correlation with the WRB could be important for communicating results among farmers. Nonetheless, it requires some refining and standardization in consultation with the farmers. The correlation between local and the WRB names is presented in Table 28.

Table 28. Correlation between local and WRB soil names in the four CASCAPE intervention kebeles in Habro Woreda

WRB name	Local name
Vertisol	Biye Guracha/Farro
Calcic Vertic Luvisol	Farro
Haplic Nitisol	Ashewa

### 3.8.2. Soil Profile Descriptions and Analytical Data

#### 3.8.2.1. Soil Profiles

A total of 5 pedons, representing major agricultural soils of four CASCAPE intervention kebeles in Habro Woreda, were opened. The intervention kebeles are Haro Chercher (1), Bareda (1), Garbi Gobe (2), and Ifa Jiru (1). The pedons in Haro Chercher, Bareda, Ifa Jiru and one pedon in Garbi Gobe were opened on level land, while one pedon in Garbi Gobe was opened on sloping landform. Furthermore, 32 auger pits (8 per kebele) were also described in these four kebeles. A total of 25 soil samples were collected from genetic horizons of the 5 pedons and analyzed for their selected physical and chemical properties at the Water Works and Design Supervision Enterprise Soil laboratory in Addis Ababa.

The results of field descriptions of the pedons' site and profile characteristics are presented in Table 29.

Table 29. Soil site and profile descriptions of pedons opened in four CASCAPE intervention kebeles of Habro Woreda (For analytical data see Table 30)

Profile ID	HW/HRO/HC/P1	Land cover	Scattered agroforestry trees, shrubs, herbaceous
Date	20/02 (dd/mm)	Land use	Crop cultivation and animal husbandry
Year	2014	Crop	Cereals, pulses, vegetables, khat, sugarcane, some fruit trees
Surveyor	Kibebew Kibret	Human influence	Vegetation intensively disturbed, irrigation, ploughing
Status	Reference profile description	Surface stone cover	Very few
Location country	Ethiopia	Surface stone size	Stones
Location region	West Hararghe	Erosion category	None
Location woreda	Habro	Crack width	Wide (2-5 cm)
Location kebele	Haro Cherecher	Crack depth	Very deep (> 20 cm)
Longitude	40°38'50.1"	Crack distance	Closely spaced (0.2-0.5 m)
Latitude	08°51'55.4"	Surface salt	None
Elevation	1734 m	Surface drainage	Slow
Map ID		Soil drainage	Slow
Map scale		Flooding frequency	None
Map unit ID		Depth to groundwater	190 cm
Topography	Gently sloping, 2-5%	Depth to bedrock	Not observable
Major landform	Level land, plain	Rootable depth	190 cm
Position on slope	Toe slope	Rooted depth	140 cm
Slope form	Straight	Depth of observation	190 cm
Slope gradient	5%	Local soil type	Biye Guracha
Geology	Igneous	Field WRB soil type	Calcic Vertic Luvisol
Parent material	Basalt basement	WRB soil type	Calcic Vertic Luvisol (Hypereutric, Clayic, Chromic)

#### Description of the soil horizons (morphology)

Horizon	Depth (cm)	Description
Ap	0-25	Very dark brown (10YR 2/2, moist) and very dark gray (10YR 3/1, dry) colour; clay; strong very coarse angular blocky structure; extremely hard when dry, very friable when moist, and very sticky and very plastic when wet; common, very fine to fine pores; very few, faint clay coatings; very few, fine coarse fragments of unspecified nature; no mottles; common, fine roots; very few burrows; clear, smooth boundary; no reaction with HCl; field pH value of 6.8.
Bt1	25-70	Black (10YR 2/1, moist) and black (2.5YR 2.5/1, dry) colour; clay; strong coarse angular blocky structure; extremely hard (dry), very friable (moist), and very sticky and very plastic (wet) consistence; common, very fine to fine pores; very few, faint clay coatings; no coarse fragments; no mottles; few, fine roots; very few burrows; clear, wavy boundary; slight reaction with HCl and field pH value of 7.
B1	70-110	Black (10YR 2/1, moist) and black (5Y 2.5/1, dry) colour; clay; strong medium angular blocky structure; extremely hard (dry), very friable (moist), and very sticky and very plastic (wet) consistence; common, very fine pores; very few, faint coatings; very few, fine coarse fragments of unknown nature; no mottles; very few, fine roots; no other indicators of biological activity; gradual, wavy boundary; slight reaction with field pH value of 7.
Bk1	110-140	Black (10YR 2/1, moist and dry) colour; clay; strong medium angular blocky structure; extremely hard (dry), friable (moist), and very sticky and very plastic (wet) consistence; common, very fine pores; very few, faint coatings; few, fine coarse fragments of unknown nature; no mottles; very few, fine roots; no other indicators of biological activity; diffuse, smooth boundary; strong reaction with HCl; field pH value of 7.5.
Bk2	140-190	Black (10YR 2/1, moist and dry) colour; clay; strong coarse angular blocky structure; extremely hard (dry), friable (moist), and very sticky and very plastic (wet) consistence; few, very fine pores; very few, faint coatings; very few, fine coarse fragments of unknown nature; no mottles; no roots and other indicators of biological activity; stron reaction with HCl; field measured pH value of 7.

Profile ID	HW/HRO/BD/P1	Land cover	Scattered agro-forestry trees, shrubs, herbaceous
Date	22/02 (dd/mm)	Land use	Crop cultivation and animal husbandry
Year	2014	Crop	Cereals, vegetables, khat, some fruits
Surveyor	Kibebew Kibret	Human influence	Vegetation intensively disturbed, ploughing
Status	Reference profile description	Surface stone cover	Very few
Location country	Ethiopia	Surface stone size	Medium gravel to stones
Location region	West Hararghe	Erosion category	Water, gully
Location woreda	Habro	Erosion area	0-5%
Location kebele	Bareda	Erosion degree	Slight
Longitude	40°37'46.9"	Crack width	Medium (1-2 cm)
Latitude	08°51'26.9"	Crack depth	Deep (10-20 cm)
Elevation	1766 m	Crack distance	Closely spaced (0.2-0.5 m)
Map ID		Surface drainage	Well
Map scale		Soil drainage	Well
Map unit ID		Depth to groundwater	Not observable
Topography	Sloping land, 5-10%	Depth to bedrock	Not observable
Major landform	Level land, plateau	Rootable depth	200 cm
Position on slope	Lower slope	Rooted depth	70 cm
Slope form	Straight	Depth of observation	200 cm
Slope gradient	6%	Local soil type	Farro
Geology	Igneous	Field WRB soil type	Vertic Luvisol
Parent material	Basalt basement	WRB soil type	Calcic Vertic Luvisol (Hypereutric, Clayic, Chromic)

### Description of the soil horizons (morphology)

Horizon	Depth (cm)	Description
Ap	0-20	Black (10YR 2/1, moist) and very dark gray (10YR 3/1, dry) colour; clay; strong very coarse sub-angular blocky to angular blocky structure; extremely hard (dry), very friable (moist), and very sticky and very plastic (wet) consistence; many, very fine to medium pores; few, distinct clay coatings; very few, fine coarse fragments of unspecified nature; no mottles; few, very fine roots; few burrows; clear, smooth boundary; no reaction with HCl; field pH value of 6.5.
Ak1	20-70	Very dark brown (10YR 2/2, moist) and very dark grayish brown (10YR 3/2, dry) colour; clay; strong coarse angular blocky structure; extremely hard when dry, friable when moist, and very sticky and very plastic (wet) consistence; common, very fine to fine pores; very few, distinct clay coatings; very few, fine coarse fragments of unknown nature; no mottles; very few, very fine roots; very few burrows; clear, smooth boundary; strong reaction with HCl; field measured pH value of 7.
Bk2	70-100	Very dark brown (7.5YR 2.5/2, moist) and very dark gray (7.5YR 3/1, dry) colour; clay; strong medium sub-angular blocky to angular blocky structure; extremely hard when dry, friable when moist, and very sticky and very plastic when wet; common, fine pores; few, faint clay coatings; very few, fine calcium carbonate fragments; no mottles; no roots and other indicators of biological activity; diffuse, smooth boundary; strong reaction with HCl and pH value of 7.
Bk3	100-130	Dark reddish brown (5YR 3/2, moist) and very dark brown (7.5YR 2.5/2, dry) colour; clay; strong medium angular blocky structure; extremely hard (dry), friable (moist), and very sticky and very plastic (wet) consistence; few, very fine pores; very few, faint clay coatings; very few, medium, calcium carbonate fragments; very few, very fine to fine black mottles; no roots and other indicators of biological activity; diffuse, smooth boundary; strong reaction; field measured pH value of 7.
Bk4	130-200	Dark reddish gray (5YR 4/2, moist) and very dark brown (7.5YR 2.5/3, dry); colour; clay; strong medium angular blocky structure; extremely hard (dry), friable (moist), and very sticky and very plastic (wet) consistence; few, very fine pores; very few, faint clay coatings; very few, fine calcium carbonate fragments; no mottles; no roots and other indicators of biological activity; extremely strong reaction with HCl; field measured pH value of 7.5.

Profile ID	HW/HRO/GG/P1	Land cover	Scattered tree species, patchy bushes, herbaceous
Date	24/02 (dd/mm)	Land use	Crop cultivation and animal husbandry
Year	2014	Crop	Cereals, vegetables, pulses, khat, coffee, some fruit trees
Surveyor	Kibebew Kibret	Human influence	Vegetation intensively disturbed, ploughing, terracing
Status	Reference profile description	Surface stone cover	None
Location country	Ethiopia	Erosion category	Water, gully
Location region	West Hararghe	Erosion area	0-5%
Location woreda	Habro	Erosion degree	Slight
Location kebele	Garbi Gobe	Crack width	None
Longitude	40°31'43.3"	Surface drainage	Rapid
Latitude	08°47'27.2"	Soil drainage	Well
Elevation	1811 m	Flooding frequency	None
Map ID		Depth to groundwater	Not observable
Map scale		Depth to bedrock	Not observable
Map unit ID		Rootable depth	200 cm
Topography	Moderately steep, 15-30%	Rooted depth	110 cm
Major landform	Medium gradient hill	Depth of observation	200 cm
Position on slope	Middle slope	Local soil type	Ashewa
Slope form	Straight	Field WRB soil type	Regosol
Slope gradient	25%	WRB soil type	Haplic Nitisol (Eutric)
Geology	Igneous and sedimentary		
Parent material	Mixed granite and sandstone		

#### Description of the soil horizons (morphology)

Horizon	Depth (cm)	Description
Ap	0-25	Brown (7.5YR 5/4, moist) and yellowish red (5YR 5/8, dry) colour; clay loam; moderate medium massive structure; hard when dry, very friable when moist, and slightly sticky and slightly plastic when wet; many, very fine pores; very few, faint clay coatings; no coarse fragments and mottles; very few, fine roots; few burrows; clear, smooth boundary; no reaction with HCl; field measured pH of 6.
A1	25-70	Very dark brown (7.5YR 2.5/3, moist) and red (2.5YR 4/6, dry) colour; sandy clay; moderate medium angular blocky; hard (dry), very friable (moist), and slightly sticky and slightly plastic (wet) consistence; many, fine to medium pores; no observable coatings; no coarse fragments and mottles; very few, very fine roots; no other indicators of biological activity; clear, smooth boundary; no reaction with HCl; field measured pH of 6.
A2	70-110	Red (2.5YR 4/8, moist and dry) colour; sandy clay; moderate medium angular blocky structure; hard (dry), very friable (moist), and slightly sticky and slightly plastic (wet) consistence; few, fine to very fine pores; no coatings; no coarse fragments and mottles; very few, very fine roots; very few burrows; clear, smooth boundary; no reaction with HCl; pH value of 6.
B1	110-140	Red (10R 4/8, moist) and red (2.5YR 5/8, dry) colour; sandy clay; moderate medium angular blocky structure; hard (dry), very friable (moist), and slightly sticky and slightly plastic (wet) consistence; few, very fine pores; no coatings; no coarse fragments and mottles; no roots and other indicators of biological activity; clear, smooth boundary; no reaction with HCl and field measured pH value of 6.
B2	140-200	Red (10YR 4/8, moist) and light red (2.5YR 6/8, dry) colour; sandy clay; moderate medium angular blocky structure; hard (dry), friable (moist), and slightly sticky and slightly plastic (wet) consistence; no mottles; no coarse fragments and mottles; no roots and other indicators of biological activity; no reaction with HCl; field measured pH value of 6.

Profile ID	HW/HRO/GG/P2	Land cover	Scattered trees, bushes, herbaceous
Date	24/02 (dd/mm)	Land use	Crop cultivation and animal husbandry
Year	2014	Crop	Cereals, khat, vegetables, coffee, some fruits
Surveyor	KIbebew Kibret	Human influence	Vegetation intensively disturbed, ploughing, irrigation
Status	Reference profile description	Surface stone cover	None
Location country	Ethiopia	Erosion category	None
Location region	West Hararghe	Sealing thickness	None
Location woreda	Habro	Crack width	Wide (2-5 cm)
Location kebele	Garbi Gobe	Crack depth	Very deep (> 20 cm)
Longitude	40°30'52.4"	Crack distance	Closely spaced (0.2-0.5 m)
Latitude	08°47'58.4"	Surface drainage	Slow
Elevation	1726 m	Soil drainage	Poor
Map ID		Flooding frequency	Not observable
Map scale		Depth to groundwater	Not observable
Map unit ID		Depth to bedrock	Not observable
Topography	Nearly level, 0.5-1.0%	Rootable depth	200 cm
Major landform	Level land, plain	Rooted depth	140 cm
Position on slope	Toe slope	Depth of observation	200 cm
Slope form	Straight	Local soil type	Farro (Biye Guracha)
Slope gradient	1%	Field WRB soil type	Calcic Vertisol
Geology	Igneous and sedimentary	WRB soil type	Calcic Vertisol (Eutric)
Parent material	Basalt and limestone basement		

#### Description of the soil horizons (morphology)

Horizon	Depth (cm)	Description
Ap	0-30	Very dark brown (10YR 2/2, moist) and very dark gray (10YR 3/1, dry) colour; clay; strong very coarse angular blocky structure; very hard when dry, very friable when moist, and very sticky and very plastic when wet; many, very fine to medium pores; very few, faint clay coatings; no coarse fragments; no observable mottles; common, very fine to fine roots; few burrows; clear, smooth boundary; no reaction with HCl; field pH of 6.5.
Ai1	30-80	Dark grayish brown (10YR 4/2, moist) and very dark grayish brown (10YR 3/2, dry) colour; clay; strong coarse angular blocky structure; very hard (dry), friable (moist), and very sticky and very plastic (wet) consistence; common, very fine to fine pores; few, distinct sand silt coatings; very few, fine coarse fragments of unspecified nature; no mottles; very few, very fine to fine roots; few burrows; very few, very fine to fine roots; very few burrows; clear, smooth boundary; no reaction with HCl; field measured pH value of 6.5; slickensides.
ACi2	80-110	Very dark brown (10YR 2/2, moist) and very dark gray (10YR 3/1, dry) colour; clay; strong very coarse prismatic structure; extremely hard (dry), friable (moist), and very sticky and very plastic (wet) consistence; common, very fine pores; very few, faint clay coatings; no coarse fragments and mottles; very few, very fine to fine roots; very few burrows; clear, smooth boundary; no reaction with HCl; field pH value of 7; slickensides.
Ci3	110-140	Black (10YR 2/1, moist) and black (2.5Y 2.5/1, dry) colour; clay; strong very coarse prismatic structure; extremely hard when dry, friable when moist, and very sticky and very plastic when wet; common, very fine pores; very few, faint clay coatings; no coarse fragments and mottles; very few, very fine roots; no other indicators of biological activity; diffuse, smooth boundary; moderate reaction with HCl; field measured pH value of 7; slickensides.
Cik1	140-200	Black (10YR 2/1, moist) and black (2.5Y 2.5/1, dry) colour; clay; strong coarse angular blocky structure; extremely hard (dry), friable (moist), and very sticky and very plastic (wet) consistence; few, very fine pores; no coatings; common, fine coarse fragments of calcium carbonate; no mottles; no roots and other indicators of biological activity; extremely strong reaction with HCl and field measured pH value of 8; slickensides.

Profile ID	HW/HRO/IJ/P1	Land cover	Scattered agro-forestry trees, bushes, herbaceous
Date	26/02 (dd/mm)	Land use	Crop cultivation and animal husbandry
Year	2014	Crop	Cereals, khat, vegetables
Surveyor	Kibebew Kibret	Human influence	Vegetation intensively disturbed, ploughing, bunding
Status	Reference profile description	Surface stone cover	None
Location country	Ethiopia	Crack width	Wide (2-5 cm)
Location region	West Hararghe	Crack depth	Very deep (> 20 cm)
Location woreda	Habro	Crack distance	Moderately widely spaced (0.5-2 m)
Location kebele	Ifa Jiru	Surface salt	None
Longitude	40°24'55.5"	Surface drainage	Well
Latitude	08°43'10.2"	Soil drainage	Well
Elevation	1748 m	Flooding frequency	None
Map ID		Depth to groundwater	Not observable
Map scale		Depth to bedrock	Not observable
Map unit ID		Rootable depth	200 cm
Topography	Sloping, 5-10%	Rooted depth	100 cm
Major landform	Level land, plateau	Depth of observation	200 cm
Position on slope	Lower slope	Local soil type	Farro (Biye Guracha)
Slope form	Straight	Field WRB soil type	Calcic Vertic Luvisol
Slope gradient	8%	WRB soil type	Calcic Vertic Luvisol (Hypereutric, Clayic, Chromic)
Geology	Igneous		
Parent material	Basalt basement		

#### Description of the soil horizons (morphology)

Horizon	Depth (cm)	Description
Ap	0-20	Very dark brown (7.5YR 2.5/3, moist) and very dark brown (7.5YR 2.5/2, dry) colour; sandy clay; strong very coarse massive; very hard (dry), friable (moist), and very sticky and very plastic (wet) consistence; very few, fine pores; common, faint sand and silt coatings; very few, fine calcium carbonate fragments; no mottles; few, very fine to coarse roots; very few burrows; clear, smooth boundary; no reaction with HCl; field pH value of 6.5.
Bt1	20-60	Black (10YR 2/1, moist) and black (2.5Y 2.5/1, dry) colour; clay; strong very coarse angular blocky structure; hard when dry, friable when moist, and very sticky and very plastic when wet; common, very fine to fine pores; very few, faint clay coatings; very few, fine calcium carbonate fragments; no mottles; very few, very fine to fine roots; very few burrows; clear, smooth boundary; slight reaction with HCl; field measured pH value of 7.
Btk1	60-100	Black (2.5Y 2.5/1, moist) and very dark gray (10YR 3/1, dry) colour; clay; strong coarse angular blocky structure; extremely hard when dry, friable when moist, and very sticky and very plastic when wet; very few fine pores; very few, faint clay coatings; very few, fine calcium carbonate fragments; very few, very fine, faint black mottles; very few, very fine to fine roots; no other indicators of biological activity; clear, smooth boundary; strong reaction with HCl; pH value of 7.5.
Btk2	100-140	Very dark grayish brown (10YR 3/2, moist) and dark gray (10YR 4/1, dry) colour; clay; strong medium sub-angular blocky to angular blocky structure; extremely hard (dry), friable (moist), and very sticky and very plastic (wet) consistence; common, very fine pores; very few, faint clay coatings; very few, fine calcium carbonate fragments; very few, very fine, faint black mottles; very few, fine calcium carbonate fragments; very few, very fine, faint black mottles; no roots and other indicators of biological activity; clear, smooth boundary; strong reaction with HCl; field measured pH value of 7.5.
Bk3	140-200	Dark brown (7.5YR 3/2, moist) and brown (10YR 4/3, dry) colour; clay; strong coarse sub-angular blocky to angular blocky structure; extremely hard (dry), friable (moist), and very sticky and very plastic (wet) consistence; common, very fine pores; very few, faint clay coatings; few, fine calcium carbonate fragments; very few, very fine, distinct black mottles; no roots and other indicators of biological activity; strong reaction with HCl and field measured pH value of 7.5.

Table 30. Selected soil physical and chemical properties of representative pedons opened on major agricultural soils in CASCAPE intervention kebeles in Habro Woreda

Parameters	HW/HRO/HC/P					HW/HRO/BD/P				
	0-25	25-70	70-110	110-140	140-200	0-20	20-70	70-100	100-130	130-200
Depth (cm)	0-25	25-70	70-110	110-140	140-200	0-20	20-70	70-100	100-130	130-200
Horizon	Ap	Bt1	B1	Bk1	Bk2	Ap	Ak1	Bk2	Bk3	Bk4
Sand (%)	30.10	14.53	13.69	11.52	18.28	18.34	22.79	13.71	13.37	25.83
Silt (%)	13.11	20.82	21.02	22.40	15.46	18.51	14.14	19.66	18.64	13.09
Clay (%)	56.79	64.65	65.29	66.08	66.26	63.15	63.08	66.63	67.99	61.08
Textural class	C	C	C	C	C	C	C	C	C	C
pH-H <sub>2</sub> O	6.96	7.39	8.05	7.87	7.63	6.36	7.04	7.56	7.71	7.79
pH-KCl	6.15	6.48	7.15	6.93	6.78	5.44	6.13	6.71	6.75	6.90
EC (μS/cm)	0.21	0.66	0.53	0.38	0.29	0.11	0.22	0.27	0.34	0.36
OC (%)	2.25	1.78	1.68	1.52	1.49	1.80	1.45	0.73	0.69	0.51
TN (%)	0.23	0.18	0.17	0.15	0.14	0.24	0.15	0.08	0.06	0.05
Av.P (mg/kg)	49.30					28.60				
Av. S (%)	1.54					0.64				
Na (meq/100 g)	1.77	1.72	1.54	2.09	1.80	0.90	1.16	1.43	1.76	1.80
K (meq/100 g)	1.23	0.83	0.87	0.69	0.66	1.06	0.79	0.72	0.70	0.71
Ca (meq/100 g)	34.69	39.13	40.33	39.41	35.88	39.38	36.72	40.36	42.65	40.72
Mg (meq/100 g)	11.71	13.04	13.15	12.84	12.25	12.98	12.53	13.45	13.93	13.43
CEC (meq/100 g)	53.26	59.08	60.99	57.76	56.13	56.45	54.00	61.33	60.08	60.27
SB (meq/100 g)	49.40	54.72	55.90	55.03	50.60	54.33	51.20	55.97	59.03	56.66
ESP (%)	3.33	2.91	2.53	3.62	3.20	1.60	2.16	2.34	2.93	2.98
Zn (mg/kg)	2.79					2.50				
Mn (mg/kg)	8.86					26.57				
Cu (mg/kg)	8.43					5.07				
Fe (mg/kg)	28.48					30.51				

HRO = Habro Woreda; HC = Haro Chercher Kebele; BD = Bereda Kebele; P = Pedon; EC = electrical conductivity; OC = organic carbon; TN = total nitrogen; Av. Available; SB = sum of bases; C = clay

Parameters	HW/HRO/GG/P1					HW/HRO/GG/P2				
	0-25	25-70	70-110	110-140	140-200	0-30	30-80	80-110	110-140	140-200
Depth (cm)	0-25	25-70	70-110	110-140	140-200	0-30	30-80	80-110	110-140	140-200
Horizon	Ap	A1	A2	B1	B2	Ap	Ati1	Ati2	Ati3	Atik1
Sand (%)	39.79	45.51	46.21	49.25	46.52	30.98	37.84	12.15	18.30	23.29
Silt (%)	23.08	16.15	14.21	9.13	12.11	22.65	8.43	31.45	20.70	16.44
Clay (%)	37.13	38.35	39.58	41.61	41.37	46.37	53.73	56.40	61.00	60.27
Textural class	CL	SC	SC	SC	SC	C	C	C	C	C
pH-H <sub>2</sub> O	5.78	5.57	5.35	5.60	5.98	6.79	7.23	7.53	7.77	8.03
pH-KCl	5.23	4.71	4.83	4.81	5.25	5.84	6.25	6.47	6.81	7.05
EC (μS/cm)	0.04	0.04	0.03	0.03	0.04	0.13	0.09	0.21	0.19	0.34
OC (%)	1.25	1.08	0.54	0.32	0.21	1.86	1.63	1.57	1.25	1.04
TN (%)	0.13	0.10	0.06	0.04	0.02	0.20	0.16	0.15	0.14	0.11
Av.P (mg/kg)	27.80					42.60				
Av. S (%)	0.75					1.21				
Na (meq/100 g)	0.61	0.84	0.53	0.49	0.56	1.54	1.40	1.98	2.15	2.33
K (meq/100 g)	0.06	0.13	0.12	0.17	0.19	0.65	0.36	0.57	0.55	0.49
Ca (meq/100 g)	14.98	15.96	15.96	15.26	15.81	38.63	34.05	38.38	42.41	43.48
Mg (meq/100 g)	4.58	5.04	4.20	4.66	5.82	12.88	11.35	13.37	14.28	14.35
CEC (meq/100 g)	25.32	30.13	31.04	29.96	33.01	58.32	50.72	57.65	61.16	62.86
SB (meq/100 g)	20.23	21.97	20.81	20.58	22.38	53.69	47.16	54.29	59.39	60.64
ESP (%)	2.45	2.79	1.71	1.64	1.70	2.64	2.76	3.43	3.51	3.70
Zn (mg/kg)	1.79					2.01				
Mn (mg/kg)	19.72					34.52				
Cu (mg/kg)	0.61					11.94				
Fe (mg/kg)	23.23					41.37				

HRO = Habro Woreda; GG = Garbi Gobe Kebele; CL = clay loam; SC = sandy clay

Parameters	HW/HRO/IJ/P				
	0-20	20-60	60-100	100-140	140-200
Depth (cm)	0-20	20-60	60-100	100-140	140-200
Horizon	Ap	Bt1	Btk1	Btk2	Bk3
Sand (%)	51.10	36.65	25.54	31.59	19.64
Silt (%)	12.22	19.33	21.58	11.95	23.89
Clay (%)	36.67	44.03	52.88	56.47	56.47
Textural class	SC	C	C	C	C
pH-H <sub>2</sub> O	6.37	7.00	7.61	7.92	7.98
pH-KCl	5.67	6.01	6.73	6.98	7.04
EC (μS/cm)	0.05	0.09	0.15	0.21	0.22
OC (%)	1.88	1.68	1.38	0.86	0.48
TN (%)	0.21	0.21	0.14	0.11	0.05
Av.P (mg/kg)	22.10				
Av. S (%)	0.82				
Na (meq/100 g)	0.81	1.21	1.73	2.12	2.25
K (meq/100 g)	0.25	0.58	0.64	0.71	0.81
Ca (meq/100 g)	16.70	41.05	39.06	40.57	39.71
Mg (meq/100 g)	5.70	13.68	12.88	13.38	13.38
CEC (meq/100 g)	34.52	59.03	56.92	60.05	59.11
SB (meq/100 g)	23.45	56.52	54.30	56.78	56.15
ESP (%)	2.33	2.05	3.03	3.53	3.81
Zn (mg/kg)	1.14				
Mn (mg/kg)	19.31				
Cu (mg/kg)	1.50				
Fe (mg/kg)	24.21				

HRO = Habro Woreda; IJ = Ifa Jiru Kebele; P = Pedon; EC = electrical conductivity; OC = organic carbon; TN = total nitrogen; Av. Available; SB = sum of bases; C = clay; SC = sandy clay

### 3.8.3. Synthesis

The morphological, physical, and chemical properties of the pedons are presented in Tables 29 and 30 in Section 3.8.2. For the discussions made hereunder, reference should be made to those tables. The results are interpreted using critical values of parameters as suggested in Booker Tropical Soil Manual (Landon, 1991), Jones (2003), FAO (2007), Karlton et al. (2013) and Allison (1973).

#### 3.8.3.1. Agronomic Interpretation of Soil Morphological Properties

##### 1. Soil Colour

The surface colour (moist) ranged from very dark brown (7.5YR 2.5/3) in the Calcic Vertic Luvisols in Ifa Jiru to very dark brown (10YR 2/2) in the Calcic Vertic Luvisols of Haro Chercher Kebele, whilst the surface colour (dry) varied from yellowish red (5YR 5/8) in the Haplic Nitisols of Garbi Gobe to very dark gray (10YR 3/1) in the Calcic Vertic Luvisols of Haro Chercher Kebele.

Also, the subsurface colour (moist) graded from red (10R 4/8) in the Haplic Nitisols of Garbi Gobe to black (2.5Y 2.5/1) in the Calcic Vertic Luvisols of Ifa Jiru Kebele. The subsurface colour (dry) ranged from black (2.5YR 2.5/1) in the Calcic Vertic Luvisols of Haro Chercher to black (2.5Y 2.5/1) the Calcic Vertisols of Garbi Gobe Kebele.

The extreme difference in colour between the Haplic Nitisols of Garbi Gobe and the others is purely related to differences in parent material. In soils of the surface layers, organic matter differences might have resulted in the observed colour variations, while within the subsurface horizons drainage difference might be the main reason for the differences observed.

## 2. Soil Structure and Consistence

At the surface horizons, moderate, medium to strong, very coarse massive, strong, coarse granular, strong very coarse sub-angular blocky, and strong, very coarse angular blocky structure types were recognized. In the subsurface horizons too, strong, medium to coarse sub-angular blocky, moderate, medium to strong, very coarse angular blocky, and strong, very coarse prismatic structure types were identified. Furthermore, wedge-shaped structure types with extensive shiny faces (slickensides) were common in Calcic Vertisols of Garbi Gobe Kebele. The massive structure was observed in Calcic Vertisols of Garbi Gobe and Calcic Vertic Luvisols of Ifa Jiru.

Hard to very hard (dry), friable to very friable (moist), and slightly to very sticky and very plastic (wet) characterize the consistence of the surface horizons. In the subsurface horizons as well, the consistence was hard to extremely hard when dry, friable to very friable when moist, and slightly to very sticky and very plastic when wet. The hard and slightly plastic consistences were recorded in the Haplic Nitisols of Garbi Gobe Kebele.

## 3. Soil Depth

The depth of the major agricultural soils, as observed from roadcuts, gullies, auger points, and pedons opened, is very deep except on the steep slopes. The minimum depth observed in auger points is 20 cm, which is a steep slope. In all other instances, the depth is more than 60 cm. Therefore, the soils on the agricultural lands do not have limitation related to their depth.

## 4. Porosity, Root Distribution and Other Features

Very few, fine to many, very fine to medium pores characterize the porosity of the surface horizons. Similarly, the porosity of the subsurface horizons varied from very few, fine pores to many, fine to medium pores. Though no

regular pattern was observed with soil depth, general decreases in pore size and also abundance were recognized.

The root distribution in the pedons and also in auger points observed depends very much on the types of plants grown and internal pore-related conditions of the soils. On average, as observed in the pedons, roots were found within 70 to 110 cm depth. Nevertheless, the sizes and abundances of the roots decreased with soil depth. This could be attributed to the general decrease in pore size with soil depth. As a result, roots identified in the deeper layers were very fine in their size.

Other important features recorded were coarse fragments, mottles, coatings, other biological activities, carbonate tests, field pH measurements, and horizon boundaries. The details of all these features are depicted in Table 29.

#### 3.8.3.2. Agronomic Interpretation of Soil Particle Size Distribution

In almost all the pedons, clay, followed by sand, is the dominant fraction. Sand content of the surface soils ranges from 18.3% in Calcic Vertic Luvisols of Bareda to 51.2% in the Calcic Vertic Luvisols of Ifa Jiru. In the subsurface soils, it ranges from 11.5 % in the Calcic Vertic Luvisols of Haro Chercher to 49.3% in the Haplic Nitisols of Garbi Gobe Kebele. Similarly, the clay content of the surface soils ranges from 36.7% in the Calcic Vertic Luvisols of Ifa Jiru to 63.2% in the Calcic Vertic Luvisols of Bareda Kebele. The clay content of the subsurface soils varies from 38.4% in the Haplic Nitisols of Garbi Gobe Kebele to 68% in the Calcic Vertic Luvisols of Bareda Kebele. With depth, sand content does not show any regular variation, while clay content slightly increased with soil depth in the Calcic Vertic Luvisols of Haro Chercher and Ifa Jiru Kebeles.

### 3.8.3.3. Agronomic Interpretation of Soil Chemical Properties

#### 1. Soil Reaction and Electrical Conductivity

The pH-H<sub>2</sub>O of the surface soils ranged from 5.8 in the Haplic Nitisols of Garbi Gobe Kebele to 7.0 in the Calcic Vertic Luvisols of Haro Chercher Kebele. In the subsurface soils, it varied from 5.4 in the Haplic Nitisols of Garbi Gobe to 8.1 in the Calcic Vertic Luvisols of Haro Chercher. The pH-H<sub>2</sub>O increased with soil depth consistently in the Calcic Vertic Luvisols of Bareda and Ifa Jiru Kebeles, and in Calcic Vertisols of Garbi Gobe Kebele.

Following pH-H<sub>2</sub>O rating of Karlton et al. (2013), the pH of the surface soils was neutral in the Calcic Vertic Luvisols of Haro Chercher and Calcic Vertisols of Garbi Gobe and moderately acidic in all the other soil types, while the pH of the subsurface soils was moderately acidic in Haplic Nitisols and moderately alkaline in all the other soil types. On the other hand, based on pH-H<sub>2</sub>O (1:2.5 soil:water suspension) interpretation guides suggested by Landon (1991), the pH of the soils was in the range of medium in the surface horizon soils and medium to high in the subsurface horizon soils. Except the pH in the Haplic Nitisols of Garbi Gobe, the pH of the other soils is in the range that is considered favorable for availability of most essential nutrient elements, activity of beneficial microorganisms and growth of most cultivated crops. The pH in the Haplic Nitisols may slightly affect availability of P.

The difference between pH-H<sub>2</sub>O and pH-KCl, in all depths and pedons, was positive indicating that the major agricultural soils of the kebeles are dominated by clay minerals that have negatively charged surfaces and have high reserve acidity.

The electrical conductivity of the soils indicates that major agricultural soils of the four kebeles are non-saline soils.

## 2. Soil Organic Carbon, Total Nitrogen and C:N Ratio

The organic carbon content of the surface soils ranged from 1.3% in the Haplic Nitisols of Garbi Gobe to 2.3% in the Calcic Vertic Luvisols of Haro Chercher Kebele. In the subsurface soils, it varied from 0.2 to 1.8%. In all the pedons, the organic carbon content of the soils followed the natural ideal trend with soil depth.

Based on ratings suggested in Landon (1991), the organic carbon content of the surface soils was very low in the Haplic Nitisols of Garbi Gobe and low in all the other soil types. Similarly, it was within the range of very low to low in the subsurface horizons.

The total nitrogen content of the surface soils varied from 0.1 in the Haplic Nitisols of Garbi Gobe to 0.2% in all the other soil types. In the subsurface soils, it ranged from 0.02 to 0.2%. Based on broad ratings suggested by Landon (1991), the total nitrogen content of the Haplic Nitisols was low, while it was medium in the other soil types. Its status in the subsurface soils was not different from low to medium recorded in the surface soils.

The C:N ratio of the soils ranged from 8:1 to 10:1 in surface soils to 8:1 to 12:1 in the subsurface soils which according to Allison (1973) shows that there is adequate nitrogen for microorganisms to decompose organic materials when added to soils. Furthermore, it also shows that the added organic matter decomposes very rapidly. The ratios obtained are also within the normal range for arable soils (Allison, 1973).

## 4. Available Phosphorus and Sulfur

The available phosphorus ranged from 22.1 mg kg<sup>-1</sup> the Calcic Vertic Luvisols of Ifa Jiru to 49.3 mg kg<sup>-1</sup>.in the Calcic Vertic Luvisols of Haro Chercher Kebele. Based on ratings suggested by Landon (1991), the

available P content of the soils was within the range of high, which means that application of external P source is not required (Landon, 1991).

The available sulfur content of the soils ranged from 0.6% in the Calcic Vertic Luvisols of Bareda to 1.5% in the same soils in Haro Chercher. Based on rating described in Landon (1991), the available S content of all the major agricultural soils was excess.

#### 5. Exchangeable Bases (Ca, Mg, K, Na)

The dominant exchangeable bases, Ca and Mg, did not show any predictable trend within soil depth in a pedon. The exchangeable Ca of the surface soils was between 16.7 meq/100 g soil in the Calcic Vertic Luvisols of Ifa Jiru and 39.4 meq/100 g soil in the same soils in Bareda Kebele. In the subsurface soils, it varied from 17.9 meq/100 g soil in the Haplic Nitisols of Garbi Gobe to 43.5 meq/100 g in the Calcic Vertisols of the same kebele. The exchangeable Ca values in the surface and subsurface soils were greater than 10 meq/100 g soil and, thus, can be considered as high (Landon, 1991). Furthermore, the exchangeable Ca of the soils was in the range of high to very high following the FAO (2006) rating.

The exchangeable Mg of all the soil types was in the range of high (Landon, 1991). Base on ratings of FAO (2006) also, the exchangeable Mg of the soils was in the range of high to very high.

Based on FAO (2006) ratings, the exchangeable K of the surface soils was low in the Haplic Nitisols of Garbi Gobe, medium in the Calcic Vertic Luvisols of Ifa Jiru and high in all the other soil types. Similarly, the exchangeable Na was high to very high in the surface soils and medium to very high in the subsurface soils (FAO, 2006). The values of exchangeable Na indicate that, except the Haplic Nitisols of Garbi Gobe, all the other major agricultural soils are potentially sodic (Landon, 1991). The exchangeable sodium percentage

values of the surface horizons also indicate that extremely sensitive crops, such as avocado, nuts, cassava, and citrus, may be affected.

## 6. Cation Exchange Capacity and Sum of Bases

In the soils of the surface horizons, it ranged from 31.9 meq/100 g soil in the Haplic Nitisols of Garbi Gobe to 58.3 meq/100 g soil in the Calcic Vertisols of the same kebele, while it varied from 34.9 to 62.9 meq/100 g soil in the subsurface soils of this same soil types. As per ratings of Landon (1991), the CEC of the major agricultural soils in the four kebeles was high to very high in soils of surface and subsurface horizons. The CEC clay of the soils varied from 84 to 134 meq/100 g soil.

The percent base saturation ranged from 68 to 96 and 72-98% in the surface and subsurface soils, respectively. These values are high to very high as per base saturation ratings of Metson (1961) and indicate that the soils are very weakly to weakly leached.

## 7. Extractable Micronutrients (Zn, Mn, Cu, Fe)

The extractable Zn values ranged between 1.1 mg kg<sup>-1</sup> in the Calcic Vertic Luvisols of Ifa Jiru to 2.8 mg kg<sup>-1</sup> in the same soils of Haro Chercher. The extractable Zn content of the soil was in the range of low in the Calcic Vertic Luvisols of Ifa Jiru and optimum in all the other soil types (Karlton et al., 2013).

The extractable Mn content of the soils also varied from 8.9 mg kg<sup>-1</sup> in the Calcic Vertic Luvisols of Haro Chercher to 34.5 mg kg<sup>-1</sup> in the Calcic Vertisols of Garbi Gobe Kebele. Following the rating suggested by Jones (2003), the extractable Mn content was medium in the Calcic Vertic Luvisols of Haro Chercher and Ifa Jiru, and in the Haplic Nitisols of Garbi Gobe Kebele, while it was high in other soil types.

Extractable Cu also varied from 0.6 mg kg<sup>-1</sup> in the Haplic Nitisols of Garbi Gobe to 11.9 mg kg<sup>-1</sup> in the Calcic Vertisols of the same Kebele. According to rating suggested by Karlton et al. (2013), the extractable Cu content of major agricultural soils in the four kebeles was low in the Haplic Nitisols of Garbi Gobe, high the Calcic Vertisols of Garbi Gobe and optimum in the other soil types.

The extractable iron content ranged from 23.2 mg kg<sup>-1</sup> in the Haplic Nitisols of Garbi Gobe to 41.4 mg kg<sup>-1</sup> in the Calcic Vertisols of the same Kebele. Based on rating suggested by Jones (2003), the extractable Fe content of major agricultural soils of the four kebeles was within the range of high.

#### 3.8.3.4. Agronomic Interpretation of Major Soil Types

The major agricultural soils in the four kebeles are the Cambisols, Nitisols, Luvisols and Vertisols. Similar to the other Woredas, the steep slopes of the interspersed hills and mountains, which are dominantly occupied by Leptosols and Regosols, are used for agricultural purpose marginally. Particularly the Leptosols are not only shallow but also are stony to the extent that it prohibits workability.

In the major agricultural soils, soil depth is not a limiting factor for production of crops. Almost all the soil types are deep enough to store adequate water and nutrients for successful production of both shallow and deep rooted crops provided that other soil conditions are not limiting. These major agricultural soils are well structured albeit the blocklike and, in some instances, the massive and prism-like structures are also common. The massive structure in the Calcic Vertisols of Garbi Gobe and Calcic Vertic Luvisols of Ifa Jiru may retard water entry and movement through the soil system and result in waterlogging conditions during the wet season. Particularly the Luvisols and Vertisols occurring on the plain land are highly susceptible to waterlogging during the wet season. As a result, farmers do

not get good yield from the main cropping season. Because of the high clay content, the soils are extremely hard when dry and, very sticky and very plastic when wet. As a result, their workability during dry and wet periods is difficult. These soils should be worked when they are at or near friable consistence in order to produce good soil tilth and also minimize destruction of the soil structure.

The pH-H<sub>2</sub>O of the Haplic Nitisols in Garbi Gobe was within the range of moderately acidic both in the surface and subsurface soils. In such pH range, the availability of P is likely to decrease although the results obtained in this study do not support this. The P is likely to be fixed by Fe and Al when the pH falls below 6.0. The pH of the surface soils in the other soil types was, nevertheless, within the range that is favorable for availability of most essential nutrient elements, activities of beneficial microorganisms and growth of most cultivated crops. However, the pH values recorded in some subsurface horizons of the Calcic Vertic Luvisols in Haro Chercher, Bareda and Ifa Jiru, and Calcic Vertisols of Garbi Gobe were in the range of moderately alkaline. This pH range may result in deficiency of micronutrients like Mn and Fe although the results obtained in this study do not support this. Particularly in areas where irrigation is being practiced, the quality of irrigation water to be used in these soils should be analyzed for its quality not to aggravate the problem.

The Haplic Nitisols in Garbi Gobe were very low and the Calcic Vertic Luvisols and Calcic Vertisols low in their organic matter content. As indicated in Plate 17, most of the farmers try to apply organic materials of different nature to their farm before the growing season starts. Nevertheless, the amount applied is far from adequate to bring about the required change in organic carbon level. Furthermore, the crop residues, particularly sorghum and maize, are used for other purposes and, hence, are not returned to the soil. Low organic matter input along with frequent tillage might have resulted in

this low level of organic carbon in these soils. Practices that improve the organic carbon level should be promoted in these kebeles. Following the low level of organic matter in the soils, their total nitrogen level was also low in the Haplic Nitisols and medium in the Calcic Vertic Luvisols and Calcic Vertisols. The results indicate these soils, specially the Haplic Nitisols, are deficient in nitrogen and, thus, require application of appropriate rate and type of N fertilizer based on site- and crop-specific recommendations. The results also indicate that the available P and S content of all the major agricultural soils were high and deficiencies of these nutrients are not expected to constrain crop production in these kebeles.

The soils contain adequate levels of Ca, Mg, and K except the Haplic Nitisols of Garbi Gobe which were low in their exchangeable K and the Calcic Vertic Luvisols of Ifa Jiru which were medium in K. Therefore, in the Haplic Nitisols of Garbi Gobe, immediate application of K containing fertilizer may be required to improve crop yield. On the other hand, the fact that all the other soil types except the Haplic Nitisols are potentially sodic is worrisome. Particularly in those areas where irrigation is being practiced, care has to be taken not to aggravate the problem. Good quality water with no Na in it has to be used. All the soils, on the other hand, have high CEC and base saturation, which indicates their potential fertility.

The Calcic Vertic Luvisols in Ifa Jiru are deficient in extractable Zn, while all the other soil types are optimum in their Zn content. The Calcic Vertic Luvisols of Ifa Jiru, therefore, require application of Zn containing fertilizer. Furthermore, the Haplic Nitisols of Garbi Gobe are deficient in copper and hence may require application of fertilizers that contain this nutrient element. All the soil types do not have Fe deficiency problems.

By and large, the soils are good except the indicated specific soil fertility problems, which can be easily corrected. The organic matter improvement

should receive more attention given the role it plays in improving the physical, chemical, and biological soil properties. The types of fertilizers that should be provided to farmers of these kebeles should contain different blends containing N, K, Zn, and Cu.

### 3.9. Agronomic Interpretation of Major Agricultural Soils in the Five Woredas

#### 3.9.1. Regosols

The Regosols, being developed on a medium gradient hill from mixed granite and sandstone parent materials, are generally shallow (50-25 cm), with weakly developed structure and moderate (25-40%) clay content. As can be seen from their water retention characteristic curve, estimated using exponential equation developed by Kibebew (2003) for major soils of Hararghe region, the soils are well drained (Figure 27). Nevertheless, their available water holding capacity was 117.9 and 88 mm/m for surface and subsurface soils and is rated as medium (100-200 mm/m) and low (< 100 mm/m) respectively (McIntyre, 1974). Therefore, their shallow depth may not enable them support successful growth of deep rooted crops, particularly under rainfed condition.

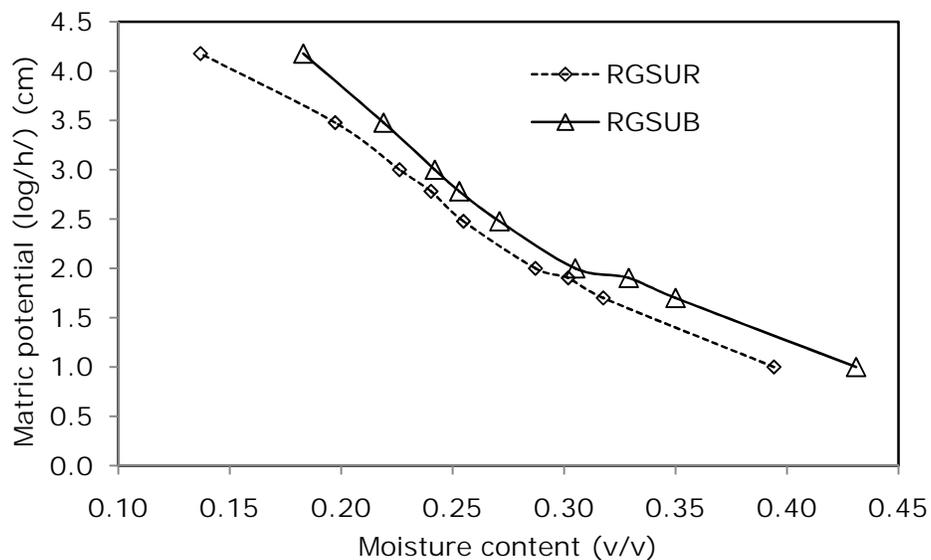


Figure 27. Estimated average water retention characteristic curves for surface and subsurface soils of Regosols in CASCAPE intervention Woredas.

Chemically, the soils (surface and subsurface) were near neutral in pH (6.6-7.3), very low (< 2%) organic carbon and low (surface) (0.1-0.2%) and very low (< 0.1) (subsurface) total nitrogen content. The soils were rich in basic cations except that they were medium (0.3-0.6 meq/100 g) (surface and subsurface) in exchangeable K. They were also high in available P (> 15 mg kg<sup>-1</sup>) and S. They were high in Fe (5.1-250 mg kg<sup>-1</sup>), medium in Mn (1.0-20.0 mg kg<sup>-1</sup>) and optimum in Cu (> 0.9 mg kg<sup>-1</sup>). They, however, were low in Zn (1-1.5 mg kg<sup>-1</sup>). Ranges of selected major properties of these soils are depicted in Table 31.

### 3.9.2. Cambisols

The Cambisols occur dominantly on landforms that cover dissected plateaus to medium gradient hills and mountains and are developed on different parent materials, such as granite, sandstones, limestones and basalt. They are moderately (100-50 cm) to very deep (> 150 cm) and, thus, have a depth that can store sufficient water and also nutrients for successful production of annual and perennial crops. The soils are generally structured with moderate to very high (> 50%) clay content at the surface and subsurface layers. From their average water retention characteristic curved in Figure 28, it can be seen that these soils are well drained regardless of their high clay content. This indicates the well aggregated nature of these soils. Their average available water holding capacity (129.3 mm/m for surface and 95.0 mm/m for subsurface soils) was in the range of medium and low for the surface and subsurface soils, respectively.

Table 31. Ranges of selected major physical and chemical properties of Regosols in CASCAPE intervention Woredas

Parameter	Layer	Mean	Median	StD	Minimum	Maximum	CV (%)
pH-H <sub>2</sub> O	Surface	6.76					
	Subsurface	6.73	6.73	0.18	6.60	6.85	2.63
pH-KCl	Surface	5.80					
	Subsurface	6.14	6.14	0.13	6.05	6.23	2.07
EC	Surface	0.06					
	Subsurface	0.06	0.06	0.00	0.06	0.06	0.00
Sand	Surface	54.77					
	Subsurface	50.85	50.85	0.38	50.58	51.12	0.75
Silt	Surface	12.34					
	Subsurface	15.02	15.02	2.30	13.39	16.64	15.31
Clay	Surface	32.90					
	Subsurface	34.14	34.14	2.69	32.24	36.04	7.87
Na	Surface	0.95					
	Subsurface	0.93	0.93	0.03	0.91	0.96	3.34
K	Surface	0.44					
	Subsurface	0.35	0.35	0.07	0.30	0.40	18.68
Ca	Surface	11.50					
	Subsurface	13.64	13.64	1.09	12.87	14.41	7.96
Mg	Surface	4.11					
	Subsurface	4.96	4.96	0.55	4.57	5.35	11.17
CEC	Surface	26.79					
	Subsurface	31.00	31.00	1.72	29.79	32.21	5.53
SB	Surface	17.00					
	Subsurface	19.88	19.88	1.67	18.70	21.07	8.42
OC	Surface	1.34					
	Subsurface	0.90	0.90	0.19	0.76	1.03	21.16
TN	Surface	0.14					
	Subsurface	0.09	0.09	0.02	0.07	0.10	22.97
ESP	Surface	3.35					
	Subsurface	3.02	3.02	0.27	2.83	3.21	8.86
AV. P	Surface	29.80					
S	Surface	0.67					
Zn	Surface	1.31					
Mn	Surface	12.27					
Cu	Surface	1.59					
Fe	Surface	14.87					

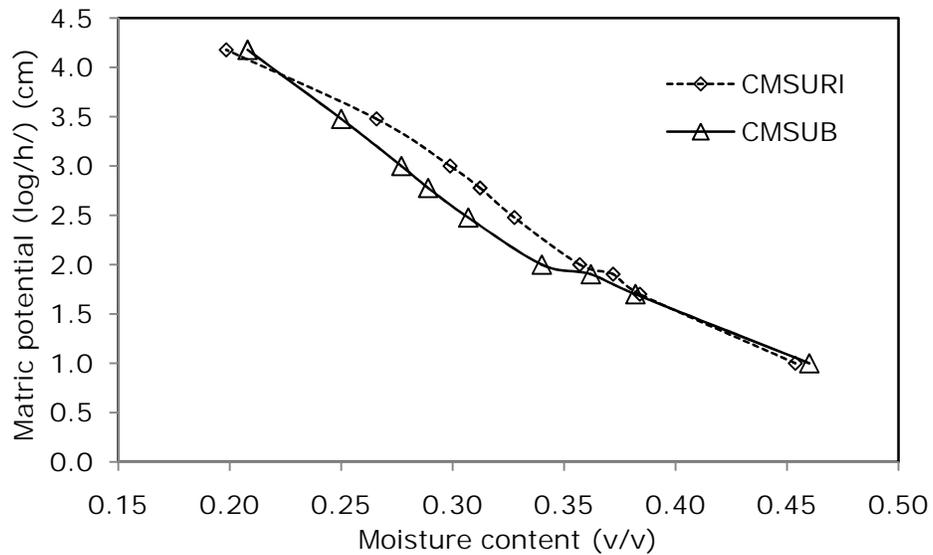


Figure 28. Estimated average water retention characteristic curves for surface and subsurface soils of Cambisols in CASCAPE intervention Woredas.

Their pH varied between moderately acidic (5.6-6.5) to moderately alkaline (7.4-8.4) (surface) and strongly acidic ( $\leq 5.5$ ) in the subsurface layers, which is favorable pH range for availability of most nutrients except boron and manganese. These soils were rich in basic cations except the medium levels of K and Na (0.3-0.7 meq/100 g) recorded in some of them. They were, however, very low to low (2-4%) in their organic carbon and low in total nitrogen. They were high in available P and S, low to optimum ( $> 1.5 \text{ mg kg}^{-1}$ ) in Zn, medium (1.0-20.0  $\text{mg kg}^{-1}$ ) to very high ( $> 50 \text{ mg kg}^{-1}$ ) in Mn, optimum in Cu, and medium (2.1-5.0  $\text{mg kg}^{-1}$ ) to high in Fe. The ranges of selected physical and chemical properties of these mapping units are presented in Table 32.

Table 32. Ranges of selected soil physical and chemical properties of Cambisols in the five CASCAPE intervention woredas

Parameter	Layer	Mean	Median	StD	Minimum	Maximum	CV (%)
pH-H <sub>2</sub> O	Surface	6.50	6.44	0.64	6.00	7.83	9.79
	Subsurface	6.62	6.59	0.66	5.52	8.00	10.00
pH-KCl	Surface	5.63	5.50	0.68	5.03	7.01	12.12
	Subsurface	5.72	5.69	0.67	4.54	7.14	11.79
EC	Surface	0.09	0.08	0.04	0.06	0.14	40.06
	Subsurface	0.08	0.07	0.04	0.04	0.19	46.11
Sand	Surface	33.45	37.25	15.60	9.77	54.25	46.65
	Subsurface	40.60	45.29	12.39	17.15	56.83	30.51
Silt	Surface	19.28	20.25	5.55	9.36	26.73	28.81
	Subsurface	16.57	16.40	2.95	12.17	22.53	17.83
Clay	Surface	47.28	41.83	12.32	36.40	66.62	26.05
	Subsurface	42.83	39.00	11.54	26.73	66.78	26.94
Na	Surface	0.83	0.87	0.12	0.61	0.95	14.90
	Subsurface	0.92	0.86	0.21	0.58	1.38	23.27
K	Surface	0.54	0.52	0.19	0.25	0.78	35.77
	Subsurface	0.38	0.36	0.14	0.17	0.74	37.15
Ca	Surface	23.97	22.13	7.23	16.16	36.81	30.14
	Subsurface	21.94	20.40	7.21	13.25	39.24	32.86
Mg	Surface	8.11	7.52	2.64	5.25	12.84	32.53
	Subsurface	7.40	6.74	2.40	4.14	13.08	32.48
CEC	Surface	41.68	36.56	8.45	32.50	54.90	20.28
	Subsurface	38.94	36.39	7.78	27.34	55.92	19.99
SB	Surface	33.46	30.96	10.04	22.43	51.27	30.00
	Subsurface	30.64	28.02	9.74	18.62	53.99	31.79
OC	Surface	1.36	1.22	0.34	1.00	2.02	24.67
	Subsurface	0.74	0.71	0.41	0.15	1.57	55.06
TN	Surface	0.16	0.16	0.05	0.10	0.25	28.49
	Subsurface	0.08	0.07	0.04	0.01	0.18	58.47
ESP	Surface	2.03	2.05	0.28	1.73	2.54	13.95
	Subsurface	2.39	2.37	0.49	1.66	3.74	20.63
AV. P	Surface	33.90	35.47	10.55	20.40	52.40	31.12
S	Surface	1.13	1.28	0.31	0.65	1.44	27.27
Zn	Surface	2.29	2.39	0.62	1.45	2.94	26.91
Mn	Surface	29.85	24.97	18.61	8.98	68.04	62.34
Cu	Surface	2.87	2.75	1.53	1.26	5.55	53.43
Fe	Surface	33.79	28.61	24.38	3.09	83.20	72.15

### 3.9.3. Nitisols

The Nitisols occur as mapping units on landforms that range from plateaus to medium gradient hills. They are formed from variety of parent materials that include granite and sandstone mixtures, sandstones and basalts. They are all very deep soils with 200+ cm soil depth and, thus, are excellent soils for production of any crop provided that their other conditions are optimum as well. They are well structured and well drained with moderate to very high clay content. The average water retention characteristic curve (Figure 29) also shows that they are relatively well drained. Because of the uniformity in their texture, the water retention characteristic curve for the surface and subsurface soils is almost the same except at saturation and permanent wilting point. Their available water holding capacity (126.4 and 97.0 mm/mm for surface and subsurface soils, respectively) was in the range of medium and low, respectively.

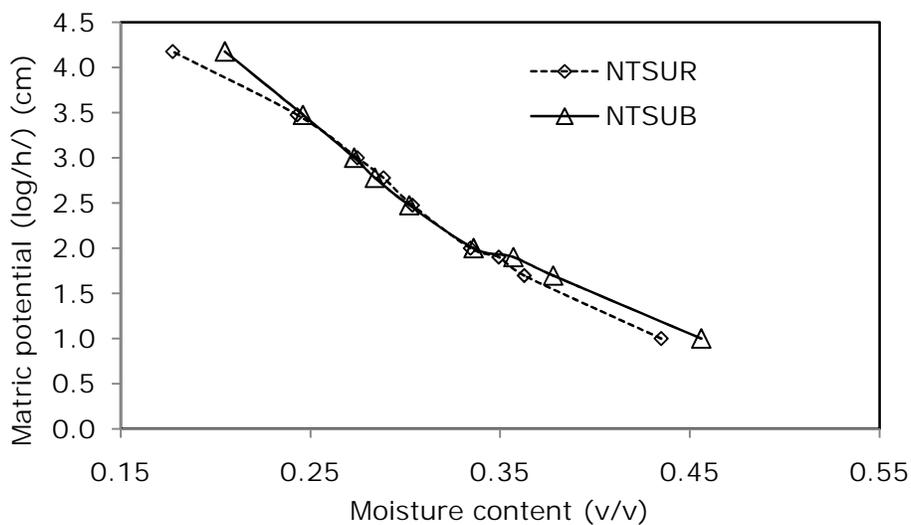


Figure 29. Estimated water retention characteristic curve of surface and subsurface soils of Nitisols in CASCAPE intervention Woredas.

Their pH ranged from strongly acidic to neutral at both the surface and subsurface layers. The strongly acidic pH range may limit availability of phosphorus albeit the soils were high in their available phosphorus content. Like the other soil types, they were very low to low in their organic carbon content and very low (< 0.1%) to medium (0.2-0.5%) in their total nitrogen content (both surface and subsurface layers). The soil were high (10-20 meq/100 g) to very high (>20 meq/100 g) in Ca, high (> 8.0 meq/100 g) in Mg, medium to high (0.7-2.0 meq/100 g) in Na, and very low (< 0.2 meq/100 g) to medium in exchangeable K. They were also high (25-40 meq/100 g) to very high (> 40 meq/100 g) in their CEC and high in base saturation (60-80). Except the very low Zn ( $\leq 1.0 \text{ mg kg}^{-1}$ ) recorded in Hawi Bilisuma of Meta and low Cu ( $\leq 0.45 \text{ mg kg}^{-1}$ ) recorded in Garbi Gobe of Habro, these soils also contain adequate levels of Zn, Mn, Cu and Fe. The ranges of the selected soil properties recorded in these soil mapping units are illustrated in Table 33.

#### 3.9.4. Luvisols

These soil mapping units are the dominant mapping units in the five CASCAPE intervention Woredas and occur on a wide range of landforms including: plains, plateaus, medium gradient hills, escarpments and mountains. They are formed from different types of parent materials, but dominantly from granites, sandstones, limestones and basalts. These are based on the exposed rocks observed during the field work. Nevertheless, those places of granite might have been occupied by the likes of limestone and the exposed granites are the results of erosion removal of the parent materials from which the soils might have been formed. Where the Nitisols occur, these soils occupy the lower positions of the landforms mentioned above. They are moderately to very deep. They can, thus, support successful growth of almost all food crops and the very deep ones can support perennial crops, such as fruits.

Table 33. Ranges of selected soil properties recorded in Nitisols of the five CASCAPE intervention Woredas

Parameter	Layer	Mean	Median	StD	Minimum	Maximum	CV (%)
pH-H <sub>2</sub> O	Surface	5.94	5.96	0.51	5.27	6.68	8.53
	Subsurface	5.96	5.87	0.67	4.93	7.12	11.23
pH-KCl	Surface	5.10	5.12	0.54	4.30	5.82	10.64
	Subsurface	5.07	4.95	0.64	4.01	6.16	12.61
EC	Surface	0.05	0.06	0.01	0.04	0.06	21.07
	Subsurface	0.05	0.04	0.02	0.03	0.09	35.99
Sand	Surface	39.86	39.79	11.70	24.30	51.79	29.35
	Subsurface	41.90	45.51	10.08	13.50	53.36	24.06
Silt	Surface	19.73	18.88	12.42	7.50	38.87	62.95
	Subsurface	14.69	12.36	7.04	7.13	33.75	47.95
Clay	Surface	40.41	39.15	4.65	36.83	48.24	11.51
	Subsurface	43.42	41.37	5.61	38.35	55.81	12.93
Na	Surface	0.73	0.75	0.07	0.61	0.80	10.13
	Subsurface	0.83	0.81	0.23	0.49	1.46	28.23
K	Surface	0.29	0.17	0.23	0.06	0.57	82.40
	Subsurface	0.24	0.18	0.12	0.10	0.43	52.34
Ca	Surface	16.63	15.80	4.04	11.76	22.68	24.32
	Subsurface	18.49	17.98	3.74	11.76	25.68	20.25
Mg	Surface	5.94	5.82	1.06	4.58	7.56	17.89
	Subsurface	6.10	6.42	1.55	3.78	8.56	25.40
CEC	Surface	33.87	32.56	6.82	25.32	44.28	20.14
	Subsurface	36.22	34.48	5.34	29.96	45.51	14.73
SB	Surface	23.59	22.49	5.13	18.43	31.55	21.75
	Subsurface	25.65	25.54	5.39	16.35	35.54	21.00
OC	Surface	1.25	1.11	0.97	0.45	2.87	77.69
	Subsurface	0.53	0.32	0.45	0.17	1.81	84.58
TN	Surface	0.12	0.10	0.10	0.04	0.28	78.35
	Subsurface	0.06	0.04	0.05	0.01	0.22	94.33
ESP	Surface	2.20	2.25	0.23	1.81	2.41	10.32
	Subsurface	2.29	2.20	0.60	1.65	4.23	26.15
AV. P	Surface	32.00	27.80	9.99	24.90	49.30	31.21
S	Surface	0.97	0.93	0.18	0.75	1.19	18.80
Zn	Surface	2.26	1.79	1.65	0.40	4.68	72.93
Mn	Surface	36.13	20.00	31.07	12.15	88.46	85.99
Cu	Surface	2.85	2.00	2.29	0.61	6.11	80.34
Fe	Surface	41.57	23.50	31.72	12.30	87.61	76.31

They are well structured (mainly block-like structure) with some of them having internal drainage problems. They are moderate to very high in their clay content. The more gradual slope of their average water retention characteristic curve shows their slow drainage characteristic (Figure 30). Their available water holding capacity, which was 129.9 and 114.0 mm/m for the surface and subsurface soils, was in the range of medium.

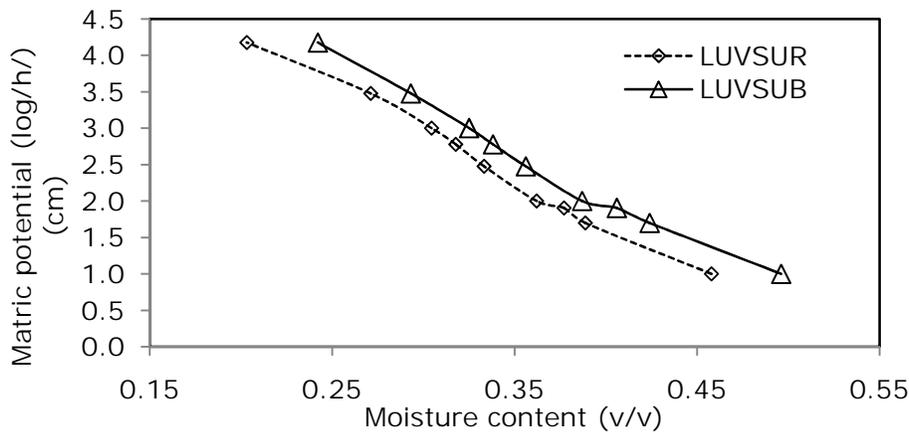


Figure 30. Estimated water retention characteristic curves of surface (LUVSUR) and subsurface (LUVSUB) soil of Luvisols in CASCAPE intervention Woredas.

They did not have serious acidity or alkalinity related problems with their pH ranging between moderately acidic to moderately alkaline reaction. Except the low exchangeable K recorded in Ifa Jiru Kebele (surface) and Kakali (subsurface), they were rich in basic cations with high to very high CEC and high (60-80) to very high (> 80) percent base saturation. Nevertheless, they were very low to low in organic carbon and low to medium (surface) and very low to medium (subsurface) in total nitrogen content. Similar to the other soil mapping units, these soils were high in their available P and S contents. Except the very low Zn in Dursitu Bilisuma of Meta Woreda, low Zn in Bilisuma of Kombolcha and Ifa Jiru of Habro, and low Cu in Ula Janata of Gurawa, the soils contain adequate levels of Zn, Cu, Mn, and Fe. The ranges of selected soil properties observed in these soil mapping units is depicted in Table 34.

Table 34. Ranges of selected soil properties recorded in Luvisols of the five CASCAPE intervention Woredas

Parameter	Layer	Mean	Median	StD	Minimum	Maximum	CV (%)
pH-H <sub>2</sub> O	Surface	6.82	6.81	0.52	6.06	7.83	7.56
	Subsurface	7.10	7.25	0.79	5.78	8.10	11.15
pH-KCl	Surface	5.95	5.98	0.52	5.13	6.96	8.79
	Subsurface	6.23	6.34	0.74	5.03	7.15	11.93
EC	Surface	0.10	0.09	0.05	0.05	0.21	46.31
	Subsurface	0.17	0.14	0.14	0.04	0.66	81.11
Sand	Surface	32.06	28.40	12.01	18.34	53.61	37.47
	Subsurface	28.36	28.03	10.76	11.52	56.35	37.95
Silt	Surface	19.22	18.19	7.32	9.28	33.35	38.07
	Subsurface	18.57	18.57	5.46	10.21	35.04	29.42
Clay	Surface	48.72	48.60	9.26	36.67	63.15	19.00
	Subsurface	53.07	56.47	10.47	28.02	67.99	19.72
Na	Surface	0.96	0.87	0.27	0.78	1.77	28.76
	Subsurface	1.27	1.15	0.40	0.75	2.25	31.17
K	Surface	0.88	1.01	0.40	0.25	1.34	45.87
	Subsurface	0.64	0.62	0.22	0.20	1.26	33.89
Ca	Surface	27.93	28.70	8.22	15.66	39.38	29.43
	Subsurface	31.27	32.94	8.09	14.50	42.65	25.86
Mg	Surface	9.32	9.50	2.74	4.94	12.98	29.45
	Subsurface	10.41	11.12	2.72	4.56	13.93	26.17
CEC	Surface	45.74	44.73	8.63	34.52	59.55	18.87
	Subsurface	49.42	50.24	9.39	30.63	61.87	19.00
SB	Surface	39.08	39.91	11.12	22.66	54.33	28.46
	Subsurface	43.59	45.89	11.06	20.71	59.03	25.38
OC	Surface	1.56	1.40	0.42	1.04	2.25	26.67
	Subsurface	0.91	0.87	0.45	0.10	1.78	49.91
TN	Surface	0.16	0.15	0.05	0.10	0.24	30.95
	Subsurface	0.09	0.07	0.05	0.01	0.21	55.56
ESP	Surface	2.12	1.93	0.54	1.41	3.33	25.46
	Subsurface	2.58	2.35	0.67	1.43	4.81	25.81
AV. P	Surface	36.08	32.25	10.73	22.10	56.00	29.75
S	Surface	1.00	1.14	0.44	0.27	1.58	43.94
Zn	Surface	2.47	2.45	1.23	0.96	5.32	49.84
Mn	Surface	22.81	19.07	16.27	6.45	57.40	71.31
Cu	Surface	2.90	2.38	2.14	0.90	8.43	73.78
Fe	Surface	27.78	25.62	16.16	9.10	62.73	58.19

### 3.9.5. Vertisols

The Vertisols are the second most dominant mapping units identified in the five CASCAPE woredas. These soils occur on relatively low lying areas, such as the valley floors, plains, plateaus, and toe slopes of medium gradient hills. They are formed on different types of parent materials that include limestones and basalts. In some areas of these soils, exposed granitic parent materials were also observed. The soils are characterized by bigger structural units, such as block-like and prism-like structure types. They also contain wedge-shaped structures with shiny faces. These features, in most of them, seem to have created impeded internal drainage conditions, particularly during the wet season. Their slow drainage characteristic can also be seen from their estimated water retention characteristic curves depicted in Figure 31. The situation worsens in the subsurface layers. They are high to very high in their clay content. Owing to their high clay content, their available water holding capacity (130.4 and 120.0 mm/m for surface and subsurface soils, respectively) was also in the range of medium (Figure XX).

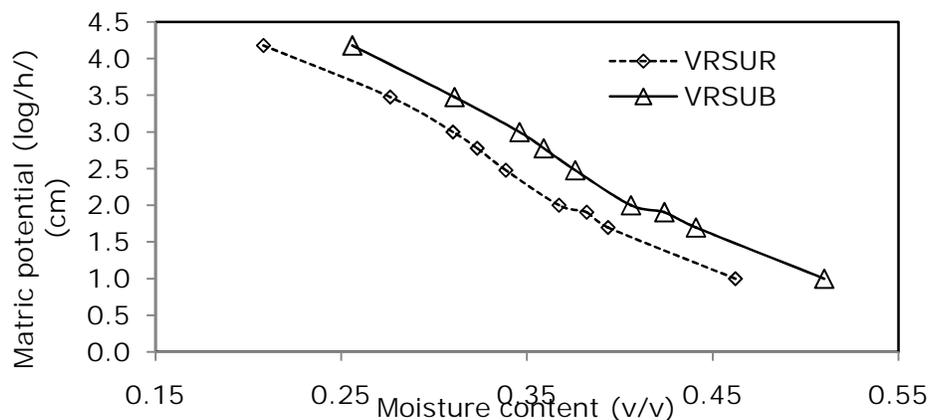


Figure 31. Estimated mean water retention characteristic curve of surface and subsurface soils of Vertisols in CASCAPE intervention woredas.

Their reaction (surface and subsurface layers) ranged from moderately acidic to moderately alkaline. They contained high level of exchangeable bases with very high CEC and high to very high percent base saturation. They,

nonetheless, were very low in their organic carbon content and low to medium (surface layers) and very low to medium (subsurface layers) in total nitrogen content. Except the very low Zn in Bilisuma of Kombolcha and Chelenko Lola of Meta, the other soils contained adequate levels of Zn, Mn, Cu and Fe. The ranges of selected physical and chemical properties of these soil mapping units are indicated in Table 35.

#### 3.9.6. Fluvisols

The Fluvisols were identified as mapping units in Finkile and Damota Jalala kebeles of Haramaya Woreda. In other woredas, they occur mainly as associations. They occur on the plains where the intermittent rivers flood the area during the wet season. They are developed on alluvial material of sandstone, limestone and granite origin. They are deep to very deep with weakly developed structure. Their clay content is low (10-25%) to moderate (surface) and moderate to very high (subsurface), while they are high (40-50%) to very high (> 50%) in their sand content. As a result, they are well drained. The relatively steep slope in Figure 32, shows their fast drainage nature. Because of an increase in clay content with depth, their drainability becomes slower. Their available water holding capacity as estimated from Figure 32, is medium at the surface layers and low in the subsurface layers.

Table 35. Selected major physical and chemical properties of Vertisols in CASCAPE intervention Woredas

Parameter	Layer	Mean	Median	StD	Minimum	Maximum	CV (%)
pH-H <sub>2</sub> O	Surface	6.99	6.82	0.70	6.15	8.15	10.05
	Subsurface	7.52	7.87	0.62	6.42	8.36	8.29
pH-KCl	Surface	6.11	5.90	0.74	5.18	7.25	12.18
	Subsurface	6.62	6.85	0.70	5.04	7.52	10.56
EC	Surface	0.10	0.09	0.05	0.03	0.21	49.82
	Subsurface	0.18	0.17	0.10	0.04	0.41	58.54
Sand	Surface	30.65	31.97	8.46	14.39	46.11	27.62
	Subsurface	23.74	22.20	7.59	11.77	40.88	31.98
Silt	Surface	15.77	17.90	5.63	6.47	22.65	35.69
	Subsurface	16.25	16.27	5.19	8.43	31.45	31.92
Clay	Surface	53.58	52.77	7.29	46.37	66.71	13.60
	Subsurface	60.01	60.74	7.08	37.92	69.95	11.80
Na	Surface	1.06	0.92	0.43	0.74	2.13	41.00
	Subsurface	1.23	1.03	0.55	0.68	3.25	44.36
K	Surface	0.64	0.63	0.16	0.42	0.90	24.69
	Subsurface	0.58	0.58	0.11	0.31	0.74	18.23
Ca	Surface	31.98	31.91	5.69	21.83	38.63	17.81
	Subsurface	35.47	35.75	4.16	28.17	43.48	11.72
Mg	Surface	10.69	10.85	1.93	7.28	12.88	18.07
	Subsurface	11.96	12.10	1.47	9.15	14.69	12.29
CEC	Surface	50.54	50.83	6.36	40.47	58.32	12.58
	Subsurface	53.57	54.03	4.97	45.20	62.92	9.27
SB	Surface	44.37	44.31	7.84	30.45	53.69	17.67
	Subsurface	49.24	49.67	5.83	39.07	60.64	11.84
OC	Surface	1.42	1.43	0.35	0.92	1.88	24.29
	Subsurface	0.73	0.67	0.40	0.17	1.63	54.76
TN	Surface	0.15	0.16	0.04	0.10	0.23	26.68
	Subsurface	0.07	0.07	0.04	0.02	0.16	55.02
ESP	Surface	2.08	1.95	0.67	1.28	3.67	32.05
	Subsurface	2.28	1.98	0.91	1.35	5.86	39.91
AV. P	Surface	28.61	25.65	8.70	18.10	42.60	30.40
S	Surface	1.08	1.18	0.23	0.59	1.28	21.41
Zn	Surface	1.92	1.72	1.13	0.70	3.87	58.76
Mn	Surface	15.93	13.40	9.74	4.60	34.52	61.17
Cu	Surface	4.09	2.91	3.12	1.75	11.94	76.26
Fe	Surface	22.43	19.82	11.28	9.03	41.37	50.26

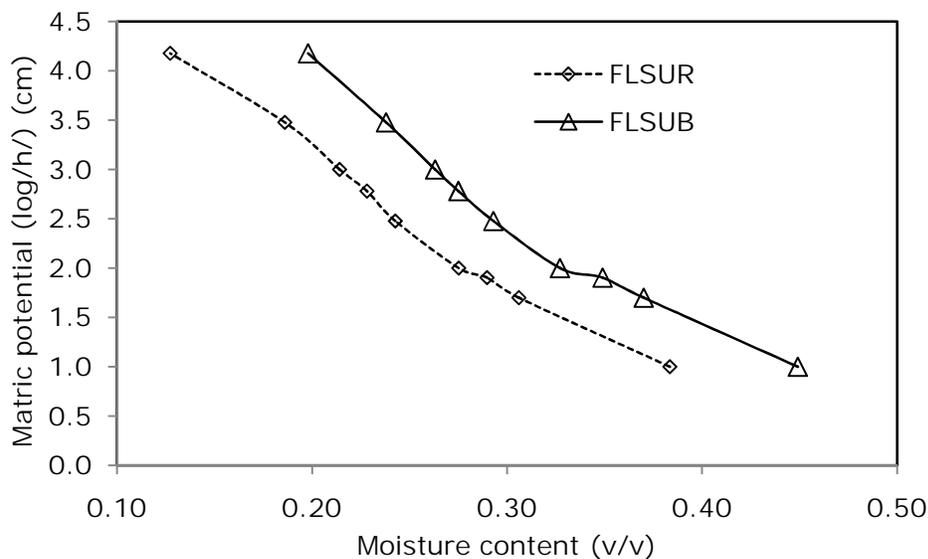


Figure 32. Estimated mean water retention characteristic curves of surface and subsurface soils of Fluvisols in CASCAPE intervention woredas.

Because of the presence of carbonate, their surface and subsurface pH was moderately alkaline. These soils were medium to high in exchangeable Na, high to very high in Ca, high in Mg, and low to medium in K. The low K was recorded in Finkile. Their CEC was in the range of high and so did their percent base saturation. They were very low in organic carbon and low in total nitrogen. They contained adequate levels of available P and S. Their micronutrient status was very low (Finkile) to low (Damota Jalala) in Zn, medium in Mn, low (Finkile) to optimum in Cu, and medium to high in Fe. The ranges of selected properties of these soils are presented in Table 36.

Table 36. Ranges of selected properties of Fluvisols in CASCAPE intervention woredas

Parameter	Layer	Mean	Median	StD	Minimum	Maximum	CV (%)
pH-H <sub>2</sub> O	Surface	7.85	7.85	0.02	7.83	7.86	0.27
	Subsurface	7.95	7.97	0.15	7.74	8.10	1.89
pH-KCl	Surface	7.05	7.05	0.01	7.04	7.06	0.20
	Subsurface	7.20	7.16	0.31	6.89	7.61	4.24
EC	Surface	0.12	0.12	0.03	0.10	0.14	23.57
	Subsurface	0.14	0.14	0.03	0.11	0.17	18.18
Sand	Surface	58.93	58.93	18.06	46.16	71.70	30.65
	Subsurface	44.49	45.84	15.13	24.90	61.37	34.02
Silt	Surface	17.00	17.00	14.04	7.07	26.92	82.59
	Subsurface	18.58	17.03	4.57	15.25	25.03	24.57
Clay	Surface	24.07	24.07	4.03	21.22	26.92	16.74
	Subsurface	36.93	37.14	10.94	23.38	50.07	29.61
Na	Surface	0.87	0.87	0.27	0.69	1.06	30.38
	Subsurface	1.00	1.04	0.24	0.68	1.22	24.02
K	Surface	0.37	0.37	0.24	0.20	0.54	65.35
	Subsurface	0.43	0.41	0.17	0.24	0.65	39.00
Ca	Surface	18.84	18.84	3.19	16.58	21.09	16.94
	Subsurface	23.93	20.44	8.26	18.59	36.23	34.51
Mg	Surface	6.35	6.35	0.97	5.66	7.03	15.26
	Subsurface	7.94	6.75	2.78	6.20	12.08	34.95
CEC	Surface	33.60	33.60	5.25	29.89	37.31	15.62
	Subsurface	39.56	34.95	10.47	33.13	55.22	26.47
SB	Surface	26.42	26.42	4.66	23.12	29.72	17.65
	Subsurface	33.29	28.32	11.32	26.35	50.18	34.00
OC	Surface	1.00	1.00	0.13	0.90	1.09	13.16
	Subsurface	0.77	0.84	0.23	0.43	0.98	30.38
TN	Surface	0.10	0.10	0.00	0.10	0.10	1.59
	Subsurface	0.07	0.07	0.02	0.04	0.09	26.31
ESP	Surface	2.57	2.57	0.39	2.29	2.84	15.12
	Subsurface	2.55	2.47	0.53	2.05	3.23	20.86
AV. P	Surface	26.90	26.90	1.41	25.90	27.90	5.26
S	Surface	1.36	1.36	0.78	0.80	1.91	57.93
Zn	Surface	0.93	0.93	0.18	0.80	1.06	19.77
Mn	Surface	4.00	4.00	2.31	2.37	5.63	57.63
Cu	Surface	1.09	1.09	0.78	0.54	1.64	71.36
Fe	Surface	4.63	4.63	2.24	3.04	6.21	48.47

### 3.9.7. Calcisols

As mapping units, these soils were identified in Lencha Kebele of Gurawa Woreda only. They occupy the middle to lower slopes of a medium gradient hill characterized by limestone basement. They are characterized by very coarse sub-angular and angular blocky and massive structure types. They are extremely hard to work when they are dry as well as wet. They are very high in their clay content. As a consequence, their water release is very slow, which means that they are slowly draining soils (Figure 33). With any application of increased suction, the water released is extremely small. This is indicated by the more gradual slope of their water retention characteristic curve (Figure 33). Their available water holding capacity was medium (100-200 mm/m).

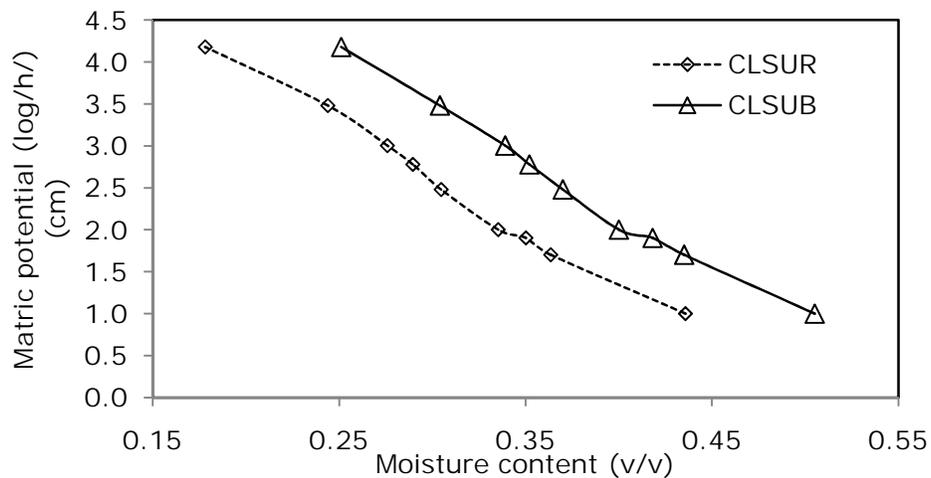


Figure 33. Estimated average water retention characteristic curves of surface and subsurface soils of Calcisols in CASCAPE intervention Woreda.

Owing to the high calcium carbonate throughout the profile, the pH was in the range of moderately alkaline at the surface and subsurface layers. They were very rich in exchangeable basic cations with very high CEC and base saturation. As was true for most other soil mapping units, these soils were also very low in their organic carbon level and low (surface) and very low (subsurface) in total nitrogen. On the other hand, their available P and S

levels were high. Their micronutrient (Zn, Mn, Cu and Fe) levels were also in the range of optimum. On these soils, the major crop grown is Khat. It is grown under both irrigated and rainfed conditions and is the major cash crop. The ranges of selected major soil properties of these mapping units are presented in Table 37.

Table 37. Ranges of selected major properties of Calcisols in Lencha Kebele of Gurawa Woreda

Parameter	Layer	Mean	Median	StD	Minimum	Maximum	CV (%)
pH-H <sub>2</sub> O	Surface	7.79					
	Subsurface	7.88	7.88	0.04	7.84	7.93	0.54
pH-KCl	Surface	6.93					
	Subsurface	6.99	7.00	0.04	6.94	7.03	0.54
EC	Surface	0.20					
	Subsurface	0.37	0.37	0.02	0.34	0.39	6.52
Sand	Surface	39.59					
	Subsurface	25.28	24.81	3.61	21.48	30.02	14.28
Silt	Surface	7.29					
	Subsurface	20.14	22.25	9.88	6.36	29.71	49.05
Clay	Surface	53.12					
	Subsurface	54.59	52.96	6.54	48.81	63.62	11.99
Na	Surface	0.82					
	Subsurface	0.98	0.98	0.03	0.95	1.01	2.65
K	Surface	0.85					
	Subsurface	0.92	0.91	0.05	0.89	0.99	4.90
Ca	Surface	33.28					
	Subsurface	29.27	29.19	0.66	28.67	30.05	2.26
Mg	Surface	11.65					
	Subsurface	9.83	9.94	0.42	9.28	10.16	4.25
CEC	Surface	51.55					
	Subsurface	44.11	44.14	1.43	42.32	45.83	3.25
SB	Surface	46.60					
	Subsurface	41.00	41.07	1.08	39.81	42.07	2.63
OC	Surface	1.35					
	Subsurface	0.36	0.36	0.21	0.13	0.57	59.04
TN	Surface	0.15					
	Subsurface	0.04	0.04	0.02	0.01	0.06	51.68
ESP	Surface	1.60					
	Subsurface	2.23	2.22	0.10	2.14	2.33	4.35
AV. P	Surface	51.50					
S	Surface	1.06					
Zn	Surface	7.26					
Mn	Surface	2.64					
Cu	Surface	2.70					
Fe	Surface	13.32					

## 4. Discussion, Conclusions and Recommendations

### 4.1. Discussion

Through exploratory survey and profile description, it was possible to observe that different soil types occur on different landforms of the five CASCAPE intervention woredas. Although there are some minor differences on the types of soils on a specific landform, the general observation indicates the existence of soil associations along a typical toposequence. Accordingly, the steepest slopes are generally dominated by Leptosols regardless of the parent material occurring in the area. They are formed from parent materials common in the five woredas. These parent materials include granites, sandstones, limestones and basalts. Next to these Leptosols, when they occur, are the Regosols. The Regosols are common on steep slopes dominated by either granite or sandstone. Because of this, they are relatively coarser in texture. Because of the dominance of erosion over deposition, these two soil types are generally shallow in their depth.

The Cambisols occur on the middle to upper slopes of mostly medium gradient hills and they are formed from different types of parent materials common in the study woredas. Those formed from coarse textured parent materials (granite and sandstone) are coarser in texture, while those formed from limestone and basalt are finer in texture (higher clay content). Following these soils types are the Nitisols which occur on the gentle slopes where both surface and internal drainage are good. They are also common on medium gradient hills and are formed from parent materials like limestones, sandstone and basalt. The Luvisols and Vertisols occupy the lower parts of the medium gradient hills. The plains and plateaus are dominantly occupied by these two soil types. They are formed from parent materials of different kinds. The most dominant ones are limestones and basalt. In areas where there are permanent or intermittent running water

bodies, Fluvisols are identified. Nevertheless, these soil types occupy a very small area in general.

Because of interaction of landform with parent material and other soil forming factors, the soils identified exhibited differences in their characteristics. The general tendency observed is that soil depth increases down the toposequence due to increase in deposition. In general terms, the soils were good in most of the soil parameters determined except in few of them where low levels of K, Zn, and Cu were recorded. The major problem common to all the major agricultural soils was their very low to low organic carbon and total nitrogen content. Although there is a common practice of applying any organic material into the farm lands, the amount applied is too low to raise the organic carbon level of the soils. Furthermore, crop residues are removed from the crop lands and used for different purposes. The continuous tillage operation also encourages fast decomposition of the small amount of organic matter added to the soil. This has exacerbated the problem. On the other hand, unlike reports of many other studies in the country, the available P content of the soils was in the range of high. This may be related to the residual effect of the DAP fertilizer applied every year.

#### 4.2. Conclusion

From the results of soil characterization and classification work in the five CASCAPE intervention Woredas involving twenty kebeles, the following conclusions can be drawn:

- There is high similarity among the Woredas in major landform, geology, climate, vegetation, and land use and management culture.
- These similarities have led to the occurrence along a typical toposequence of similar soil types at least at RSG level.
- The diversity of major soil types is more in a kebele than it is among kebeles.

- The minor differences among soils in a toposequence and among kebeles indicate different potentials and limitations, and, thus, different soil-specific management requirements.
- All the major agricultural soils studied are low in their organic carbon content and, consequently, total nitrogen.
- In some of the soils, deficiency of nitrogen, potassium, Zn, and Cu are common. The old tradition of applying nitrogen and phosphorus fertilizers only has to change since the deficiencies are more. Site-specific recommendations need to be developed.
- The existence of significant variability in major soil properties among the same RSGs indicates that soil management may not be based on soil type alone. Additional factors, such as management, need to be taken into account for making effective recommendations.
- The major mapping units common among the twenty kebeles in the five CASCAPE intervention woredas are Leptosols/Regosols/Cambisols-Nitisols/Luvisols-Vertisols with Leptosols, Luvisols, and Vertisols covering an area that can be mapped in all the kebeles. The only soil type identified in one kebele (Lencha) only is Calcisol developed on medium gradient hill on limestone basement.

#### 4.3. Recommendations

The recommendations made are based solely on the results of this study and focus mainly on the major constraints to crop production. The following recommendations are forwarded:

1. The study made now is not exhaustive, since it focused more on soil parameters that indicate chemical fertility alone. The soil physical parameters related to soil-water retention and availability, for instance, are not included. This should, therefore, receive more attention in the future given the difference water will bring to the livelihood of the farming community in particular and the country at large.

2. The fact that the organic matter content in all major agricultural soils of the 20 kebeles is very low to low is very much alarming. Resolving this problem requires an integrated approach, for the causes are multifaceted. Broad areas of interventions directly related to improving the organic matter content of the soils may include minimizing tillage frequency, maximizing the amount of plant residue returned to the soils, and maximizing water- and nutrient use efficiency of plants and measures to reduce erosion.
3. In almost all the 20 kebeles, fertilizer application is based on blanket recommendation. To improve these, experiments should be done to develop site- and crop-specific fertilizer recommendations of those nutrient elements found to be deficient.
4. The critical values used to interpret the results are only indicative and are, probably, based on results obtained in other soils. The current results should be supported by tissue analysis and critical values should be developed for the different soil types with their inherent properties that affect the dynamics of a parameter under the existing environmental conditions such as climate.

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## ANNEXES

Annex 1. Auger IDs related to major soil types and soil mapping units

Woreda	Kebele	Auger code	Longitude	Latitude	Major soil type	Mapping unit
HARAMAYA	Finkile	HMY/FI/A1	42°03'8.41"	09°46'45.6"	Luvisol	Luvisols
		HMY/FI/A2	42°03'8.44"	09°46'03'34.6"	Luvisol (Rhodic)	Luvisols
		HMY/FI/A3	42°02'24.5"	09°27'37.6"	Luvisol (Chromic)	Luvisols
		HMY/FI/A4	42°02'25.2"	09°27'14.6"	Nitisol (Rhodic)	Luvisols
		HMY/FI/A5	42°01'56.1"	09°26'43.7"	Vertisol	Calcic Vertisol
		HMY/FI/A6	42°01'38.1"	09°27'10.1"	Calcic Vertisol	Calcic Vertisol
		HMY/FI/A7	42°01'39"	09°27'03"	Fluvisol	Fluvisols
		HMY/FI/A8	42°01'51"	09°27'41"	Cambisol	Cambisols
	DamotaJalala	HMY/DJ/A1	42°05'15"	09°25'38"	VerticCambisol	Cambisols
		HMY/DJ/A2	42°04'54"	09°25'36"	Cambisol	Cambisols
		HMY/DJ/A3	42°04'32"	09°25'12"	Cambisol	Cambisols
		HMY/DJ/A4	42°04'09"	09°24'46"	Cambisol	Cambisols
		HMY/DJ/A5	42°04'08"	09°25'31"	Vertisol	Vertisol
		HMY/DJ/A6	42°03'23"	09°25'21"	Vertisol	Vertisol
		HMY/DJ/A7	42°03'07"	09°25'04"	Vertisol	Vertisol
		HMY/DJ/A8	42°03'14"	09°24'55"	Regosol	Regosol
	KuroJalala	HMY/KJ/A1	41°59'22"	09°28'41"	Luvisol	Luvisols
		HMY/KJ/A2	41°59'55"	09°28'37"	Luvisol	Luvisols
		HMY/KJ/A3	41°59'03"	09°27'34"	Calcic Vertisol	Calcic Vertisol
		HMY/KJ/A4	41°59'36"	09°28'12"	Luvisol	Luvisols
		HMY/KJ/A5	42°00'21"	09°28'09"	Fluvisol	Fluvisols
		HMY/KJ/A6	42°00'23"	09°27'47"	VerticLuvisol	Luvisols
		HMY/KJ/A7	42°00'42"	09°27'34"	Vertisol	Vertisol
		HMY/KJ/A8	42°00'21"	09°26'24"	Vertisol	Vertisol
	Ifa Oromia	HMY/IO/A1	41°58'15"	09°25'12"	Calcic Vertisol	Calcic Vertisol
		HMY/IO/A2	41°57'54.3"	09°25'25"	Calcic Vertisol	Calcic Vertisol
		HMY/IO/A3	41°58'48"	09°25'37"	Calcic Vertisol	Calcic Vertisol
		HMY/IO/A4	41°56'56.4"	09°26'32"	Nitisol	Nitisol
		HMY/IO/A5	41°56'48"	09°26'13"	Calcic Vertisol	Calcic Vertisol
		HMY/IO/A6	41°57'24"	09°26'18"	Nitisol	Nitisol
		HMY/IO/A7	41°58'40"	09°27'07"	Nitisol	Nitisol
		HMY/IO/A8	41°57'13"	09°26'23"	Regosl	Nitisol

Woreda	Kebele	Auger code	Longitude	Latitude	Major soil type	Mapping unit
Kombolcha	Bilisuma	KOM/BL/A1	42°05'59.1"	09°28'20.4"	VerticLuvisol	VerticLuvisol
		KOM/BL/A2	42°06'13.3"	09°28'06"	Regosol	Regosol
		KOM/BL/A3	42°06'06"	09°27'51"	VerticLuvisol	VerticLuvisol
		KOM/BL/A4	42°05'39"	09°27'26.2"	Luvisol	VerticLuvisol
		KOM/BL/A5	42°06'21"	09°26'33"	Calcic Vertisol	Calcic Vertisol
		KOM/BL/A6	42°06'29.9"	09°27'31"	GrumicVertisol	GrumicVertisol
		KOM/BL/A7	42°06'58.3"	09°27'10.7"	GrumicVertisol	GrumicVertisol
		KOM/BL/A8	42°06'26"	09°27'22.3"	GrumicVertisol (Chromic)	GrumicVertisol
	Egu	KOM/EG/A1	42°06'58.3"	09°30'03"	VerticLuvisol (Rhodic)	VerticLuvisols (Rhodic, Chromic)
		KOM/EG/A2	42°06'40.9"	09°29'30"	VerticLuvisol (Chromic)	VerticLuvisols (Rhodic, Chromic)
		KOM/EG/A3	42°06'20.9"	09°30'40.4"	GleyicVertisol	Calcic GleyicVertisols (Chromic, Rhodic)
		KOM/EG/A4	42°06'54.2"	09°28'54.1"	Calcic GleyicVertisol	Calcic GleyicVertisols (Chromic, Rhodic)
		KOM/EG/A5	42°06'36.3"	09°28'40"	HaplicRegosol	HaplicRegosol
		KOM/EG/A6	42°05'36.3"	09°29'01.9"	GleyicVertisol	Calcic GleyicVertisols (Chromic, Rhodic)
		KOM/EG/A7	42°05'43.7"	09°29'29.6"	Calcic GleyicVertisol (Chromic)	Calcic GleyicVertisols (Chromic, Rhodic)
		KOM/EG/A8	42°05'11"	09°29'09.2"	Calcic Vertisol (Rhodic)	Calcic GleyicVertisols (Chromic, Rhodic)
	Were Mahamed	KOM/WM/A1	42°10'58.8"	09°26'58.1"	Leptosol	Lithic Leptosols
		KOM/WM/A2	42°10'59.3"	09°27'21.6"	Fluvisol	Calcic Fluvisols
		KOM/WM/A3	42°11'54.1"	09°28'33.7"	Calcic VerticLuvisol	Calcic VerticLuvisols
		KOM/WM/A4	42°10'45.4"	09°28'10.1"	Fluvisol	Calcic Fluvisols
		KOM/WM/A5	42°10'15.3"	09°28'04"	Vertisol (Rhodic)	GleyicVertisols (Rhodic)
		KOM/WM/A6	42°10'09.6"	09°27'52.4"	Calcic Vertisol	GleyicVertisols (Rhodic)
		KOM/WM/A7	42°09'59.9"	09°27'54.3"	Calcic Fluvisol	Calcic Fluvisols
		KOM/WM/A8	42°10'43"	09°28'22.3"	GleyicVertisol	GleyicVertisols (Rhodic)
	Kakali	KOM/KK/A1	42°08'21.4"	09°29'24.1"	Calcic VerticLuvisol	Calcic VerticLuvisols
		KOM/KK/A2	42°08'28.3"	09°29'7.4"	Calcic VerticLuvisol	Calcic VerticLuvisols
		KOM/KK/A3	42°08'25.2"	09°28'28"	VerticLuvisol (Rhodic)	VerticLuvisol (Rhodic)
		KOM/KK/A4	42°08'42"	09°28'37"	Arenosol	VerticLuvisol (Rhodic)
		KOM/KK/A5	42°08'16.9"	09°27'60"	LuvicNitisol	LuvicNitisols

Woreda	Kebele	Auger code	Longitude	Latitude	Major soil type	Mapping unit
Meta		KOM/KK/A6	42°08'08.30"	09°27'58"	LuvicNitisol	LuvicNitisols
		KOM/KK/A7	42°07'53"	09°27'53.2"	LuvicNitisol	LuvicNitisols
		KOM/KK/A8	42°07'48.7"	09°29'27.6"	Regosol	Regosols
	Chelenko Lola	MTA/CL/A1	41°37'52.2"	09°25'30.8"	Regosol	Regosols
		MTA/CL/A2	41°37'53"	09°25'22.9"	Nitisol (Rhodic)	LuvicNitisols (Rhodic)
		MTA/CL/A3	41°37'35.6"	09°25'98"	Calcic Vertisol	Calcic Vertisols
		MTA/CL/A4	41°37'06"	09°24'38.3"	Calcic Vertisol	Calcic Vertisols
		MTA/CL/A5	41°36'19.2"	09°22'5.3"	Calcic Fluvisol	Calcic Fluvisols
		MTA/CL/A6	41°36'57.5"	09°25'09"	Calcic Vertisol	Calcic Vertisols
		MTA/CL/A7	41°36'55.9"	09°25'21.2"	LuvicNitisol (Rhodic)	LuvicNitisols (Rhodic)
		MTA/CL/A8	41°37'19.1"	09°25'30.9"	HaplicLuvisol (Chromic)	HaplicLuvisol (Chromic)
	Bekelcha Oromia	MTA/BO/A1	41°39'18.1"	09°23'3.3"	Leptosols	Leptosols
		MTA/BO/A2	41°39'5"	09°23'28.4"	Cambisol	Cambisols
		MTA/BO/A3	41°38'47.8"	09°23'25.9"	Calcic GleyicVertisol	Calcic GleyicVertisols
		MTA/BO/A4	41°38'22.1"	09°23'23"	Luvisol	Luvisols
		MTA/BO/A5	41°38'0.5"	09°23'44.3"	Calcic Vertisol	Calcic GleyicVertisol
		MTA/BO/A6	41°39'30.7"	09°25'20.9"	Regosols	Regosols
		MTA/BO/A7	41°38'52.7"	09°24'42.3"	Cambisol (Chromic)	Cambisols
		MTA/BO/A8	41°38'25.4"	09°24'52.1"	Cambisol	Cambisols
	HawiBilisuma	MTA/HB/A1	41°43'11.7"	09°26'32.3"	Luvisol	Luvisols
		MTA/HB/A2	41°43'17.2"	09°26'14.1"	VerticLuvisol	VerticLuvisols
		MTA/HB/A3	41°42'53.2"	09°25'51.7"	VerticLuvisol	VerticLuvisols
		MTA/HB/A4	41°42'38.6"	09°26'21.6"	VerticLuvisol	VerticLuvisols
		MTA/HB/A5	41°42'35.8"	09°26'46.9"	VerticLuvisol	VerticLuvisols
		MTA/HB/A6	41°42'34.9"	09°26'58.7"	Leptosol	Leptosols
		MTA/HB/A7	41°44'39.6"	09°25'29.9"	Calcic Vertisol	CalicVertisols
		MTA/HB/A8	41°43'22.9"	09°24'49.6"	Vertisol	CalicVertisols
	DursituBilisuma	MTA/DB/A1	41°35'12.8"	09°23'56.8"	Calcic Vertisol (Chromic)	Calcic Vertisols (Chromic)
		MTA/DB/A2	41°35'59.4"	09°24'10.3"	VerticLuvisol (Rhodic)	VerticLuvisols (Rhodic, Nitic)
		MTA/DB/A3	41°36'17.5"	9°23'59.8"	NiticLuvisol (Rhodic)	VerticLuvisols (Rhodic, Nitic)
MTA/DB/A4		41°34'58.2"	09°24'45.8"	VerticCambisol	VerticCambisols (Skeletal)	
MTA/DB/A5		41°35'20.5"	09°24'57.8"	Cambisol (Skeletal)	VerticCambisols (Skeletal)	
MTA/DB/A6		41°35'37.2"	9°25'3.1"	Calcic Vertisol	Calcic Vertisols (Chromic)	

Woreda	Kebele	Auger code	Longitude	Latitude	Major soil type	Mapping unit
Gurawa		MTA/DB/A7	41°36'19.5"	09°24'58.2"	LuvicNitisol	LuvicNitisols
		MTA/DB/A8	41°36'11.9"	09°25'7.7"	Calcic VerticLuvisol (Rhodic)	Calcic VerticLuvisols (Rhodic)
	Rasa Janata	GRW/RJ/A1	41°48'40.1"	09°11'51.8"	VerticLuvisol	VerticLuvisols
		GRW/RJ/A2	41°48'38.3"	09°11'29.1"	VerticLuvisol	VerticLuvisols
		GRW/RJ/A3	41°38'34.7"	09°11'16.4"	Calcic Vertisol	Calcic Vertisol
		GRW/RJ/A4	41°48'00"	09°11'20.6"	VerticCambisol	Calcic Vertisol
		GRW/RJ/A5	41°47'48.9"	09°10'5.4"	GleyicVertisol	GleyicVertisols
		GRW/RJ/A6	41°47'52.4"	09°47'52.4"	Vertisol (Rhodic)	GleyicVertisols
		GRW/RJ/A7	41°47'31.6"	09°11'8.4"	LuvicNitisol	LuvicNitisol
		GRW/RJ/A8	41°47'41"	09°11'52.4"	Vertisol	Calcic Vertisols
	Ula Janata	GRW/UJ/A1	41°49'22.3"	09°08'39.4"	VerticLuvisol	VerticLuvisols
		GRW/UJ/A2	41°49'4.4"	09°08'49"	VerticLuvisol	VerticLuvisols
		GRW/UJ/A3	41°48'50.9"	09°09'21.3"	Vertisol	Vertisols
		GRW/UJ/A4	41°49'11.5"	09°09'33.9"	Regosol	Regosols
		GRW/UJ/A5	41°49'11.7"	09°09'54.7"	Regosol	Regosols
		GRW/UJ/A6	41°48'57.9"	09°10'0.8"	Luvisol (Rhodic)	Luvisols (Rhodic)
		GRW/UJ/A7	41°47'33.4"	??	VerticCambisol	??
		GRW/UJ/A8	41°48'9.2"	09°09'56.6"	Vertisol	Vertisols
	Lencha	GRW/LH/A1	41°46'41"	09°12'51.1"	GleyicLuvisol	GleyicLuvisols
		GRW/LH/A2	41°46'17.2"	09°12'38.6"	Cambisol	RendzicLeptosols
		GRW/LH/A3	41°46'25.3"	09°12'3.8"	Leptosols	RendzicLeptosols
		GRW/LH/A4	41°46'54.6"	09°11'49.1"	LuvicNitisol	LuvicNitisols
		GRW/LH/A5	41°46'44.3"	09°10'54.2"	LuvicNitisol (Rhodic)	LuvicNitisols
		GRW/LH/A6	41°46'37.6"	09°10'13.6"	VerticCalcisol	VerticCalcisols
		GRW/LH/A7	41°47'8.9"	09°09'59.2"	Vertisol	Vertisols
		GRW/LH/A8	41°46'49.5"	09°09'0.8"	Vertisol	Vertisols
	LaftollaTatesa	GRW/LT/A1	41°46'50"	09°01'42.1"	LuvicNitisol (Rhodic)	LuvicNitisols
		GRW/LT/A2	41°46'38.6"	09°01'56.2"	Leptosol	RendzicLeptosols
GRW/LT/A3		41°46'38"	09°02'5.5"	VerticLuvisol	VerticLuvisols	
GRW/LT/A4		41°46'26"	09°01'47.9"	LuvicNitisol	LuvicNitisols	
GRW/LT/A5		41°46'9.5"	09°01'44.4"	Cambisol (Rhodic)	Cambisols (Rhodic)	
GRW/LT/A6		41°46'8.4"	09°24'5.5"	VerticCambisol	VerticCambisols	
GRW/LT/A7		41°45'55.3"	09°03'25.4"	LuvicNitisol	LuvicNitisols	

Woreda	Kebele	Auger code	Longitude	Latitude	Major soil type	Mapping unit
		GRW/LT/A8	41°45'38"	09°03'26.7"	VerticCambisol	VerticCambisols
Habro	HaroChercher	HRO/HC/A1	40°39'35.2"	08°51'59.1"	Vertisol	Vertisols
		HRO/HC/A2	40°39'50.3"	08°51'18.7"	Vertisol	Vertisols
		HRO/HC/A3	40°40'13.9"	08°51'29.4"	Vertisol	Vertisols
		HRO/HC/A4	40°40'10.4"	08°50'35.8"	Luvisol (Rhodic)	Luvisols (Rhodic)
		HRO/HC/A5	40°40'45.7"	08°52'2.7"	VerticLuvisol	VerticLuvisols
		HRO/HC/A6	40°40'42.4"	08°49'45.6"	Calcic Vertisol	Calcic Vertisols
		HRO/HC/A7	40°39'50.4"	08°52'26.4"	Vertisol	Vertisols
		HRO/HC/A8	40°40'1.2"	08°51'48.8"	Vertisol	Vertisols
	Bareda	HRO/BD/A1	40°38'59.3"	08°52'34.3"	Cambisols	Cambisols
		HRO/BD/A2	40°38'36.1"	08°52'0.2"	VerticLuvisols	VerticLuvisols
		HRO/BD/A3	40°38'43.6"	08°51'26.6"	VerticLuvisol	VerticLuvisols
		HRO/BD/A4	40°39'15.4"	08°51'14.4"	Calcic Vertisol	Calcic Vertisols
		HRO/BD/A5	40°37'47"	08°51'20.4"	VerticLuvisol	VerticLuvisols
		HRO/BD/A6	40°38'11.2"	08°50'45.6"	Fluvisol (Clayic)	Fluvisols (Clayic)
		HRO/BD/A7	40°38'36.6"	08°50'45.2"	VerticLuvisol	VerticLuvisols
		HRO/BD/A8	40°39'3.3"	08°51'43.7"	Calcic Vertisol	Calcic Vertisols
	GarbiGobe	HRO/GG/A1	40°30'20.2"	08°47'31.9"	Regosol	Regosols
		HRO/GG/A2	40°30'6.4"	08°47'54.8"	Nitisol	Nitisols
		HRO/GG/A3	40°30'50.5"	08°47'52.2"	Vertisol	Calcic Vertisols (Eutric)
		HRO/GG/A4	40°30'51.4"	08°48'21.5"	Calcic Vertisol (Eutric)	Calcic Vertisols (Eutric)
		HRO/GG/A5	40°31'43.1"	08°47'27.4"	Nitisol	Nitisols
		HRO/GG/A6	40°31'16.4"	08°47'33.9"	Regosol	Regosols
		HRO/GG/A7	40°31'25.5"	08°48'8.8"	Nitisol	Nitisols
		HRO/GG/A8	40°32'15.2"	08°48'5.0"	Nitisol	Nitisols
	IfaJiru	HRO/IJ/A1	40°24'29.8"	08°43'17.8"	Nitisol	Nitisols
		HRO/IJ/A2	40°24'47.6"	08°43'22.8"	Calcic Vertisol	Nitisols
		HRO/IJ/A3	40°25'0.5"	08°42'50.2"	Vertisol	Vertisols
		HRO/IJ/A4	40°25'12.4"	08°43'23.1"	Nitisol	Nitisols
		HRO/IJ/A5	40°25'24.9"	08°43'40.9"	Vertisol	Vertisols
		HRO/IJ/A6	40°25'11.1"	08°42'59.7"	Vertisol	Vertisols
		HRO/IJ/A7	40°25'14.9"	08°42'50.6"	Luvisol	Luvisols
		HRO/IJ/A8	40°25'32.9"	08°43'13.2"	Leptosol	Leptosols

Annex 2. Number and Identity of Soil Samples Collected for the CASCAPE Woredas Agricultural Soils Characterization Work, Eastern Cluster and Submitted to Water Works Design and Supervision Enterprise, Addis Ababa  
 Consultant: KibebewKibret (Dr.)

S. N <sup>o</sup>	Sample code	Unit of measure	Quantity Submitted	Remark (Real Code)
1	HMY/FI/020/P1	Number	1	
2	HMY/FI/2036/P1	>>	1	
3	HMY/FI/3645/P1	>>	1	
4	HMY/FI/45170/P1	>>	1	
5	HMY/FI/030/P2	>>	1	
6	HMY/FI/3060/P2	>>	1	
7	HMY/FI/60105/P2	>>	1	
8	HMY/FI/105200/P2	>>	1	
9	HMY/FI/020/P3	>>	1	
10	HMY/FI/2040/P3	>>	1	
11	HMY/FI/4068/P3	>>	1	
12	HMY/FI/68120/P3	>>	1	
13	HMY/FI/027/P4	>>	1	
14	HMY/FI/2764/P4	>>	1	
15	HMY/FI/6490/P4	>>	1	
16	HMY/FI/90140/P4	>>	1	
17	HMY/FI/140200/P4	>>	1	
18	HMY/DJ/020/P1	>>	1	
19	HMY/DJ/2050/P1	>>	1	
20	HMY/DJ/5080/P1	>>	1	
21	HMY/DJ/025/P2	>>	1	
22	HMY/DJ/2550/P2	>>	1	
23	HMY/DJ/5090/P2	>>	1	
24	HMY/DJ/90150/P2	>>	1	
25	HMY/DJ/020/P3	>>	1	
26	HMY/DJ/2090/P3	>>	1	
27	HMY/DJ/016/P4	>>	1	
28	HMY/DJ/1630/P4	>>	1	
29	HMY/DJ/3050/P4	>>	1	
30	HMY/KJ/025/P1	>>	1	
31	HMY/KJ/2580/P1	>>	1	
32	HMY/KJ/80160/P1	>>	1	
33	HMY/IO/035/P1	>>	1	
34	HMY/IO/3565/P1	>>	1	
35	HMY/IO/65110/P1	>>	1	
36	KOM/EG/025/P1	>>	1	
37	KOM/EG/2545/P1	>>	1	
38	KOM/EG/4560/P1	>>	1	
39	KOM/EG/6090/P1	>>	1	
40	KOM/EG/90110/P1	>>	1	
41	KOM/EG/020/P2	>>	1	
42	KOM/EG/2080/P2	>>	1	
43	KOM/EG/80180/P2	>>	1	
44	KOM/WM/020/P1	>>	1	

S. N <sup>o</sup>	Sample code	Unit of measure	Quantity Submitted	Remark (Real Code)
45	KOM/WM/2050/P1	>>	1	
46	KOM/WM/50130/P1	>>	1	
47	KOM/WM/130180/P1	>>	1	
48	KOM/KL/015/P1	>>	1	
49	KOM/KL/1558/P1	>>	1	
50	KOM/KL/5888/P1	>>	1	
51	KOM/KL/88140/P1	>>	1	
52	KOM/KL/140200/P1	>>	1	
53	KOM/BL/015/P1	>>	1	
54	KOM/BL/1540/P1	>>	1	
55	KOM/BL/4060/P1	>>	1	
56	KOM/BL/015/P2	>>	1	
57	KOM/BL/1540/P2	>>	1	
58	KOM/BL/4080/P2	>>	1	
59	KOM/BL/80140/P2	>>	1	
60	KOM/BL/140180/P2	>>	1	
61	KOM/BL/020/P3	>>	1	
62	KOM/BL/2065/P3	>>	1	
63	KOM/BL/6595/P3	>>	1	
64	KOM/BL/95-180/P3	>>	1	
65	MTA/CL/020/P1	>>	1	
66	MTA/CL/2060/P1	>>	1	
67	MTA/CL/60110/P1	>>	1	
68	MTA/CL/110150/P1	>>	1	
69	MTA/CL/150200/P1	>>	1	
70	MTA/CL/020/P2	>>	1	
71	MTA/CL/2050/P2	>>	1	
72	MTA/CL/5080/P2	>>	1	
73	MTA/CL/80130/P2	>>	1	
74	MTA/CL/130185/P2	>>	1	
75	MTA/BO/010/P1	>>	1	
76	MTA/BO/1030/P1	>>	1	
77	MTA/BO/3050/P1	>>	1	
78	MTA/BO/5070/P1	>>	1	
79	MTA/BO/015/P2	>>	1	
80	MTA/BO/1560/P2	>>	1	
81	MTA/BO/6095/P2	>>	1	
82	MTA/BO/95135/P2	>>	1	
83	MTA/BO/135185/P2	>>	1	
84	MTA/HB/030/P1	>>	1	
85	MTA/HB/30100/P1	>>	1	
86	MTA/HB/100120/P1	>>	1	
87	MTA/HB/120180/P1	>>	1	
88	MTA/HB/030/P2	>>	1	
89	MTA/HB/30130/P2	>>	1	
90	MTA/HB/130200/P2	>>	1	
91	MTA/DB/030/P1	>>	1	
92	MTA/DB/3060/P1	>>	1	
93	MTA/DB/6090/P1	>>	1	

S. Nº	Sample code	Unit of measure	Quantity Submitted	Remark (Real Code)
94	MTA/DB/90165/P1	>>	1	
95	MTA/DB/017/P2	>>	1	
96	MTA/DB/1760/P2	>>	1	
97	MTA/DB/60130/P2	>>	1	
98	MTA/DB/130190/P2	>>	1	
99	GRW/RJ/035/P1	>>	1	
100	GRW/RJ/3590/P1	>>	1	
101	GRW/RJ/90180/P1	>>	1	
102	GRW/RJ/035/P2	>>	1	
103	GRW/RJ/3560/P2	>>	1	
104	GRW/RJ/60110/P2	>>	1	
105	GRW/RJ/110150/P2	>>	1	
106	GRW/RJ/150200/P2	>>	1	
107	GRW/UJ/020/P1	>>	1	
108	GRW/UJ/2050/P1	>>	1	
109	GRW/UJ/5070/P1	>>	1	
110	GRW/UJ/70110/P1	>>	1	
111	GRW/UJ/110170/P1	>>	1	
112	GRW/UJ/015/P2	>>	1	
113	GRW/UJ/1535/P2	>>	1	
114	GRW/UJ/3560/P2	>>	1	
115	GRW/UJ/6080/P2	>>	1	
116	GRW/LH/020/P1	>>	1	
117	GRW/LH/2045/P1	>>	1	
118	GRW/LH/4570/P1	>>	1	
119	GRW/LH/70110/P1	>>	1	
120	GRW/LH/110145/P1	>>	1	
121	GRW/LH/020/P2	>>	1	
122	GRW/LH/2045/P2	>>	1	
123	GRW/LH/4590/P2	>>	1	
124	GRW/LH/90120/P2	>>	1	
125	GRW/LH/120200/P2	>>	1	
126	GRW/LT/020/P1	>>	1	
127	GRW/LT/2050/P1	>>	1	
128	GRW/LT/5067/P1	>>	1	
129	GRW/LT/67160/P1	>>	1	
130	GRW/LT/030/P2	>>	1	
131	GRW/LT/3060/P2	>>	1	
132	GRW/LT/6085/P2	>>	1	
133	GRW/LT/85120/P2	>>	1	
134	HRO/HC/025/P1	>>	1	
135	HRO/HC/2570/P1	>>	1	
136	HRO/HC/70110/P1	>>	1	
137	HRO/HC/110140/P1	>>	1	
138	HRO/HC/140200/P1	>>	1	
139	HRO/BD/020/P1	>>	1	
140	HRO/BD/2070/P1	>>	1	
141	HRO/BD/70100/P1	>>	1	
142	HRO/BD/100130/P1	>>	1	

S. N <sup>o</sup>	Sample code	Unit of measure	Quantity Submitted	Remark (Real Code)
143	HRO/BD/130200/P1	>>	1	
144	HRO/GG/025/P1	>>	1	
145	HRO/GG/2570/P1	>>	1	
146	HRO/GG/70110/P1	>>	1	
147	HRO/GG/110140/P1	>>	1	
148	HRO/GG/140200/P1	>>	1	
149	HRO/GG/030/P2	>>	1	
150	HRO/GG/3080/P2	>>	1	
151	HRO/GG/80110/P2	>>	1	
152	HRO/GG/110140/P2	>>	1	
153	HRO/GG/140200/P2	>>	1	
154	HRO/IJ/020/P1	>>	1	
155	HRO/IJ/2060/P1	>>	1	
156	HRO/IJ/60100/P1	>>	1	
157	HRO/IJ/100140/P1	>>	1	
158	HRO/IJ/140200/P1	>>	1	
159	HRO/IJ/025/P2	>>	1	Duplicate
160	HRO/IJ/2590/P2	>>	1	Duplicate
161	HRO/IJ/90138/P2	>>	1	Duplicate
162	HRO/IJ/138200/P2	>>	1	Duplicate
	Total		162-4	

**Note:**

HMY = Haramaya  
KOM = Kombolcha  
MTA = Meta  
GRW = Gurawa  
HRO = Habro