FARMERS' INDEGENIOUS KNOWLEDGE OF SOIL FERTILITY CLASSIFICATION AND MANAGEMENT IN OMO NADA, LIMU SEKA AND GERA DISTRICTS OF JIMMA ZONE, SOUTH WESTERN ETHIOPIA

M.Sc. THESIS

BY

FEKADU DERIBA KELBESSA

JANUARY 2016

JIMMA, ETHIOPIA

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MSc THESIS APPROVAL SHEET

We, the undersigned, member of the Board of Examiners of the final open defense by **Fekadu Deriba Kelbessa** have read and evaluated his/her thesis entitled **"Farmers Indigenous Knowledge of Soil Fertility Classification and Management in Omo Nada, Limu Seka and Gera Districts of Jimma Zone, Southwestern Ethiopia"** and examined the candidate. This is therefore to certify that the thesis has been accepted in partial fulfillment of the requirements for the degree Master of Science in **Natural Resource Management (Soil Science)**

Dr. Gudina Legesse Name of the Chairperson	Signature	23/01/2016 Date
Dr. Eyasu Eliyas Name of Major Advisor	Signature	23/01/2016 Date
Mr. Aberham Bantirgu Name of the Internal Examiner	Signature	23/01/2016 Date
Dr. Girma Abera Name of the External Examiner	Signature	Jan 23 2016 Date

DEDICATION

This thesis is dedicated to my Grandfather **Kelbessa Yadata** who was passed away during this thesis defense.

BIOGRAPHICAL SKETCH OF THE AUTHOR

The author, Fekadu Deriba Kelbessa, was born on August 23, 1981 G.C in Roge Mudana Peasant Association, Nono Benja district, Jimma Zone of Oromia National Regional State. He attended Elementary, Junior Secondary and Secondary Schools at Ilu, Tulu Milki, Kuyu district North Showa and Jimma Zone, respectively. Following the completion of High School, he joined Mekelle University Faculty of Dry land Agriculture in 2003 and graduated with B.Sc Degree in Land Resource Management and Environmental Protection (soil and water conservation stream) in July 2006. After graduation, he was employed by the Oromia Bureau of Agriculture to work as soil and water conservation at Jimma Zone, Limu Seka and Nono Benja districts and he has been serving as expert, head office until he joined the graduate studies program of Jimma University College of Agriculture and Veterinary Medicine to pursue his M.Sc. study in the field of soil science specialization.

STATEMENTS OF THE AUTHOR

I declare that this thesis is my genuine work that all references and materials used for the citation of thesis have been duly acknowledged. The thesis has been submitted in partial fulfillment of the requirements for the degree of Master of Science at Jimma University College of Agriculture and Veterinary Medicine (JUCAVM) and is reserved at the JUCAVM Library to be made available to users. I solemnly declare that this thesis work is not submitted to any other institution anywhere for the award of any academic degree, diploma, or certificate. Brief citations from this thesis are allowable without special permission, provided that accurate acknowledgement of source is made. Permission for extended quotation or duplication of the manuscript in whole or in part may be granted by the Natural Resource Department Head, or Dean of School of Graduate Studies of Jimma University. In all other instances, however, permission should be obtained from the author.

Name: Fekadu Deriba Kelbessa

Signature ____________________

Place: Jimma, Ethiopia

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LIST OF ACRONYMS

BPEDORS	Bureau of Planning and Economic Development of Oromia Regional State
CEC	Cation Exchange Capacity
CSA	Central Statics Agency
CASCAPE	Capacity building for Scaling up Evidence based best practice in Ethiopia
FAO	Food and Agriculture Organization
FGD	Focus Group Discussion
GGC	Gera Ganji Chala
GWK	Gera Wanja Kersa
LSS	Limu Seka Seka
LSD	Limu Seka Dora
masl	Meter Above Sea Level
MoA	Ministry of Agriculture
OC	Organic Carbon
OND	Omo Nada Doyo Yaya
ONB	Omo Nada Bidaru
ONRS	Oromia National Regional State
PAs	Peasant Associations
PBS	Percent Bases Saturation
ppm	Parts Per Million
RSG	Reference Soil Group
SSA	Sub Sahara Africa
USDA	United States Department of Agriculture
UNESCO	United Nations Education, Science and Culture organization
WRB	World Reference Bases

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ABSTRACT

The study was conducted in Omo Nada, Limu Seka and Gera districts of Jimma Zone, South Western Ethiopia on farmers' indegenious knowledge of soils. The study was designed to understand farmers' perception and indegineous knowledge on soils, to characterize and map the dominate soil type, identify fertility indicators using focus group discussions and transect walk with key informat. Furthermore, inerviews were performed to correlate or match scientifically characterized eleven soil profiles. Farmers' were able to view and map their soils; they use soil color, texture, yield, water holding capacity, topographic position as criteria for characterization, and as indicators of soil fertility and type of crop allocation with input and yield changes over time. The laboratory data revealed that clayey textured soils, silt/clay ratio greater than 0.15 with depth in all profiles and soil bulk density ranges between 1.01g cm^{-3} to 1.16g cm^{-3} at the surface to slightly increases with depth in all profiles and higher porosity. The pH of surface soil profiles ranges from moderately acidic to very strongly acid. Low percentage of organic carbon are registered in Omo Nada district Doyo Yaya profiles OND1, OND2, and Limu Seka district Dora LSD and total N contents of the profiles varied from (0.13% to 0.46%) and low in profiles of OND1, OND2 and OND3 and corresponding to lower value of organic matter (2.19%, 2.6%) but higher percentages at surface horizons soils than the subsoil horizons are recorded. The available P contents of the surface soil profiles were higher but in farmers perceived reddish infertile soils profiles OND1, OND2, LSD and Gera district Wanja Kersa profile GWK were medium. Leaching of the some exchangeable cations throughout, surface and subsoil horizon was observed. The cation exchange capacity value greater than 40 meq/100g of soil was observed in profiles of Gurracha/Magala dark red brown soils and less than 38.72 meq/100g of soil was observed in the Dimaa/red soils identified by farmers. The BS greater than 50% in, Omo Nada district Doyo Yaya profile OND3, Nada Bidaru profile ONB1, ONB2, and Gera district Ganji Chala profile GGC1 where farmers identify dominant soil type Dimaa/red and Gurracha/Magalaa dark red brown and fertile soils, and less than 50% were observed in profiles of OND2, LSS1, LSD and GWK at surface soil horizons were indicated that farmers perceived as infertile red soils where as valid with scientific characterization. Hence, the scientific orders the soils studied were Nitisols, Luvisols, Phaeozems, Cambisols and Gleyisols of WRB and Alfisols, Ultisols, Mollisols, and Inceptisols soils based on USDA soil taxonomy, and it correlate with the indigenous knowledge of farmers' red, dark red brown and grayish soil type respectively. Farmers perceived soil profiles of OND1, LSD, were infertile red soil correlate with the chemical results except profile ONB2 red soil deviated from farmers' perceptions, LSS2 and ONB1 were moderate fertile dark red and the dark red brown and grayish soil types were perceived as fertile soils correlate with the analyzed scientific procedures. Farmers' were perceived their soil fertility status and recognized and able to map their soil types that occurs in their PAs, these helps in decision making in soil fertility management, technology transfer and adoption. Therefore, working with indigenous farmers are relevant in soil fertility management and since they are the ultimate decision makers and farming experience of their soils rather than ignoring indigenous knowledge to solve complex problems.

Key words: Correlation, Farmers' perception, Soil fertility, Indegenious knowledge

1. INTRODUCTION

1.1. Background

Indigenous knowledge referred to as ethnoscience a traditional, accumulated knowledge, skill and attitudes of local peopole derived from their direct interaction with environment (Dawoe *et al.,*2012). It is dynamic and complex bodies of know-how, practices and skills that are developed and sustained by peoples/communities with shared histories and experiences (Beckford and Barker, 2007). WinklerPrins (1999) stated that indigenous knowledge sometimes referred to as indigenous technical knowledge of soil properties, management, and uses possessed by people living in a particular environment for some period of time. According to Bassols and Zinck (2003) ethnopedology of soils aims to document and understand the local approaches to soil perception, classification, appraisal, and use and managements and it is a hybrid disciplines structured from a combination of natural and social sciences.

Therefore, indigenous knowledge of soils facilitates dynamic information systems critical in soil fertility management decision making (Saito *et al.,* 2006). There is an increasing demand for basic information on soils as a means to produce food (Sharu *et al.*, 2013). This provides necessary basic information to create functional soil classification schemes, and assess soil fertility in order to unravel some unique soil problems in an ecosystem. The coupling of both scientific and local soil fertility characterization, classification and soil mapping by local farmers provides a powerful resource for the benefit of mankind especially in developing countries like Ethiopia, when we look at the total dependence of rural population, 85% of the people on natural resources (especially soils) for economic development and food security (Abebe *et al.*, 2011). Ethiopia has a diverse soil resource largely because of diverse topography, climatic conditions and geology (Ashenafi *et al.,* 2010). Low productivity in agriculture sector, due to land degradation; nutrient depletion; complete removal of crop residue from the fields; lack of integrated soil fertility management practices; imbalance inorganic fertilizers use; and lack of comprehensive soil information. Soil fertility characterization provides the information for our understanding of the physicochemical properties of the soils we depend on to grow crops, sustain ecosystem as well as support livelihoods.

Belay (1992) stated that farmer' perceptions, attitudes and knowledge are the most important sociocultural factors influencing the use and management of land. Yiferu and Taye (2011) stated that local farmers have acquired knowledge from generations of experience and experimentation, but decline of soil fertility is the major constraints to smallholders farmers for crop production (Corbeels *et al.,* 2000; Ejigu and Pound, 2005), inadequate supply of nutrients, and lack of information on soil and land characteristics (Atofarati *et al.,* 2012). According to Corbeels *et al.* (2000) most researchers worry on the appropriate amount and type of input to increase yield but the problem is lack of proper understanding of indigenous knowledge of farmers on soils and its management. The approach emphasized the use of external inputs and expensive technologies, and often disregarded farmers' knowledge understanding and managing the soil resources. Ejigu and Pound (2005) revealed that Ethiopian farmers have provide themselves to be very resilient to the decline in soil fertility and very adaptive to change such challenges due to level of their indigenous knowledge and skills in managing soil. Even if farmers can access and afford meaningful quantities of the correctly balanced fertilizers they should not be seen as the solution to declining soil fertility only a partial solution.

Farmers are responsive to the decline in soil fertility in their traditional methods and experience developed from generation to generation arresting and reversing such constraints. Therefore, improving farmers' knowledge and their capacity to observe and experiment is an essential element (Deugd *et al.,* 1998). Such visualization and classification of soil types and fertility status has important implications for management decisions including allocation of crops and sources of fertility by soil type. Desbiez *et al.* (2004) stated that until recently, indigenous knowledge of farmers' on soil fertility has been largely ignored by soil researchers, but with increasing use of participatory research approaches, it is becoming clear that farmers have a well-developed ability to perceive differences soil types and level of fertility between and within fields on their farms. Farmers make refined evaluation and classification of their soils based on soil physical properties (Eyasu, 2002; Ejigu *et al.,* 1995). According to Getahun (2006) farmers have their own indigenous way of classifying, describing and characterizing local soil types in their fields based on the soils characteristics, problems, and their suitability for various crops. Understanding local reality is crucial for the potential success or failure of any type of agriculturally based development (Saito *et al.,* 2006). It's clearly a cross or mix between knowledge and practice and comprises the roots of modern scientific soil classification (WinklerPrins and Sandor, 2003). Hence, in order to design more appropriate research and development programs it is necessary to understand farmers' knowledge and perceptions of soils (Corbeels *et al.,* 2000).

1.2. Statement of the Problem

Many development projects and policies had failed because of ignorance of indigenous knowledge, failure of understanding and perceive existing situation of their local condition (Corbeels *et al*., 2000; Yiferu and Taye, 2011). Decline of soil fertility is identified as one of a key challenge to meet the growth and transformation program in Ethiopia. Because of low application of commercial fertilizers, below the nutrient removals in harvested crop products, crop residues removal from the field and overgrazing leads to massive loss of agricultural soil to water erosion. Hence, the southwestern Ethiopia, Jimma zone has significant amount of rainfall areas compare to the others and expected to nutrient loss through leaching (Abush *et al.,* 2011; Abebe and Endalkachew, 2012).

Fertilizer recommendation has focused only on DAP (Di-ammonium phosphate) and urea fertilizers at blanket rates (100 kg DAP and 100 kg urea per ha) irrespective of the soil types and crops. The lack of site and crop specific recommendations has resulted in unbalanced nutrient supply which prohibited increases response to the applied nutrients. According to the law of the minimum, plant growth is controlled not by the total amount of nutrients available, but by the deficiency of one nutrient, since crops remove many nutrients from the soil. The other problem is local circumstance and special scale issues that are vital in farmers' soil management decisions are not taken into account. The rich indigenous knowledge of farmers soil classification, characterization, fertility management and maintenance are also completely ignored preferring to work with simple solutions to solve complex problems of soil fertility maintenance. Thus, one can argue that lack of such flexibility, local adaptation and overlooking of the local knowledge is a major reason why farmers are applying fertilizers at rates far below the blanket recommendation or none at all.

However, issuing site and crop specific fertilizer recommendation requires proper understanding of farmers existing knowledge and management of their soils. Ignoring the farmers' perception, knowledge, priorities and interests resulted in limited adoption of recommended technologies. Therefore, these research findings were dealt with the existing farmers' perception and indigenous knowledge of soil fertility with management practice and soil type to provide the base line for local farmers in agricultural input, used for agronomist, governments and non government organization. Therefore, the study districts were selected for its technology transfer and for the best practice of scaling up strategies. The study was conducted in the December 2014 up to June 2015.

1.3. Justification of the Study

Recently, the project, Capacity Building for Scaling up of evidence based best practices for increased Agricultural Production in Ethiopia (CASCAPE) has commissioned a detailed soil characterization and classification study in selected districts in Jimma Zone of Oromia Regional State. The study conducted profile description and soil classification according to the IUSS Working Groups WRB (2006) system classification. Soil physicochemical properties of selected pedons have been determined through laboratory analysis. However, it was felt necessary to substantiate the findings with indigenous system of characterization and classification thereby documenting local knowledge on soils and matches/mismatches between the two systems. Building on farmers' perceptions, knowledge and system of classification is hypothesized to increase relevance of the research findings to local realities, needs and priorities. Therefore, incorporation of indigenous knowledge in the design or technology transfer processes of soil classification, mapping and characterization will improve the livelihood of success. Nevertheless, there was no information conducted in the study area. Therefore, this piece of work is set out to understand and document the two systems of soil description and classification is believed to improve communication between researchers/scientists and farmers in joint experimentation and technology development endeavors. Attempts were made to understand how the scientifically identified dominant soil types were visualized and classified by farmers. The laboratory data generated from the scientific study was later used to do the matching between the two systems of classification and characterization.

1.4. Objectives

To capture and document farmers' perceptions, knowledge of soil and understand how this perception guides soil fertility management at farm level. The specific objectives

- To assess the farmers perceptions, knowledge and system of classification of soils that occur in the kebele
- To correlate farmers' characterization and mapping with scientific classification.
- To examine how general perceptions of soils are reflected in the soil fertility managements decisions at farm level.

1.5. Research Questions

- How farmers perceive soils, soil fertility status and its change over time?
- What local indicators are used to assess change in soil fertility over time?
- How do farmers characterize and map the soils occurring in their kebele?
- How does an indigenous method of soil description and classification correlate with scientific descriptions, characterization and classification?
- How does the prevalent local systems of knowledge and classification of soil influence soil fertility management practices at farm level?

2. LITERATURE REVIEW

2.1. Indigenous Knowledge and Perception of Soils

Local knowledge is a resource from which scientists can learn something real, valuable, and important (WinklerPrins and Sandore, 2003). Local soil knowledge it is known as indigenous knowledge of soil properties and management possessed by people living in a particular environment for a given period of time (WinklerPrins and Sandore, 2003). According to Payton *et al.* (2003) stated that it is the unique, existing within and developed around specific conditions of women and men indigenous to a particular area. Local soil knowledge is complex, multifaceted, and often quite subtle in its expression. It involves much experiential trial and error, but also includes scientific processes. The integrating or relating the synergy of local and scientific knowledge systems is a central issue (Payton *et al*., 2003).

Buthelezi *et al.* (2013) studied the use of scientific and indigenous knowledge in agricultural land evaluation and soil fertility studies of two villages in South Africa. The farmers' soil classification and their fertility assessment, correlate with the scientific evaluation. The study revealed that there is a significant agreements between the two approaches is due to the fundamental similarities can complement each other to produce a mixture approach that is highly an attribute of indigenous knowledge and that will help improve the relevance, adaptation and adoption of scientific interventions that provide the in depth knowledge of soil processes.

Desbieza *et al.* (2004) stated that farmers' perceptions and assessment of soil fertility were found to be more 'holistic' than those of researchers. It is known that farmer have a well-developed ability to perceive differences in soil resources between and within fields on their farms. Suggesting that in their perception the local soil classification is well correlated with soil fertility and productivity. The other study conducted by Raji *et al.* (2011) also found that there is a strong correlation of indigenous soil classification with soil science approaches could be better achieved with the WRB system, especially on the soil surface. However, the farmers' soil map was very similar in outline to the soil map by the scientists.

2.2. Local System of Soil Classification

According to Corbeels *et al.* (2000) farmers have developed a local system of soil classification based on their experience of the potential and constraints of their soils. They have used various criteria to differentiate soil types occurring in their peasant association/PAs using easily identifiable physical properties such as soil color (black, reddish, brownish, and light colored). According to Abush *et al*. (2011) farmers in the survey area reported four major types of soils based on color, (black, reddish brown, brown and gray), and two types based on texture (clay and sandy). Other criteria included crop performance or yield, topographic position, workability, soil depth and surface stoniness, water holding capacity the ability to retain moisture, manure requirements, drainage, soil compaction, structure, cracking patterns and erodibility (Corbeels *et al.*, 2000 and Abera, 2006).

The two most common physical characteristics of soil that farmers use are color and texture, in accordance with their catenary and topographic positioning (Abera, 2006). The same authors stated that yield is the most important criterion, and farmers are also aware that soil productivity is closely related to its position within the landscape, the topographic position, the soil's depth, its capacity to hold water, and the presence of stones. According to Abera (2006) farmers in the Tigray Region use black soils, are the most fertile high organic matter and are perceived as suitable for staple crops such as hard wheat, teff, and corn; brown soils having low levels of nutrients used for fast-growing and more stress resistant crops such as barley, wheat, lentil and occasionally flax; and red soils are usually found on steep slopes, on convex and knoll landscape, these soils are poor to moderate in terms of productivity and fertility. They characterize the soil as poor in water holding capacity, low in soil organic matter and hence low in yield. They indicated that these red soils cannot give a good yield without application of manure or chemical fertilizers

Mitiku (1996) cited in Corbeels *et al.* (2000) showed that, as farmers believe mainly in terms of physical parameters that several factors determining soil's fertility as the black soils are relatively fertile, which has a high organic matter content and a high cation exchange capacity (CEC) of soil. In contrast, chemical soil analysis revealed that white, light shallow soils represent a heterogeneous group of soils of varying of low CEC and organic matter content.

According to Ejigu and Pound (2005) studied in southern Ethiopia, soil physical characteristics such as low water holding capacity or soil moisture stress causes crops wilt quickly on soils of "*Bossolo, Shafe-ancho, Bokinta* and *Gobo"* (depending on local name). But black soil '*Kareta*' retains moisture for a longer period. Physical characteristics of '*Talla*' soils crack and become hard and cracking when drying, leading to stunted growth and pests. The depth and workability of soil is understood by farmers "*Gobo, Charia* and *Gorbo"* soils are deep, while "*Bokinta, Barta* and *Shafe-ancho"* are shallow and "*Talla* and *Chare*" soils are hard to plough in dry and wet conditions. "*Gobo, Gorbo* and *Barta"* are easily worked under any conditions. According to Abera (2006) such soil classification are "perceptual" dimension criteria are not strongly recognized by farmers in the areas, only older and experienced farmers use this technique to assess field workability, suitability classes for certain crops and sensitivity to certain agricultural problems.

According to Ejigu and Pound (2005) stated that participatory local soil mapping recognized were drawn by farmers on the ground. Physical features and soil types were distinguished by using different materials drawn a free hand village administrative map on the ground. This was transferred onto paper and farmers then drew boundaries of the locally named soil types. After further group discussion and agreement about soil categories and boundaries a corrected local soil map was produced. It is a useful tool for starting to explore local soil classes and their distribution and provided a basis for planning subsequent farmer-led soil transect walks (Payton *et al.,*2003).

2.2.1. Soil color

Soil color is one of the most important morphological properties of soil, which can be highly influenced by the amount of proteins present in the soil. Color is used as one of the important diagnostic criteria in soil classification (Brady and Weil, 2002). According to Abera (2006) soil color is the most common easily observable physical characteristics of soil that farmers use in soil characterization and its fertility status. It often reflects the soil's hidden parent materials. Dark brown or black color soil indicates that the soil has high organic matter content. Dawoe *et al*. (2012) found on local knowledge and perceptions in Ghana reported that farmers recognized the presence of soil organic matter, soil fauna, and high water holding capacity in black color soils. Wet soil will appear darker than dry soil. However the presence of water also affects soil color by affecting the oxidation rate. Soil that has high water content will have less air in the soil, specifically less oxygen. Light colored soils are located at the lower slope position sandy in textured by feel method, prone to flooding during the rainy season due to its hydrological characteristics especially high water regime (Nwankwo *et al.*, 2011). Farmers recognized that red and brown colors soils on well drained, reddish color soils are deep soils, found in upper slope position. This perception reflects the soils oxidation statuses are more common, as opposed to in wet (low oxygen) soils where usually appears grey due to their position on the catena or landscape (Nwankwo *et al.*, 2011).

Desbiez *et al*. (2004) reported that farmers classified their soils more according to their color rather than texture. The main properties of these different soils were stated by farmers to be the soil fertility, manure requirement, erosivity, and moisture retention. Scientifically, the presence of specific minerals can also affect soil color. The light and red colored soils is indicated very low organic matter content, presence of Fe and Al oxides and hydroxides, have acidic soil reactions and low percent base saturation (Gabayew, 2015). Manganese oxide causes a black color, glauconitic makes the soil green, and calcite can make soil in arid regions appear white. Belay (1996) attributed the more or less uniform dark color which characterized the A horizon to depths of more than 120 cm to pedoturbation and mixing of organic matter enriched surface soils in an alkaline environment.

The study conducted by Ahmed (2002) reported that moist soil color of both the cultivated and grazing lands of the lower elevation zones of very dark gray in the surface whereas the subsoil horizons were characterized by variable soil color which varied from black to dark gray for the grazing land and from very dark gray to very dark grayish brown for the cultivated land.

2.2.2. Soil texture and structure

Texture of the surface soil layer has some influence on soil properties and gives farmers a clear indication to soil characterization. Texture and structure are the most common criteria noted in studies on local systems of soil classification reflect the physical properties of soils.

Farmers are well acquainted with these characteristics through their daily observations of soils, and particularly of their surface soils. Other criteria mentioned by farmers are soil compaction, structure, cracking patterns, stoniness, drainage, and the ability to retain moisture. All of these physical characteristics are related to soil texture (Corbeels *et al.,* 2000).

Saito *et al.* (2006) also found similar description of soil texture in their study of indigenous knowledge of farmers of Northern Laos. Farmers preferred loamy and clayey (black) soils to sandy (Red, white and yellow) ones because loamy and clayey soils had a higher water-holding capacity for the reason that clay soil particles are fine textured by nature and able to hold appreciable amount of soil water especially at times of water shortage than sandy soil whereby the coarse nature couldn't allow water to stay for long rather easily percolate in the soil profile. According to Gebeyaw (2015) study in North Wollo, farmers indicated that, black or dark color soils, the major limitation is sticky when wet and hard when dry; making it difficult to till. Interestingly, farmers used properties of feel and touch of wet and dry soils as a means to identify the soil texture and to assess their water holding capacity (Abera, 2006).

2.3. Farmers' Soil Fertility Management Practices

Farmers practices to improve soil productivity through traditional method of restoring soil productivity. According to Corbeels *et al.* (2000) farmers practices seasonal fallow period that is leaving the land uncultivated for one or two seasons. The same author reported that most common seasonal fallow practiced by farmers in the Northern Tigray by growing chickpea or vetch as a green manure crop to improve black soils, lentil improves brown soils, linseed improves white soils, and teff improves black and red soils. Since fallow period is no longer possible, they now rotating crops on the fields away from their homesteads and careful matching of crops to soil potentials. The same author reported that early variety and large grain varieties could not grow well on poor soil. Furthermore, they stated that late duration varieties produced low yields on good soil because they produced more leaves than grain and was likely to lodge, and that late varieties crops grow better than early varieties on poor soil due to its longer growing period. Crop rotation is an important soil fertility management practices by farmers depending on the soil type and drainage condition they rotated taro with either maize or beans. The research finding shows well awareness farmers on the benefit of crop rotation (Corbeels *et al.,* 2000; Yifru and Taye, 2011 and Buthelezi *et al.,* 2013).

Corbeels *et al.* (2000) showed that some farmers' burn crop residues they consider that the ash acts as fertilizer and increases crop yields. According to Yifru and Taye (2011) conducted on local perceptions of soil fertility management in southeastern Ethiopia, farmers of the study area were well aware of the advantage of returning crop residues to soil fertility. The practice of decomposing crop residues in situ was locally termed *'Shemsu'* (meaning decomposition). In addition, farmers understood that if crop residues were not well decomposed before planting, it could compete for nutrient because of immobilization of nutrient and there by leads to the stunting of crop growth. They argued that increasing the frequency of tillage is one way of improving soil productivity (Abera, 2006; Yifru and Taye, 2011). Farmers aware when and what to plant on heavy clay soils, the timing of seeding particular crops that are suited to specific areas with special characteristics and requirements are based on land properties and preparations. Crops such as grass pea (*Lathyrus sativus*) and chickpea (*Cicer arietinu*) are usually planted in marshy and deep soil areas around the end of August because those crops can with stand the excess moisture and utilize the residual soil moisture after the rain ceases. Other crops such as teff are planted in a well-prepared, well-drained seed beds on relatively shallow soils (Abera, 2006).

According to Ejigu and Pound (2005) conducted on soil fertility practices, stated that farmers rate the extent to which soil needs fertilizers and responds to them. Farmers rate fertilizers responsive soil and productivity or performance of crops and crop diversity, black and reddish brown soils as highly responsive to fertilizers, and also red soil having poor fertility, also farmers' rate whitish and reddish soils as very susceptible to erosion.

2.4. Scientific Methods of Soil Classification

The soil physicochemical properties and diagnostic horizons are relevant for the detailed soil characterization and classification. These are soil texture and structure, particle and bulk density data, total porosity, and the chemical properties that are mainly influenced by the chemical components are soil reaction, soil organic matter, organic carbon, total nitrogen, cation exchange capacity, available phosphorous discussed as follows.

2.4.1. Physical properties

2.4.1.1. Soil texture and structure

Particle size is an important soil physical property, depending on the size distribution, primary particles (textural fractions) or soil separates is the relative amount of sand, silt, and clay found in a soil. Particle size distribution refers to the "quantitative" and a qualitative measure of the particle size that constitutes the solid fraction and based on "feel" of the soil material, which may be coarse, gritty, fine, or smooth (Lal and shukla, 2004). According to Brady and Weil (2002) determination of soil texture by feel methods is a great practical value in soil survey, land classification and in any investigation in which soil texture may play a role. Among the numerous and the most commonly used systems of classifying separates into different size classes are the U.S. Department of Agriculture and the International Society of Soil Science. Soil texture affects total porosity, pore size, and surface area.

The knowledge of soil texture is the key to developing an overall soil maintenance and improvement plan because it in part, determines water intake rate (infiltration), water storage in the soil, the ease of tilling the soil, the amount of aeration (vital to root growth), and also influence soil fertility (Gupta, 2000). It is one of the inherent soil properties less affected by management and which determines nutrient status, organic matter content, air circulation and water holding capacity of a given soil (Hillel, 1980).

The soil textural class varied with positions of soils in the landscape. It ranged from silt clay loam in the upper slopes to clayey in the lower slope positions; suggesting that amount of clay increases down slope (Mohammed *et al.,* 2005). The Vertisols in the lower toe slopes were much heavier than those on the upper parts and this was mainly attributed to the relatively finer texture of the fresh alluvium reaching the slope positions and its more intense weathering due to higher moisture supply at the site (Belay, 1996). The rate of increase in stickiness or ability to mould of soil as the moisture content increases depends on the content of silt and clay, the degree to which the clay particles are bound together into stable granules and the organic matter content of the soil. According to IUSS Working Group WRB (2007) Nitisols are deep, well-drained, red, tropical soils with diffuse horizon boundaries and a subsurface horizon with at least 30 percent clay and moderate to strong angular blocky structure elements that easily fall apart into characteristic shiny, flat-edged or nut-shaped elements.

Soil structure is one of the most important soil physical properties, the term structure relates how the soil fits together primary particles are arranged into secondary particles called aggregates (or peds) which is very sensitive to soil management practices. The formation and maintenance of a high degree of aggregation are among the most difficult tasks of soil management, and yet they are among the most important properties and complex, the reasons for the complexity is the range of scales it expresses from a few A to several cm, the dynamic nature attributes vary in time and space, the attributes observed at any given time reflect the net effect of numerous interacting factors which may change at any moment, since they are a potent means of influencing ecosystem function (Brady and Weil, 2002; Lal and shukla, 2004). Both biological and physicochemical processes are involved in the formation of soil aggregates and classified based on shapes and size classes.

2.4.1.2. Particle and bulk densities

Loose and porous soils have low weight per unit volume than compacted soils with limited pore spaces (Gupta, 2000). The presence of iron oxides and various heavy minerals increases the average value of particle density whereas the presence of organic matter lowers it. However, in most mineral soils, the mean particle density is about 2.6 g cm^{-3} -2.7g cm^{-3} (Hillel, 1980). Soils having low and high bulk densities exhibit favorable and poor physical conditions, respectively. Bulk densities of soil horizons are inversely related to the amount of pore space and soil organic matter content.

Textural variations also influence the value of bulk density. For example, clay, silt clay and clay loam surface soils show low bulk density as compared to sands and sandy loam soils which show high bulk density values (Gupta, 2000). Any factor that influences soil pore space will affect soil bulk density. The solid particles of the fine textured soils tend to be organized in porous granules, especially if adequate organic matter is present. In such aggregated soils, pores exist between and within granules. This ensures high total pore space and a low bulk density. In sandy soil, however, organic matter contents generally are low; the solid particles are less likely to be aggregated, and the bulk densities are commonly higher than in the finer-textured soil (Brady and Weil, 2002). They have also stated that bulk densities of subsoil layers are generally higher than surface soils, probably because of lower organic matter contents, less aggregation, fewer roots and other soil dwelling organisms, and compaction caused by the weight of the overlying layers. According to Ahmed (2002) the surface soil layers possessed lower particle density values than the subsoil horizons and the highest particle density (2.93 g cm^{-3}) was obtained at the subsoil horizon (57-95cm depth) in grazing land soils of the middle elevation. The same author also reported that bulk density showed greater variation with profile depth and higher bulk density was obtained at the subsoil horizons under all the elevation zones and land use types considered in the study.

2.4.1.3. Soil porosity

For soils with the same particle density, the lower the bulk density, the higher is the percent pore space (total porosity). Total porosity of soil usually lies between 30 to 70% and may be used as a very general indication of the degree of compaction in a soil in the same way as bulk density is used. As is the case with bulk density, management exerts a decisive influence on the pore space of soils (Brady and Weil, 2002).

Coarse-textured soils tend to be less porous than fine-textured soils, though the mean size of individual pores is greater in the former than in the latter (Hilell, 1980). Sands with a total pore space of less than about 40% are liable to restrict root growth due to excessive strength whilst in clay soils limiting total porosities are higher and less than 50% can be taken as the corresponding value. The decrease in organic matter and increase in clay that occur with depth in many profiles are associated with a shift from macro pores to micro pores (Brady and Weil, 2002).

2.4.2. Chemical properties

2.4.2.1. Soil reaction (pH)

Soil reaction (pH) is mostly related to the nature of the parent material, climate, organic matter and topographic situations (Tamirat,1992). Soil organic matter, or humus, contains reactive carboxylic and phenolic groups that behave as weak acids releasing H^+ to the soil solution. The soil organic matter content varies with the environment, vegetation, and soil; thus, its contribution to soil acidity varies accordingly. In peat and muck soils and in mineral soils containing large amounts of organic matter, organic acids contribute significantly to soil acidity. Clay minerals such as kaolinite (1:1) and montimorillonite (2:1) can buffer soil pH. High clay and/or high organic content soils exhibit greater buffering capacity than sandy or low organic matter soils.

The major acidification processes are due to the export of basic cations in agricultural products and through leaching (Smith *et al.,* 1995). Soil acidification is therefore due to either natural or other soil manipulation processes imposed by human being. Soil pH increased with depth of soil profile and relatively high pH was observed at subsoil horizons in Alfisols of Bako area (Wakene, 2001) and Mount Chilallo conducted by (Ahmed, 2002) and in Vertisols of the central highlands of Ethiopia (Tamirat, 1992). The soils in high altitude and those with higher slopes had low pH values, probably suggesting the washing out of solutes from these parts (Belay, 1996, 1998; Abayneh, 2001and Mohammed *et al.,* 2005).

Physicochemical characterization of Nitisol in southwestern Ethiopia conducted by Abebe and Endalkachew, (2012) and Alemayehu (2009) reported that in the same area a medium acidic varying between 5.0 and 6.1 stated that the soil pH $_{H2O}$ less than the critical level (6.5-8.5) given by Landon (1991). Because of loss of base forming cations down the soil profiles through leaching and high amount of rainfall (>1000mm) that results leaching of cations, all of the soil samples had also very low electrical conductivity.

Continuous cultivation practices, excessive precipitation, steepness of the topography and application of inorganic fertilizers could be ascribed as some of the factors which are responsible for the reduction of pH in the soil profiles at the middle and upper elevation zones (Mokwunye, 1978; Ahmed, 2002). Benton (2003) reported that soil reaction pH $_{(H2O)}$ ranges between extremely acidic (< 4.5) to very strongly alkaline (> 9.1). According to Brady and Weil (2002) soil pH classes ranges, the pH $_{H2O}$ values recorded at the surface horizons of all pedons opened qualify for moderately acidic soils. Whereas based on the pH values measured in the KCl solution, the soils were strongly acidic throughout the entire depth of all pedons. The decrease in soil pH when measured in KCl solution indicates that appreciable quantity of exchangeable hydrogen (H) has been released in to the soil solution through exchange with potassium (K) in the KCl solution.

2.4.2.2. Soil organic matter, organic carbon and total nitrogen

Soil organic matter is originally produced by living organisms (plant or animal) that is returned through biological decomposition process that includes the physical breakdown and biochemical transformation of complex organic molecules of dead material into simpler organic and inorganic molecules. The fraction of organic matter may be divided into aboveground comprises plant and animal residues and belowground consists of living soil fauna and micro flora, partially decomposed plant and animal residues, and humic substances (FAO, 2005). Organic matter content and relative composition (quality) in soils differ with composition and/or diversity and population of native trees and grass species growing in the area. Generally, higher soil organic matter contents were observed at the surface layers than subsoil soil horizons in all opened profiles at different sites (Tamirat, 1992; Yohannes, 1999; Mitiku, 2000; Abayneh, 2001; Wakene, 2001 and Ahmed, 2002).

According to Ahmed (2002), the highest values of organic matter and total nitrogen were found at the upper elevation under the virgin natural vegetation soil. Continuous and intensive cultivation practices might be attributed for the deterioration of soil aggregates and low return of plant biomass to the soil system in the cultivated soils. Human activity influences soil organic matter contents and biological activity of soils. This results in a reduction of soil biota, both in biomass and diversity. Where there are no longer organisms to decompose soil organic matter and bind soil particles, the soil structure is damaged easily by rain, wind and sun (FAO, 2005).

The cultivated land of upper part of soil registered higher organic matter (2.26%) and total nitrogen (0.29%) when compared to the less eroded cultivated soils on the foot slope and toe slope areas (Belay, 1997). The relatively higher organic matter and nitrogen contents of this soil probably resulted from frequent fallowing and addition of organic manure. Soil organic matter influences soil physical, chemical, and biological properties related to Soil quality. Reeves (1997) argued that the soil organic carbon interrelation role on soil structure and physical properties has been extensively reviewed and one of the most important soil quality indicator and Bationo *et al.* (2005) stated that an index of sustainable land management and it is closely associated with clay and silt contents and clay type and which plays an important role in supplying plant nutrients, enhancing cation exchange capacity, improving soil aggregation and water retention and supporting soil biological activity.

Under similar climatic conditions, the organic matter content in fine texture soils is two to four times higher than that of coarse textured soils (Prasad and Power, 1997; FAO, 2005). The amount of organic matter and total nitrogen contents in the upper topsoil were higher under zero tillage as compared to continuous mono cropping. The reasons for the low organic matter content are thought to be rapid rate of mineralization favored by the climatic and soil conditions as well as the total removal of crop residues for animal feed and source of energy (Abayneh, 2001). In general, organic matter is the primary source of nitrogen, phosphorus and sulphur and a temporary sink for most plant nutrients. Moreover, organic matter is important in maintaining soil tilth, adding the infiltration of water and air circulation, promoting water retention, reducing erosion and controlling the efficiency and fate of applied pesticides (Gregorich *et al.,* 1994). The percentage of soil organic matter ranged from < 1 very low, 1 to 2 low, 2 to 3 moderate, 3 to 5 high and >5 very high (Murphy 1968) and < 0.86 very low, 0.86 to 2.59 low, 2.59 to 5.17 moderate, and >5.17 high Tekalign (1991) respectively.

Nitrogen is one of the essential nutrient elements that is taken up by plants in greatest quantity after carbon, oxygen and hydrogen, but is one of the most deficient macronutrients in crop production (Mesfin, 1998). The total nitrogen content of soils ranges from less than 0.02% in subsoil to greater than 2.5% in peat soils which is attributed to the generally low biomass productions and fast oxidations of organic matter in such climatic zones (Tisdale *et al.*, 2002). There is a strong positive relationship between soil nitrogen and soil organic matter content. Low total nitrogen content and therefore N deficiency is visible in highly weathered soils of the humid and sub humid tropics due to leaching (Tisdale *et al.,* 2002). On the other hand, applications of plant materials with both large C:N ratios and lignin contents such as cereal straw and grasses generally favor nutrient immobilization, organic matter accumulation and humus formation, with increased potential for improved soil structure development (FAO, 2005). The rate of total nitrogen in soil values in percentage is given by (Murphy,1968) as follows; low (< 0.10), medium (0.10-0.15), high (0.15-0.25), very high (> 0.25) very low (< 0.05), low (0.05-0.12), medium (0.12- 0.25), high (> 0.25) (Tekalign, 1991) and (< 0.01) very low, (0.01- 0.12) low, (0.12- 0.25) medium, (> 0.25) high (Berhanu,1980) respectively.

2.4.2.3. Cation exchange capacity

Cation exchange capacity (CEC) is the ability of the soil solid phase to attract or store and exchange cationic nutrients with the soil solution and render them available to plants through exchange reactions (Muller-Samann and Kotschi, 1994). Cation exchange capacity is an important parameter of soil because it gives an indication of the type of the dominant clay mineral present in the soil and its capacity to retain nutrients against leaching. The CEC is strongly affected by the nature and amount of mineral and organic colloids present in the soil. Soils with large amounts of clay and organic matter have higher CEC than sandy soils low in organic matter. In the surface horizons of mineral soils, where the contents of organic matter and clay in the soil are significantly high, organic matter and clay fractions frequently contribute similar values to the CEC. While in the sub soils, particularly where Bt horizons exist, more CEC is contributed by clay fractions than by organic matter due to the decline of the latter with profile depth (Foth, 1990). According to Ahmed (2002), the overall higher CEC values registered in the subsoil horizons of the soils of Mount Chilalo were due to high clay (montimorillonite) accumulation or exchangeable bases that bring about higher CEC values at the subsoil layers of soil profiles. On the other hand, Wakene (2001) reported the highest CEC value on the surface layers of the soil profile at Bako area under the virgin land soil.

According to Abebe and Endalkachew (2012) reported that the mean value of CEC ranges between 25 to 30 cmolec(+)/kg while the rest have CEC less than 25 Cmolec (+)/kg. In many Nitic horizons, the CEC (by 1*M* NH4OAc) is less than 36 cmolec (+)/kg clay, or even less than 24 cmolec (+)/kg clay. The clay assemblage of Nitisol is dominated by kaolinite/ (Meta) halloysite which has the CEC value of 3-15 cmolec (+)/kg (WRB, 2007). Fasil and Charles (2009) reported that the amount of clay and mainly the type of clay mineral are responsible factors for CEC. On the contrary, Mohammed *et al.* (2005) reported that the values of CEC were uniformly high throughout most profiles and did not show any clear pattern of variability among horizons of the profiles except two pedons, which showed slight decrease with depth.

2.4.2.4. Exchangeable base and percent base saturation

Of the essential elements, potassium (K) is the third after nitrogen and phosphorus, most likely to limit plant productivity. The variation in the distribution of potassium depends on the mineral present, particle size distribution, degree of weathering and soil management practices (Wakene, 2001). According to the same author, potassium content of a given soil depends on the climatic condition and degree of soil development, the intensity of cultivation and the parent material from which the soil is formed. Potassium exists as unavailable, readily available and slowly available forms. However, of the total potassium present in the soil, the largest portion (90-98%) is found in a relatively unavailable form to plants whereas only 1 to 2% of the soil K is readily available to plants (Brady and Weil, 2002). Available K exists in soils in solution while exchangeable K is adsorbed on the soil colloidal surfaces from where it is slowly released to soil solution so as to be available to plants. Plants then directly absorb K from the soil solution where it is found in the most readily available form for plant absorption (Brady and Weil, 2002),

Brady and Weil (2002) reported that farming without fertilizers for over a century depleted the exchangeable potassium in a sandy soil. Although, it is believed that Ethiopian soils have no potassium problem, it was reported by Alemayehu (1990) that potassium deficiency was observed in Alfisols at Wollega former state farms subjected to intensive cultivation. The greater the proportion of clay minerals high in potassium, the greater will be the potential potassium availability in a soil (Tisdale *et al.,* 2002). High values of exchangeable K were recorded for the surface horizons and the value generally decreased down the profile (Mulugeta, 2000; Abayneh, 2001; Mohammed *et al.,* 2005). Berhanu (1980) described that soils consisting of exchangeable K values (greater than 0.77), (0.51 to 0.77), (0.26 to 0.51) and (less than 0.26 cmolec (+) kg^{-1}) are rated as high, moderate, low and very low, respectively.

Exchangeable form of Calcium (Ca) occurs largely in acidic and humid region soils as primary minerals. Soils having 2:1 layer silicates have higher CEC and thus retain larger amount of calcium or magnesium. Soil pH is inversely related to exchangeable calcium. In acid soils, which can have high exchangeable Aluminum, Calcium concentration becomes low (Prasad and Power, 1997). Wakene (2001) reported that continuous cultivation and inorganic fertilizers application resulted in declining of soil pH and caused loss of basic cations and especially under intensive cropping of inherently poor soils, the deficiencies of Calcium and Magnesium are common. Some research works conducted on Ethiopian soils indicated that exchangeable Ca and Mg cations dominate the exchange sites of most soils and contributed higher to the total percent base saturations particularly in the Vertisols (Mesfin,1998). Although different crops have different optimum ranges of nutrient requirements, the response to Calcium fertilizer is expected from most crops when the exchangeable calcium is less than 0.2cmol (+) kg^{-1} of soil, while 0.5cmol (+) kg^{-1} of soil was the deficiency threshold level in the tropics for magnesium (Landon, 1991).

Percent base saturation (BS) tells what percent of the exchange sites are occupied by the basic cations. It is the percentage of the CEC occupied by the basic cations Ca^{2+}, Mg^{2+} and K^{+}. Basic cations are distinguished from the acid cations H^{+} and Al^{3+}. At an approximate soil pH 5.4 or less, Al^{3+} is present in a significantly high concentration that hinders growth of most plant species, and the lower the soil pH, the greater the amount of toxic Al^{3+}. Therefore, soils with a high percent base saturation are generally more fertile because little or no acid cation Al^{3+} that is toxic to plant growth, a higher pH soils more buffered against acid cations from plant roots and soil processes that acidify the soils and contain greater amounts of the essential plant nutrient cations for use by plants. According to Landon (1991) soils having BS greater than 60% are rated as fertile soil due to its actual percentage of cation exchange sites occupied by exchangeable bases. Depending on soil pH, the soil's base saturation may be a fraction of CEC or approximately equal to CEC. In general, if the soil pH is below 7, the base saturation is less than CEC. At pH 7 or higher, soil clay mineral and organic matter surfaces are occupied by basic cations, and thus, base saturation is equal to CEC.

2.4.2.5. Available phosphorus

Next to nitrogen, phosphorus has more wide spread influence on both natural and agricultural ecosystems than any other essential elements. The term available-P is often used to express the amount of soil P in solution which can be extracted or mined by plant roots and utilized by the plant for growth and development during its life cycle. It is also referred to as labile P. In most natural ecosystems such as forests and grass lands, phosphorus uptake by plants is constrained by both the low total quantity of this element in the soil, and by the very low solubility of the scarce quantity that is present. Variability of the levels of available phosphorus (P) was related to land use scenario, altitude, slope position and other characteristics, such as contents of clay and calcium carbonates (Mohammed *et al.,* 2005). The availability of P in the soil varied with variations in soil reaction, total P reserves in the soil and the particle size distribution. In addition, availability of P was strictly dictated by the land use pattern, where the concentration was lower in grazing land than crop land. This might be because of the fertilizer and some crop residue effect that increases P on crop lands than the grazing lands that are over grazed and exposed for erosion (Birru, 1999).

Available P was high at the upper most horizon of the profile and decreased further with depth (Mulugeta, 2000). The lower concentration of available P at depth is due to fixation by clay and Ca, which were found to increase with profile depth. According to Piccolo and Huluka (1986) finding on Nitisols there is accumulation of total phosphorus in the upper part of B-horizons due to frequent wetting and drying or a chemical precipitation by Fe. The available phosphorous is reported below the critical level given by (Landon, 1991 and Sanchez *et al.,* 1982) (10-15 ppm) ranged from (7.19 - 12.16 ppm) Bray 1 extraction methods (Abebe and Endalkachew, 2012). Because of its fixation by Al and Fe, their presence is expected at the pH values of the soils of the study areas (Tisdale *et al.,* 1993). High phosphorous sorption capacity of Nitisol was also reported by WRB (2007).

Studies in many regions have shown that soils devoted to crop production lost far more phosphorus to streams than do those covered by relatively undisturbed forest or natural grasslands (Brady and Weil, 2002). According to the same authors, erosion tends to transport predominantly the clay and organic matter fractions of the soil, which are relatively rich in phosphorus, leaving behind the coarser soil particles lower in phosphorus fractions. Thus, compared to the original soil, eroded sediments are often enriched in phosphorus by a ratio of two or more. The concentration of available-P is always low because of continuous plant uptake (Abdu, 2006). The amounts of the various discrete chemical fractions of P, which are formed in soil, determine the relative effectiveness of phosphatic fertilizers on crop growth, and are related to the genesis of soils. Phosphorus extracted by the Bray and Kurtz p-1 method has been shown to be well correlated with crop yield response on most acid and neutral soils (Pierzynski, 2000). The lowest values of available phosphorus extracted by both Olsen and Bray II extraction methods were obtained at the extreme lower subsoil depths both in cultivated and grazing lands (Ahmed, 2002). Most of the soils in Ethiopia show deficiency for inherent available phosphorus (Murphy, 1968). Oxisols, Ultisols, Vertisols and Alfisols are generally low in total phosphorus while Andisols or Andepts (volcanic ash soils) are generally high in phosphorus contents (Mesfin, 1996).

Topsoil phosphorus is usually greater than that in subsoil due to sorption of the added phosphorus and greater biological activity and accumulation of organic material in the former. However, soil phosphorus content varies with parent material, extent of pedogenesis, soil texture, and management factors such as rate and type of phosphorus applied and soil cultivation. The rate at which the plant absorbs phosphate ions is influenced by their concentrations in the solutions. However, the amount of phosphate available in the soil solution at any one time is very small, usually considerably less than one ppm.

2.4.3. **Diagnostic horizons, properties and materials**

Soil horizons, properties and materials are intended to reflect features which are widely recognized as occurring in soils and which can be used to describe and define soil classes.

Diagnostic horizons and properties are characterized by a combination of attributes that reflect widespread, common results of the processes of soil formation (Bridges, 1997 cited in WRB, 2006) or indicate specific conditions of soil formation. Their features can be observed or determined by appearance, measurability, importance, relevance and quantitative criteria, either in the field or in the laboratory and require a minimum or maximum expression to qualify as diagnostic (WRB, 2006). Diagnostic horizons can be at the surface (epipedon) or subsurface layers. Both World Reference Base and USDA soil taxonomy classification systems define diagnostic horizons more or less similarly. The definition of diagnostic horizons and characteristics according to World Reference Base is the same as that of the Soil Taxonomy except for few classes.

According to world Reference base the argic horizon is a subsurface horizon with distinct higher clay content than the overlying horizon. These horizon is identified by textural differentiation illuvial accumulation of clay; predominant pedogenesis formation of clay in the subsoil; destruction of clay in the surface horizon; selective surface erosion of clay; upward movement of coarser particles due to swelling and shrinking; biological activity. The mollic horizon is a thick, well-structured, dark-colored surface horizon with a high base saturation and a moderate to high content of organic matter. The nitic horizon (from Latin nitidus, shiny) is a clay-rich subsurface horizon. It has moderately to strongly developed polyhydric structure breaking to flat-edged or nutty elements with many shiny ped faces, which cannot or can only partially be attributed to clay illuviation. A plinthic horizon is a subsurface horizon that consists of an Fe-rich (in some cases also Mn-rich), humus-poor mixture of kaolinitic clay (and other products of strong weathering, such as gibbsite) with quartz and other constituents, and which changes irreversibly to a layer with hard nodules, a hardpan or irregular fragments on exposure to repeated wetting and drying with free access of oxygen.

Diagnostic soil properties are complex soil attributes that involve several soil characteristics and reflect present or past soil forming mechanisms and diagnostic soil materials reflect the original soil parent materials, in which pedogenesis processes have not yet been so active that they left a significant mark.

3. MATERIALS AND METHODS

3.1. Description of the Study Area

3.1.1. Location

The study was conducted in *Omo Nada, Limu Seka and Gera* districts of Jimma Zone, south western Ethiopia. They are located at 72 km in the east, 109 km in the north and 98 km in the west of Jimma Zonal administrative town respectively. The districts encompass 39, 38 and 24 Peasant Association (PAs), of them Doyo *Yaya* and *Nada Bidaru, Seka* and *Dora,* and *Ganji Chala* and *Wanja Kersa* are the two PAs selected respectively from *Omo Nada, Limu Seka* and *Gera* districts, which are located at a distance of 3 and 10, 17 and 34, and 30 and 6km from Nada, Atinago and Chira districts town respectively (Table 1 and Figure 1) (MoA district office; CASCAPE PRA, 2014).

Table 1. Description of the study area

Sites location	Altitude (m)	Coordinates	Mean Annual RF (mm)	Mean Annual Temperature (°C)
Omo Nada	880 -3,344	7°17'to 7°49'N 37°00' to 37°28'E	800-1822.3	25 - 33
Limu Seka	1,400 -2,200	8° 05' to 8° 35'N, 36° 46' to 37° 00'E	1280.6 -2583.6	11.9 -31.9
Gera	1,500 -3,200	7° 30' to 7° 45' N, 36° 00' to 36° 30'E	1414.1 -2256.9	10.3 - 27

Source: Mean Annual RF and Temperature (ENM-Jimma Brach Directorate, 2015)

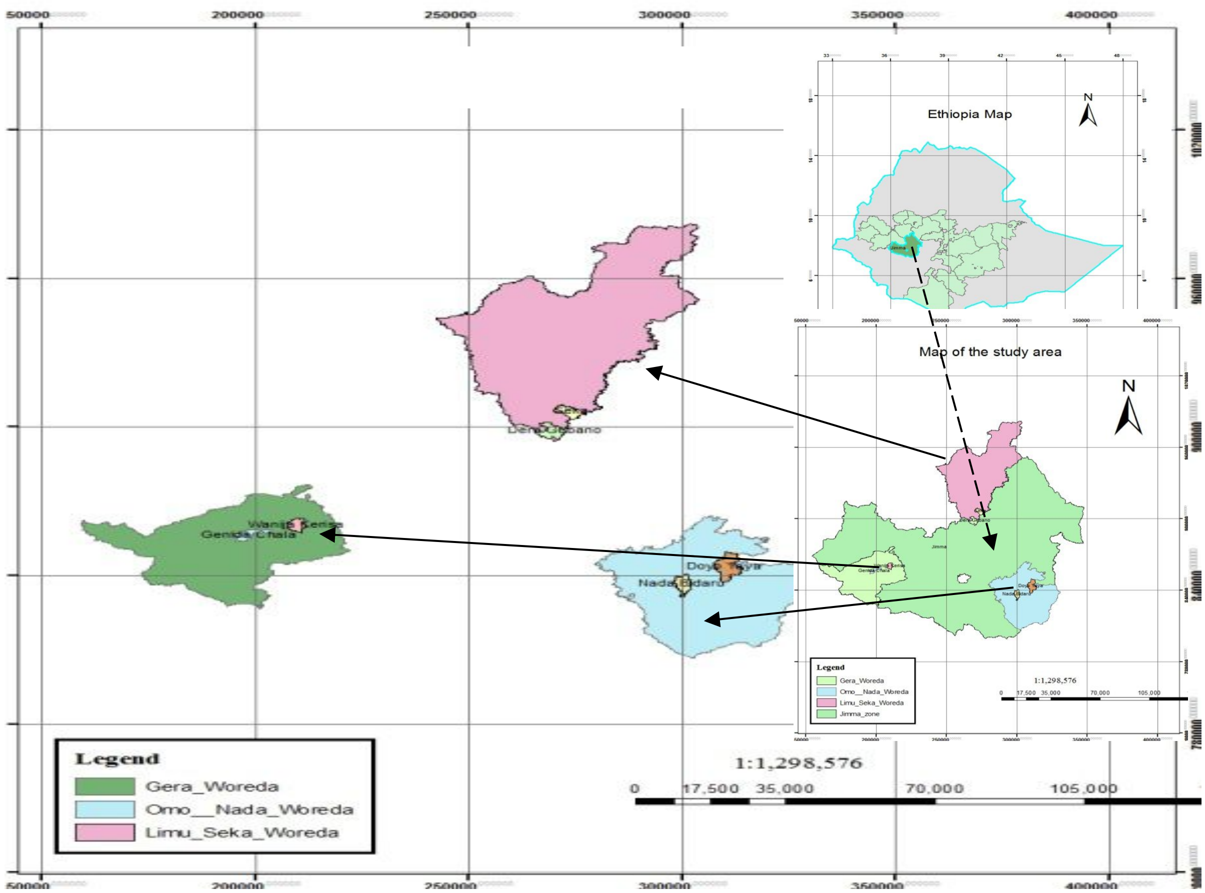


Figure 1: Location Map of the study area

3.1.2. Socio economic and demographic features

Jimma Zone is mostly known from south western Ethiopia for its vegetation coverage, suitability for coffee, crop, livestock and bee production. The dominant crops being maize, teff, coffee, sorghum, barley, wheat, different pulse crops, finger millet, fruits, vegetables and spices. Human population of the Jimma Zone is 2,486,155, out of the total population, 94 % live in the rural areas. The total estimated population of *Omo Nada, Limu Seka* and *Gera* districts are 254,417, 164,000 and 132,238 out of these 127,625 are male and 126,792 are women, 21,300 male headed household and 1100 female headed households and 18,816 male-headed households and 385 female-headed households respectively (CSA, 2007, MoA district office). The land cover categories of the districts comprise about 26.5% potential arable or cultivable land of which 23.4% under annual crops, 7.0% pasture, 56.6% forest and the remaining 9.9% was classified as degraded, built-up or otherwise unusable. Except *Omo Nada*, coffee is the main means of income for most farmers in both districts and *Gera* endowed with natural forests and animals (MoA districts offices).

3.1.3. Climate and agro- ecology

The agro-ecological zones of the districts fall under warm humid lowlands and tepid sub humid highlands. Gera district has a diversity of terrain giving the area ecologically distinct areas (MoARD, 2005; CASCAPE PRA, 2014). The mean monthly rain fall and mean temperature of the study area shown on figure 2.

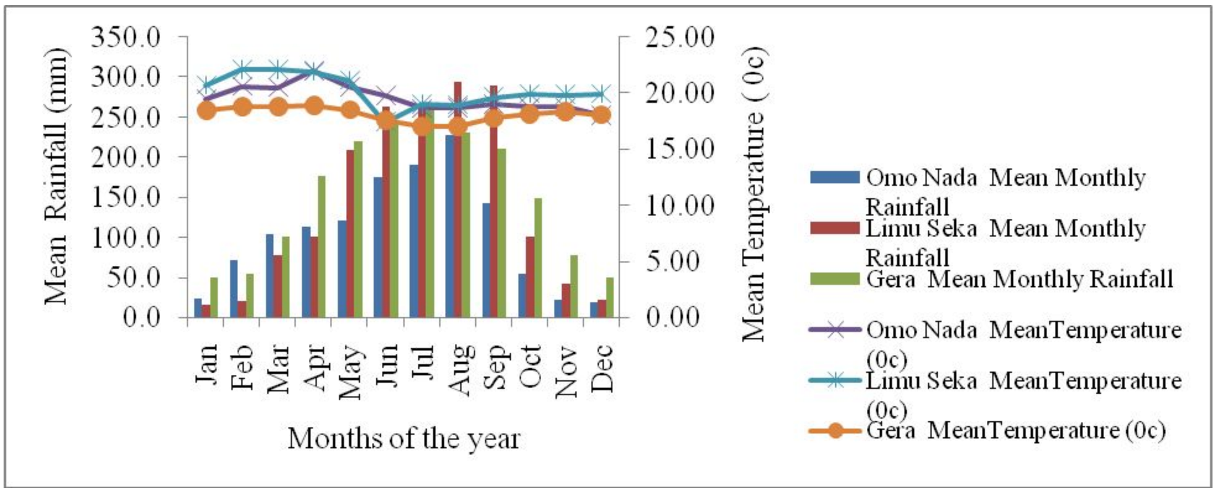


Figure 2. Mean rain fall and mean Temperature of the study area (2000-2013)
Source: ENM-Jimma branch Directorate (2015)

3.1.4. Geology and Soil

The major soil groups of the zone are 35% Nitisol, 15% Vertisols, and 50% others soils. The geology and soils of Ethiopia fall within the geological structural units of the horn of Africa. In south western Ethiopia, the parent materials of soils are basalt igneous rock (piccolo and Huluka,1986) and the recent study by Alemayehu (2009) and Dumon (2010) showed that the parent materials for soils of the Gilgel Gibe catchment are dominantly basaltic lava flows and Hawaite, other studies (Ochtman *et al.,* 1977; cited in Feyera A, 2010) describe soils of the study area as are deep red highly weathered soils that belong to the USDA soil classification Order Oxisols and Ultisols, Oxisols/ Rhodic Ferrasols occur in the 1500-2000mm annual rainfall of western and southwestern Oromia as in Jimma, Ilubabor and Wollega.

3.1.5. Land use, major crops and vegetation

The total land coverage of Jimma Zone is 18,696 km^2, of which 49.6% of the zone total area devote to cultivation, while the remaining 50.4% of the total area of land were under vegetation cover (22.8% under forest, 18% under woodland, 9.6% under grassland) (BPEDORS, 2000; ONRS, 2011).

Omo Nada district has total land coverage of 165,602.66 hectares, out of these 48,984 hectares are currently covered by forest and grazing land, while 94,725 hectares are used for crop production. *Limu Seka* district has a total of 169,400 hectares, out of these 10,241 hectares are currently covered by forest and bush, while 38,874 hectares are used for crop production and *Gera* district has a total land coverage of 112,212 hectares, out of these 80,830 hectares are currently covered by coffee, while 21,733 hectares are used for crops production respectively (MoA district office and CASCAPE PRA, 2014).

The total land coverage of *Doyo Yaya* and *Nada Bidaru* 4593.18 hectares and 2214.3 hectares, cultivated land 2537 hectares and 1223.45 hectares, forest land 287 hectares and 138.39 hectares, grazing land 1141.4 hectares and 550.27 hectares settlement land 255 hectares and 123 hectares respectively. The major crops of the district maize, teff, wheat, sorghum, barely, bean, and field pea are the main means of income next to livestock rearing for the farmers in district (MoA district office). The total land coverage of *Dora* and *Seka* are around 3,500 and 2,500 hectares respectively, and the total cultivated land is 1200 and 700 hectares while the forest covers 40 and 785 hectares of the total land size respectively. The majors crops of the PAs maize, sorghum, teff, finger millet, sesame and coffee is the dominant cash crops of the study area. And *Ganji Chala* and *Wanja Kersa* PAs, total land coverage are around 992 and 3220.02 hectares and the total cultivated land is 992 and 1011 hectares while the coffee covers 892 and 892.47 hectares of the total land size respectively. Next to coffee, honey production and livestock are the most important income generating activities for the majority of the farmers (MoA district offices).

3.2. Methods of the Study

3.2.1. Sampling design

Out of 17 rural districts found in Jimma Zone the three districts *(Omo Nada, Limu Seka and Gera)* were the CASCAPE project conducted soil characterization and classification following the scientific methods. From each districts two PAs per district were purposively selected previously by CASCAPE team. Therefore, the present study selected the non-boundaries CASCAPE intervention PAs.

3.2.1.1. Focus group discussion (FGD)

Participants were selected on the bases of geographic location (high land, mid high land and low land) of the HH within the PAs and villages (HH from different corners of the target area were included), and the experiences of farmers on the farming activities (working on the field) well knowledgeable farmers were purposively selected from each PAs employed by (Geilfus, 2008 and Krueger, 2002). Accordingly, three groups of FGD were selected constituted of total 29 participants from *Doyo Yaya* PAs; one group of FGD was selected constituted of total 12 participants from *Nada Bidaru* PAs; Two groups of FGD were selected constituted of total 16 participants from *Seka;* one group of FGD was selected constituted of total 11 participants from Dora PAs; Two groups of FGD were selected constituted of total 16 participants from *Ganji Chala;* Two groups of FGD were selected constituted of total 17 participants from *Wanja Kersa* PAs and total of 11 focus groups, total of 101 participants were held for discussion in *Omo Nada*, *Limu Seka* and *Gera* districts respectively, were selected for the focus group discussion.

The numbers of the group depend on the information or new ideas of the participants were saturated. Discussions were made with randomly selected 8-12 respondent in each group under the guidance of a moderator. Check lists were prepared and explored farmers' perceptions and indigenous knowledge of soil classification and assessed the indicators they use, local name, management practice and major land use of their fields were discussed and which were take place and followed the previously opened eleven soil profiles study sites in two PAs per three CASCAPE districts (Appendix I), where soil samples was collected and classified following according to the scientific descriptions (WRB, 2006). Using this technique Qualitative and quantitative basic descriptive information and detailed information, which might be difficult to collect through the all farmers regarding soil and indigenous knowledge of farmers on soil fertility classification, local soil type, name and their criteria were collected. These were provided for designing appropriate participatory soil mapping, transect walk with key informants and interviews.

3.2.1.2. Participatory soil mapping

These were conducted with 10 to13 key informants of local farmers who are land holders, elders, knowledgeable of the soils and their PAs boundaries. They were draw their PA boundaries map with different soil type occur in their PAs, followed by many researchers (Ejigu and pound, 2005; Corbeels *et al*., 2000 and Nethononda and Odhiambo, 2011). The farmers were requested to identify and describe each soil types existed based on their observations, understanding and experience. Farmers were also requested to indicate areas were soil profiles previously opened, coded according to soil characteristics and others land resources (Roads, forest, rivers, public services and crop lands). The soil map of the PAs drawn on the flip charts was later transferred to the computer.

3.2.1.3. Transect walk

Transact walk with key informants (Development Agents, a knowledgeable farmer, teachers and local responsible leaders and agriculture experts) were used to conduct a field discussion on the soil types of their PAs focusing on their land use, management practices, topographic position (drainage, slope) to illustrated these features in a diagram. The best route for the transect walk were used, capturing the information and the diagram was sketched with key features (local soil type, land use, major crops grown, vegetation, soil fertility status and management practices, topography and drainage patterns and others public resources) along the transect were recorded on the note book (Appendix II). This method has often been widely used by researchers recently (Corbeels *et al*., 2000) and (Abera, 2006) in North Tigray, (Barrios and Trejo, 2003) in Latin America and (Tittonell *et al*., 2005) in western Kenya were used.

3.2.1.4. Key informant interviews

Key informant interviews were following the methods of Geilfus (2008) and Krueger (2002) used to gather the information of their PAs soil types, fertility status and management practices and others land features. Accordingly, 13 from *Doyo Yaya*, 12 from *Nada Bidaru*, 12 from *Seka*, 12 from *Dora*, 12 from *Ganji Chala* and 13 from *Wanja Kersa* PAs key informants (Development Agents, a knowledgeable farmer, teachers and local leaders and agriculture experts) were selected and the total of 74 key informants from *Omo Nada*, *Limu Seka* and *Gera* districts respectively, were used. A check list of key questions were used to guide a discussion about the information gathered during the transect walk. Across the route detailed information was captured in the study area (Appendix II).

3.2.1.5. Correlate farmers characterization with scientific characterization

Analytical soil laboratory data obtained from CASCAPE done in Water Works Design and Supervision Enterprise Laboratory, the analytical data was interpreted and the field survey qualitative and quantitative data was compiled matched /mismatched the two approaches. The figure (3) shows methods for combining scientific and local knowledge of soil employed by Payton *et al.* (2003).

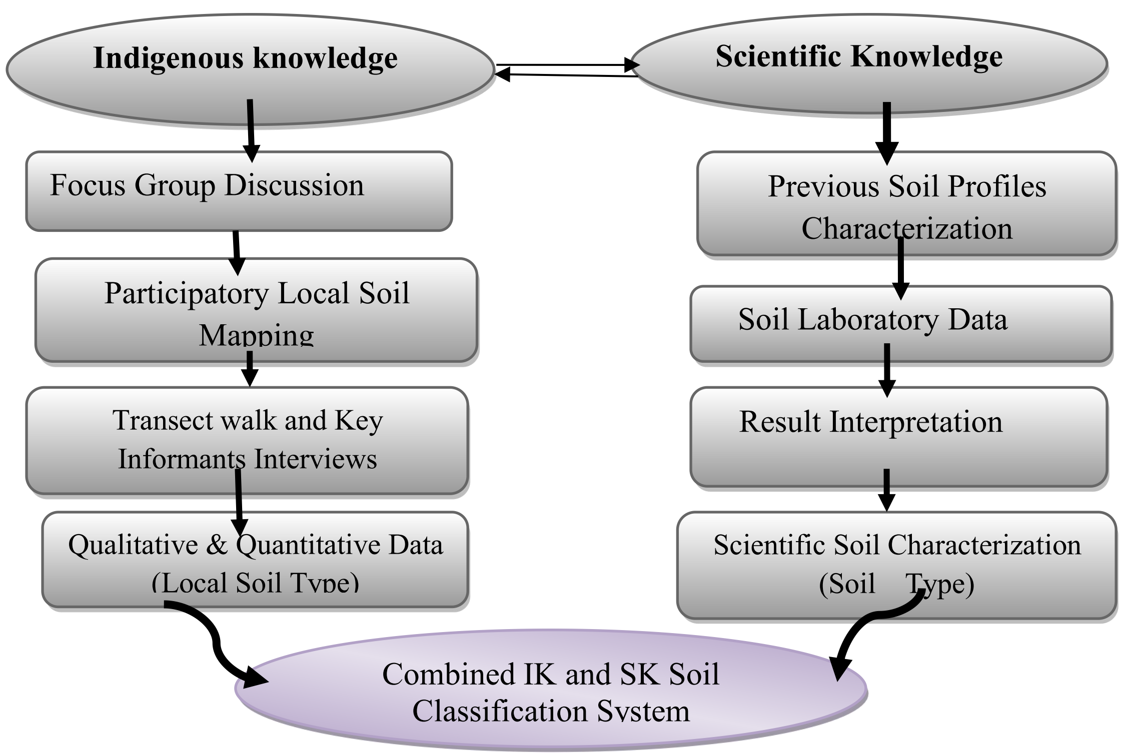


Figure 3.Methodology for combining scientific and Local Knowledge of soil classification system

3.2.2. Data collection period

This study was collected between December 2014 and June 2015. Focus group discussion data was collected during January 2015 to March 2015, and followed by the farmers' participatory soil mapping. The transect walk with key informants and interviews were carried out at the end of June 2015 because of the transect walk activities helps for observation of farmers soil map and others interest features data collection.

3.2.3. Data collection methods to specific objectives

Data were collected by PRA tools in two phases. In phase one focus group discussion/FGD participatory soil mapping with local farmers and in phase two transect walk with key informants and interviews in each of the selected districts and uses of previously compiled soil laboratory data of the study areas.

3.2.3.1. Assessing farmers indigenous knowledge of soil fertility indicators

Farmers' soil fertility indicators in the studied area were investigated through FGD, key informants interviews employed by researchers (Corbeels *et al*., 2000; Abera, 2006; Yifru and Taye, 2011), easily observable soil fertility indicators were similarly used by (Corbeels *et al*., 2000; Pound & Ejigu, 2005; Abera, 2006; Dawoe *et al.,* 2012 and Gebeyaw, 2015). How farmers perceive a fertile soil and conversely an infertile soil, changes of soil fertility (the present situation and past), listing of the major crops and estimation of yield data (100kg/ha) were gathered, the reasons for yield changes and driving forces, listing the appearance of weeds and shrubs plants, and response to those changes in crop pattern (crop rotation, fallow duration) were captured following the methods of (Yifru and Taye, 2011; Gebeyaw, 2015) noticeable change over time on their farm land followed as (Corbeels *et al.,* 2000;Tittonell *et al.,*2005; Abera, 2006; Dawoe *et al.,*2012 and Buthelezi *et al.,*2013).

3.2.3.2. Farmers' classification and characterization of soil type

Farmers' soil classification and characterization based on the easily observable physical properties of soils were documented. The others soil characteristics that are not observable but experienced and knowledgeable farmers was observe those characteristics were gathered and captured through discussion, transect walk with key informants and interviews. They list local criteria of classifying soils variables or soil physical properties, soil types and name according to their fertility and potential productivity, in a similar way that were done at different locations following as (Corbeels *et al.,* 2000; Abera, 2006; Buthelezi *et al.,* 2013 and Gebeyaw, 2015).

3.3. Data Analysis

The qualitative and quantitative obtained data were analyzed using basic descriptive statistics (such as mean, percent) soil type, name and characteristics of their farm land.

4. RESULTS AND DISCUSSION

The results of the survey studies, soil characterization, farmers participatory soil mapping and transect diagram and the secondary data of soil laboratory analyses of the physicochemical characteristics of the soil profile samples were used to understand and capture farmers indigenous knowledge of soils substantiated with scientific characterization according to WRB and USDA soil taxonomy classification. The results obtained are presented and discussed in the following sections.

4.1. Farmers' Perception and Classification of Soils

In the present study four soil types were distinguished by focus group discussion and with key informants' interviews in each PAs of the study area. These soils are *Gurracha/Magalaa* that means Dark red to brownish*, Dimaa/Bildimaa* that means Reddish, *Dalacha/Suphee* that means Grey colored and *Koticha* that means black colored soils. The types of the soil distinguished were different with districts but similar types were distinguished with PAs. The same soil types were identified for both PAs of *Omo Nada* district *Gurracha/Magalaa* (Dark red brown colored soil), *Dimaa/Bildimaa* (Reddish colored soil) and *Dalacha/Suphee* (Grey colored soil). For both PAs of *Limu Seka* district *Dimaa* (Reddish colored soil), *Gurracha/magalaa* (Dark red brown colored soil), *Koticha* (black colored soil) were identified, while *Dimaa* (Reddish colored soil), *Gurracha magalaa* (Dark red brown colored soil) and *Dalacha suphee* (Grey colored soil) were identified for both PAs of *Gera* district as shown (Table 2).

Farmers use soil color to differentiate fertility status of their field. Accordingly they designate fertile soil dark color and infertile is reddish color. The criteria used by farmers were similar with across the groups and PAs of a districts. Farmers have experience to recognize their soil based on easily identifiable soil physical properties. Most important criteria that the farmers' use for classification are soil color, fertility status depending on the yield, soil workability, soil texture, depth of top soil, the topographic position of the field and its capacity to hold water. FGD of *Wanja Kersa* group, *Gera* district were ranked these criteria in the following order yield > color > topography > soil depth > water holding capacity > texture and FGD of

Doyo Yaya three groups used the same order; yield > topography > color > texture > water holding capacity > soil depth. In general, yield, color, topography, water holding capacity and texture are the most important criterion for all farmers in all study area (Table 2). Farmers' awareness on soil productivity is closely related to its position within the landscape. The present findings were similar with those results reported by Abera (2006), Corbeels *et al.* (2000) and Gebeyaw (2015).

Farmers have their indication for those criterions, *Gurracha/Magalaa* which means dark red brown colored soils that are fertile except for *Seka* and *Dora* considered as moderately fertile due to its moisture contents, soil organisms or fauna and high biomass, support of crop growth and high yield than others soils, whereas *Dimaa* red colored soils are infertile except *Nada Bidaru* PA considered as moderately fertile this soil is shallow in depth, severity in water erosion, low water holding capacity causes crop wilt in short duration, low yield and need more inputs than others soils and *Dalacha /Suphee* grayish colored soils are fertile but this soil type has constraints of water logging during high rainfall difficulty to managed as shown on (Table 2). Specifically, farmers perceived fine textured and deep fertile soils at the lower slope position due to accumulation of top surface soils from the middle and upper slope position but they perceived with its physical constraints of these soils hard when dry to fallow and high water holding capacity.

The present study indicated that local farmers from all districts and PAs have perceived different soil fertility status but the same soil types except *Limu Seka* district at *Seka* and *Dora*. According to Saito *et al.* (2006) farmers indentify soils depending on their physical properties mainly on the basis of soil color, texture, stoniness and weediness. Soil color is related to specific chemicals, physical and biological properties of soils in the study area. The reddish color of soils are might be due to presence of hematite in the free forms of oxides common in well oxidized soils, blackness color the presence of organic matter and gray or blush color indicates reducing condition of the soils. Soil color reflects the hidden soil constituents that parent materials of soil were formed; therefore farmers distinguished different soil colors to determine its fertility status. According to Pound and Ejigu (2005) scientists classify soils according to their chemical, physical and biological properties, which they relate to the parent materials from which the soil is derived, whereas farmers can classify their soils on the spot from evidence at the time and knowledge of past performance. This indicated that the Nitisols and others humid tropical soils physical properties of soils that have characterized the humid red tropical soils (WRB, 2007) and the study conducted on Nitisols of Jimma area indicated that various profiles have different color matrix ranged from dark brown to dark reddish brown and finally to brown and yellowish red (Alemayehu, 2009).

From both FGD and interviews it can be concluded that farmers have their own criteria either in group or individual to perceive their soil on the spot that are directly or indirectly affect crop yield. Accordingly, crop yield directly related to soil productivity. A soil constraint that affects crop growth and productivity such as poorly drained, weeds, diseases etc are considered in farmers' soil fertility classification and soil characterization. This is in line with the findings of Sheleme (2011) reported that soil materials removed from up slopes were continuously deposited and resulted in the development of a thick A horizon, indicating variation in soil characteristics due to difference in slope position. Atofarati *et al.* (2012) also indicated the influence of slope position on pH and exchangeable acidity.

Table 2. Farmers' criteria of soil classification and their perceived properties at *Omo Nada, Limu Seka* and *Gera* districts (FGD)

Districts	PAs	Local name	Soil characteristics					
			Color	Fertility status	Workability	Texture	Depth	Slope position
O/ Nada	D/ Yaya	*Guracha/ Magalaa*	Dark red brown	Fertile	Easy to fallow	Fine	Deep	US
		Dimaa/Bildima	Red	Infertile	Easy to fallow	Moderate	Medium	MS
		Dalacha/Suphee	Grayish	Fertile	Hard when dry	V. Fine	V. Deep	LS
	N/ Bidaru	*Gurracha/Magalaa*	Dark red brown	Fertile	Moderate	Fine	Deep	SA & US
		Dimaa	Red	Moderate	Easy to fallow	Moderate	Medium	MS
		Dalacha/Suphee	Grayish	Fertile	Hard when dry	Fine	V. Deep	TS
L/Seka	Dora	*Dimaa*	Red	Infertile	Easy to fallow	Moderate	Medium	US & MS
		Gurracha/Magalaa	Dark red brown	Moderate	Moderate	Fine	Deep	SA & US
		Koticha	black	Fertile	Hard when dry	V. Fine	V. Deep	BS
	Seka	*Dimaa*	Red	Infertile	Easy to fallow	Fine	Medium	MS
		Gurracha/Magalaa	Dark red brown	Moderate	Moderate	Medium	Deep	US & BS
Gera	W/kersa	*Dimaa*	Red	Infertile	Easy to fallow	Coarse	Shallow	MS
		Dalacha/Suphee	Grayish	Fertile	Hard when dry	Fine	deep	TS
		Gurracha/Magalaa	Dark red brown	Fertile	Moderate	Medium	Medium	SA & BS
	G/Chala	*Dimaa*	Red	Infertile	Easy to fallow	Sandy	Shallow	MS
		Gurracha/Magalaa	Dark red brown	Fertile	Moderate	Medium	Medium	US & LS
		Dalacha/Suphee	Grayish	Fertile	Hard when dry	Fine	Medium	TS

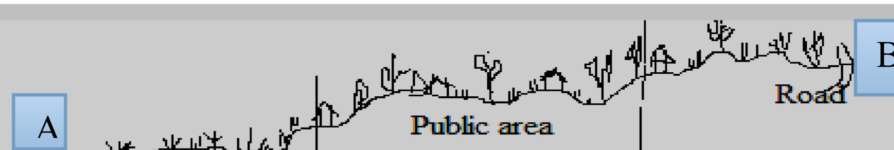
SA=Summit slope, US=Upper slope, MS=Middle slope, LS=Lower slope, BS=Bottom slope, TS=Toe slope.

Source: Own survey, 2015

4.2. Transect Diagram and Participatory Soil Mapping

4.2.1. Transect diagram of Doyo Yaya and Nada Bidaru PAs

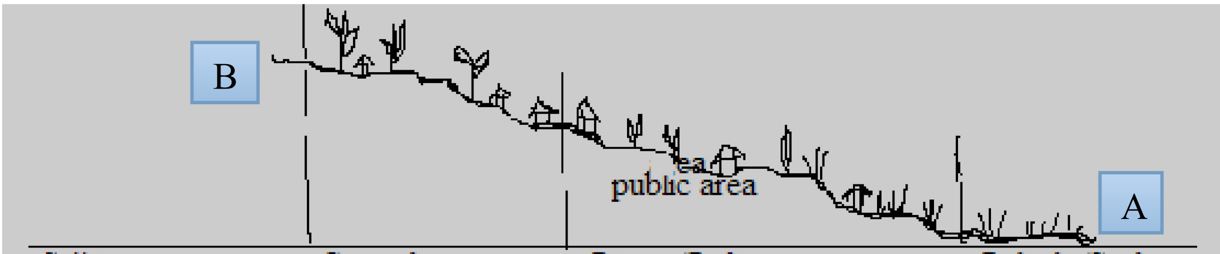
The transect diagrams shown on figure 4a and 4b of *Doyo Yaya* and *Nada Bidaru* PAs, *Omo Nada* district illustrate how the farmers' viewed, understood main variations in topography and others key features for classifying soils. As indicated *Dalacha, a* grayish soils at the lower toe slope position used only for farming of teff without urea fertilizers. However, maize production on this farmland perceived to be impossible since urea application would be lost by high water content of the soil. *Dimaa,* red soils that exist in at middle slope position in the landscape used for plantation forestry, farmland and others uses. *Gurracha/Magala* dark red brown soils on the upper slope on the landscape position the most fertile soils cultivated intensively than other soils (Figure 4a). Figure 4b indicated *Nada Bidaru* PA *Dimaa* red soil cultivated intensively whereas *Gurracha/Magala* dark red brow soil found on the upper position near and with dense natural forest covers recently used for cultivation and the most fertile, the farmers indicated that these area unfavorable condition (crop rest) and early lodging on some crop growth.



Soil type	*Dalacha/Suphee/whitish*	*Dimaa/Red*	*Gurracha /Dark red*
Land use	Farm land, grazing land	Farming land, grazing land, residential area	Farming land, grazing land, residential area
Soil fertility status	fertile	infertile	Fertile
Vegetation covers	Grass	FN, FP, Avocado, chat	Enset, chat, eucalyptuses
Management practice	Fertilizers application, crop rotation	Fertilizer application Manuring, crop rotation,	crop rotation, fertilizer application
Slope position	Toe slope	Middle slope	Upper slope
Elevation (m)	1800-1900	1900-2100	2100-2200
Village name	Edo kara	Egu Ilfata	Yaya kuyu

FN =forest with wood lands, FP = plantation forest, A to B = transect walk direction
Sources:own survey, 2015

Figure 4a. Transect diagram of *Doyo Yaya* PA Omo Nada district



Soil type	*Gurracha*	*Dimaa /Red*	*Dalacha/Suphee*
Land use	Farm land and grazing land	Farming land, grazing land and residential area	Farming land only
Soil fertility status	Fertile	infertile	Fertile
Vegetation covers	FN, FP and enset	Avocado, enset, chat	-
Management practice	manuring, minimum fallow duration	Fertilizers application, crop rotation, fallow duration	fertilizer (DAP)
Slope position	Upper slope	Middle slope	Toe slope
Elevation (m)	2200-2300	1800-2200	1800
Village	Gute	Bidaru	Bidaru

FN =forest with wood lands, FP = plantation forest, A to B = transect walk direction
Sources:own survey, 2015

Figure 4b. Transect diagram of *Nada Bidaru* PA Omo Nada district

4.2.2. Participatory soil mapping of Doyo Yaya and Nada Bidaru PAs

Participatory soil map of *Doyo Yaya* and *Nada Bidaru* PAs, of Omo Nada district illustrated on figure 5. It shows how farmers' map soil types of their PAs. The letter coded by OND1, OND2 and ONG indicated that red, grayish and dark red brown soils of *Doyo Yaya* PA and the letter coded as NBD, NBK and NBG indicated that red, grayish and dark red brown soils of *Nada Bidaru* PA.

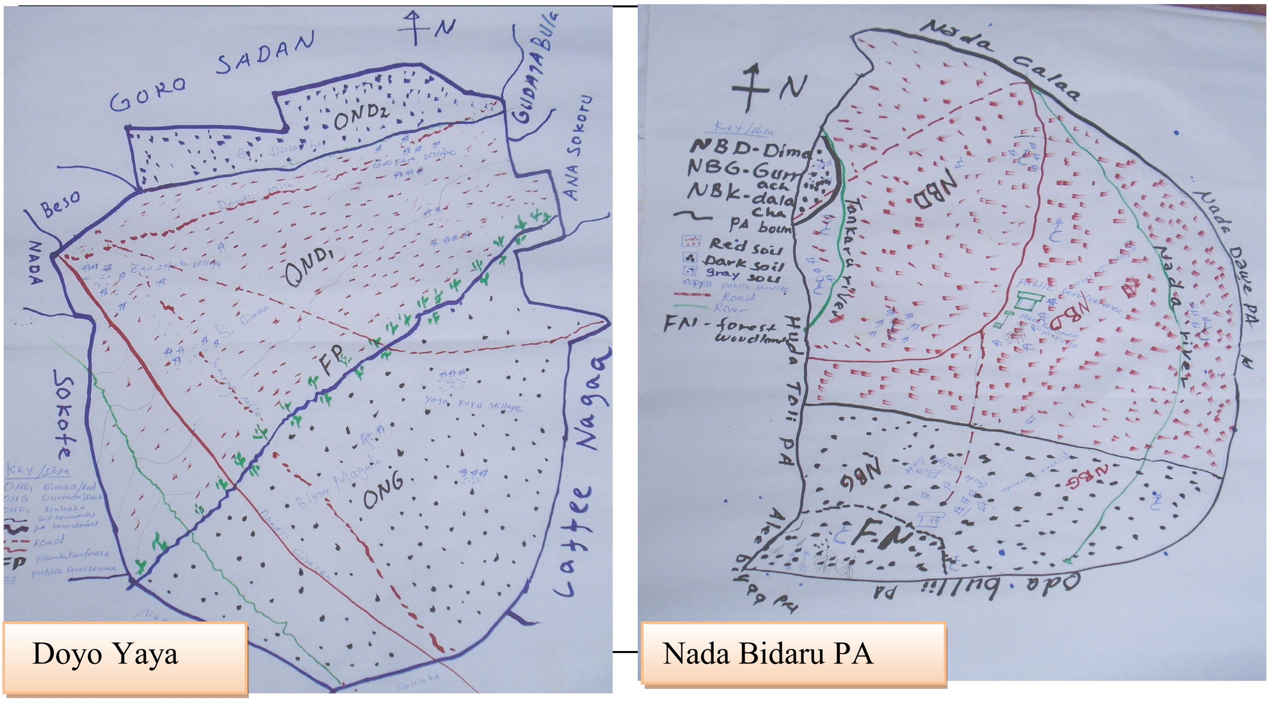


Figure 5. Participatory soil mapping of *Doyo Yaya* and *Nada Bidaru* Omo Nada District

4.2.3. Transect diagram of Seka and Dora PAs

The transect diagrams shown on figure 6a and 6b of *Seka* and *Dora* PAs respectively, of *Limu Seka* district. It illustrates *Koticha,* a black color soils at bottom slope position that is not used intensively for crops but used for grazing and seasonal irrigation in *Seka* and *Dora* respectively, without input. This soil type was not mentioned during discussion with focus groups perhaps due to its constraints of water holding and workability. Whereas more fertile cultivated land and natural woodlands forest with coffee present on upper slope position shown on figure 6a and 6b. The middle and lower slope position of *Dimaa,* red soils are dominated by fruit trees, coffee and eucalyptus. This implies that the shift from cropland to such eucalyptus might be due to decline in fertility status of farmland. This is leads to farm land loss for small holder's farmers in the study area.

Soil type	*Gurracha*	*Dimaa*	*Koticha*
Land use	Farm land grazing land, residential area	Farming land, grazing land residential area	Grazing land
Soil fertility status	Fertile	infertile	Fertile
Vegetation covers	Grass, coffee	Avocado, mango enset, chat and FP(eucalyptus) coffee	Shrubs
Management practice	Fertilizers application	Fertilizers and homestead manuring	No
Slope position	SA and US	MS and LS	BS
Elevation (m)	2200	1900	1750

FN =forest with wood lands, FP = plantation forest, SA=Summit slope, US=Upper slope, MS=Middle slope, LS=Lower slop, BS= bottom slope, A to B = transect walk direction
Sources:own survey, 2015

Figure 6a. Transect diagram of *Seka* PA Limu Seka district

Soil type	*Gurracha /dark red &brown*	*Dimaa /Red*	*Koticha/Black*
Land use	Forest and farm land (coffee)	Farming land, grazing land, residential area	Farm land and grazing land
Soil fertility status	Fertile	infertile	Fertile
Vegetation covers	FN and coffee Forest	Avocado, eucalyptus, mango and chat	Shrubs and grass
Management practice	No input	Fertilizers application, manuring, crop rotation	No input
Slope position	SA &US	MS to LS	bottom
Elevation (m)	2000	1800	1700
Village name	Botor	Ilamu and dong	Ilamu

FN =forest with wood lands, FP = plantation forest, SA=Summit slope, US=Upper slope, MS=Middle slope, LS=Lower slope, A to B = transect walk direction
Sources:own survey, 2015

Figure 6b. Transect diagram of *Dora* PA Limu Seka district

4.2.4. Participatory soil mapping of Seka and Dora PAs

As shown on the figure 7 the participatory soil map of *Seka* and *Dora* PAs, *Limu Seka* district. The coded letter as LSD, LSG and LSK represent *Dimaa, Gurracha/Magala* and *Koticha* indicated red, dark red brown, and black soils of *Seka* and coded letter LDD, LDG and LDK represent red, dark red brown and black *Koticha* soils of the *Dora* PAs of *Limu Seka* district respectively.

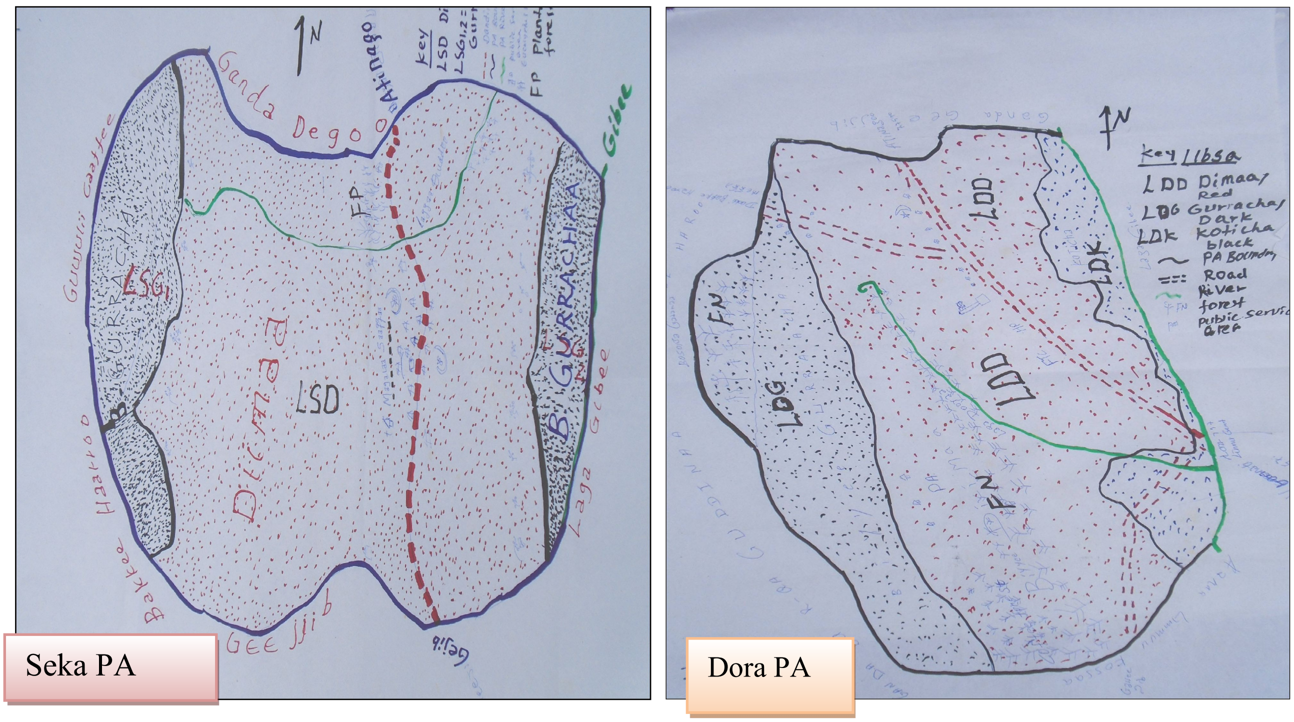


Figure 7. Participatory soil mapping of *Seka* and *Dora* PAs of Limu Seka district

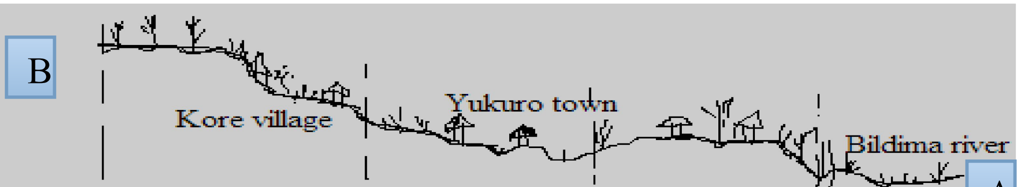
4.2.5. Transect diagram of Ganji Chala and Wanja Kersa PAs

The transect diagrams shown on figure 8a and 8b of *Ganji Chala* and *Wanja Kersa* PAs of Gera district. It illustrates *Gurracha/Magala,* a dark red brown soils the most fertile cultivated with coffee forest and woodlands. Exist on upper slope and middle slope position in the landscape in both PAs. Whereas *Dimaa,* red soils found in middle slope position which is continuous cropping or no fallow duration as a result low fertile land than those of *Dalacha,* grayish soils found under lower slope position farmers perceived as fertile soil but it has physical constraints to till or management due to season fluctuation of water table, high water holding capacity during rainy and hard when dry.

Soil type	*Dalacha/Suphee/whitish*	*Dimaa /Red*	*Gurracha/Dark red or brown*
Land use	Farming land, grazing land	Farm land, grazing land, residential area	Farming land, grazing land, residential area
Soil fertility status	Fertile	Infertile	Fertile
Vegetation covers	Grass	Coffee forest, chat, eucalyptus,	FN,FP forest coffee Avocado, enset
Management practice	Fallow duration(short term) and crop rotation	Fertilizers application, manuring, composting	Manuring, crop rotation
Slope variation	LS	MS	US
Elevation (m)	1900	2100	2200
Village name	Warware	Chala	Gure

FN =forest with wood lands, FP = plantation forest, US=Upper slope, MS=Middle slope, LS=Lower slope ,
A to B = transect walk direction
Sources:own survey, 2015

Figure 8a. Transect diagram of *Ganji Chala* PA Gera district



Soil type	*Gurracha*	*Dimaa/sefo*	*Gurracha*	*Dalacha/Suphee*
Land use	Farm land grazing land, residential area	Farming land grazing land, residential area	Farming land, grazing land, residential area	Farming land, grazing land
Soil fertility status	Moderate	infertile	Moderate	Fertile
Vegetation covers	forest coffee, chat, eucalyptus, FN,FP	Avocado, enset eucalyptus	Avocado, enset, coffee forest	-
Management practice	Fertilizers application, manuring, composting	Fertilizers application, crop rotation, fallow duration		Fallow duration, fertilizer application
Slope position	Upper slope	Middle slope	Lower slope	Toe slope
Elevation (m)	2200	1900-2000	1890	1800
Village name	Wacara Qarsa	Yukuro	Agalofilo	Agalofilo

FN =forest with wood lands, FP = plantation forest, A to B = transect walk direction
Sources:own survey, 2015

Figure 8b. Transect diagram of *Wanja Kersa* PA Gera district

4.2.6. Participatory soil mapping of Ganji Chala and Wanja Kersa PAs

As shown on the participatory soil map of *Ganji Chala* and *Wanja Kersa* PAs of *Gera* district on figure 9. The code letter GGD1, GGG and GGD2 represent *Dimaa, Gurracha/Magala, Dalacha/Suphee,* indicated that red, dark red brown, and grayish soils of *Ganji Chala* PA and the letter coded as GWD, GWG and GWK represent *Dimaa, Gurracha/Magala* and *Dalacha /Suphee* indicated that red, dark red brown, grayish soils of *Wanja Kersa* PAs, of *Gera* district respectively.

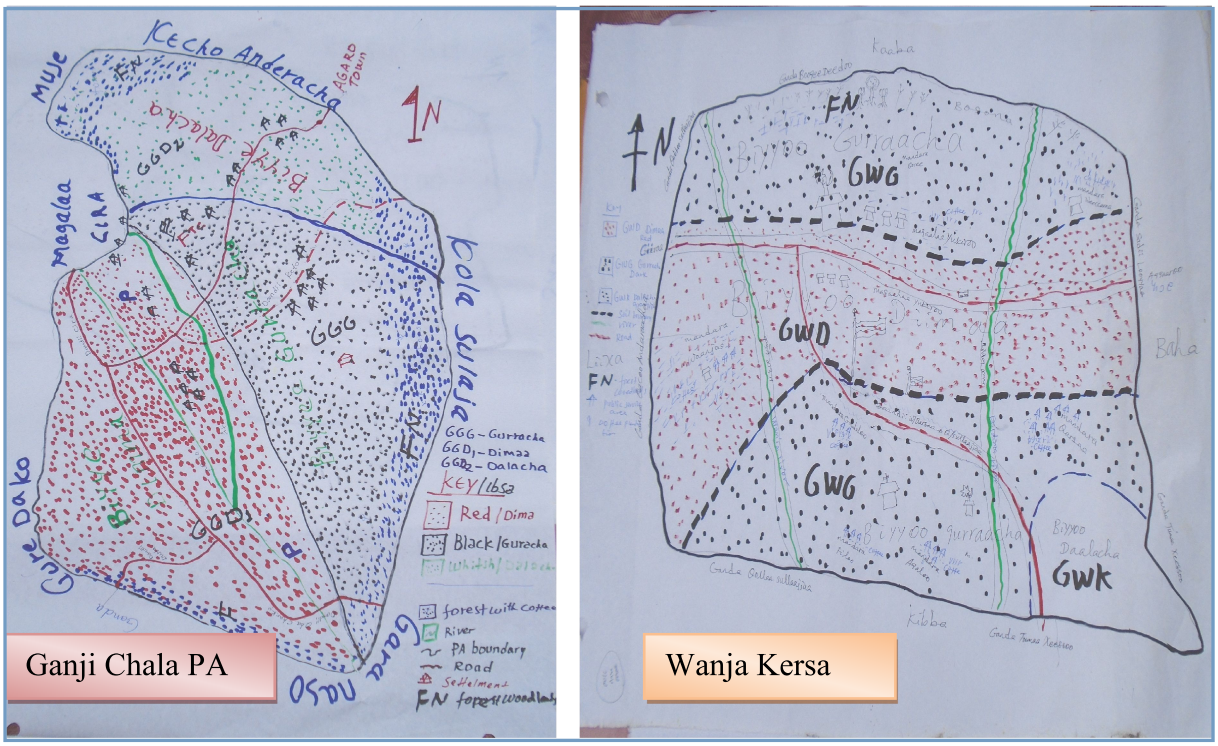


Figure 9. Participatory soil mapping of the *Ganji Chala* and *Wanja Kersa* PAs of *Gera* districts

4.3. Farmers' Soil Fertility Management Practice

Farmers are responsive to the perceived soil fertility decline through experienced way of management practices, adapting their farming system by practices of crop allocation with input required for that particular land (Table 3). In discussion with farmers we learned that they plant sesame and sorghum crops on infertile land and they used crop rotation with legumes and others are planted on good /fertile land in *Omo Nada* and *Limu Seka* districts. Secondly, shifting their land use system of infertile land to grazing land, this implied causes or sources of farmland loss to small holders' farmers and conservation practices with plantation in (*Gera* and *Limu Seka*) districts. Thirdly, choices of short duration crop (early variety) for infertile land than long term duration crop in all study areas. During discussion and key informant interviews their management practices to perceived soil fertility were practices of crop rotation, some crop residues left and but they used for others (fodder, fencing, fire wood) indicated that only few farmers retain crop residues in their field but they aware of the advantages of returning crop residues to soil fertility. Low rate of mineral fertilizer application except for maize crop on red infertile soil reported by Gebeyaw (2015) in North Wollo farmers were used below the blanket recommendation due to the current escalating prices of chemical fertilizers, manure (wet) enclosed at homestead and fallow duration they know the benefits of fallow duration to restore soil fertility but currently they practices seasonal fallowing that is leaving the land fallow for one to two seasons. These results confirmed with findings Gebeyaw (2015) in North Wollo and Eyasu (1997) studied on soil fertility maintenance methods in Wolaita, Pound and Ejigu (2005) conducted on soil fertility practiced and learning from farmers; Saito *et al.* (2006) stated that farmers choices of crops on different soils to plant in good soils/fertile soils while others crops planted on poor soils in fertile soils, they pointed out that sesame grow better than others crops on infertile soils.

Table 3. Farmers' management practices crop allocation and inputs in the study area

Local name of soil	Color	Major crops grown	Input application per ha
		Omo Nada (Doyo Yaya and Nada Bidaru PAs)	
Dimaa	Red	Maize, Sorghum, Teff	100kg DAP and urea for maize and 50 kg DAP for teff, No for sorghum
Gurracha/Magala	Dark red brown	Wheat, Barley, Teff, Bean and Enset	50kg DAP for both wheat & barley
Dalachaa/Suphee	Grayish	Teff	50kg DAP only
		Limu Seka (Seka and Dora PAs)	

Dimaa	Red	Coffee, Maize, Sorghum, Teff, Finger millet, Niger	100kg DAP & urea for maize and teff
Gurracha/Magala	Dark red brown	Maize, Sorghum, Teff, Finger millet	100kg DAP & urea for maize and traditional methods used
Koticha	Black	No, used for others	No
Gera (Ganji Chala and Wanja Kersa PAs)			
Dimaa	Red	Coffee, Maize, Sorghum, Teff, Perennial crops	50kg DAP and urea and wet manure for maize
Gurrach/Magala	Dark red brown	Coffee, Maize, Teff, Enset Perennial crops	Wet manure and rare inorganic fertilizers
Dalachaa	Grayish	Teff, Maize	No input

Source: Owen survey, 2015

4.3.1. Farmers' perception of soil fertility indicators

Eleven groups discussion were made across the three districts to understand farmers' perception and knowledge on fertile soil and infertile soil. It became clear from the group discussions in all districts farmers perceived fertile soil as productive land or fertile land as *"xa'oo/furda*" which literally means fat and "*Gurracha/Magala*" means dark red brown color. Farmers also perceived soil fertility through its outcomes such as crop performance and yield, and include all soil factors affecting plant growth. Conversely, infertile soil is *"diimilee* or *keyate"* which literally means reddish shallow soil cannot support plant growth for (*Seka* and *Wanja Kersa*) PAs groups, *"lafaa dadhabe/ borqii"* and *seefoo/gogaa* means low fertile and none at all and very thin and dry soil (low water holding capacity); needed more input and managements but low yield or none at all for *(Doyo Yaya, Seka* and *Dora)* PAs groups. This term indicated its outcomes, its challenges to crop growth not productive and all soil factors hindering plant growth. These definitions were coincided with the international soil science society (ISSS, 1998). A scientist assesses and describes soil fertility in the field and laboratory according to physicochemical properties but they lack of the limiting factors that the farmers include soils' capacity for sustainable productivity.

According to Corbeels *et al.* (2000) in their study in northern Ethiopia, Tigray indicated that farmers' perceptions of soil fertility are not limited to the soil nutrient status. They relate soil fertility with crop performance and yield. Therefore, the yield variation between present and past indicated that the decrease in soil fertility (Table 4). These findings in line with Eyasu

(2002) reported that poor crop yield in climatically good season, change in soil color and thickness, reduced growth and change in color, and shift in weed biomass are indicators used by farmers soil fertility decline. Abush *et al*. (2011) conducted in the western Ethiopia stated that important indicators of change in the soil fertility status. Similarly Corbeels *et al.* (2000) reported that the reduction of crop yield or productivity was farmers' principal indicator mentioned frequently.

Table 4. Farmers' perception on changes of major crops yield over years

Major crops	Scientific name	Average yield 100kg ha^{-1}		Reasons for yield changes
		Present	past 20 years	
Maize	*Zea mays*	26.64±14.77	40.61±25.20	Decline of soil fertility,
Teff	*Eragrostis tef*	6.98±3.78	11.09±6.42	Continuous cropping,
Sorghum	*Sorghum bicolor*	10.45±11.27	20.12±22.30	Climate change,
Barely	*Hordeum sp.*	2.41±9.63	2.58±5.97	Low application of
Wheat	*Triticum sp.*	4.65±7.52	1.89±8.76	fertilizer and soil erosion

Source: Owen survey, 2015

The others indicators mentioned were weed plants and some shrubs species to evaluate soil fertility status. Farmers were listed on fertile dark red brown and black color soils broad leaves plant and on infertile red soil yellow leaves, rocky outcrops, crops wilting at the end of the rainy seasons and weed plant species (Table 5). These results agree with many findings that reported soil color, crop yield and performance, soil workability, presence of plant indicators, water holding capacity and level of fertility are farmers mentioned indicators (Desbiz *et al.,* 2004; Dawoe *et al*., 2012 and Gebeyaw, 2015). According to Buthelezi *et al.* (2013) indicated that farmers' soil fertility assessments are mainly concerned with food security and their perception are more holistic than those of researchers.

Table 5. Farmers' perception of soil fertility indicators plant

Local name*	Scientific name	Spp.type	Soil fertility status
Chokorsa	*Cynodon dactylon*	H	Fertile

Mujaa	*Snowdina polystarch*	H	Fertile
Asangira	*Datura stramonium*	H	Fertile
Chomoto	*Amaranths spp*	H	Fertile
Hiddi adii	*Solanum sp*	S	Infertile
Hiddi gurracha	*Solanum sp*	S	Fertile
Kusayee	*Lippia adoensis Hochst ex.walp*	S	Moderate
Lafto	*Acacia catechu*	T	Infertile
Siddisa	*Medicago burweed*	H	Infertile
Tufo	*Guizotia scabra(Vios).chiav*	H	Fertile
Andoode	*Phytikacca dodecandra*	S	Fertile
Qorxobbii	*Plantago lanceolata.L*	H	Infertile

*Local name Afan Oromo, H=Herbaceous, S=shrubs, T=Tree
Source: own survey, 2015

The driving forces resulted for soil fertility changes on their farmlands were pointed out the depletion of natural resources for seeking farm land (deforestation), soil erosion (seriously mentioned from *Doyo Yaya, Nada Bidaru* and *Seka* FGD discussion), low application of input that is imbalance application (only DAP) *Nada Bidaru*, *Ganji Chala* and *Wanja Kersa* group discussants, continuous cropping practice or no fallow duration in some groups mentioned minimum fallow duration practices and free grazing practices exercised in all study area. These results were coincided with report of Eyasu (1998) findings of soil erosion, long term mono-cropping, low input and poor soil fertility management practices are some causes of low soil fertility problems. The result indicated that farmers of the study area are able to aware the soil fertility losses and levels of their farm land in line with Maro *et al*. (2013) reported that similar distribution of farmers awareness on soil fertility decline as a problem mentioned. According to Abush *et al*. (2011) reported the soil fertility decline and loss perceived by farmers in their farming experience over time.

4.4. Physicochemical Properties of Soil Classification

The results of laboratory analyses of the physicochemical characteristics of the eleven soil profile samples were used to characterize and classify the soils based on the WRB and USDA soil classification system and to correlate with the farmers' perception of soil fertility classification. The results obtained are presented and discussed in the following sections.

4.4.1. Selected physical properties of soils

4.4.1.1. Particle size distribution (Texture)

In generally, the soils of the study area had high clay content except *Gera* district *Ganji Chala* PA profile GGC1. The percentage of clay in surface soil was 58.57%, 48.30%, 44.59% in *Omo Nada* district *Doyo Yaya* PA profiles OND1, OND2, and OND3 respectively, and 44.59%, 42.44% in *Omo Nada* district *Nada Bidaru* PA profiles of ONB1 and ONB2 respectively. Relatively, lower percentage of clay in surface soil was 33.84% in *Limu Seka* district *Seka* PA profile LSS1, 38.53% in profile GGC1 and 38.83% in *Gera* district *Wanja Kersa* PA profile GWK respectively. The clay percentage of the soil within depth increased in all profile, due to migration of clay from surface to subsoil horizons except profile GGC1. Abayneh (2005) confirm the existence of clay migration in the profile Nitisols with argic horizons generally have increasing clay contents to the Bt horizons, which is, attributed to illuviation of clay particles translocated from the surface layers.

The silt/clay ration evident in the progressive decreases and having greater than the index value of 0.15 with depth of all profiles, these indicated that the soils are at an advanced stage of development and young parent materials. Van Wambleke (1962) used silt/ clay ratio as an index to estimate the degree of weathering, and postulated that the higher the ratio the lower the degree of weathering. Textural classes of the surface horizons were clay for all the study area except for the LSS1, GGC1 and GWK which was clay loam (Table 6). Although texture is an inherent soil property, topographic position may contribute directly for the change in particle size distribution (Mohammed *et al.,* 2005).

4.4.1.2. Bulk density and total porosity

The bulk density of the soils varies between 1.01g cm^{-3} to 1.16g cm^{-3} at the surface to slightly increases at underlying horizon in all profiles. The bulk densities of underlying horizons are higher than the surface soils due to high organic matter content of the surface soils. According to Miller and Donahue (1995), for good plant growth, bulk densities should be below 1.4g cm^{-3} and 1.6g cm^{-3} for clay and sand soils, respectively. The bulk density values observed in the study area of soil were within the normal range for mineral soils. The result in line with FAO (2006) report that the low bulk density reflects the total soil porosity which is create favorable environment for root penetration, aeration and desirable changes in hydrological function such as improve water infiltration.

The weighted average of total porosity of soils ranged between 55.55% to 59.17%, 57.67% to 59.17% and 57.81% to 60.88% respectively, that is determined from the relationship of bulk density and particle density data (Table 6). The result indicated the soils dominated by fine fraction of clay minerals and reflection of high organic matter content of surface soils, this result inverse with Wakene (2001) reported low total porosity was the reflection of the low organic matter content and the high bulk density that was imposed by the use of tillage activity and intense grazing of the fallow land of Bako area. The soils had clay textural classes; the proportion of the clay particle was not more than 61.89% that is lies almost in the usual range of porosity (30% and 70%) as shown (Table 6). According to London (1991), sands with a total pore space of less than 40% are liable to restrict root growth due to excessive strength whilst in clay soils, limiting total porosities are higher and less than 50% can be taken as corresponding value.

Table 6. Selected soil physical properties of the study area of soil profile

Horizon	Depth (cm)	Particle size (%)			Silt/clay	STC	BD (g/cm^3)	TP (%)
		Sand	Silt	Clay				
Omo Nada- Doyo Yaya profile 1 (OND1)								
Ap	0-15	18.42	23.01	58.57	0.39	C	1.06	60.00
AB	15-30	13.15	16.95	69.90	0.24	C	1.17	55.85
Bt1	30-60	15.27	16.95	67.79	0.25	C	1.01	61.89
Bt2	60-80	10.87	23.34	65.79	0.35	C	1.13	57.36
Doyo Yaya profile 2 (OND2)								
Ap	0-10	22.30	29.40	48.30	0.61	C	1.08	59.25
AB	10-30	15.81	25.26	58.93	0.42	C	1.03	61.13
Bt1	30-65	16.00	23.10	60.90	0.38	C	1.06	60.00
Bt2	65-110	13.70	18.94	67.35	0.28	C	1.15	56.60
Bt3	110+	17.72	16.88	65.40	0.26	C	1.09	58.87
Doyo Yaya Profile 3 (OND3)								
Ap	0-15	23.56	31.85	44.59	0.71	C	1.16	56.23
B	15-40	21.25	29.80	48.95	0.61	C	1.16	56.23
Bt1	40-75	17.88	15.13	67.00	0.23	C	1.18	55.47
Bt2	75-110	12.78	19.62	67.59	0.29	C	1.18	55.47
Bt3	110+	10.44	24.03	65.53	0.37	C	1.21	54.34
Nada Bidaru profile 1(ONB1)								
Ah	0-20	27.80	27.61	44.59	0.62	C	1.03	61.13
AB	20-35	19.26	19.12	61.62	0.31	C	1.08	59.25
Bt1	35-60	16.80	17.07	66.13	0.26	C	1.13	57.36
Bt2	60-100	12.57	21.32	66.10	0.32	C	1.13	57.36
BC	100+	13.71	25.26	61.04	0.41	C	1.14	56.98
Nada Bidaru Profile 2 (ONB2)								
Ah	0-8	32.10	25.46	42.44	0.60	C	1.01	61.89
AB	8-28	15.81	23.15	61.04	0.38	C	1.08	59.25
Bt1	28-50	15.27	27.54	57.19	0.48	C	1.12	57.74
Bt2	50-85	16.84	17.06	66.10	0.26	C	1.15	56.60
Bt3	85+	29.42	10.69	59.88	0.18	C	1.06	60.00
Limu Seka –Seka PA profile 1 (LSS1)								
Ah	0-10	33.39	32.78	33.84	0.97	CL	1.03	61.13
AB	10-28	24.44	11.71	63.85	0.18	C	1.15	56.60
Bt1	28-55	11.39	20.28	68.32	0.27	C	1.11	58.11
Bt2	55-105	13.95	26.56	59.49	0.45	C	1.08	59.25
Bt3	105+	11.98	28.63	59.39	0.48	C	1.04	60.75
Seka profile 2 (LSS2)								
Ah	0-12	22.59	22.58	54.84	0.41	C	1.14	56.98
BA	12-30	12.73	23.13	64.14	0.36	C	1.21	54.34
Bt1	30-90	12.24	26.43	61.33	0.43	C	1.12	57.74
Bt2	90-145	11.82	28.68	59.49	0.48	C	1.04	60.75
Bt3	145+	11.61	26.62	61.77	0.43	C	1.06	60.00

C=Clay, CL=Clay Loam, STC=Textural Class, BD= Bulk density, TP= Total Porosity

Table 6.*Continued*

Horizon	Depth (cm)	Particle size (%)			Silt:clay	STC	BD(g/cm^3)	TP (%)
		Sand	Silt	Clay				
Limu Seka- Dora PA profile 1 (LSD)								
Ah	0-10	17.48	29.62	52.90	0.56	C	1.06	60.00
Eg1	10-35	43.56	14.63	41.81	0.35	C	1.02	61.51
Eg2	35-75	17.34	33.91	48.75	0.69	C	1.04	60.75
Bt1g	75-115	16.39	27.87	55.74	0.50	C	1.21	54.34
Bt2g	115-150	5.71	23.57	70.72	0.33	C	1.20	54.72
Gera- Ganji Chala profile 1 (GGC1)								
AP	0-23	43.28	18.19	38.53	0.47	CL	1.05	60.37
AB	23-30	30.44	21.40	48.15	0.44	C	1.04	60.75
Bt1g	30-45	33.27	34.95	31.77	1.10	CL	1.15	56.60
Bt2g	45-70	34.70	34.25	31.04	1.10	CL	1.12	57.74
Bt3g	70+	32.99	31.91	35.10	0.91	CL	1.23	53.58
Ganji Chala profile 2 (GGC2)								
Ap	0-25	24.21	18.41	57.38	0.32	C	1.02	61.51
Bt1g	25-45	5.51	30.07	64.43	0.47	C	1.01	61.89
Bt2g	45-90	5.73	31.07	63.20	0.49	C	1.02	61.51
Bt3g	90-125	8.26	28.80	62.94	0.46	C	1.03	61.13
Bt4g	125+	12.81	21.24	65.95	0.32	C	1.25	52.83
Gera –Wanja Kersa profile 1(GWK)								
Ap	0-13	43.92	17.26	38.83	0.44	CL	1.07	59.62
AB	13-26	20.14	12.95	66.91	0.19	C	1.02	61.51
Bt1	26-34	6.95	21.64	71.41	0.30	C	1.02	61.51
Bt2	34-75	6.40	21.52	72.08	0.30	C	1.04	60.75
Bt3	75-120	4.24	26.90	68.86	0.39	C	1.02	61.51
Bt4	120+	5.19	29.83	64.98	0.46	C	1.05	60.37

C=Clay, CL=Clay Loam, STC=Textural Class, BD= Bulk density, TP= Total Porosity

4. 4.2. Selected chemical properties of soil

4.4.2.1. Soil reaction (PH)

The average results of the soil reaction PH $_{H2O}$ (1:2.5 H_2O) and PH $_{KCl}$ (1:2.5 KCl) of study area are presented in (Table 7). The pH of the profiles of the study area was classified as moderately acidic, strongly acid and very strongly according to the value given by (Murphy, 1968; Tekalign, 1991 and Benton, 2003). This pH value indicated that might be due to hydrogen ions (H^+) that are released when high level aluminum (Al^{3+}) and manganese in the soil react with water molecules and pH $_{KCl}$ less than PH $_{H2O}$ indicated the hydrolysis of the Al displaced by K, rather cations such as K, Ca and Mg are abundant (Fall, 1998). Almost in all profiles the pH values decreased within depth of OND1, OND2, ONB1, LSS1, GGC2 and GWK profiles, and increases in profiles OND3, ONB2, LSS2, LSD and GGC1 with soil depth respectively, and acidity increase from moderate to very strongly acidic from surface to subsoil's horizons vice verse. In profiles LSD, LSS2 and GGC1 are very strongly acidic at the surface than the underlying horizons these might affects physicochemical and biological properties of soils because of out of the optimum pH for most crops (pH 5.5-7) and might be causes metal toxicity and solubility (Al toxicity pH <5.5) and Mn solubility and toxicity. Because more and less H^+ ions are released from increased and decreased organic matter decomposition, which is caused by increased and decreasing organic matter content with depth conceded with Buol *et al.* (2003).

4.4.2.2. Organic carbon, total nitrogen and organic matter

The percentage of soil organic carbon content of surface soil horizon of the study area ranges between 1.27% to 3.93% decreases within depth in all profiles (Table 7). This indicated that the surface of Nitisols and Alfisols may contain several percentage of OC (WRB, 2007 and Soil survey staff, 2003). According to the classification of soil OC as per the ranges suggested by Tekalign (1991) and London (1991) the lowest percentage of OC are registered in profiles OND1, OND2, and LSD this indicated that the low shoot and root growth of crops and natural vegetation, the rapid turnover rates of organic material, removal crop residues observed as a result of intensive cultivation/ continuous cropping and lack of organic fertilizer addition. Relatively the highest value in surface horizon profiles are LSS1, ONB1, ONB2 and GGC2 are 3.21%, 3.73%, 3.93% and 3.03% respectively, it might be due to rate of soil organic matter decomposition. The result in line with the rapid decline of SOC levels with continuous cultivation reported by researchers (Reeves, 1997 and Bationo *et al.*, 2006).

The soil C: N ratio slightly varies with depth might be due to the result of microbial activities of mineralization of organic residues. In profiles OND1, OND2 and OND3 indicated that have low nitrogen content in the soil than the respective profiles. Foth and Ellis (1997) reported that soils with C: N ratios in the range of 10-12 provide nitrogen in excess of microbial needs.

The total nitrogen contents of the profiles varied from 0.13% to 0.46% at the surface horizons (Table 7). The total N content of the surface horizons of the study area are normally rated as low to medium based on the classification of Landon (1991). The surface soil horizons of total N moderate between the ranges of (0.12 to 0.25%) and high (greater than 0.25%) according to the rating of (Berhanu, 1980 and Tekalign, 1991) and the weighted average throughout the profiles ranges between (0.05 to 0.12%) low in profiles of OND1, OND2, OND3, LSS2, LSD, GGC1 and GGC2, and (0.12 to 0.25%) moderate in profile of ONB1, ONB2, LSS1 and GWK. However, the lower value of total N percentage OND1 and OND2 corresponds to the profile having lower value of OM (2.19%, 2.60%) and moderate value for OND3 of OM (3.24%) respectively, and the higher amount of total N percentage at surface soil horizons was recorded in the surface horizons with the higher organic matter content (5.53%,6.43%,6.78%,4.34%, 4.19%, 5.07%, 5.22% and 4.98%) respectively. The percentages of OM at surface horizons soils are higher than the subsoil horizons (decreasing with depth increases) this indicated that surface horizon soils are might be continuous accumulation of undecomposed and partially decomposed plant and animal residues. With WRB (2006) report indicated that particular under forest or tree crops in Nitisols in the surface soils are accumulation of OM observed or undecomposed. In general, forest clearing followed by conversion into agricultural fields, continuous cropping and removal of crop residues from cultivated lands in OND1 and OND2 brought about remarkable depletion of the soil OM stock. Therefore, the findings of this study are in line with the results of studies reported by Solomon *et al.* (2002) stated that multiple role of OM reflects the soil quality and fertility status because of it plays the multiple roles.

4.4.2.3. Exchangeable bases

Exchangeable Ca followed by exchangeable Mg was found to pre dominated the exchange complex of the soil colloidal particles in all of the soils of the study area. According to FAO (2006) rating the exchangeable Ca ranges between (10-20 meq/100g of soil) was high recorded in all profiles except GWK profile, were recorded (8.22 meq/100g of soil) is medium rating (5-10 meq/100g of soil) and exchangeable Mg ranges between (3-8 meq/100g of soil) were high recorded in all profiles except GWK profile, were recorded (2.93 meq/100g of soil) is medium rating (1-3 meq/100g of soil) respectively. Generally, the concentrations of exchangeable Ca varies with increasing depth at OND3, LSS1, LSD and GGC2 profiles and decreased with increasing depth at the profiles OND1, OND2, ONB1, ONB2, LSS2, GGC1 and GWK constantly throughout the profile.

Exchangeable Mg varies in OND3, ONB1, ONB2, LSS2, GGC2, LSD profiles and decreased with increasing depth at the profiles OND1, OND2, LSS, GGC1, and GWK. This might be due to the presence of Ca and Mg bearing parent materials (Fe-Mg rich rock) (WRB, 2006) at the site of soil profile that has contributed much to the high exchangeable Ca and Mg contents on the soil exchange complex. In accordance with that of Landon (1991) rating of soil characteristics, exchangeable Ca and Mg of the study areas as a whole except the underlying horizons of GWK are categorized at a high level. This might be indicated leaching of base cation in the profile sites.

The exchangeable Na according to Landon (1991) rating at profiles of ONB1 and ONB2, LSS1 and LSS2 very high concentration were recorded at the bottom horizon both at surface and underlying horizons. The exchangeable Na contents of the surface and subsoil horizons soils were not causes deterioration of soil structure and Na toxicity.

The exchangeable K was categorized as higher according to Berhanu (1980) rating of soil characteristics, in all profiles except GGC1 low throughout the profile, LSS1 low in surface horizon and LSS2 and LSD both are low in subsoil horizons respectively. The result disproves the common idea that Ethiopian soils are rich in K, but it agrees with Wakene (2001) reported K deficiency in Dystric Nitisols of Bako area. The recent study Tolessa *et al*. (2014) also reported the decline of exchangeable K with depth in the Nitisols area.

4.4.2.4. Cation exchange capacity (CEC) and percentage base saturation (PBS)

Cation exchange capacity describes its potential capacity to supply nutrient cation to the soil solution for plant uptake depends on soil texture, organic matter contents, and the dominate type of clay minerals present. There was a slight variation in CEC in the surface and subsoil horizons of the soil profiles. In the surface horizons, the highest CEC value of greater than 40 meq/100g of soil was recorded in the *Gurracha/Magala* dark red brown soil perceived by local farmers fertile, profile of (ONB1, LSS2 and OND3) coded on the participatory soil map of PAs (ONG, LSG and DYG) respectively.

On the other hand, the lower CEC of soils 38.72 meq/100g of soil was recorded in the *Dimaa,* red infertile soils identified by local farmers coded on the participatory soil maps of PAs GWD, DYD, and LSD profile (GWK, OND1 and LSS1) soil surface respectively (Table 7). This result implies that the soils may have high buffering capacity against induced change and these soil profiles might be indicated the presence of high nutrient reserves. According to Landon (1991) and Murphy (2007) soil having CEC greater than (40 meq/100g of soil) rated as very high and (20-40 meq/100g of soil) rated as high.

The percentage of base saturation (by1*M* NH_4 OAc at pH 7.0) were greater than 50%, where farmers identify dominant soil type *Dimaa, Gurracha*/*Magala* and *Dalacha* or red, dark red brown and grayish soils fertile except *dimaa* red soils perceived as infertile coded as DYD, NBD, GGD1 profiles of OND1, ONB2 and GGC2, *Gurracha*/*Magala* dark red brown fertile soils coded as DYG and NBG, profiles of OND3 and ONB1, and *Dalacha* soils fertile coded as GGD2 profiles of GGC1. The result indicated that the nature of Nitisols higher PBS at the surface of the soils couple with organic matter contents and available nutrients and also true for Cambisols of Eutric base status, Phaeozems with rich humus content and Luvisols base rich surface horizon that indicate the fertility status of the soils (WRB, 2006). However, the profiles of OND2, LSS1, LSS2, LSD and GWK were less than 50% base saturation at surface soil horizons (Table 7), where indicated that local farmers perceived as infertile red soil coded as DYD, LSD, LDD and GWD might be due to continuous cultivation and crop residues removal for others uses. According to Landon (1991), Murphy (2007) the PBS of surface horizon rated as moderate to high, medium to high and very high respectively. Therefore, based on this rating, the PBS in all study area could be categorized into moderate/ medium to high indicating that moderately fertile to fertile soils of the study area. Thus, according to Landon (1991) soils having percent base saturation greater than 60% are rated as fertile soil because of PBS is more comprehensive in soil classification than exchangeable and cation exchange capacity due to its actual percentage of cation exchange sites occupied by exchangeable bases.

4.4.2.5. Available phosphorus

The available P extracted by the Olsen method of the profiles of the study area ranged from 10.20 mg kg^{-1} to 29.50 mg kg^{-1} at the surface horizons (Table 7). According to Olsen *et al.* (1954) and Cottienie (1980) the level of Olsen extractable P in the soil rated as low when less than (10 mg kg^{-1}), and medium (10-17 mg kg^{-1}) high (18-25mg kg^{-1}) and very high (greater than 25mg kg^{-1}) respectively. According to Olsen *et al.* (1954) rating available P contents at the surface horizons in all profiles are high, but according Cottienie (1980) rating available P in profiles OND1, OND2, OND3, LSD, GGC1 and GWK are medium, this indicated that the profiles of OND1 and OND2 are low organic matter content perceived by farmers as reddish infertile soils (Figure 5). But profiles of ONB1, ONB2 and LSS2 are rated as high and LSS1 and GGC2 are rated as very high. The accumulation of available P in the upper surface horizons is might be due to presence of iron (Fe) chemical precipitation through wetting and drying the upper part and management practices of surface horizons. Batjes, (2011) reported attributed to the increment of clay content and clay type which can cause fixation of P and it depends on the soil reaction. Thus, the result is agreed with IUSS Working Group WRB (2006) stated that P-fixation is considerable in Nitisols soils but not acute P-deficiencies. However, available P in Nitisols is below its critical level due to continuous plant uptake (Abdu, 2006), and fixation and low pH values of the soils of Jimma zone areas are reported (Abebe and Endalkachew, 2012).

Table 7. Selected chemical properties of soils profiles of the study area

Depth (cm)	pH $_{H2O}$	pH $_{KCl}$	OC (%)	OM (%)	TN (%)	C:N	CEC	PBS	Exchangeable Cations				TEB	AV.P (mg/kg)
									Na	K	Ca	Mg		
Omo Nada- Doyo Yaya Profile 1 (OND1)														
0-15	5.89	5.02	1.27	2.19	0.13	9.77	37.08	60.32	1.63	1.61	14.14	4.99	22.37	13.10
15-30	5.42	4.83	0.82	1.41	0.07	11.71	45.17	44.52	1.47	1.67	12.72	4.24	20.11	-
30-60	5.54	4.71	0.59	1.01	0.05	11.80	46.09	44.33	1.73	1.74	12.72	4.24	20.43	-
60-80	5.61	4.78	0.42	0.72	0.04	10.50	46.55	43.80	1.73	1.7	12.72	4.24	20.39	-
Doyo Yaya Profile2 (OND2)														
0-10	5.43	4.79	1.51	2.60	0.15	10.10	47.02	43.17	1.64	1.85	11.76	5.04	20.30	10.2
10-30	5.21	4.50	1.19	2.05	0.10	11.90	41.54	48.44	1.79	1.53	11.76	5.04	20.12	-
30-65	5.03	4.49	0.80	1.37	0.07	11.43	46.57	43.23	1.79	1.54	12.60	4.20	20.13	-
65-110	5.04	4.39	0.35	0.60	0.04	8.75	48.39	38.62	1.73	1.83	10.92	4.20	18.69	-
110+	5.10	4.42	0.29	0.50	0.03	9.67	41.09	48.67	1.92	2.12	11.76	4.20	20.00	-
Doyo Yaya Profile 3 (OND3)														
0-15	5.46	4.76	1.88	3.24	0.16	11.75	41.48	65.45	1.71	1.7	17.81	5.94	27.15	10.80
15-40	5.25	4.69	1.62	2.79	0.13	12.46	46.09	54.61	1.81	1.32	16.11	5.94	25.17	-
40-75	5.38	4.76	1.04	0.06	0.10	10.4	61.87	43.62	1.79	1.24	17.12	6.85	26.99	-
75-110	5.52	4.77	0.92	1.58	0.09	10.22	56.82	51.16	1.95	1.2	18.14	7.78	29.07	-
110+	5.60	4.69	0.74	1.27	0.08	9.25	59.63	45.46	1.80	1.12	17.28	6.91	27.11	-
Nada Bidaru PA profile 1 (ONB1)														
0-20	5.60	4.88	3.21	5.53	0.31	10.35	47.93	65.72	1.81	1.71	19.50	8.48	31.50	21.30
20-35	5.23	4.59	1.55	2.67	0.18	8.61	56.23	47.15	1.83	0.95	16.96	6.78	26.51	
35-60	5.28	4.47	0.98	1.69	0.10	9.80	56.69	40.60	1.84	0.83	15.26	5.09	23.02	
60-100	5.27	4.53	0.57	0.98	0.06	9.50	48.39	41.85	1.62	0.82	13.57	4.24	20.25	
100+	5.14	4.45	0.31	0.53	0.03	10.33	37.43	75.10	2.01	0.90	18.48	6.72	28.11	
Nada Bidaru PA profile 2 (ONB2)														
0-8	5.56	4.79	3.73	6.43	0.40	9.33	40.56	90.73	2.08	2.49	21.20	11.02	36.80	19.90
8-28	5.89	5.02	1.66	2.86	0.18	9.22	38.35	64.04	1.88	2.55	15.12	5.04	24.59	-
28-50	5.42	4.83	1.25	2.16	0.13	9.62	35.49	63.08	1.95	2.63	13.57	4.24	22.39	-
50-85	5.54	4.71	0.77	1.33	0.09	8.55	39.63	50.59	2.01	2.77	11.02	4.24	20.05	-
85+	5.61	4.78	0.38	0.66	0.04	9.50	40.10	51.55	1.94	0.92	12.72	5.09	20.67	-

Table 7.*Continued*

Depth (cm)	pH H2O	pH KCl	OC (%)	OM (%)	TN (%)	C:N	CEC	PBS	Exchangeable Cations				TEB	AV.P (mg/kg)
									Na	K	Ca	Mg		
Limu Seka –Seka PA profile 1 (LSS1)														
0-10	5.12	4.52	3.93	6.78	0.46	8.54	33.33	47.79	2.08	0.41	9.24	4.2	15.93	27.90
10-28	5.13	4.36	1.16	2.00	0.13	8.92	35.95	56.79	1.94	1.21	12.72	4.24	20.10	
28-55	5.19	4.47	0.63	1.09	0.10	6.30	53.46	34.30	1.86	1.22	11.02	4.24	18.34	
55-105	5.21	4.76	0.53	0.91	0.07	7.57	32.26	47.27	2.01	1.37	8.48	3.39	15.25	
105+	5.60	4.88	0.20	0.34	0.04	5.00	31.80	51.48	2.03	1.62	9.33	3.39	16.37	
Seka PA profile 2 (LSS2)														
0-12	5.23	4.59	2.52	4.34	0.25	10.08	46.06	46.70	2.23	2.16	12.84	4.28	21.51	19.50
12-30	5.28	4.47	1.21	2.09	0.13	9.31	37.89	66.48	1.63	0.88	15.96	6.72	25.19	-
30-90	5.27	4.53	0.83	1.43	0.09	9.22	32.99	58.90	1.94	0.63	12.65	4.22	19.43	-
90-145	5.14	4.45	0.49	0.84	0.06	8.17	29.01	55.67	2.03	0.56	10.17	3.39	16.15	-
145+	5.56	4.79	0.33	0.57	0.04	8.25	32.75	47.05	1.96	0.72	9.34	3.40	15.41	-
Dora PA profile 1 (LSD)														
0-10	4.99	4.36	2.43	4.19	0.27	9.00	41.28	44.02	1.83	1.15	11.82	3.38	18.17	14.7
10-35	4.55	3.75	0.97	1.67	0.10	9.70	27.21	62.81	1.83	0.24	10.85	4.17	17.09	
35-75	4.68	3.81	0.50	0.86	0.04	12.50	31.68	49.72	1.91	0.32	10.14	3.38	15.75	
75-115	5.2	4.39	0.23	0.39	0.03	7.67	35.26	37.92	1.99	0.28	7.68	3.41	13.37	
115-150	5.53	4.6	0.18	0.31	0.02	9.00	54.49	46.36	2.31	0.76	15.97	6.21	25.26	
Gera –Ganji Chala PA profile 1 (GGC1)														
0-23	4.59	3.71	2.94	5.07	0.31	9.48	40.32	55.73	1.63	0.37	15.35	5.12	22.47	16.8
23-30	4.76	4.00	1.51	2.60	0.16	9.44	44.45	49.04	1.91	0.29	14.48	5.11	21.0	
30-90	5.11	4.39	0.33	0.57	0.04	8.25	28.01	52.12	1.71	0.22	9.29	3.38	14.60	
90-145	5.25	4.67	0.29	0.50	0.04	7.25	36.15	52.86	1.85	0.20	12.79	4.26	19.11	
145+	5.47	4.81	0.19	0.33	0.03	6.33	35.95	43.37	1.86	0.16	10.18	3.39	15.59	

OC= Organic Carbon, OM= Organic matter, TP= total Nitrogen, C:N= Carbon Nitrogen ratio, CEC= Cation exchange capacity, PBS= percent base saturation, TEB = Total exchangeable base

Table 7.*Continued*

Ganji Chala PA profile 2 (GGC2)														
0-25	6.24	5.45	3.03	5.22	0.32	9.45	56.61	51.69	0.93	2.51	18.94	6.89	29.26	29.5
25-45	5.37	4.28	1.18	2.03	0.13	9.08	46.48	38.73	1.97	4.06	8.55	3.42	18.00	
45-90	4.82	4.01	0.33	0.57	0.07	4.71	38.47	42.14	1.82	2.45	8.53	3.41	16.21	
90-125	4.64	3.86	0.17	0.30	0.04	4.25	37.90	36.28	1.98	1.57	7.65	2.55	13.75	
125+	4.83	3.88	0.16	0.28	0.02	8.00	60.53	39.57	2.11	0.62	15.91	5.30	23.95	
Gera -Wanja Kersa profile 1 (GWK)														
0-13	5.12	4.53	2.89	4.98	0.29	9.97	38.72	45.48	1.68	1.34	11.16	3.43	17.61	12.60
13-26	5.10	4.32	2.08	3.59	0.20	10.40	43.85	40.43	2.39	1.61	10.30	3.43	17.73	
26-34	5.14	4.46	1.43	2.47	0.14	10.21	38.36	43.04	1.89	1.71	9.47	3.44	16.51	
34-75	5.07	4.37	0.72	1.24	0.09	8.00	36.32	33.18	1.64	1.85	6.00	2.57	12.05	
75-120	5.27	4.55	0.43	0.74	0.06	7.17	33.06	39.87	1.81	2.8	6.00	2.57	13.18	
120+	4.89	4.21	0.20	0.34	0.04	5.00	33.68	36.97	1.77	2.19	6.37	2.12	12.45	

OC= Organic Carbon, OM= Organic matter, TP= total Nitrogen, C:N= Carbon Nitrogen ratio, CEC= Cation exchange capacity, PBS= percent base saturation, TEB = Total exchangeable base

4.5. WRB and USDA Soil Taxonomy Classification

Based on the obtained laboratory analytical data the soil profiles of the study area were classified according to IUSS Working Group WRB, (2007; 2014) and USDA Soil Taxonomy (2003, 2015). Profiles of *Doyo Yaya*, (OND1, OND2 and OND3), *Nada Bidaru*, (ONB1 and ONB2) *Seka* (LSS1 and LSS2), *Dora* (LSD), *Ganji Chala* (GGC1 and GGC2) and *Wanja Kersa* (GWK) were fulfilled the following physicochemical properties.

The profiles exhibited very deep, clayey textural classes and clay rich subsurface horizons more than 30% clay contents and accumulation through the profiles, silt/clay ratio in all profiles greater than 0.15, lower bulk density and higher pore space (50-60%). High base saturation at epipedon and cation exchange capacity registered between 27 to 50 meq/100g of soils. The $pH_{(H2O)}$ and $pH_{(KCl)}$ measured were low, organic matter and organic carbon contents were decreases with depth in all study area. These characteristics are fulfilled Nitic, argic and cambic subsoil horizons and satisfy the soil references Nitisols, Luvisols, Phaeozems and Cambisols respectively, of IUSS Working Group WRB (2007 and 2014) and argillic, kandic and mollic surface and subsoil horizons of Alfisols, Ultisols, Inceptisols and Mollisols respectively, of Soil survey staff (2003, 2010 and 2015).

Therefore, profile OND1 had silt/clay ratio less than 0.4, the upper surface horizon diagnostic criteria does not qualified dark colored surface with moderate to high organic matter content but base saturation (by 1*M* NH_4 OAc at pH 7.0) greater than 50%. However, argic horizon within 100cm of the soil surface and a base saturation (by 1*M* NH_4OAc at pH 7.0) of 50 percent or more in the major part between 50 and 100cm from the soil surface. The profiles exhibited more base status, clay rich subsoil and high activity clay soils. Therefore, fulfilled the requirements of Luvisols qualified as Cutanic Luvisols. Profile OND2 had a base saturation (by 1*M* NH_4 OAc at pH 7.0) less than 50% throughout the profile and clay rich in subsoil horizons qualified for “Dystric” base status. Hence, the profile named as Luvic Nitisols. According to USDA soil taxonomy classification profile of OND1and OND2 had shows evidences of clay illuviation indicated argillic subsoil horizons and slightly decreasing with depth at the lower horizons. The cation exchange capacity of the soil horizons was greater than 35meq/100g of soil and base saturation greater than 50% fulfilled the requirements of mollic horizon and less than 50% respectively. The profiles, classified as Alfisols soil order, both are Typic Hapludalfs. Profile OND3 shows evidence of clay illuviation in subsoil, average base saturation (by 1*M* NH_4 OAc at pH 7.0) greater than 50% and higher CEC, C/N ratio between 10-12, PH ranges 5 to 7, having humus rich top soils and 1.62% moderate to high organic carbon at a certain underlying depth. Therefore, the profile can be classified as Luvic Phaeozems. According to USDA soil taxonomy the Profile has clay accumulation in subsoil horizons, mollic epipedon and base saturation greater than 50%. The profile classified as Mollisols soil order, Argiudolls great group soils. Profile ONB1 and ONB2 had cation exchange capacity greater than 24meq/100g of soil and base saturation (by 1*M* NH_4 OAc at pH 7.0) greater than 50% at the epipedon and greater than 50% throughout and higher porosity of the profile respectively. Therefore, the profiles classified as Luvic Nitisols and Haplic Cambisols respectively. According to USDA soil taxonomy the profiles had shows evidences of clay accumulation in subsoil horizons, cation exchange capacity less than 50 meq/100g of soil and base saturation greater than 50% but the latter profile has very high throughout the profile. The pH $_{(H2O)}$ and pH $_{(KCl)}$ are less than 5.5 and 5; organic carbon and organic matter content decrease with depth. Therefore, profiles classified as Alfisols and Inceptisols soil orders, fulfilled the great groups of Mollic Paleudalfs and Typic Eutrudepts respectively (Table 8).

Profile LSS1, LSS2 and LSD had cation exchange capacity greater than 24meq/100g of soil for each profiles and base saturation (by 1*M* NH_4 OAc at pH7.0) less than 50% in subsoil horizon of profile LSS1, and both profiles are less than 50% in surface soil horizon but greater than 50% base saturation in subsoil horizon of LSS2 and qualified as Dystric base status soils respectively. Therefore, both of the profiles qualified as Luvic Nitisols reference soil group and LSD profile also less than 50% base saturation in some horizons but high PBS at certain depth and evidence of clay content with a lower content in the topsoil and a higher content in the subsoil. Therefore, the profiles qualified as Dystric base status and Albic properties. The profiles qualified as Albic Luvisols reference soil group. Based on USDA soil taxonomy profile LSS1 and LSS2 had clay accumulation in subsoil horizons, both cation exchange capacity less than 35 meq/100g of soil in some horizons and base saturation less than 35% and greater than 50% in sub soil horizons respectively. Therefore, profiles classified as

Ultisols and Alfisols soil order, Typic Kandiudults and Typic Kandiudalfs soil groups respectively. Profile LSD had a kandic subsoil horizons, cation exchange capacity less than 35meq/100g of soil in most horizons and base saturation greater than 50% in certain depth. PH $_{(H2O)}$ and pH $_{(KCl)}$ less than 5 at surface soil horizon. Therefore, profile LSD classified as Ultisols soil order and Typic Kandiudults great group of USDA soil group (Table 8).

Profile GGC1 had base saturation (by 1*M* NH_4 OAc at pH 7.0) greater than 50% throughout the profile, higher concentration of Fe and Mn, high OC and OM contents and with textural difference and decrease in clay content. Therefore, the profile qualified the plintic Gleysols. This is coincided with WRB (2007) stated soils shows concentration of Fe and Mn on the ped surfaces and in loamy clay soils the iron oxides and hydroxide are concentrated on the aggregated surfaces resulted indicators of gleyic color patterns. Based on USDA soil taxonomy profile GGC1 had clay loam texture, kandic subsoil horizons in which more depth the clay distribution significantly decreases and cation exchange capacity less than 35 meq/100g of soil in subsoil horizons but base saturation greater than 50%. Therefore, profile GGC1 classified as Mollisols soil order, Typic Argiaquolls of USDA soil great group. Profiles GGC2 and GWK had less than 50% base saturation, Dystric base status. Both profile qualified Luvic Nitisols respectively. Based on USDA soil taxonomy profile GGC2 has clay accumulation in subsoil horizons and qualified the mollic epipedon horizon. Therefore, classified as Alfisols soil order, mollic Kandiudalfs of USDA soil great group. Profile GWK had a kandic subsoil horizons, clay accumulation and increasing in clay content with depth, cation exchange capacity less than 35meq/100g of soil in most horizons and base saturation (by 1*M* NH_4OAc) less than 35% in some horizon and more porous profile. Therefore, classified as Ultisols soil order, Typic Kandiudults of USDA soil great group (Table 8).

Table 8. WRB and USDA Soil Taxonomy classification

Profile	USDA soil Taxonomy				WRB	
	order	suborder	Grate group	subgroups	Majorgroup	Units
OND1	Alfisols	Udalfs	Hapludalfs	Typic Hapludalfs	Luvisols	Cutanic Luvisols
OND2	Alfisols	Udalfs	Hapludalfs	Typic Hapludalfs	Nitisols	Luvic Nitisols
OND3	Mollisols	Udolls	Argiudolls	Typic Argiudolls	Phaeozems	LuvicPhaeozems
ONB1	Alfisols	Udalfs	Paleudalfs	Mollic Paleudalfs	Nitisols	Luvic Nitisols
ONB2	Inceptisols	Udepts	Eutrudepts	Typic Eutrudepts	Cambisols	HaplicCambisols
LSS1	Ultisols	Udults	Kandiudults	Typic Kandiudults	Nitisols	Luvic Nitisols
LSS2	Alfisols	Udalfs	Kandiudalfs	Typic Kandiudalfs	Nitisols	Luvic Nitisols
LSD1	Alfisols	Udalfs	Kandiudalfs	Andic Kandiudalfs	Luvisols	Albic Luvisols
GGC1	Mollisols	Aquolls	Arigiaquolls	Typic Arigiaquolls	Gleysols	plinthic Gleysols
GGC2	Alfisols	Udalfs	Kandiudalfs	Mollic Kandiudalfs	Nitisols	Luvic Nitisols
GWK1	Ultisols	Udults	Kandiudults	Typic Kandiudults	Nitisols	Luvic Nitisols

4.6. Correlation of Indigenous and Scientific Soil Classification

The correlation or validation of the relationship between indigenous knowledge of soil with scientific characterization is presented on Table 9. The present study indicated that local farmers perceived their soils' capacity for sustainable productivity depending on the physical properties of the soils, they are not only limited to the nutrient status of soils. The major soil physical properties color, texture, depth, workability and slope position are some important criteria to that farmers use to characterize/ classify their soils fertility status. In these study area farmers use the most observable criteria that are used to distinguish their soils color and texture such as dark red brown soil color more fertile and red or reddish "*diimilee*" color are less fertile or non-productive. They perceived soil textures as determinate of water holding capacity, aeration and workability during the rainy season after and before rains. Those soils are correlated with the scientific analyzed fine texture clayey soils of all profiles except LSS1, GGC1and GWK of profiles. Farmers categorized the soil formed on steep slope position as shallow soils as the soils' forming factors influencing the water flow and materials redistribution of soil and whereas flat and moderate slope position soils are very deep and fertile. In general, farmers perception were valid with the scientific approaches at the lower slope position more deep horizons and accumulation of fine materials.

According to farmers' perception the sites of OND1 and OND2 were infertile "*Dimaa*", red soil. Similarly, scientific study show that these soils are low in OC and OM, total N, medium in available P and low in CEC and moderate PBS. Farmers perceived fertile dark red brown "*Gurracha/Magala*" soils in area of upper slope position opened OND3 profile shows moderate organic matter, low total nitrogen contents, medium in available P, but higher in CEC and PBS. Hence, the profiles valid with farmer perception because of had higher CEC and PBS among the three profiles of *Doyo Yaya* PA. In landscape position both infertile red soils Luvisols and Nitisols found in the foot slope and back slope position respectively, but dark red brown soils, Phaeozems found on the shoulder (upper slope) position. This is in line with a framework for international classification, correlation and communication, WRB (2006) Nitisols occurs in middle slope with association of others soils in the tropics.

Farmers' perceived the soils of sites of ONB2 site as infertile red soil but the scientific study showed that the soils had high OC, OM, total N, CEC, PBS, and medium in available P. Similarly, they perceived the soils of LSD and GGC2 sites as infertile red soils, while the scientific study of these profiles showed that the soils were very strongly acid, medium in available P, low in exchangeable K, CEC and PBS. Soil profiles LSS1 and GWK were also showed low in CEC and PBS. This result shows all red soils are not infertile but LSD and GGC2 valid with the farmers' perception infertile soils. On the other hand they perceived moderately fertile soils in areas of profiles LSS2 and ONB1 (*Seka* and *Nada Bidaru* PAs) respectively, the physicochemical analyzed of profiles showed surface soil horizons high in available P and CEC, high PBS in ONB1, but profile LSS2 showed that low in total nitrogen, PBS in surface horizon, exchangeable K and CEC, and LSS2 site of farmers moderate fertile dark red soil types are correlate with the analyzed scientific procedures.

These perceptions are correlate/validate with the dark red brown, red and gray color of humid tropical soils of IUSS Working Group WRB (2007 and 2014) and USDA soil taxonomy (2003 and 2015) classification such as Nitisols, Luvisols, Phaeozems and Alfisols, Ultisols and Mollisols and Inceptisols respectively.

Table 9. Correlation of farmers' perception with WRB and USDA soil classification

Profile No	Map code	Local soil type*	Fertility Status	WRB	USDA
OND1	OND	Dimaa	Infertile	Cutanic Luvisols	Alifisols
OND2	OND	Dimaa	Infertile	Luvic Nitisols	Alifisols
OND3	ONG	Gurracha/Magala	fertile	Luvic Phaeozems	Mollisols
ONB1	NBG	Gurracha/Magala	Moderate	Luvic Nitisols	Alifisols
ONB2	NBD	Dimaa	Infertile	Haplic Cambisols	Inceptisols
LSS1	LSD	Dimaa	Infertile	Luvic Nitisols	Ultisols
LSS2	LSG	Gurracha/Magala	Moderate	Luvic Nitisols	Alifisols
LSD1	LDD	Dimaa	Infertile	Albic Luvisols	Ultisols
GGC1	GGD2	Dalachaa	Fertile	plinthic Gleysols	Mollisols
GGC2	GGD1	Dimaa	Infertile	Luvic Nitisols	Alifisols
GWK	GWD	Dimaa	Infertile	Luvic Nitisols	Ultisols

*For those soil profile opened only

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

Farmers' perception and indigenous knowledge of soils characterization in the study area shows local people perceive fertile soil as *"xa'oo/furda*" means fertile land and "*Gurracha/Dalacha*" dark red brown color soils a productive land. While, infertile soil is *"diimilee* or *keyate"* reddish shallow soil cannot support plant growth *"lafaa dadhabe/ borqii"* and *seefoo/gogaa* means poor fertile land. Farmers used easily observable soil fertility indicators such as soil color, crop yield, soil texture, and perceptual criteria that are not easily observed but used by most experienced farmers such as soil workability, water holding capacity, weed plants and some shrubs species to indicate fertility status. They also pointed out and perceive the change of soil fertility status and natural resources depletion due to search for farm land, soil erosion, application of low input, continuous cropping and free grazing practices resulted in decline of yield. Based on their criterion they were able to rank according to their importance of soil characteristics such as soil color, texture, water holding capacity, workability, fertility status and slope position. In addition to that the transect diagram and participatory local soil mapping of each PAs showed that, how local farmers explained, observe and attitudes to local resources in their locality.

The result revealed that fine textured clayey, the higher silt/clay ratio greater than the index value of 0.15 evident an advanced stage of soil development and young parent materials. The physical properties of soils also showed that lower bulk density, higher total porosity of the soils might be due to the fine fraction of clay minerals and reflection high organic matter content of the surface soils favorable for good plant growth. The chemical properties of the soils showed that soil reaction pH were ranges between moderately acidic to very strongly acid in the profiles of *Limu Seka* and *Gera* districts recorded out of the optimum pH ranges correlate with the farmers' perception infertile soils except profile GGC1. Soil organic carbon content at surface soil horizons was observed to be higher but decreases within depth in all profiles. However, low percentage of OC is registered in profiles OND1, OND2, and LSD. The low total nitrogen corresponds with the lower value organic matter recorded on the surface soils horizons. Cation exchange capacity of the study area of surface and subsoil profiles are greater than 40 meq/100g in the dark red brown, red and grey soils but less than 38.72 meq/100g in red soils. Percent base saturation greater than 50 were observed in farmers' perceived as fertile dark red brown soils and less than 50% where recorded in farmers' perceived as infertile reddish soils.

Farmers' indigenous knowledge of soil classification correlates with the scientific study of soil physicochemical properties. These showed that soil profiles OND1 and OND2 fulfilled the Cutanic Luvisols and Luvic Nitisols of WRB and both are Alfisols of USDA and farmers classified them as red soils type that are infertile soils, and OND3 Luvic Phaeozems and Mollisols of USDA clay rich in subsoil horizons and farmers classified them as darker red soils type that are fertile soil of *Doyo Yaya* PA. Profiles of ONB1 and ONB2 qualified the Luvic Nitisols and Haplic Cambisols of WRB and Alfisols and Inceptisols of USDA and farmers classified them as darker red soils type and red soils that are moderate fertile and infertile soils respectively. profiles of LSS1, GGC2 and GWK are qualified Luvic Nitisols of WRB, and Ultisols for both and Alfisols for GGC2 of USDA, farmers' classified them as red soils type that are infertile soils, and profile of LSD qualified Albic Luvisols of WRB and Ultisols of USDA, and farmers' classified this as red soil type that was infertile soil. Profiles of LSS2 and GGC1 are qualified Luvic Nitisols and Plintic Gleysols soils of WRB major soil group and Alfisols and Mollisols of USDA respectively, and farmers identified as darker red and grayish soil types and that are classified as fertile soils.

Indigenous knowledge based farmers soil fertility classification in the selected districts of Jimma Zone, southwestern Ethiopia were matched with the scientific study procedures of soil physicochemical properties characterization and classification in all profiles except with profile of ONB2 where farmers perceived as infertility soil, deviated from that of scientific study results. Indicated that all red soils are not infertile soil but others limiting factors are included in the farmers perception affects crop growth. Indigenous knowledge, farmers are responsive for the decline of soil fertility at their farm level to solve soil constraints and since they are unlimited capacity and decision makers. Thus, incorporate in any agricultural development program facilitate and improve soil researchers, government and non government organization, agricultural expertise involved in livelihood improvement in the study area and as the National and regional aspects. Therefore, this study is really, practical, scientific and valuable in observation, explain and understand the existed resource of farmers' finger print study.

5.2. Recommendations

- ☞ Practically working with indigenous people or experienced farmers in soil classification and management help farmers to develop self confidence and capacitate their knowledge rather than ignoring indigenous knowledge and working with simple solution to solve complex problems related to soils for sustained production and improved livelihood.

- ☞ Understanding and working with indigenous knowledge for technology transfer and adoption needed flexibility, local adaptation and overlooking of farmers' perception and soil fertility management with integrated and holistic approaches is important.

- ☞ Farmers are an ultimate decision makers and managers of soils therefore, their involvement in any development activities could improve and sustain the livelihood of success and improve the management of soils and increase the soil productivity.

- ☞ For the further future incorporation/ correlation of national soil map with indigenous soil map at national, regional and at local level is needed for communication between scientists and farmers in agricultural activities.

- ☞ Application of inorganic fertilizers with organic manuring, crop residues, mulching and also crop rotation and intercropping practices increases soil fertility because of due to low available phosphorus in the soils of the study area causes P fixation or sorption causes deficiency of P fertilizers.

- ☞ Any fertilizer recommendation should involve the farmers and should aim to give a broad ranges of option based on the local indigenous soil classification.

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APPENDICS

Appendix I 1. Check-list of focus group discussion and interviews

1. Perceptions and knowledge on soil fertility

    1.1 .Ask how the farmers perceive a fertile soil? Conversely, an infertile soil?

    1.2 .Do you see any change in the fertility status of the agricultural soils in your village?

    1.3 If yes, describe the changes now compared in the past

    1.4 What indicators do you use to evaluate changes in soil fertility status? List soil fertility indicator plants?

    1.5 What are the driving forces that resulted in those changes (e.g., soil erosion, low levels of fertilizer application; continuous cropping/no fallow etc?)

    1.6 How do you respond to the declining soil fertility (e.g., application of manure, mineral fertilizer, etc)

    1.7 Describe how changes in soil fertility affected crop yields – compare yields of major crops now and in the past (use table below)?

    Appendix Table 1. The major crop yields in the past and present

N.S	Major crop	Yield in the past (20 years ago) (q/ha)	Yield at present (last season) (Q/ha)	Reasons for the change?

    1.8 How important is soil fertility decline explaining decline in crop yields now than in the past?

2. Farmers description and management of soils

    2.1 How many types of soils do you recognize in your kebele?

    2.2 Can you name them (use local naming)?

    2.3 On what basis do you distinguish these soil types (your criteria of classification)?

    2.4 Can describe these soils according to their properties (use the table below)?

Appendix Table 2. Local soil description according to their properties

S.N	Local name of soil	Criteria of classification/farmers' soil characteristics					
1		C1	C2	C3	C4	C5	C6

2.5. How do you manage the soils according to their properties (allocation of crops and inputs according to soil type) (use the table below)

Appendix Table 3. Soil management practices by local indigenous farmers

S.N	Local name of the soil	Major crops grown	Soil fertility management practices
1			
2			

3. Can you map the distribution of these soils in your kebele (use 10-13 key informants to do the mapping on a flip chart) (map should later be transferred onto computer).
   3.1 Draw the kebele map on the ground
   3.2 Then locate the different soil types
   3.3 Give codes for different soil types

4. See if the scientifically described soil type is included in the farmers' description, classification and mapping? If not ask them to describe and classify that particular soil type?

Appendix II 1. Transect Walk Check List

Check lists for key informant interview (development agents, District MoA experts, local leaders and indigenous land holders more experienced farmers)

Name ________________________ Date ________________Sign ___________

Education status _________ your profession

Name of researcher ______________________date ______________

List of key questions were used to guide a discussion about the information gathered during the transect walk.

1. Discuss which route that covers the main variations in topography and others key features would like to follow on the walk.
2. Begin the walk starting from the edges to the end of the area, and stop at key features or new zone (soil type, land use, vegetation, residential area, topographic so on) and record on note book and after complete the walk discuss and describe the key characteristics of areas/features come across.
3. How many soil type and local name of soil on the route?
4. Can draw the diagram on the large sheet of paper with areas of interests?
5. What type of land use do you observe?
6. List the major crops grown?
7. List management practices?
8. List soil fertility status? Fertile, moderate and infertile?
9. List the drainage classes (well drained, moderately well drained, somewhat poorly drained, poorly drained and very poorly drained) elevation ranges, and slope position (Summit, upper slop, middle slope, lower slope, toe slope, and bottom or flat)?